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Full Length Article

Magnitude and variability of gait characteristics when walking on an irregular surface at different speeds

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ABSTRACT

Different modes of perturbations have been used to understand how individuals negotiate irregular surfaces, with a general notion that increased locomotion variability induces a positive training stimulus. Individuals tend to walk slower when initially exposed to such locomotion tasks, potentially influencing the magnitude and variability of biomechanical parameters. This study investigated theeffects of gait speed on lower extremity biomechanics when walking on an irregular (IS) and regular surface (RS). Twenty physically active males walked on a RS and IS at three different speeds (4 km/h, 5 km/h, 6 km/h). Lower extremity kinematics (300 Hz) and surface electromyography (3000 Hz) were recorded during the first 90 s of gait. Two-factor repeated measures ANOVA was used to determine surface and speed effects ($p < 0.05$). Gait speed influences walking biomechanics (kinematic and muscle activity parameters) the same irrespective of surface condition. As walking speed increased, sagittal shoe-surface angle, maximum ankle inversion, ankle abduction, knee and hip flexion increased during stance phase when walking on the IS and RS ($p < 0.05$). Increasing walking speed caused increased muscle activity of the tibialis anterior, peroneus longus, gastrocnemius medialis, vastus medialis and biceps femoris ($p < 0.05$) on the IS and RS during the gait cycle. Increased gait, kinematic and muscle activity variability was reported at lower walking speed on both the IS and RS. Further, irrespective of gait speed, walking on an IS triggers postural adjustments, higher muscle activity and increased gait variability compared to RS walking. Our findings suggest the benefits of training on the irregular surface may be further enhanced at slower gait speeds.

1. Introduction

Humans are exposed to uneven terrains in their everyday lives. These are either intentionally chosen, like during trail-walking, or unintentionally experienced, like facing cobbled sidewalks (Daley, 2008; Gates, Wilken, Scott, Sinitski, & Dingwell, 2012; Voloshina, Kuo, Daley, & Ferris, 2013). Methods that induce gait instability on purpose, such as unstable footwear, have received increasing interest, as being regarded to provide general functional training benefits (Apps, Sterzing, O'Brien, Ding, & Lake, 2017; Nigg, Federolf, Tscharner, & Nigg, 2012; Romkes, Rudmann, & Brunner, 2006; Stöggl & Müller, 2012) or being used as rehabilitation tools (Landry, Nigg, & Tecante, 2010; Waddington & Adams, 2004; Wedderkopp, Kaltoft, Lundgaard, Rosendahl, & Froberg, 1991; Wester, Jespersen, Nielsen, & Neumann, 1996). These methods require the neuromuscular system to continually make alterations to counteract the instability induced, which has been observed through an increase in movement variability (Apps et al., 2017). Regular use

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of these methods is suggested to enhance balance and train lower-limb musculature (Nigg et al., 2012). Recently, irregular surfaces have been used to investigate the effects of less predictable and variable instability during locomotion (Sterzing, Apps, Ding, & Cheung, 2014; Muller & Blickhan, 2010; Voloshina et al., 2013).

When initially exposed to an irregular surface (IS), the infinite landing possibilities impair users' ability to sense and control ground contact during walking, causing them to rely on active and passive lower-extremity alterations to maintain stability (Sterzing et al., 2014). Individuals demonstrated increased hip and knee joint flexion with lower ankle dorsiflexion during the gait cycle when walking on an irregular surface (Apps et al., 2017; Gates et al., 2012; Muller & Blickhan, 2010; Sterzing et al., 2014). Increased muscle activation of the gastrocnemius medialis (GM), vastus medialis (VM) (Apps et al., 2017; Voloshina et al., 2013), peroneus longus (PL) (Sterzing et al., 2014) and biceps femoris (Apps et al., 2017) are also acute responses. Further, increased variability in lower-limb kinematics and muscle activity is evident (Apps et al., 2017; Gates et al., 2012; Sterzing et al., 2014; Voloshina et al., 2013), which is associated with functional training benefits (Apps et al., 2017; Latash, 2012; Sterzing et al., 2014).

Locomotion speed is an important performance indicator which influences the biomechanical and physiological elements of movement. Alterations in gait speed influence metabolic cost (Moore, Jones, & Dixon, 2014; Russell, Braun, & Hamill, 2010), alter foot-strike patterns (Keller et al., 1996) and can cause the walk to run transition (Van Caekenberghe, Segers, De Smet, Aerts, & Clercq, 2010). It is widely documented that altering gait speed also influences the fundamental biomechanical characteristics of bipedal locomotion, such as spatio-temporal parameters, joint kinematics, kinetics, and muscle activity (Chiu & Wang, 2007; den Otter, Geurts, Mulder, & Duysens, 2004; Nymark, Balmer, Melis, Lemaire, & Millar, 2005; Schwartz, Rozumalski, & Trost, 2008; Van der Linden, Kerr, Hazlewood, Hillman, & Robb, 2002). Increasing gait speed is associated with reduced ground contact time, with individuals displaying increased hip and knee joint flexion during ground contact (Nymark et al., 2005; Schwartz et al., 2008; Van der Linden et al., 2002). Muscle activity of the GM, soleus, rectus femoris (RF) and biceps femoris (BF) increase with increasing walking speed during stance phase (den Otter et al., 2004). Gait variability has been found to reduce with increasing gait speed on regular surfaces (Almarwani, Van Swearingen, Perera, Sparto, & Brach, 2016; Dingwell, Cusumano, Cavanagh, & Sternad, 2001; Dingwell & Marin, 2006; Li, Haddad, & Hamill, 2005), where slower walking speeds pose a more challenging task to an individual's motor control of gait (Hausdorff, 2004, 2005). On irregular surfaces where instability is already present, reducing speed might further destabilise users, potentially enhancing the training stimulus. However, it is currently unknown if individuals respond similarly to speed changes when walking on regular and irregular surfaces.

When exploring how individuals initially respond to methods that induce gait instability, researchers often adopt self-selected speeds (Grimmer, Ernst, Gunther, & Blickhan, 2010; Romkes et al., 2006; Wurdeman, Yentes, Huben, & Stergiou, 2012), whereby individuals will generally walk slower when exposed to unstable situations (Romkes et al., 2006; Wurdeman et al., 2012). This likely influences the magnitude of kinematic and muscle activity documented. As methods inducing instability are often used for training or rehabilitation purposes, understanding how walking speed influences the magnitude and variability of gait parameters in unstable situations is needed to ensure people are exposed to the right locomotion speed, to have them benefit the most from variable stimuli. Therefore, identifying how gait speed influences gait characteristics in an unstable condition is an important issue to address.

The purpose of this study is to determine initial changes in walking biomechanics on an unpredictable irregular surface, when walking speed is altered. This research is explorative in nature to determine if walking biomechanics alter similarly between regular surface and irregular surface walking when speed is altered. Based on previous research, it was hypothesised that walking on an irregular surface triggers postural adjustments, higher muscle activity and higher movement variability compared to walking on a regular surface, irrespective of gait speed.

2. Methods

2.1. Participants

Twenty physically active male sport science students (mean (SD): 22.2 (2.0) years; 1.80 (0.06) m; 67.1 (5.3) kg; 21.7 (1.8) kg/m^2) participated in this research. Participants had no previous experience of instability training and had no lower extremity injuries in the previous six months. Ethical approval was granted from the corresponding University Human Research Ethics Committee and participants provided written informed consent.

2.2. Instrumentation

All walking trials were performed on a treadmill (Pro XL, Woodway Inc., WI, USA). The treadmill belt slats were covered with Velcro strips (700 mm × 58 mm), which served as the regular surface (RS). The irregular surface (IS) was created by randomly fixing four types of EVA foam dome shaped inserts (diameter:140 mm) of different heights (10 and 15 mm) and hardness (40 and 70 Asker C) to the treadmill belt via Velcro attachment, as used in previous research (Fig. 1) (Apps et al., 2017; Sterzing et al., 2014). To eliminate visual targeting of foot placements, participants were instructed to look straight ahead during all trials.

Three-dimensional kinematics were collected using an eight-camera motion analysis system (300 Hz) (T40 series, Vicon, Oxford, UK). Twenty-four reflective markers (diameter: 14 mm) were attached to the left leg after respective palpation and marking. Anatomical markers were placed on the tip of the shoe, dorsal metatarsal head 1 and 5, distal posterior heel, lateral calcaneus, lateral and medial malleoli, lateral and medial femoral epicondyles, the greater trochanter, left and right anterior superior iliac spine and left and right posterior superior iliac spine. Rigid, lightweight tracking plates with 4 maker clusters were placed on the lateral thigh and shank. Additional markers were placed on the tip distal posterior heel and lateral calcaneus of the right shoe.

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