EFFECTS OF FATIGUE ON MOVEMENT VARIABILITY DURING STRETCH-SHORTENING CYCLE

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Although lower limb injury has been linked to fatigue, it is unknown whether movement variability may act as a protective mechanism, possibly reducing the risk of an athlete developing an overuse injury. Therefore, the aim of this study was to establish the effects of fatigue on movement variability during the stretch-shortening cycle. Thirteen male athletes performed a submaximal stretch-shortening cycle (SSC) fatigue protocol, with three-dimensional kinematic and kinetic recorded for each participant's lower limbs. When fatigued, athletes substantially increased their movement variability, whilst maintaining similar kinematics compared to when non-fatigued, suggesting that athletes with flexible motor behaviours and adaptability increase their movement variability when fatigued and, in turn, may decrease their risk of a developing an overuse injury.

KEY WORDS: landing, fatigue, movement variability, lower limb injury.

INTRODUCTION: Traditionally treated as noise within data (Bartlett, Wheat, & Robins, 2007) or to be an unimportant (Bartlett, et al., 2007) or confounding issue for experimental design, it has now been suggested that movement variability is essential for functional adaptation to dynamic environments (Davids, Shuttleworth, Button, Renshaw, & Glazier, 2004) and a protective mechanism against overuse injuries (James, Dufek, & Bates, 2000; Bartlett, et al., 2007). Movement variability is thought to allow better load distribution among different tissues (James, et al., 2000; Bartlett, et al., 2007), different areas within the same tissue, or within the same tissue or location at different times (James, et al., 2000). By enabling longer adaptation time for tissues between loading events, this may allow the detrimental effects of repetitive loading to be reduced (James, et al., 2000). Therefore, movement variability may be considered a protective mechanism against overuse injuries by altering the characteristics of loading application to minimise accumulation of load in a central region (James, et al., 2000).

Alternatively, lower limb fatigue may be a mechanism that increases injury risk (Ostenberg & Roos, 2000; Hawkins, Hulse, Wilkinson, Hodson, & Gibson, 2001; Chappell, Herman, Knight, Kirkendall, Garrett, & Yu, 2005), as a higher incidence of injuries occur towards the end of both halves (Hawkins, Hulse, Wilkinson, Hodson, & Gibson, 2001) or in the later part of competitive team games (Ostenberg & Roos, 2000; Hawkins, et al., 2001). It is thought that fatigue has the potential to alter the way athletes land, in turn, modifying their knee joint forces (Chappell, et al., 2005), as fatigued muscles are thought to have less ability to absorb the loads generated during jumping and landing tasks (Nicol, Komi, Horita, Kyröläinen, & Takala, 1996). It is remains unknown, however, whether fatigue-induced alterations to an athlete's movement variability alter an athlete's risk of developing overuse injuries in sports that involve repetitive landings. As repetitive SSC muscle action is characteristic of running (Horita, Komi, Nicol, & Kyröläinen, 1996; Nicol, Avela, & Komi, 2006) and dynamic jumping and landing movements (Horita, et al., 1996; Nicol, et al., 2006), a fatigue protocol requiring repeated use of the SSC offers an ideal model to investigate lower limb fatigue (Nicol, et al., 2006). Therefore, this study aimed to investigate the effects of fatigue on movement variability during the SSC. It was hypothesized that in response to fatigue, participants would increase their movement variability during the SSC compared to a non-fatigued condition.

METHODS: Thirteen skilled male athletes (23.7 ±4.0 y; 183.0 ±6.2 cm; 82 ±10.4 kg), who reported no history of traumatic lower limb injuries were recruited to perform a familiarisation session of the fatigue protocol and, a minimum one week later, performed the fatigue protocol (Edwards, Steele, McGhee, Cook, & Purdam, 2011). At each session, the participants completed a 5- to 10-min warm-up of cycling on an ergometer (Monark Model 818E, Sweden), followed by a familiarisation with the SSC exercise on the sledge apparatus, and the taking of a pre-fatigue blood lactate sample from the participant's fingertip. The participants then performed three maximal SSC exercises, followed by the fatigue protocol, after which post-fatigue blood lactate samples were immediately taken. Participants performed the maximal and submaximal SSC exercises on a custom-built 23 kg sledge apparatus, which had a seat that glided along a track inclined 23.6° from the horizontal. The fatigue protocol involved participants repeatedly performing sets of 30 submaximal SSC efforts, immediately followed by 30 seconds rest. The protocol continued until the participants were deemed to be fatigued either when they could no longer reach 70% of their maximal SSC exercise rebound height for three out of five submaximal SSC exercises or when the participants self-terminated the fatigue protocol as they felt that they could no longer continue. An increase in blood lactate of at least 6 mmol/L was also used to confirm fatigue using an Accusport blood lactate analyser (Boehringer Mannheim, Germany).
During each of the submaximal and maximal SSC efforts, ground reaction forces generated at landing were recorded (1,000 Hz) using two multichannel force platforms (Kistler, Winterthur, Switzerland) that were fixed to the sledge frame, perpendicular to the sliding track. The participant's three-dimensional lower limb motion during each SSC effort was recorded (100 Hz) using an OPTO*TRAK*® 3020 motion analysis system (Northern Digital, Waterloo, Canada). The kinetic and kinematic data were time synchronised and collected using ToolBench software (Version 3.00.34, Northern Digital, Waterloo, Canada).
Analyses of the kinematic and kinetic data were performed using Visual 3D software (Version 3, C-Motion, Maryland, USA). The raw kinematic coordinates (f_c=8 Hz) and the ground reaction forces (f_c=50 Hz) were initially filtered using a fourth-order zero-phase-shift Butterworth digital low pass filter. Although data for each lower limb were collected, this study was restricted to data calculated for each participant's dominant limb, defined as the lower limb the subject used to kick a ball and all participants were right leg dominant. For the last 10 SSC exercise efforts in the first and final set, the within-subject coefficient of variation (CV) were calculated for the ankle and knee joint angles at initial-force platform contact and at the times of the peak resultant vertical ground reaction force during the during the landing phase (F_{RL}) and propulsion phase (F_{RP}), at the time of the peak knee flexion angle ($Knee_{MAX}$), and takeoff. Using the statistical analysis software PAWS (Version 17, SPSS Inc.), a repeated measured ANOVA was used to estimate the within-subject (error) variance for each variable in each fatigue-condition. Movement variability was assessed as the coefficient of variation (CV), expressed as a percentage, and was calculated by dividing the square root of the within-subject (error) variance by the fatigue-condition mean. A ratio of the CV of the two fatigue-conditions that differed by a factor of less than 0.85 or greater than 1.15 was deemed to indicate substantial between-fatigue conditions differences in movement variability (Hopkins & Hewson, 2001). The data were then analysed using a series of paired *t*-tests to show the magnitude of the effects. Effect sizes were calculated and magnitudes were assessed using the following criteria: <0.19=trivial; 0.20-0.49=small; 0.50-0.79=moderate; and >0.80=large (Cohen, 1988).

RESULTS: When fatigued, participants displayed increased movement variability of the ankle joint angle at the time of the peak $Knee_{MAX}$, peak F_{VP} and take-off, and knee joint angle at the time of IC and peak F_{VP} when compared to the non-fatigued condition (Table 1). In contrast, movement variability decreased in the fatigue condition compared to the non-fatigue condition for ankle joint angle at the time of the peak F_{VL}. Participants only displayed moderately less knee flexion at the time of the peak F_{VL} when fatigued compared to non-fatigued condition.

Table 1: Movement variability of stretch-shorting cycle between non-fatigued and fatigued conditions.

Event	Ankle Joint Angles						Knee Joint Angles					
	Non-Fatigued		Fatigued		CV Ratio	d_a	Non-Fatigued		Fatigued		CV Ratio	d_a
	Mean	CV %	Mean	CV %			Mean	CV %	Mean	CV %		
IC	36.9	7.6%	41.6	7.3%	1.04#	0.46	25.2	13.1%	25.3	16.1%	0.81#	0.03†
Peak F_{VL}	84.4	5.8%	86.2	3.4%	1.68*	0.27	66.4	10.6%	61.9	10.5%	1.02#	0.58†
Peak $Knee_{MAX}$	88.5	2.6%	89.6	15.2%	0.17#	0.16	86.1	3.6%	84.5	4.1%	0.90#	0.16†
Peak F_{VP}	87.3	8.7%	88.2	25.3%	0.34#	0.12	76.4	9.7%	74.6	22.6%	0.43#	0.23†
Take-off	33.6	10.9%	32.3	76.2%	0.14#	0.11	10.3	52.0%	9.6	47.9%	1.09#	0.13†

Initial foot-force platform contact (IC), peak resultant ground reaction force during the landing phase (F_{VL}), and peak vertical ground reaction force during the propulsion phase (F_{VP}).
*Indicates substantial different within-subject CV ratio by a factor >1.15 with *non-fatigued* condition displaying higher movement variability compared to fatigued condition.
#Indicates substantial different within-subject CV ratio by a factor <0.85 with *fatigued* condition displaying higher movement variability compared to non-fatigued condition.
†Indicates moderate effect between fatigue-conditions.

DISCUSSION: Although fatigue has been associated with an increased risk of overuse injuries as fatigued muscles are thought to have less ability to absorb the loads generated during repetitive loading, participants may counteract this negative effect by adapting to the ever changing environmental conditions by altering their movement variability. The results of this study support our hypothesis that when fatigued, participants increased their movement variability to adapt to these changing demands and conditions.

Movement variability may be considered a protective mechanism against overuse injuries by altering the characteristics of loading application to minimise accumulation of load in a central region (James, et al., 2000), and the detrimental effects of repetitive loading may be reduced by enabling longer adaptation time for tissues between loading events (James, et al., 2000). This suggests that if an individual displays a lack of movement variability in response to ever changing task demands and environmental conditions, they may utilise rigid, inflexible motor behaviours with limited adaptability (Stergiou, Harbourne, & Cavanaugh, 2006), and increase the risk of developing an overuse injury (James, et al., 2000; Bartlett, et al., 2007).

The effect of fatigue during the SSC lead to high response variability and large inter-individual variations (Regueme, Nicol, Barthelemy, & Grelot, 2005), which may explain why the only moderate difference between fatigue conditions was decreased knee flexion at the time of the peak F_{VL}. The lack of between-fatigue condition effects may be a limitation of utilising a vertical landing task as the experimental protocol as our previous research has shown that most significant between-fatigue condition differences were evident during a horizontal landing rather than the vertical landing task (Edwards, 2010).

CONCLUSION: Increases in movement variability can act as a protective mechanism to counteract the negative effects of fatigue by altering the magnitude, rate, frequency and/or application site of a load to prevent an overuse injury compared to a non-fatigue condition. This suggests that an athlete with rigid, inflexible motor behaviours with limited adaptability does not increase their movement variability when fatigued and, in turn, may increase their risk of a developing an overuse lower limb injury.

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