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Differences in strike index between land treadmill and aquatic treadmill running in experienced distance runners

By

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Approved:

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Differences in strike index between land treadmill and aquatic treadmill running in experienced distance runners

Context: Strike index is a measure of the point on one’s foot that initially contacts the ground, represented as a percentage of the total foot length. When running in water an individual is exposed to the physical properties of water, buoyancy and drag. These forces may cause one’s strike index to be greater when running on an aquatic treadmill, when compared to running on a land treadmill.

Objective: To determine if strike index is greater when running on an aquatic treadmill (ATM) than when running on a land treadmill (LTM).

Design: Cross-sectional.

Setting: University sports medicine clinic.

Patients or Other Participants: University track & field and cross country athletes (n=15).

Intervention: Participants completed two sessions of running across two days: One on the LTM and one on the ATM. Participants were analyzed at five different velocities: 2.91, 3.13, 3.35, 3.58, & 3.8 meters per second.

Main Outcome Measures: A 2 (treadmill type: LTM vs. ATM) x 5 (velocity: 2.91, 3.13, 3.35, 3.58, & 3.8 m/s) repeated measures analysis of variance (ANOVA) with an α = .05 determined whether treadmill type and running velocity affected strike index.

Results: Treadmill type had a significant main effect on strike index ($F_{1,28} = 7.5$, $p = 0.01$). Mean ± SD values for SI on the LTM and the ATM were 43.08 ± 23.23% and 64.05 ± 19.80%, respectively.

Conclusions: When running on an ATM, participants had significantly greater strike indices compared to running on a LTM. These results have implications for potential increases or decreases in injury if the ATM is used for training purposes.

Key Words: strike index; aquatic treadmill; land treadmill

INTRODUCTION

Strike index (SI) quantifies how one’s foot contacts the ground at the beginning of the stance phase of gait. SI is reported as a percentage of the total foot length, with lower percentages indicating a more posterior point of contact, while greater percentages indicate a more anterior point of contact along the foot.[1] Differences in SI may be related to running-related injuries, such that experienced distance runners who are rearfoot (posterior) strikers may have approximately twice the rate of repetitive stress injuries than forefoot (anterior) strikers.[2] Previous research has shown that forefoot strikers, as opposed to rearfoot strikers, produce lower ground reaction forces. More specifically, forefoot strikers exhibit lower impact peak ground reaction forces and reduced vertical ground reaction force loading rates.[3-5] Forefoot strikers also exhibit lower stress at the patellofemoral joint but greater Achilles tendon loading.[6-8] The greater Achilles tendon loading may be attributed to a more plantar flexed position at foot strike, and may be of concern for a possible increase in injury risk.[6] The lower ground reaction forces, lower loading rates, and lower patellofemoral joint stress associated with forefoot strike patterns may be beneficial in relation to running-related injuries, while greater Achilles tendon loading may not be.

One potential injury prevention technique is underwater running.[9,10] Running in water provides an environment where buoyancy and drag forces are greater compared to running on land. Buoyancy is a force that acts in the vertical direction and is equal to the weight of the water that is displaced by the body being submerged.[11] The buoyancy due to water causes a decrease in the weight an individual must support while submerged, with less body weight support the more the body is submerged.[12-14] These buoyant forces help to decrease the impact that must be absorbed by the musculoskeletal system during the stance phase of running.[13] Drag, or fluid resistance, is a resistive force that slows the motion of an object moving through the water.[11] The frontal area of the body moving through the water proportionally affects the magnitude of the drag (i.e. the greater the frontal area, the greater the drag).[12,13]

The buoyancy and drag forces associated with the aquatic environment may also affect lower extremity muscle activation patterns, which can lead to kinematic changes. For example, previous research has shown less gastrocnemius activation with more total tibialis anterior activation during underwater treadmill running compared to overground running.[15] Is this increase in tibialis anterior activation during underwater running sufficient for counteracting drag forces, or does the ankle remain plantarflexed at foot strike during underwater running relative to overground running? If the drag forces associated with underwater running prevent ankle dorsiflexion typically seen just prior to footstrike, then the foot may be predisposed to a greater strike index (i.e. more anterior footstrike pattern). Thus, the purpose of this study was to test whether strike index (SI) is greater when running on an aquatic treadmill (ATM) compared to on a land treadmill (LTM). We hypothesized that SI would be greater while running on the ATM compared to running on the LTM.

METHODS

Participants

Fifteen experienced (>5 years of competitive running) distance runners (6 males, 9 females), free of orthopedic injury, from a university Division I cross country and track

& field teams were asked to participate in this study. Participants' age and years of competitive running (mean ± SD) were 20.07 ± 1.94 years and 6.6 ± 1.35 years, respectively. We also quantified participants' amount of ATM experience in years, such that a 'year' of experience was equivalent to the use of an ATM >10 times across two consecutive seasons of competition (cross country & track and field). For example, a participant would have one year of ATM experience if he/she used the ATM five times during the cross country season and seven times during the track & field season (12 times total). The mean (± SD) amount of ATM experience was 0.27 ± 0.59 years. All participants provided informed consent, and this study was approved by Utah State University's Institutional Review Board.

General procedures

Although SI is typically calculated using an instrumented force platform, we instead estimated SI from a set of previously derived regression equations.[1] To do so, we used static, non-reflective markers placed on the participant's left shoe at the following locations: (A) posterior aspect of the calcaneus; (B) on the dorsal side of the foot at the third metatarsophalangeal joint; and (C) on the lateral malleolus (Fig. 1). All landmarks were identified through palpation. A still shot photo of the foot was taken while the participant stood flat-footed on land. From this photo, the standing angle ($AB_{standing}$) was calculated as the angle between vector AB and the anteroposterior axis. For the still shot photo, the anteroposterior axis was defined as the horizontal vector that is parallel to the ground extending from point A towards the anterior of the foot.[1] In this study, the LTM was set to a 1% grade to account for physiological (VO_2) similarities to over ground running.[16] For analysis purposes, the anteroposterior axis was zeroed for each trial with respect to the treadmill set to a 1% grade, accounting for the 0.54° incline of the treadmill. The angle $AB_{standing}$ was then used to calculate the foot strike angle (FSA).[1] Additional calculations are described below in Data Analysis.

Participants completed two sessions of running across two days: One on land using the land treadmill (LTM; Freemotion Fitness, Logan, UT) and one underwater on an aquatic treadmill (ATM; HydroWorx 2000, Middleton, PA). Participants were instructed to "run how you feel that you normally would" prior to each session. The LTM session was conducted first to allow for the use of the same shoes during the ATM session the following day. Each session lasted ~10 minutes, including five minutes of familiarization to the treadmills at 2.2 meters per second (m/s) and five minutes of testing. As previously stated, the LTM was set to a 1% grade incline for all familiarization and testing due to its physiological (VO_2) similarities to over ground running.[16] Participants were immersed at the level of the xiphoid process, which required them to support ~29% of his or her body weight.[14] After the familiarization phase, participants ran for one minute at five different velocities: 2.91, 3.13, 3.35, 3.58, & 3.8 m/s (maximum velocity of ATM used in this study). Other biomechanical measures have been studied in experienced runners at comparable velocities[3,5,17], suggesting that these treadmill settings were appropriate for testing our hypotheses. Video data were analyzed only for seconds 21-40 of each minute per running velocity. Participants wore the same shoes during each session, and static markers were placed on the foot each day.

Data analysis

Video data were captured from a lateral view (Fig. 1) with a GoPro camera (Model Hero 3+, Woodman Labs Inc., Halfmoonbay, CA), sampling at 120 Hz for both sessions. Participants were required to run between two specific points (92 cm apart, centered on the treadmill) while on the treadmills to ensure they would be in the center of the frame, minimizing any barreling ('fish-eye') distortion. Video data were analyzed with Logger Pro 3.8.4 (Vernier Software & Technology, Beaverton, OR). An origin (x=0, y=0) was set within each video at the bottom left corner. Analysis began with the first initial contact of the left foot, and continued for five consecutive left foot strikes. The initial contact of each foot strike was defined as the frame during which compression of the sole of the shoe can be seen *and* not seen in the prior frame. A single researcher digitized each video and placed a point on markers A and B, using Logger Pro 3.8.4 software (see reliability in Results). These points yielded x and y coordinates that were used to determine the FSA of the five consecutive foot strikes. With these two points, the slope was calculated using Equation 1:

$$\frac{(y_2-y_1)}{(x_2-x_1)}=\text{slope} \qquad \textit{(Eq. 1)}$$

Applying the slope to a unit triangle, the angle of the foot relative to the horizontal (anteroposterior axis) was calculated with Equation 2:

$$\tan^{-1}(\text{slope})=\theta \qquad \textit{(Eq. 2)}$$

After this angle is calculated for both standing ($AB_{standing}$) and initial contact ($AB_{footstrike}$) the foot strike angle (FSA) was calculated with Equation 3:

$$AB_{footstrike}-AB_{standing}=FSA \qquad \textit{(Eq. 3)}$$

Strike index (SI) was then calculated with the shod-condition equation (Eq. 4) derived by Altman and Davis[1]:

$$\frac{(\mathrm{FSA}\text{-}27.4)}{\text{-}0.39}=\mathrm{SI} \qquad \textit{(Eq. 4)}$$

The average strike index (five foot strikes) was calculated for each of the five velocities for both LTM and ATM running, yielding ten SI values per participant.

Intra-rater variability in data processing

To ensure intra-rater variability of marker placement and initial contact estimation, we measured the coefficient of variation (C_v) for both the LTM and ATM using Equation 5[18]:

$$C_v = \left(1+\frac{1}{4n}\right)\times\frac{\mathrm{st.dev}}{\mathrm{mean}} \qquad \text{(Eq. 5)}$$

Mean and standard deviation values of FSA were taken from 15 estimations of initial contact of the left foot from two videos (one per treadmill type). The videos were randomized for participant number, treadmill type, and treadmill velocity.

Statistical analysis

Statistical analysis was conducted using SPSS software Version 21 (IBM, Armonk, NY) with α = .05. A 2x5 repeated-measures analysis of variance (ANOVA) was used to test for main and interaction effects of treadmill type (LTM vs. ATM) and running velocity (2.91, 3.13, 3.35, 3.58, & 3.8 m/s) on mean strike index. Both factors (treadmill type and running velocity) were within-subject. A Greenhouse-Geisser correction was used (due to sphericity being violated) to determine the significance level of the effect of velocity on SI, as well as the interaction between velocity and treadmill type. Effect sizes for significant differences were calculated using a Cohen's d calculation.

RESULTS

Intra-rater variability

Values of coefficient of variation were 0.016 for the LTM, and 0.015 for the ATM. These values show low variance between the rater's placement of markers and initial contact estimation across participants, trials, and treadmill type.

Strike Index

Figure 2 illustrates differences in SI between running on land and in water. There was a significant main effect of treadmill type ($F_{1,28} = 7.5$, $p = 0.01$), but no effect for velocity ($F_{4,112} = 2$, $p = 0.151$) and no interaction between velocity and treadmill type ($F_{4,112} = 1.3$, $p = 0.272$). Mean ± SD values for SI on the LTM and the ATM were 43.08 ± 23.23% and 64.05 ± 19.80%, respectively (Table 1). Effect sizes for differences in SI between treadmill types varied by running velocity, ranging from $d = 0.68$ at 2.91 m/s to $d = 1.05$ at 3.58 m/s.

DISCUSSION

The purpose of this study was to test whether SI is greater when running on an ATM compared to on a LTM. As hypothesized, strike index was significantly greater (i.e. more anterior) while running on the ATM compared to the LTM, regardless of running velocity. To our knowledge, this is the first study to systematically compare strike indices between land and underwater running.

The physical properties of water allow for individuals to support less body weight while running, yet still require them to resist the drag forces to move their limbs through the water. This interaction between buoyancy and drag may allow the ATM to be a potential alternative tool for training, rather than LTM or overground running, particularly when an individual has orthopedic or neurological limitations. Previous research has also shown that individuals may have similar cardiorespiratory responses on an ATM to those on a LTM.[19] This emphasizes the opportunity for the ATM to be used as an alternative training tool. If so, then one must understand how running underwater affects key aspects of running performance, such as strike index. Although this study was cross-sectional in design, and did not incorporate any training protocol, it may provide a 'snapshot' of how running kinematics are different on land and in water. SI on the ATM was approximately 1.5 times greater than when running on the LTM, demonstrating that participants had a more anterior foot strike pattern when running underwater compared to on land.

Studies have suggested that a more anterior foot strike pattern over time may be beneficial in reducing injuries because of lower vertical ground reaction forces and joint loading[2-5,7,20] compared to more posterior foot strike patterns. On the contrary, studies have also suggested that a more anterior foot strike pattern over time may actually contribute to injuries due to increased loading of the Achilles tendon.[6,7,21] These equivocal findings illustrate how additional research is needed to determine if training under conditions that systematically shift foot strike patterns anteriorly 1) can reduce injury risk and 2) are appropriate for runners with an injury history. Findings from this study do, however, suggest that the ATM may be an appropriate training tool that can shift one's foot strike pattern in the anterior direction in conditions of low body weight support (due to buoyancy), regardless of running speed. Whether prolonged use of the ATM for training leads to lasting changes in an individual's strike pattern when running on land is, however, still unknown.

In conclusion, the strike index (SI) of experienced distance runners was significantly greater on the ATM than on the LTM across five different running velocities. These differences in SI were not affected by the change in velocity and there was no interaction between the velocity and type of treadmill. Instead, the differences in SI were due only to treadmill type in this study. Although these findings are a 'snapshot' of the kinematic changes that occur while running on an ATM, they suggest that repeated exposure to (i.e. training on) the ATM may affect an individual's running form on land.

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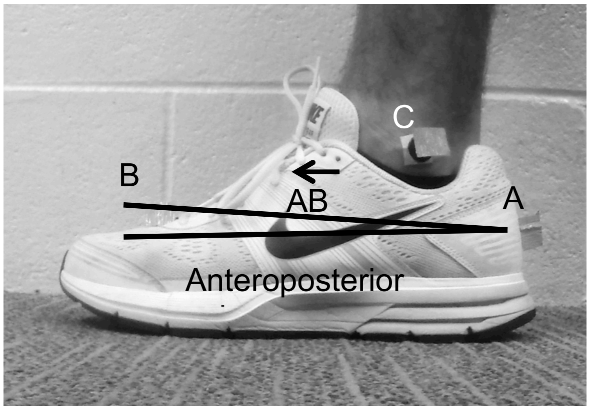
LEGEND TO FIGURES

Figure 1. Marker placement on a participant’s left foot for calculating standing angle ($AB_{standing}$) as described in the Methods.

Figure 2. Mean SI across velocities for the two treadmill types (solid line: ATM; dashed line: LTM). Error bars indicate standard error. Higher values indicate more anterior foot strike patterns.

Table 1. Mean strike index values with standard deviation (SD) for each velocity and treadmill type.

Strike Index (%)		2.91 m*s^{-1}	3.13 m*s^{-1}	3.35 m*s^{-1}	3.58 m*s^{-1}	3.8 m*s^{-1}
Aquatic Treadmill	Mean	63.9	63.8	65.0	66.0	61.6
	SD	23.6	22.3	19.1	18.5	17.2
Land Treadmill	Mean	47.5	44.0	44.0	40.8	39.1
	SD	24.3	22.9	23.4	23.8	24.0



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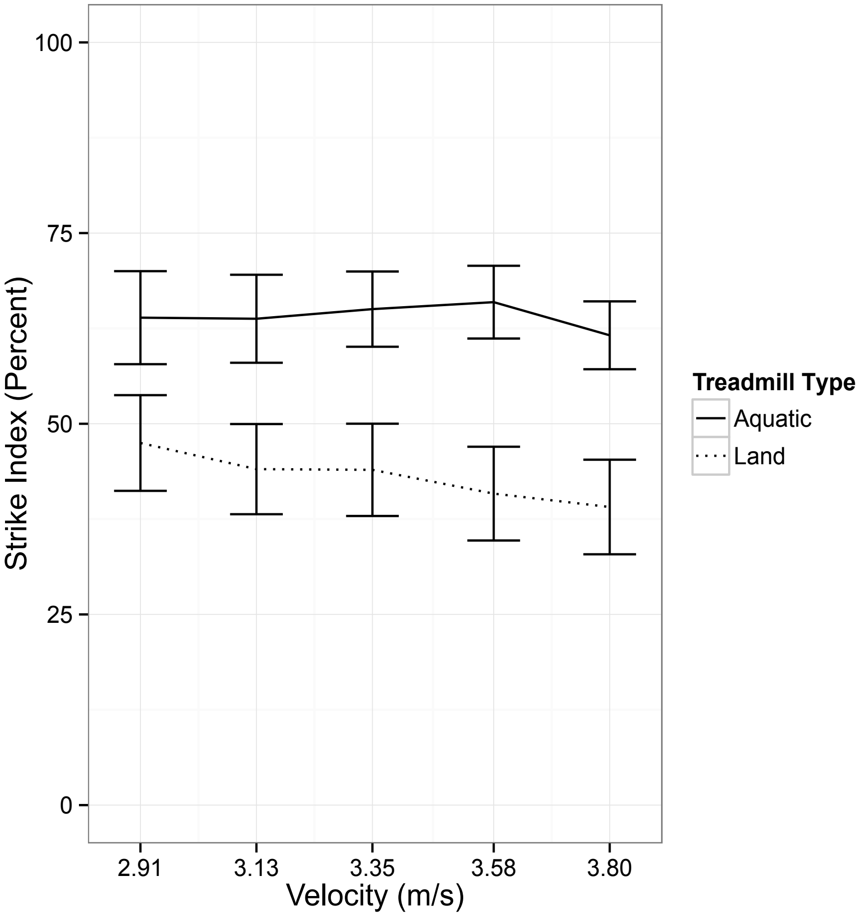

Figure 2. Mean SI across velocities for the two treadmill types. Error bars indicate standard error (solid line: ATM; dashed line: LTM). Higher values indicate more anterior footstrike patterns.