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Full Length Article

Adaptation of lower limb movement patterns when maintaining performance in the presence of muscle fatigue

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A B S T R A C T

Adaptations in lower limb movement patterns were examined when performance was maintained during a fatiguing repetitive loading task. Forty recreationally active male and female participants performed single-leg hopping to volitional exhaustion at 2.2 Hz to a submaximal height. Spatio-temporal characteristics, mechanical characteristics and variability of the knee-ankle and hip-knee joint couplings were determined at 20% increments during the duration of the hopping task. Variability of the knee-ankle and hip-knee couplings in the flexion/extension axis significantly increased during the loading and propulsion phases during the hopping task ($p < 0.05$). Performance (vertical stiffness, hopping frequency and height) did not change significantly during the task ($p > 0.05$), however foot contact time increased progressively during this task ($p < 0.05$) and maximum hop height significantly decreased after the task ($p < 0.05$). The observed increase in variability between adjoining lower limb segments demonstrated the ability of the neuromotor system to adapt and maintain performance even with the onset of fatigue. This finding highlights that during the performance of a rapid and repetitive loading activity, performance can be preserved when there is variability in the neuromotor system.

1. Introduction

Variability is an inherent characteristic of human movement that occurs at multiple levels of movement organisation (Preatoni et al., 2013). Although low variability in performance output is desirable, variability in the movement between couplings (two joints or segments) (Fig. 1) has been suggested to play a functional role and contribute to a successful performance output during repetitive tasks (Hamill, Palmer, & van Emmerik, 2012; Latash, 2012; Preatoni et al., 2013). Coupling variability may provide flexibility to the system by permitting adaptation to movement errors or changes in intrinsic or extrinsic factors, such as fatigue or the environment respectively (Bartlett, Wheat, & Robins, 2007; Hamill et al., 2012; Hamill, van Emmerik, Heiderscheit, & Li, 1999; Preatoni et al., 2013). Therefore, greater coupling variability is postulated to be beneficial by permitting multiple movement solutions to a specific task (Bartlett et al., 2007; Hamill et al., 2012, 1999; Preatoni et al., 2013). However, too much or too little coupling variability may be detrimental to the musculoskeletal system and associated with pathology whereby, optimal variability is within the range of these extremes (Bartlett et al., 2007; Hamill et al., 2012, 1999; Preatoni et al., 2013).

There are conflicting findings in the literature of changes in coupling variability as fatigue progresses during repetitive tasks. Coupling variability of the thigh-shank and the shank-foot did not change during running to fatigue (Miller,

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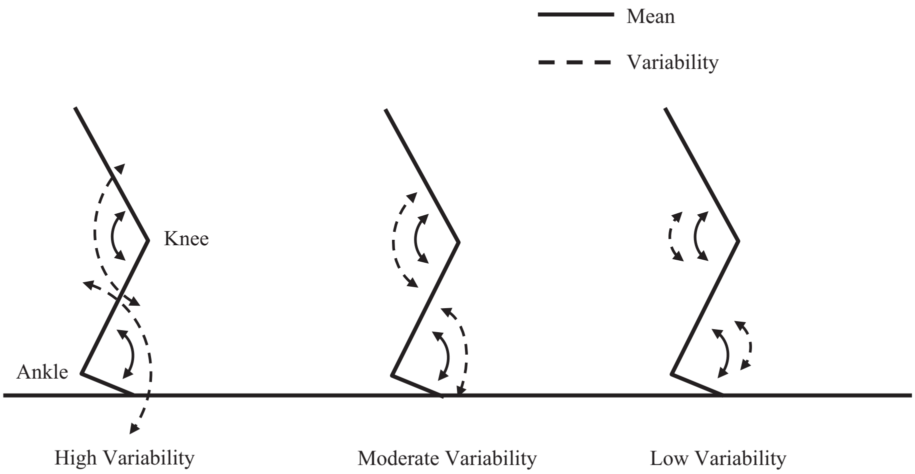

Fig. 1. Schematic diagram representing mean (solid line) movement for each joint of the knee – ankle coupling over a consecutive number of cycles with the variability (dashed line) overlayed. Although mean joint movement remains the same, coupling variability is high on the left, moderate in the middle and low on the right.

Meardon, Derrick, & Gillette, 2008). In contrast, variability of the hip-knee coupling decreased during a 45° anticipated cutting task following an isolated hamstring fatigue protocol (Samaan, Hoch, Ringleb, Bawab, & Weinhandl, 2015). Further, variability of the shank-rear foot coupling was shown to increase during treadmill walking following localised fatigue of the tibialis posterior muscle (Ferber & Pohl, 2011). Trunk-thigh and thigh-shank coupling variability also increased during the performance of a repetitive maximal vertical jump test (Dal Pupo, Dias, Gheller, Detanico, & Santos, 2013).

These conflicting findings may be due to the measure of variability being sensitive to either, differences in tasks between studies or changes in the performance output that would likely occur during a fatiguing task (Miller et al., 2008). Thus, performance output characteristics that modulate leg stiffness and were not reported in previous studies, such as stride length (Miller et al., 2008), force output (Samaan et al., 2015) or jump height (Dal Pupo et al., 2013), may have changed as fatigue increased and may have directly affected the measurement of coupling variability. Further, it is difficult to differentiate possible effects due to warm-up, motor learning during repetitive tasks or fatigue, when coupling variability was not measured regularly (Dal Pupo et al., 2013; Ferber & Pohl, 2011; Miller et al., 2008; Samaan et al., 2015) during a repetitive task.

It remains unclear as to whether the reported changes in coupling variability were due to changes in task performance or in fact due to fatigue. The purpose of this study was to examine the effect of local muscle fatigue on coupling variability when performance output was maintained during a repetitive loading task. It was hypothesised that coupling variability would increase when performance output was maintained in the presence of increasing muscle fatigue.

2. Methods

2.1. Participants

Forty recreationally active males (n = 20) and females (n = 20) (mean ± standard deviation (SD) 22.7 ± 3.0 years of age; 1.7 ± 0.1 m in height; 68.8 ± 10.7 kg in mass) volunteered to participate in this study. All participants were healthy and reported participating in exercise for between 1 and 4 h per week. Participants reported no past or current history of lower limb pathology, injury, pain or lower limb fracture within the six months prior to testing. Participants were excluded if they had a history of lower limb surgery(s). Ethical approval (H1074) was granted by the University of Western Sydney Human Research Ethics Committee and all participants provided written informed consent prior to testing.

2.2. Instrumentation

Kinetic and kinematic data were collected synchronously during single-leg, on-the-spot hopping to volitional exhaustion. Kinetic data were sampled from a multicomponent 600 × 400 mm force plate (Advanced Mechanical Technology, Inc., model BP400600-1000, Watertown, MA) at 1500 Hz. Kinematic data were sampled using an Optotrak Certus System (Northern Digital Inc., Waterloo, Canada) at 150 Hz (First Principles, Version 1.2.4) and processed using Visual 3D (C-Motion, Version 4, Germantown, MD).

2.3. Participant preparation

Following measurement of each participant's height and body mass, a warm-up and a hopping familiarisation period was completed (Hobara, Kobayashi, Kato, & Ogata, 2013). To indirectly control task performance of vertical stiffness, a target