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Original article

Stride length–velocity relationship during running with body weight support

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Abstract

Background: Lower body positive pressure (LBPP) treadmills can be used in rehabilitation programs and/or to supplement run mileage in healthy runners by reducing the effective body weight and impact associated with running. The purpose of this study is to determine if body weight support influences the stride length (SL)–velocity as well as leg impact acceleration relationship during running.
Methods: Subjects ($n = 10$, 21.4 ± 2.0 years, 72.4 ± 10.3 kg, 1.76 ± 0.09 m) completed 16 run conditions consisting of specific body weight support and velocity combinations. Velocities tested were 100%, 110%, 120%, and 130% of the preferred velocity (2.75 ± 0.36 m/s). Body weight support conditions consisted of 0, 60%, 70%, and 80% body weight support. SL and leg impact accelerations were determined using a light-weight accelerometer mounted on the surface of the anterior-distal aspect of the tibia. A 4×4 (velocity × body weight support) repeated measures ANOVA was used for each dependent variable ($\alpha = 0.05$).
Results: Neither SL nor leg impact acceleration were influenced by the interaction of body weight support and velocity ($p > 0.05$). SL was least during no body weight support ($p < 0.05$) but not different between 60%, 70%, and 80% support ($p > 0.05$). Leg impact acceleration was greatest during no body weight support ($p < 0.05$) but not different between 60%, 70%, and 80% support ($p > 0.05$). SL and leg impact accelerations increased with velocity regardless of support ($p < 0.05$).
Conclusion: The relationships between SL and leg impact accelerations with velocity were not influenced by body weight support.

Keywords: Overuse injury; Rehabilitation; Running economy; Stride length–speed

1. Introduction

A lower body positive pressure (LBPP) treadmill uses air pressure in a way that an upward directed force is applied to the user, effectively reducing body weight.[1–8] There is a growing body of research on the biomechanics and physiological response during running at reduced body weight via an LBPP treadmill. For example, it is known that as body weight support increases, ground reaction forces,[3,5,8] metabolic cost,[2,8] and lower extremity muscle activity (in general)[4,6,7] decrease.

Running velocity (m/s) is the product of stride length (SL) (m/stride) and stride frequency (strides/s), and it follows that there is a wealth of information on these parameters during running. For example, it is known that changes in SL more so than stride frequency are closely related to changes in running submaximal velocity[9–11] such that, in general, SL increases as velocity increases.[9–11] Likewise, there is a link between SL and impact characteristics such that the longer the stride the greater the impact.[9,11,12]

Despite the wealth of knowledge on SL and stride frequency, there are only limited data on SL or stride frequency during running with body weight support. Raffalt et al.[8] reported the SL increased as body weight support increased from 0 to 25%, 50%, and 75% support as well as with increasing running velocities (from 2.8 m/s to 6.1 m/s). Gojanovic et al.[2] also reported that SL increased as body weight support increased from 0 to 5%, 10%, and 15% levels of support during a maximal effort graded exercise test (velocities starting at 2.7 m/s). However, there is still a need for more information on these basic kinematic descriptors since the data are limited to elite runners running at high speeds[8] and during maximal

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effort.[2] Information about the SL–velocity (or stride frequency–velocity) relationship during body weight support running at velocities that runners would self-select (*vs*. a prescribed velocity or at maximal velocity) as well as other body weight support levels is important because it gives insight into preferred gait pattern of a runner during submaximal effort—which would be likely used during a rehabilitation program, for example.

Ultimately, how body weight support influences gait patterns may influence decisions about magnitude of body weight support and treadmill speed to use during rehabilitation. Therefore, the purpose of this study was to determine if body weight support influences the SL–velocity relationship during running with an emphasis on high levels of body weight support. Additionally, since impact characteristics may be a risk factor for running overuse injuries,[13] the purpose was to determine if impact characteristics are influenced by body weight support and velocity by measuring leg impact accelerations. It was hypothesized that SL and impact acceleration would increase across velocities at each body weight support level. It was also hypothesized that SL would increase and leg impact accelerations decrease with increases in body weight support.

2. Methods

2.1. Subjects

Ten subjects (4 males, 6 females: 21.4 ± 2.0 years, 72.4 ± 10.3 kg, 1.76 ± 0.09 m) volunteered to participate in this study and gave written informed consent. All subjects were physically active and were comfortable running on the treadmill. All subjects completed all conditions and were free from injury that would interfere in any way with the ability to run on a treadmill. The study was approved by the Institutional Review Board of the host institution.

2.2. Instruments

An LBPP was used for all running conditions (Version 1.20, model: G-Trainer Pro; Alter-G, Inc., Fremont, CA, USA) and subjects were given time to practice using the treadmill prior to testing. To measure SL and leg impact acceleration, an accelerometer (model: 352C67, PCB Piezotronics, Depew, NY, USA) was secured on the surface of the skin at the anterior-distal medial aspect of the tibia. The sensitive axis of the accelerometer was aligned parallel to the long axis of the tibia and held tight to the surface of the skin using an elastic wrap.

2.3. Procedures

After being set up in the LBPP treadmill, subjects performed a self-directed warm-up for up to 10 min that included having subjects run at a variety of body weight support levels. After warm-up, preferred velocity was determined by having the subject self-select a velocity that he/she felt could be maintained for 30 min. The velocity display was hidden from view and the researcher increased/decreased velocity based upon subject feedback. Once the subject selected a velocity, that velocity was recorded and the treadmill was stopped and the process repeated for a total of three times. The test velocity was the average of the three trials and is referred to herein as the preferred velocity.

Subjects completed a total of 16 different running conditions consisting of specific velocity and body weight support combinations. Running velocities tested were 100%, 110%, 120%, and 130% of the preferred velocity. Body weight support conditions consisted of 0, 60%, 70%, and 80% body weight support (i.e., effective weight of 100%, 40%, 30%, and 20% of body weight). Order of conditions was always from slow to fast velocity and in order of increasing body weight support.

Leg acceleration data were collected for 20 s (sample rate: 1000 Hz). Each condition lasted at least 1 min in order to allow an acclimation period (at least 30 s) and a recording period.

2.4. Data reduction

A custom MATLAB program (Version R2010b; MathWorks, Natick, MA, USA) was written to identify 11 consecutive leg impact peak accelerations (leg impact acceleration). Stride frequency was calculated as the inverse of the time between consecutive impact peaks (i.e., 1/stride time, units: Hz). SL (m/stride) was calculated by dividing velocity (m/s) by stride frequency (Hz). For each condition, the 10 SLs and 11 impact accelerations were averaged to represent that condition for each subject. That average value per subject-condition was then used for analysis.

2.5. Statistical analysis

The independent variables in this study were body weight support and velocity. Each dependent variable (SL, leg impact acceleration) was compared across conditions using a 4 (velocity: 100%, 110%, 120%, 130% of preferred velocity) × 4 (body weight support: 0, 60%, 70%, 80% of body weight) repeated measures analysis of variance ($\alpha = 0.05$). If there was a significant interaction between velocity and body weight support, Bonferroni *post hoc* test was used.

3. Results

SL was not influenced by the interaction of body weight support and velocity (Fig. 1A; $F(9, 72) = 1.6$, $p = 0.130$). SL was influenced by body weight support ($F(3, 24) = 21.2$, $p < 0.001$) with SL being shortest during no body weight support ($p < 0.05$) but not different between 80%, 70%, and 60% body weight support levels ($p > 0.05$). SL was influenced by velocity ($F(3, 24) = 115.6$, $p < 0.001$) such that as velocity increased, SL increased regardless of body weight support.

Leg impact acceleration was not influenced by the interaction of velocity and body weight support (Fig. 1B; $F(9, 72) = 1.6$, $p = 0.296$). Leg impact was influenced by body weight support ($F(3, 24) = 6.0$, $p < 0.001$) with leg impact being greatest during no body weight support ($p < 0.05$) but not different between 80%, 70%, and 60% body weight support