Controlling total body momentum during landings under fatigued and non-fatigued conditions

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Introduction

The mechanical objective of a landing following by a jumping task is to control and redirect the total body momentum (McNitt-Gray et al, 1993). Exposure to high repetition of the large external reaction force (3 – 11 times body weight) experienced during landing in order to control total body momentum posts a major risk for lower extremity injury in athletes participating in jumping and landing activities. High incidence of lower extremity injury reported during the second half a game or training session of sports involving jumping and landing activities (NCAA, 1989) suggests localized muscle fatigue contributes to injury. The purpose of this study was to determine if female volleyball players modify lower extremity control when performing the same landing task under fatigued and non-fatigued conditions. We hypothesized that the degree of asymmetrical loading between legs during the landing of volleyball blocks (McNitt-Gray et al., 1998) was likely to increase with fatigue and induce greater mechanical demand on the lower extremity. We expected, however, that individuals would use the same set of muscles to control forces and moments induced by the reaction force.

Methods

Four female volleyball players (186 ± 7 cm, 668.61 ± 58 N), who played the position of outside hitter and middle blocker, volunteered to serve as subjects in accordance with the Institutional Review Board for Human Subjects. All subjects were injury-free at the time of data collection and medically cleared for full participation in practice and games. During the non-fatigued landing condition, the subjects moved laterally to the left using normal footwork, jumped from the floor and blocked a suspended ball with palms facing the ball, landed, and immediately moved laterally to the right using their normal landing strategy. The fatigued condition started when the athletes were unable to reach 90% of their maximum jump height for three consecutive trials. Sagittal plane kinematics (200 Hz), ground reaction force (1600 Hz) and electromyogram (EMG) (1600 Hz) of seven lower extremity muscles were collected simultaneously. These three data sets were synchronized at time of foot contact. Inverse dynamics (Elftman, 1939) was used to calculate net joint moment (NJM) at the ankle, knee, and hip. EMG data were filtered (10 – 350 Hz band pass filter), rectified and integrated. The EMG data were normalized to the maximum value observed during land and stop task (McNitt-Gray et al., submitted). Binned (20 ms) NJM and normalized integrated EMG were compared within subject between tasks. Between task differences in average integrated EMG and NJMs were tested using the 95% confident interval.

Results & Discussion

Differences in mechanical demand (lower extremity net joint moments) were associated with the differences in reaction force during landing. Greater reaction forces imposed on the lead leg were observed during the fatigued condition than the non-fatigued condition for two of four subjects. As a result, the NJMs of at least one joint was significantly greater during the fatigued condition than the non-fatigued condition for these two subjects (Figure 1a). One of the remaining two subjects experienced similar reaction force and NJM during
the impact phase of both landing conditions. The other subject encountered less reaction force during the fatigued condition than the non-fatigued condition and demonstrated significantly less NJMs (Figure 1b). During the impact phase, an out of phase oscillation of the knee and hip NJM was observed in both landing tasks (McNitt-Gray et al. 1993; accepted; submitted). These results suggest subjects respond differently to fatigue. When accounting for electromechanical delay (40 ms, Komi and Gollhofer, 1997) muscle activation patterns and EMG levels fluctuated with NJM demands, but the set of muscles used by an individual was the same between conditions. In both landing conditions, co-activation of the knee flexors and extensors was observed prior and immediately after contact suggesting impedance-like control (Hogan, 1985; McNitt-Gray et al., accepted) to accommodate the rapid out-of-phase oscillation of the knee and hip NJMs observed immediately after contact. These results further suggest that this impedance-like control may not be affected by the fatigued condition. Between subject differences in the modifications of lower extremity joint kinetics and muscle activation patterns suggest response to fatigue is subject specific and must be considered when attempting to establish a causal relationship between loading and injury.

![Figure 1](image_url)

**Figure 1.** Reaction force and mean (± SD) of integrated (20 ms bins) knee NJM during the fatigued (opened square) and non-fatigued (filled diamond) of two exemplar subjects: a) subject experienced a significantly greater reaction force during the fatigued than the non-fatigued condition, b) subject encountered a significantly less reaction during fatigued than the non-fatigued condition. The impact phase was defined as the interval from contact (time zero) to the local minima in the vertical reaction force (dashed vertical line). The secondary phase was defined as the interval from the end of the impact phase to the time of knee extension (dotted vertical line). Significant differences in between landing conditions (*p < 0.05) are noted for the knee NJM.

**References:**
McNitt-Gray, J. L., et al., (Accepted) *Journal of Biomechanics*.

**Acknowledgements:**
This project was funded in part by the National Collegiate Athletic Association and Intel. The authors would like to thank James Eagle, Dr. Jackie Heino, Dr. Michelle Welch, and Dr. Barry Munkasy for their help with data collection.