

Effect of tailwind conditions on step length and step frequency in sprinting: An experimental approach

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Abstract:

Tailwinds are theoretically known to reduce air resistance during sprinting, leading to increased sprint velocity. While the influence of wind speed on sprint performance has been extensively studied, its specific effects on spatiotemporal variables such as stride length and frequency remain underexplored. This study aimed to examine the effects of varying tailwind levels on step length and step frequency during sprinting using an experimental approach. Thirteen male collegiate sprinters completed 60-meter all-out sprints under three wind conditions: no wind (0 m/s), low tailwind (2.5 m/s), and high tailwind (6.0 m/s). The experiment was conducted in an indoor facility lined with 120 m of urethane rubber. Eighteen industrial fans and one large blower were used to create tailwind environments of low and high conditions. Sprint velocity and spatiotemporal parameters were recorded using a motion capture system and analyzed across conditions. A Friedman test was performed to examine the differences in each spatiotemporal variables under the three wind speed conditions. Bonferroni correction was used for post-hoc testing to adjust for multiple comparisons. The results demonstrated significant increases in sprint velocity in both the low (+0.95%) and high (+1.27%) tailwind conditions compared to the no wind ($p < 0.05$), whereas no statistically significant differences were observed in step length or step frequency. On the other hand, there were no statistically significant changes in step length or step frequency. However, individual analyses showed that either step length or frequency changed for each athlete, which contributed to the increase in speed. These results suggest that the increase in sprinting speed due to tailwind is not due to a uniform mechanism, but depends on the individual athlete's adaptive style.

Key Words: maximum sprint, over speed, wind, track and field, assisted training

Introduction

In track and field competitions, rankings are determined by measurable indicators such as time and distance. Although quantifiable, these metrics are influenced by environmental factors, especially wind speed (Hollings et al., 2012). In particular, tailwinds are known to enhance sprint performance by reducing aerodynamic drag (Ward-Smith, 1999). Reflecting this, World Athletics classifies performances recorded with tailwinds exceeding 2.0 m/s as “wind-assisted” and not eligible for official recognition (*World Athletics Competition Rules*, 2025).

Several studies have theoretically examined the relationship between wind speed and 100-meter sprint performance, including those employing numerical models to predict race times (Dapena & Feltner, 1987; Mureika, 2001). More recently, research based on publicly available competition data has applied statistical modeling to explore this relationship, further confirming the significant effect of wind speed on sprint performance (Moinat et al., 2018). These findings underscore that wind is not merely a background variable, but a critical factor shaping both athletic outcomes and competition regulations. In addition to wind, towing and downhill are means of achieving high sprint velocity with assistance. Both assisted sprinting methods such as towing and downhill slopes increase sprint velocity by increasing step length and decreasing stance time (Cecilia-Gallego et al., 2022; Nakayama et al., 2023). Therefore, similarly to tailwinds, increased sprint velocity may result in changes in step length and step frequency. While there is evidence for the effect of wind speed on sprint performance, there is limited empirical data on how wind affects the spatiotemporal characteristics of sprinting, i.e., step length and step frequency. In particular, there is a lack of field-based analyses that quantify how reduced air resistance due to tailwind influence these parameters under competitive conditions. Therefore, a detailed understanding of this relationship is essential to complement the existing literature and to develop biomechanical insights into sprint performance.

The purpose of this study was to examine the effect of tailwind on step length and step frequency during sprinting using an experimental approach. The study hypothesized that a tailwind would increase step length and sprint velocity. Investigating these issues will lead to devising step patterns adapted to tailwinds and training methods that take advantage of tailwinds.

Material & methods

Participants

Thirteen male college students who were member of track and field teams and routinely trained for short-distance sprinting participated in the study (age: 18.8 ± 1.4 years, height: 1.72 ± 0.04 m, weight: 66.7 ± 5.9 , personal best 100 m record in competition: 10.73–12.03 s). Although the participants had occasionally sprinted under tailwind conditions during regular training and competitions, they had not undergone systematic or continuous training in a tailwind environment prior to the experimental measurements. The study was approved by the Ethical Review Committee of Chukyo university, and all participants provided written informed consent before participating in the study (Approval No. 2020-24).

Experimental setup and wind conditions

In this study, three wind velocity conditions (non: 0 m/s, low: 2.5 m/s, high: 6.0 m/s) were set, and the effects of tailwinds with different wind velocities on sprinting were examined by comparing. The magnitude of the wind velocity was set to 2 m/s or greater, which affects sprinting (Moinat et al., 2018). The experiment was conducted in an indoor facility lined with 120 m of urethane rubber. Eighteen industrial fans (OPF-45S, NAKATOMI) and one large blower (GRL -804, Kamakuraseisakuzyo) were used to create tailwind environments of low and high conditions (Fig. 1a). Industrial fans were placed on both sides, along the length of the 60-m track between 32.5 m and 55 m (Fig. 1b).

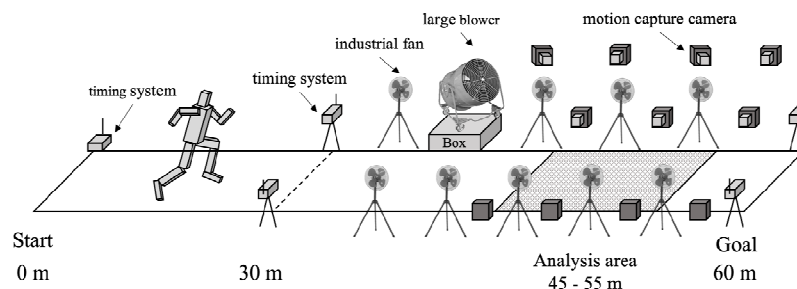


Figure 1 (a)

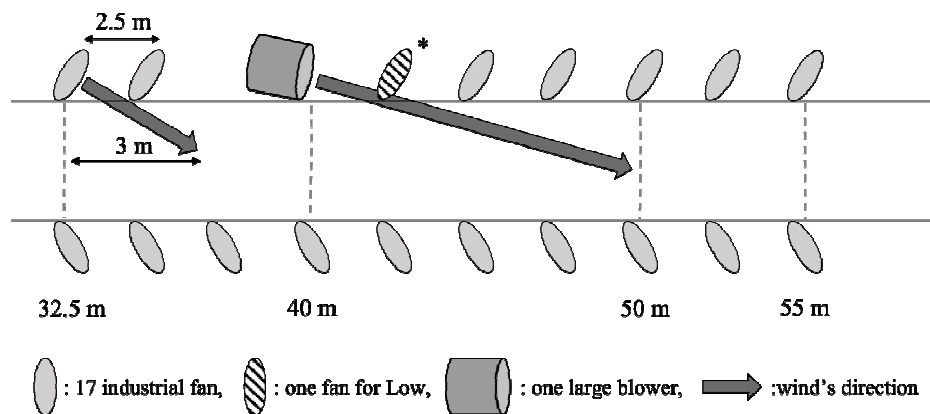


Figure 1 (b)

Figure 1. Experimental environment (a) A schematic diagram of the experimental environment is shown; however, the number of fans is not exact. (b) This diagram shows the exact locations, numbers, and orientations of the fans in low and high conditions.

All industrial fans were placed such that the center of the fan was 1.10 m above the ground. Industrial fans were placed at 2.5 m intervals along the direction of travel. The fans were aligned to face the center of the track at a point 3 m forward from the center of the fan (Fig. 1b). The large blower was placed on a platform 40 m from the starting point, with the center of the fan at 1 m. The blower was oriented such that the center of the fan faced 50 m from the start. In the low condition, only industrial fans were used; 18 fans were installed with one additional fan in front of the large blower, and the large blower was turned off. Under the high condition, the large blower and 17 industrial fans were used. The wind velocities under each condition are shown in Figure 2.

An anemometer (Testo 400 and Testo 06359431, Test) was used to measure the wind velocity every 2.5 m from 30 m to 60 m, where the fans were installed. The anemometer was mounted at a height of 1.2 m on a freestanding pole and placed at the measurement point. Measurements were obtained five times at 5-second intervals, and the wind velocities obtained were described. The average wind velocity obtained was used as the representative values for the low and high conditions. In non condition, the wind velocity was 0 m/s in all sections of the track.

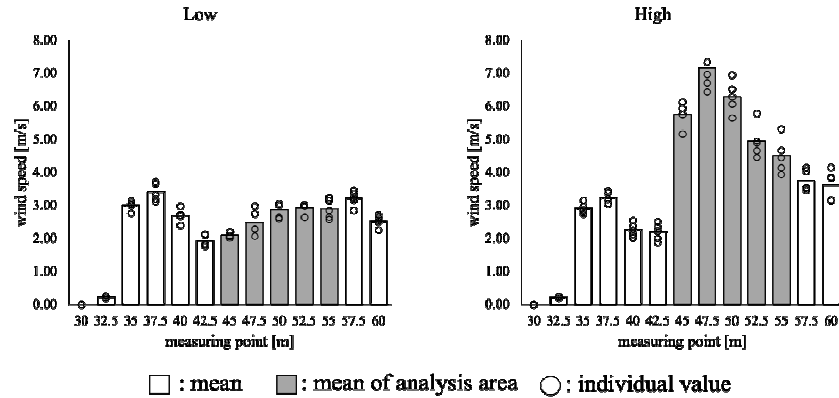


Figure 2

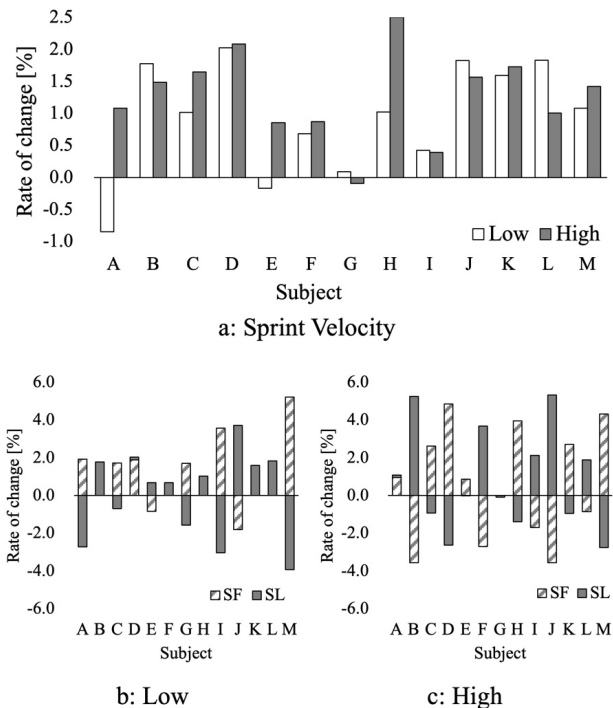


Figure 3

Figure 2. Wind speed Individual and average wind speed values at each measurement point are shown; the analysis area shows the motion capture range.

Figure 3. Percent change between no-wind and tailwind conditions (low and high) for the subject

Upper row: (a) rate of change in sprint velocity, Lower row: (b) rate of change in step for low condition, (c) rate of change in step for high condition

Measure

All participants wore form-fitting clothing and spiked shoes. The participants performed an optional warm-up for 60 min to be able to run at maximum velocity. Subsequently, each participant performed a 60-m all-out sprint in the non, low, and high conditions. Owing to time and equipment constraints, the three conditions were measured over 1 day. The order of measurement was as follows: non condition was measured first; subsequently, the low and high conditions were measured randomly. The number of trials was limited to a

maximum of two for each condition to account for fatigue, and the number of trials was performed at the subject's discretion. The rest period between each condition was 20 min. Before the measurement of each condition, the subjects performed an arbitrary number of trials runs to familiarize themselves with the experimental environment.

Data collection and analysis

An electric timing device (Tci Timing System, Brower) was used to measure the times at 0–30 m, 0–60 m, and 30–60 m sections for each condition. To obtain the kinematic variables of the sprint, 47 reflective markers were affixed to the subject, and three-dimensional position coordinates were recorded using 20 motion capture systems (Vicon) at a sampling rate of 500 Hz. The motion capture system was placed such that a 40–50 m section of the track would be analyzed (Fig. 1a). Since a fan was sandwiched between the camera and the runner, the camera was positioned to view downward at every interval between the fans, and a camera was placed in a position to view down diagonally from above between the fans. The global coordinate system was defined by the x-, y-, and z-axes in the left-right, front-back, and top-bottom directions, respectively.

Data were analyzed using MATLAB R2021b (MathWorks Inc., Natick, MA, USA). Each subject's fastest 60-m sprint among the trials obtained with the phototubes was used in the analysis of each condition. The position coordinates of the markers obtained by motion capture were smoothed using a Butterworth low-pass filter with a cut-off frequency of 30 Hz, based on residual analysis (Winter, 2009). In this study, the analysis range was defined as the step cycle from the point where the leg touched the ground after the 45-m point as the first step until the next step of the same leg. Touchdown and take-off were identified using toe marker coordinates and vertical acceleration (Nagahara & Zushi, 2013). The period from touchdown to take-off was the support phase, the period from take-off to touchdown of the next leg was the flight phase, and the period from take-off to the ground contact of the same leg was the swing phase.

We used a whole-body model for analysis, including 16 rigid segments (head-neck, thorax, lumbar, pelvis, upper arms, forearms, hands, thighs, shanks, and feet) linked by 15 joints (Dumas et al., 2007a, 2007b; Sado et al., 2022). For the hand, elbow, ankle, and knee joints, the midpoints of the two markers affixed to the inside and outside of the joints were used as the joint centers. A right-handed local coordinate system for each segment (SCS) was defined for each frame. The joint coordinate system (JCS) was defined based on the SCS defined in the distal and proximal segments. The whole-body center of mass (CoM) was calculated based on Dumas et al. (2007a). The whole-body velocity vector was calculated using the time derivative of the CoM position vector. The sprint velocity was the average value of the horizontal component (y-axis) of the CoM velocity vector for one step of the analysis interval. Step length was defined as the distance between the CoM during the support leg touchdown and the CoM during the swing leg touchdown. The step frequency was the reciprocal of the time between the support leg touchdown and the swing leg touchdown. The contact time and flight distance were defined as the elapsed time between the support and flight phases, respectively. The contact time and flight time were defined as the elapsed time between the support and flight phases, respectively.

Statistical analysis

The normality of each variable was checked using the Shapiro–Wilk test. A Friedman test was performed to examine the differences in each spatiotemporal variables under the three wind speed conditions. Bonferroni correction was used for post-hoc testing to adjust for multiple comparisons. Cohen's d was used as an effect size for the differences between trials. The thresholds for the interpreting Cohen's d were follows: < 0.2 (trivial), 0.2 – <0.6 (small), 0.6 – 1.2 (moderate), and > 1.2 (large). The significance level was set at $p < 0.05$ for all analyses. A parallel statistic was used, SWC proposed by Hopkins et al. (2009) to make a qualitative analysis of the performance variables.

Results

The mean and standard deviation (SD) of sprint velocity under each condition were as follows: non wind (9.54 ± 0.23 m/s), low wind (9.63 ± 0.27 m/s), and high wind (9.66 ± 0.27 m/s) (Table 1). A significant difference in sprint velocity was observed according to the Friedman test ($p = 0.002$). Post-hoc comparisons revealed that sprint velocity was significantly higher in both the low ($p = 0.014$, $d = -1.07$) and high ($p = 0.001$, $d = -1.75$) wind conditions compared to the non-wind condition. However, there was no significant difference between the low and high wind conditions ($p = 0.732$, $d = -0.42$).

Discussion

We examined the impact of tailwind on step length and step frequency through an experimental sprinting. The results demonstrated that both low and high tailwind conditions significantly increased sprint velocity compared to no wind. We hypothesized that a tailwind would increase step length and sprint velocity. The results of the experiment showed an increase in the sprint velocity in the low (+0.95%) and high (+1.27%) conditions compared to that in the non (Table 1). However, there were no statistically significant differences in other

parameters. Thus, we supported the hypothesis that a tailwind increases sprint velocity, but did not support the hypothesis that a tailwind increases step length.

Table 1

Variable	Units	Group mean $\pm$ SD			χ^2	Friedman p	Kendall's W	Cohen's d effect size (95% IC)			SWC I R: D/NC/I	
		Non	Low	High				Non vs Low	Non vs High	Low vs High	Non-Low	Non-High
Sprint Time												
0-30m	s	4.14 $\pm$ 0.14	4.15 $\pm$ 0.14	4.14 $\pm$ 0.13	2.71	0.258	0.01	-0.40 (-0.96, 0.18)	-0.08 (-0.62, 0.47)	0.39 (-0.19, 0.94)	4 / 8 / 1	3 / 7 / 3
30-60m	s	3.17 $\pm$ 4.15	3.15 $\pm$ 0.09	3.16 $\pm$ 0.10	4.54	0.103	0.18	0.46 (-0.12, 1.03)	0.20 (-0.35, 0.75)	-0.27 (-0.82, 0.29)	1 / 10 / 2	2 / 8 / 3
0-60m	s	7.30 $\pm$ 0.19	7.29 $\pm$ 0.20	7.30 $\pm$ 0.21	2.26	0.323	0.09	0.14 (-0.41, 0.69)	0.10 (-0.45, 0.64)	-0.04 (-0.58, 0.51)	2 / 5 / 6	3 / 3 / 7
Step Pramer												
Sprint velocity	m/s	9.54 $\pm$ 0.23	9.63 $\pm$ 0.27	9.66 $\pm$ 0.27	12.15	0.002 ^{ab}	0.47	-1.07 (-1.74, -0.37)	-1.75 (-2.62, -0.86)	-0.42 (-0.98, 0.16)	1 / 3 / 9	0 / 2 / 11
Step Length	m	2.15 $\pm$ 0.09	2.15 $\pm$ 0.07	2.16 $\pm$ 0.08	0.84	0.657	0.03	0.02 (-0.53, 0.56)	-0.28 (-0.83, 0.28)	-0.32 (-0.87, 0.25)	4 / 4 / 5	5 / 3 / 5
Step Frequency	Hz	4.45 $\pm$ 0.21	4.49 $\pm$ 0.19	4.48 $\pm$ 0.23	1.12	0.571	0.04	-0.53 (-1.10, 0.06)	-0.19 (-0.73, 0.37)	0.15 (-0.40, 0.69)	1 / 6 / 6	4 / 3 / 6
Stance Distance	m	0.9 $\pm$ 0.09	0.9 $\pm$ 0.08	0.90 $\pm$ 0.08	1.85	0.397	0.07	0.07 (-0.48, 0.61)	-0.11 (-0.65, 0.44)	-0.17 (-0.72, 0.38)	4 / 6 / 3	3 / 5 / 5
Flight Distance	m	1.25 $\pm$ 0.07	1.25 $\pm$ 0.08	1.26 $\pm$ 0.08	0.15	0.926	0.01	0.02 (-0.53, 0.56)	-0.16 (-0.70, 0.40)	-0.19 (-0.73, 0.37)	6 / 0 / 7	7 / 1 / 5
Stance Time	s	0.094 $\pm$ 0.010	0.094 $\pm$ 0.010	0.09 $\pm$ 0.009	0.62	0.734	0.02	0.33 (-0.23, 0.88)	0.18 (-0.37, 0.73)	-0.11 (-0.65, 0.44)	3 / 9 / 1	3 / 10 / 0
Flight Time	s	0.131 $\pm$ 0.008	0.129 $\pm$ 0.008	0.13 $\pm$ 0.009	0.08	0.679	0.03	0.27 (-0.29, 0.82)	0.09 (-0.46, 0.63)	-0.12 (-0.66, 0.43)	5 / 3 / 5	6 / 3 / 4
Touchdown Distance	m	0.25 $\pm$ 0.04	0.25 $\pm$ 0.04	0.25 $\pm$ 0.04	2.00	0.37	0.08	-0.27 (-0.82, 0.29)	-0.28 (-0.83, 0.28)	-0.01 (-0.55, 0.54)	1 / 7 / 5	1 / 7 / 5
Takeoff Distance	m	0.53 $\pm$ 0.04	0.53 $\pm$ 0.05	0.53 $\pm$ 0.04	0.64	0.73	0.03	0.36 (-0.21, 0.91)	0.10 (-0.45, 0.65)	-0.27 (-0.82, 0.29)	4 / 8 / 1	4 / 6 / 3

Table captions

Significant post-hoc: non vs low = α ; non vs high = β ; low vs high = γ . IC: Confidence interval. SWC I R: Smallest Worthwhile Change Individual Response; D/NC/I: Decrease / No Change / Increase.

The increased sprint velocity is due to the reduced aerodynamic drag resulting from the tailwind. A tailwind has been shown to have an effect on the relative air velocity experienced by the runner in the direction of their travel. It has been determined that this effect can lead to a reduction in drag, thereby creating a favorable environment for sprinting (Ward-Smith, 1999). Increasing sprint speed requires an increase in either step length or step frequency or both (Hunter et al., 2004). However, it has been reported that there is a trade-off between these factors, and that different players exhibit different characteristics (Salo et al., 2011). In this study, the responses to step length and step frequency were found to be non-uniform, with individual differences being evident (Fig 3, 4). For example, Subjects B and J increase their sprint velocity by increasing the step length in the High condition. On the other hand, Subjects C, D, and H increased the step frequency in the High condition to increase their sprint velocity. The results suggest that changes in step patterns that contribute to increased sprint velocity vary from individual to individual, and that tailwind have different adaptive strategies for increasing sprint velocity. In addition, in Figure 4, the greater the change in either step length or step frequency in the High condition, the greater the percentage increase in sprint velocity. Also, even if the step length had increased and the step frequency had decreased, an increase in velocity and vice versa would have occurred. It suggests that even if one variable is reduced, a tailwind can produce enough step changes to increase speed. Cecilia-Gallego et al. (2022) stated that in assisted sprint training, there are runners who can adapt to sprinting at supramaximal velocity and those who cannot. The rate of change in sprint velocity in this study and the differences in step length and step frequency adaptation also suggest that sprint velocity increases in sprints with a tailwind, but that there are individual differences in step change.

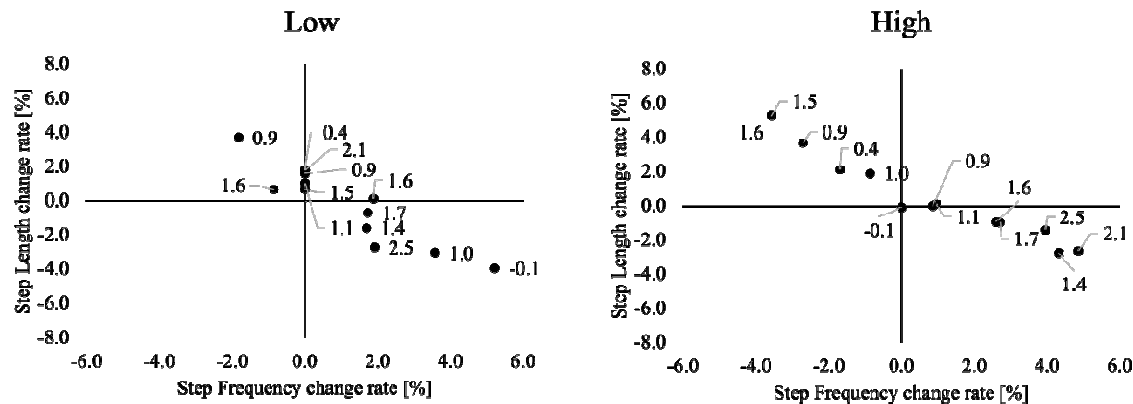


Figure 4. Percentage change in step length and step frequency
Numbers indicate the rate of change in sprint velocity

This study was the first to experimentally create a tailwind environment using fans. However, as shown in Figure 1, the magnitude of the wind velocity varied, and it should be considered that the results of this study were obtained for a certain range of wind velocities. Since the fan wind irradiation was directed toward the height of the torso (1.20 m), the magnitude of the wind velocity near the lower limbs and head may have caused errors with the wind velocity of the torso. However, since the majority of the surface area involved in air

resistance is the fuselage, this effect was considered negligible. Since the irradiation point differs from natural wind in this experiment using a fan, it is possible that the results may differ depending on the natural wind and the experimental environment setting.

Conclusions

This study demonstrated that tailwinds during the maximum speed phase significantly increased sprint velocity. Tailwinds of approximately 2.5 m/s and 6.0 m/s both enhanced speeds compared to no wind conditions (+0.95% and +1.27%, respectively), with no additional group-level gain observed under the stronger tailwind. Contrary to the initial hypothesis, these improvements were not accompanied by consistent changes in stride length or stride frequency at the group level. Instead, athletes displayed different adjustment patterns—some increased speed through longer strides, while others did so through higher stride frequency. In practical terms, monitoring each athlete's spatiotemporal response and instructing them to emphasise either stride length or stride frequency, depending on individual tendencies, may facilitate better use of tailwind assistance. Controlled tailwind sessions offer a valuable setting for identifying and refining each athlete's stride adaptations.

Conflicts of interest - The authors have no conflicts of interest to report

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