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Effects of treadmill running velocity on lower extremity coordination variability in healthy runners

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ABSTRACT

With a growing interest in coordination variability and its role in endurance running, it is important to identify the effect of running velocity. The purpose of the current study was to investigate the effect of treadmill running velocity on the coordination and variability of coordination of lower extremity couplings of healthy runners during stance. Fourteen apparently healthy runners ran on a split-belt force instrumented treadmill at five different velocities. Continuous relative phase (CRP) was used to quantify coordination and variability (vCRP) between lower extremity couplings of the right limb (thigh-shank, thigh-foot, shank-foot) during three phases of stance (loading, mid stance, and propulsion). Multiple one-way repeated measure ANOVAs were conducted to identify differences among velocity conditions at each phase and discrete events (initial foot contact, peak knee flexion during stance, and toe-off). Thigh internal/external rotation (IR/ER)-Shank abduction/adduction (AB/AD) coupling was different during the propulsive phase ($p = 0.02$). Thigh flexion/extension-Shank flexion/extension showed the greatest differences in vCRP across velocity conditions with differences occurring during loading phase, mid stance, propulsive phase, and peak flexion ($p < 0.05$). Additionally, significant differences were seen in Thigh FL/EX-Shank FL/EX (toe-off, $p = 0.01$) and Thigh FL/EX-Foot inversion/eversion (IN/EV) (toe-off, $p = 0.032$). Interestingly, the decreases in vCRP values were accompanied by changes in center of mass vertical motion during stance, but not knee flexion angles. Increases in running velocity led to a more constrained running pattern through a reduction in degrees of freedom.

1. Introduction

Running is a popular sport as evident by the 17 million people who finished an endurance running event (Bush, 2016). It is well established that runners are highly susceptible to overuse injuries (Goss & Gross, 2012; Van Gent et al., 2007), with the incident rate increasing for those training for a marathon (Fredericson & Misra, 2007). Although the running injury mechanism is multifactorial, recent research has explored a possible link between coordination pattern variability and running injuries (Hamill, Palmer, & Van Emmerik, 2012; Hamill, van Emmerik, Heiderscheit, & Li, 1999; Li, Van Den Bogert, Caldwell, Van Emmerik, & Hamill, 1999; Miller, Meardon, Derrick, & Gillette, 2008; Van Emmerik, Rosenstein, Mcdermott, & Hamill, 2004).

Movement coordination variability is the between-stride variability in coordination couplings within a condition, measured as the

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standard deviation (Miller et al., 2008). It is used as a way to identify a functional role in healthy pattern development, which differs from the traditional view of all movement variability being undesirable (Hamill et al., 1999; Preatoni et al., 2013). Coordination variability during performance may be able to be used to infer the health of the neuro-muscular system's ability to generate the desired movement outcome (Preatoni, Ferrario, Dona, Hamill, & Rodano, 2010). For example, runners who had a history of an overuse injury demonstrated a reduction in coordination variability retrospectively (Hamill et al., 2012; Miller et al., 2008). Although connections between or among performance, coordination variability and injury prevention are not fully understood, movement pattern variability may be representative of healthy movement patterns (James, Dufek, & Bates, 2006).

There is limited understanding of how healthy runners adjust coordination and variability of those patterns in response to running perturbations (Hafer, Silvernail, Hillstrom, & Boyer, 2016) and whether there is a prospective connection to run performance. Utilizing a modified vector coding method, perturbations in stride frequency have shown decreased coordination variability in healthy runners (Hafer et al., 2016). However, there is a paucity of data on coordination of healthy runners (regardless of performance and/or injury). It is important to further explore coordination as a possible metric to monitor during a run or throughout a run training program because a change in coordination may be an indication of a new stress placed on the runner. As training requires adjustments in both volume and intensity, or running velocity, it is important to understand how a runner's movement coordination variability is affected by such perturbations when runners have the ability to self-select a running style.

Since run performance is directly linked to running velocity, it seems critically important to determine the influence of changes in running velocity on coordination pattern variability. Therefore, the purpose of the current study was to investigate the effect of changes in running velocity on the coordination patterns and variability of coordination of lower extremity couplings of healthy runners. Coordination couplings were analyzed using continuous relative phase and variability of continuous relative phase. Previous research identified changes in coordination and coordination variability in response to manipulating preferred running patterns (Hafer et al., 2016). Therefore, it was hypothesized that as treadmill running velocity increased beyond preferred, coordination couplings would be adjusted and coordination variability would decrease as velocity increased. In addition, we evaluated center of mass motion and knee flexion during the stance phase as kinematic descriptors of lower extremity compliance.

2. Methods

2.1. Participants

Fourteen participants (9 men and 5 women; 24 ± 2 yrs; 75.2 ± 12.4 kg; 1.71 ± 0.10 m) completed treadmill running at five speeds. All participants arrived at the Sports Injury Research Center where the protocol was explained and they then signed a university-approved informed consent to participate. All participants were free from any lower extremity injury that may have interfered with their ability to run on a treadmill. Inclusion to participate in the study included comfort with treadmill running, indicated by previous running history and self-reporting during warm-up.

2.2 Procedures

All running trials were conducted on a split-belt force instrumented treadmill (FIT, Bertec Corporation, Columbus, OH, USA). Treadmill speed was adjusted by a member of the research team at an acceleration of $1\,\text{m·s}^{-1}\text{·s}^{-1}$. Participants completed a five-minute minimum, self-selected velocity, warm-up period on the treadmill to ensure they were comfortable. Following the warm-up period, participants identified a preferred comfortable running velocity on the treadmill, while blinded to the treadmill velocity display. Participants were instructed to identify a treadmill running speed that they felt they could comfortably maintain for 30 min. A researcher controlled the treadmill velocity and was instructed by the participant to increase or decrease the treadmill velocity until they identified the velocity representative of their 30-minute pace. The researcher then stopped the treadmill. This process was repeated three times with the average of three trials calculated and used to determine the speed settings for all five velocity conditions.

Participants were then instrumented with a cluster marker set modeling the lower extremity and trunk during all trials. Rigid clusters were attached to the lateral aspects of the thigh and shank segments using elastic sporting wraps made of nylon and Lycra (SuperWrap Fabrifoam; Exton, PA, USA) and secured using duct tape. The pelvis, feet, and trunk were modeled using individual 14 mm reflective markers secured with double-sided tape and Cover Roll adhesive tape (BSN Medical, Hamburg, Germany). Kinematic data were collected at 200 Hz using 12-infrared cameras (Bonita; Vicon Motion Systems Ltd., Oxford, UK). Kinetic data were collected at 2000 Hz from a single force platform of the FIT for all participants and trials.

The treadmill running protocol consisted of five running velocities, determined as a function of the self-identified running velocity. The five velocity conditions included: preferred running velocity (PRV), PRV – $0.25\,\text{m·s}^{-1}$ (PRV-0.25), PRV + $0.25\,\text{m·s}^{-1}$ (PRV + 0.25), PRV + $0.5\,\text{m·s}^{-1}$ (PRV + 0.5), and PRV + $1.0\,\text{m·s}^{-1}$ (PRV + 1.0). Reported as a function of the runners preferred running velocity, PRV-0.25 was between 89 and 93% of PRV, PRV + 0.25 between 107 and 111%, PRV + 0.5 between 115 and 119% and PRV + 1.0 was between 129 and 145% of PRV. The selection of the running velocities favored increasing the running velocity because that represents the most likely condition during a training program. All conditions were randomly assigned for all participants to minimize order effects. Each velocity condition consisted of approximately two minutes of running on the treadmill, with the first minute used to allow achievement of a steady running pattern at that treadmill velocity. Following the first minute, two 20-second trials were collected with 10 s between trials. A minimum of one-minute rest was required between velocity conditions and up to five minutes if needed.