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Does providing real-time augmented feedback affect the performance of repeated lower limb loading to exhaustion?

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ABSTRACT

Introduction: This study aimed to determine whether real-time augmented feedback influenced performance of single-leg hopping to volitional exhaustion.
Methods: Twenty-seven healthy, male participants performed single-leg hopping (2.2 Hz) with (visual and tactile feedback for a target hop height) or without feedback on a force plate. Repeated measures ANOVA were used to determine differences in vertical stiffness (k), duration of flight (t_f) and loading (t_l) and vertical height displacement during flight (z_f) and loading (z_l). A Friedman 2-way ANOVA was performed to compare the percentage of trials between conditions that were maintained at 2.2 Hz $\pm$ 5%. Correlations were performed to determine if the effects were similar when providing tactile or visual feedback synchronously with the audible cue.
Results: Augmented feedback resulted in maintenance of the t_f, z_f and z_l between the start and end of the trials compared to hopping with no feedback ($p < 0.01$). With or without feedback there was no change in t_l and k from start to end. Without feedback, 21 of 27 participants maintained >70% of total hops at 2.2 $\pm$ 5% Hz and this was significantly lower ($p = 0.01$) with tactile (13/27) and visual (15/27) feedback. There was a strong correlation between tactile and visual feedback for duration of hopping cycle (Spearman's $r = 0.74$, $p \leq 0.01$).
Conclusion: Feedback was detrimental to being able to maintain hopping cadence in some participants while other participants were able to achieve the cadence and target hop height. This indicates variability in the ability to use real-time augmented feedback effectively.

1. Introduction

The use of augmented feedback to affect motor performance is commonplace during exercise, training and rehabilitation [1]. Feedback is commonly provided during or after performance of a motor task, providing knowledge of performance or results [2]. When feedback is provided during the performance of a motor task in real-time it is thought to allow an individual to adapt their motor system instantaneously, rather than after completion of the task. This is particularly relevant to the performance of sustained and repetitive tasks such as during gait retraining [3] or tasks that may induce fatigue.

There are demonstrable changes in ground reaction force, leg spring mechanics, loading rate, kinematics and neuromuscular characteristics during running induced fatigue [4]. There is also evidence supporting the finding that fatigue induces changes in the central nervous system, such as alterations in cortical excitability [5]. Although it is not known whether these changes were deleterious or protective of the musculoskeletal system, a key strategy during training and rehabilitation has been to aim to maintain a consistent motor performance during the onset of fatigue and towards exhaustion. A recent and innovative study demonstrated that a combination of visual and auditory feedback provided in real-time, was able to influence vertical displacement and step frequency during treadmill running at 16 km h^{-1} [6]. This finding suggests that augmented feedback could be an effective method for controlling or inducing changes in motor performance during a task requiring rapid and repetitive movement. Findings such as a decrease in triceps surae muscle strength [7] and lower limb kinematic changes [8] following prolonged running, provide the impetus to use real-time augmented feedback to influence

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motor performance which was altered. There are numerous variables such as mechanical work during running [6] that are commonly used in human movement studies. Measures which may describe performance in a motor task may also include spatiotemporal and mechanical characteristics.

The hopping task has been used to examine the effects of repeated and rapid loading of the lower limb muscles [9]. It has been reported that by simultaneously controlling hopping frequency and hop height, work output remained constant throughout double-leg hopping [10]. However, no study has evaluated the effectiveness of different types of augmented feedback to control motor performance during single-leg hopping to fatigue. Further, the efficacy of using augmented feedback to control motor performance during single-leg hopping more closely represents common gait patterns such as walking and running. Empirically determining whether motor performance is able to be controlled using augmented feedback may provide an innovative approach to investigate the effects of fatigue on the motor system during rapid loading tasks.

The dual task interference paradigm is well recognised. However, it is not known how the provision of more than one type of feedback or cue during a rapid and repeated lower limb loading task would interfere with the performance or consistency of the task. Studies have examined the dual task paradigm during performance of a number of different dynamic activities involving lower limb function such as postural control [11] and gait [12]. However, these tasks have used cognitive distraction and been most commonly performed in participants with impairment of gait and postural control, at a self-selected pace and not required rapid and repeated loading to exhaustion. Of specific interest in the current study was the use of augmented feedback which is commonplace during sporting activities and rehabilitation. Therefore, the purpose of this investigation was to determine whether real-time augmented feedback affected a change in performance and strategy of single-leg hopping to exhaustion.

2. Methods

Twenty seven healthy, recreationally active males (means (SD)) (22.4 years (2.7) of age, 178.6 cm (5.7) in height, 78.6 kg (11.6) in body mass) volunteered to participate in this study. Ethical approval was granted by the institutional human research and ethics committee and participants provided written and informed consent prior to testing.

All participants were male, aged between 18 and 35 years and were participating in at least 3 hours of low to moderate physical activity every week for the six month period prior to testing with the aim to control for the amount of training under load which participants had been exposed to [13]. Elite or highly trained athletes were not specifically excluded based on the inclusion criteria which were consistent with participants being exposed to a minimum level of physical activity. Participants were excluded if they reported an injury to the lower limb, back or spine in the six-month period immediately prior to testing or any on-going chronic injury or pain in these regions to ensure that performance was not influenced by pain or physical impairment.

Participants wore above knee shorts and a loose fitting shirt during testing. Standing height, height to the level of the canthus and body mass were recorded. Participants conducted a warm-up that included walking overground for 5 min at a brisk pace (~6–8 km/h) followed by a series of lower limb and trunk static stretches [14]. All hopping trials were performed barefoot on the self-reported dominant leg [15]. Participants then performed a familiarisation period hopping on a force plate with (visual or tactile) and without feedback to hop to a target height. Participants were instructed to keep their hands on their hips and hop in synchrony with a metronome at 2.2 Hz [16]. Participants were also instructed to hop without contacting their heel with the force plate and minimising forwards, backwards and sideways translation. Familiarisation trials were performed for 10 s with a minimum 60 s rest between efforts. Each participant then completed a pre-test trial lasting 20 hops during which vertical ground reaction force (vGRF) data was recorded (Kistler 9286B data acquisition type 5691A1). This data was used to calculate the target hop height for each participant for the three trials performed to volitional exhaustion.

Real-time visual feedback was provided by placing a 1450 mm × 500 mm mirror in front of the force plate with a strip of tape (15 mm wide) adhered horizontally across the mirror at the top of the target hop height. For this condition, participants were instructed to hop to a height such that they could no longer see a reflection of their eyes as it was obscured by the tape. Real-time tactile feedback was provided by instructing the participant to hop to a height such that their head lightly touched a series of 5 mm wide elastic bands placed horizontally above their head. The sham feedback condition required the participant to hop with the mirror placed 2 m in front of the force plate and with a 30 mm diameter circular marker adhered over the sternum. The participant was instructed to focus their attention on the marker reflection as it was observed in the mirror in front of the participant. Viewing the marker in the mirror by the participant as they hopped did not provide any information about the target hop height.

The three hopping trials were performed in a random order and a 10 minute rest period [17] was maintained between trials to allow recovery between trials. Throughout each trial participants were instructed to maintain hop frequency with the metronome and maintain the correct hop height in the feedback conditions. No prioritisation of each requirement was instructed. Once testing was completed, each participant performed a cool-down by walking overground for 5 min and performing a series of lower limb static stretches [18].

2.1. Data processing

To calculate the target hopping height, five consecutive hops from the pre-test trial were identified and the peak vGRF for each hop cycle was labelled. The target hop height was determined as the mean of the vertical displacement of the centre of mass (COM) during flight phase (z_f) for the five hop cycles, added to the standing height of the participant (h). Eq. (1) was used to determine z_f for each hop cycle (complete flight phase and subsequent contact phase).

$$z_f = \frac{1}{2} \cdot g \cdot \left(\frac{t_f}{2}\right)^2 \quad (1)$$

where z_f represents vertical displacement of the COM during the flight phase from peak height during flight to initial contact (IC), g was the acceleration due to gravity and t_f was the total duration of the flight phase.

The target hop height with visual and tactile feedback was calculated as z_f added to the participant's height to the lateral canthus in standing.

Vertical ground reaction force data for each trial were filtered using a Low Pass Butterworth filter with a low-pass cut-off frequency of 50 Hz (Bioware™ version 5.1.0.0). The data was then exported to a Microsoft excel spreadsheet (Microsoft Excel 2010). The total hopping duration of each trial was determined. For each trial the hop cycles that were performed at 2.2 Hz ± 5% (i.e., hop cycle duration ranging from 433 to 478 ms) were included for the initial analyses to compare start and end periods. All hopping trials were truncated to include the first ten (start period) and last ten (end period) consecutive hop cycles performed at 2.2 Hz ± 5%. A hop cycle