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Full Length Article

Multi-plane, multi-joint lower extremity support moments during a rapid deceleration task: Implications for knee loading

Jeffery T. Podraza[a,b,*], Scott C. White[b], Dan K. Ramsey[b,c]

[a] Department of Physical Therapy, D'Youville College, Buffalo, NY, United States
[b] Department of Exercise and Nutrition Sciences, University at Buffalo, Buffalo, NY, United States
[c] Department of Health Professions Education, D'Youville College, Buffalo, NY, United States

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ABSTRACT

The principle of lower limb support, and the contribution of hip, knee and ankle moments to an overall limb support strategy for an impact-like, rapid deceleration movement may help explain individual moment magnitude changes, thereby providing insight into how injury might occur or be avoided. Twenty subjects performed single limb, impact-like, deceleration landings at three different knee flexion angles in the range of 0–25, 25–50 and 50–75°. Kinematic and kinetic measures identified hip, knee and ankle moment contribution to limb support moments (LSMs) in three planes. Repeated measures ANOVA compared LSMs and the contribution of individual joint moments at initial contact (IC) and 50 ms after. There were no significant differences in the overall LSMs at IC in any plane when the deeper knee flexion landings (25–50° and 50–75°) were compared to the 0–25° landing position but there were significant changes in the 50 ms period after IC. There were greater overall extensor LSMs, less resistance to medial opening of the knee and decreased support against internal tibia rotation when landing in greater knee flexion. The role of individual joint moments changed rapidly in the 50 ms period after initial landing; and, the relative contribution of the hip and ankle moments depended on the degree of limb flexion at landing. Analyses of individual joint moments emphasized the critical role that the hip joint moments have in balancing potentially injurious knee moments in all three planes for all three landing conditions.

1. Introduction

Muscles crossing the hip, knee and ankle joints work synergistically to support the upper body and prevent lower limb collapse during the support phase of locomotion activities (Winter, 2009). This concept of overall limb support was advanced based on sagittal plane analyses of the gait of normal subjects and those with different pathologies. A relatively consistent net, lower limb support (extensor) moment (LSM) pattern was identified (Winter, 1993); the pattern however, was achieved with considerable ankle, knee and hip moment variability (Winter, 1980, 1984). It was suggested that individual joint moments "… should not be looked at in isolation but rather as part of a total integrated synergy in a given movement task" (Winter, 2009, p. 125). Similarly, Plagenhoef (1971) Illustrated how ankle, knee and hip moment magnitudes change with the orientation of body segments in static, sagittal plane analyses of knee bend positions with a Barbell. He proposed that potentially injurious moments at specific joints could be identified through the analysis of the orientation and motion of body segments (Plagenhoef, 1971, p. 57). Identifying how joint moments trade-off relative to their combined requirement for a given movement task may help explain magnitude changes, thereby providing insight into how injury might occur or be avoided.

* Corresponding author at: 115 Kimball Tower, University at Buffalo, Buffalo, NY 14214-3000, United States.
E-mail address: podrazaj@dyc.edu (J.T. Podraza).

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Excessive moments and unbalanced loading from a rapid deceleration landing has been associated with knee injuries such as "non-contact" ACL strain (Hewett, Myer, & Ford, 2006; Li, Rudy, & Sakane, 1999; Markolf, Burchfield, Shapiro, Finerman, & Slauterbeck, 1995; Pandy & Shelburne, 1997). Impact-like, rapid deceleration tasks have not been studied using the LSM approach. Hip, and ankle kinematics and kinetics are considered factors related to the magnitude of knee moments that could result in injury (Flemming, Renstrom, & Ohlen, 2001; Hashemi, Breighner, Chandrashekar, Slauterbeck, & Beynnon, 2010; Hewett et al., 2006; Powers, 2010; Quatman, Quatman-Yates, & Hewett, 2010; Yu, Lin, & Garrett, 2006). For example, flatfoot or dorsiflexed deceleration landings with increased hip flexion and the knee near full extension are considered a factor in ACL strain (Boden, Dean, Feagin, & Garrett, 2000; Boden, Torg, Knowles, & Hewett, 2009). Deceleration movement tasks have been used to investigate knee joint moment magnitudes (Bates, Ford, Meyer, & Hewett, 2013; Bobbert, Huijing, & Schenau, 1987; Chappell & Limpisvasti, 2008; Cortes, Morrison, Van Lunen, & Onate, 2012; Dai et al., 2015; Hewett, Stroupe, Nance, & Noyes, 1996; Jones, Herrington, Munro, & Graham-Smith, 2014; Kipp, McLean, & Palmieri-Smith, 2011; Laughlin et al., 2011; Podraza & White, 2010; Steele & Brown, 1999; Yu et al., 2006), but few have manipulated the landing posture (Cortes, Morrison, Van Lunen, & Onate, 2012; Dai et al.,2015; Laughlin et al., 2011; Podraza & White, 2010); and these analyses have been limited to a single plane or joint. The magnitude of knee moments may depend on the relative contribution of ankle and hip moments to achieve overall limb support. No studies have investigated how hip, knee and ankle moments change for an impact-like, deceleration movement landing with different degrees of knee flexion.

This study reports LSMs in the sagittal, frontal, and transverse planes and describes the relative contribution of the hip, knee, and ankle moments to the LSMs when landing at three different knee flexion angles. The LSM concept has not previously been extended to frontal and transverse planes where the movement control strategies may be different from preventing limb collapse. For example, frontal plane ankle and hip moments work in synergy to control medial-lateral balance during single support when walking (Mackinnon & Winter, 1993). The narrow base of support with a single limb landing may provide insight into moment synergies required for a rapid, deceleration-landing task. Additionally, little is known about how individual lower limb joint moments might share support in the transverse planes. Using the LSM as the denominator for expressing the contribution of individual moments normalizes their role to the overall demands of the task. It was expected that the summed lower limb support moment in all three planes of motion would change with knee flexion when landing at initial contact (IC), and for a 50 ms time epoch after. The relative contribution of hip and ankle extensor moments in generating the LSM may be an effective synergistic strategy to support the knee and potentially avoid greater knee moments. It was hypothesized that if the LSM increased, the hip, and ankle extensor moments, hip and ankle abductor moments, and hip and ankle internal rotator moments would share more of the overall LSM, thereby alleviating the knee moment magnitude. Understanding the relative contribution of individual joint moments to overall limb support may suggest how injury could occur and contribute to the scientific basis for developing prevention programs to reduce injuries.

2. Methods

2.1. Participants

Twenty healthy, active college-age subjects, 10 males and 10 females (age: 22.8 ± 2.7 years, mass: 69.98 ± 13.95 kg, height 1.72 ± 0.08 m) participated in this study. The protocol was approved by a University Institutional Review Board. Written informed consent was obtained from each subject. Participants had no history of lower extremity injury requiring surgical intervention and no current hip, knee, or ankle injuries based on a medical screening questionnaire.

2.2. Protocol

Twenty-five retro-reflective markers were placed on the lower limbs (Hewett, Myer, & Ford, 2005) along with a markered rigid shell affixed to the pelvis. Pelvis and lower extremity segmental motion was tracked at 120 Hz and reconstructed in three-dimensional space using an 8-camera motion analysis system (Vicon Nexus 1.8, Oxford metrics; UK) synchronized with ground reaction forces (Kistler Instrument Corp. Amherst, NY) sampled at 1080 Hz. Motion capture at 120 Hz is consistent with studies using similar movement protocols (Boeth et al., 2013; Chappell, Creighton, Giuliani, Yu, & Garrett, 2007; Dai et al., 2015; Hart et al., 2009; Huston, Vibert, Ashton-Miller, & Wojtys, 2001; Stasi, Logerstedt, Gardinier, & Snyder-Mackler, 2013). Each subject underwent standing calibration to determine joint centers of rotation, define respective segmental coordinate axes, and establish neutral alignment from which subsequent kinematic measures were referenced. Hip joint centers were calculated via Visual 3D (V3D) software version 5.10-2 (C-Motion, Inc. Germantown, MD) through use of a CODA pelvis model and regression equation format (Bell, Pederson, & Brand, 1989, 1990). Knee and ankle joint centers were determined in V3D based on distal joint segment position.

To simulate a sudden deceleration landing, subjects approached a bench from a set distance (~4 m), stepped onto a bench (height = 10.5 cm) then dropped forward and down for a single limb landing near the force plate center (10.5 cm down, ~30 cm forward) with the contralateral limb. Standardized, subacute, in vivo analysis movement tasks such as landing from a jump (Hewett, Lindenfeld, Riccobene, & Noyes, 1999; Hewett et al., 1996, 2005; Ramsey et al., 2001) or tasks that elicit higher shear forces (Steele & Brown, 1999) are often used in the literature to investigate biomechanical factors that could be related to non-contact ACL injuries and gender differences. This task was chosen because it simulates impact-like vertical forces in combination with rapid negative acceleration shear forces requiring joint moment responses to prevent lower limb collapse.

The cadence of the approach, step on the bench and landing were matched to an audible metronome set to a rhythm of 100 beats per minute. Subjects chose which limb was analyzed and practiced landing with a knee flexion angle falling within the target ranges: 1) 0–25°, 2) 25–50°, and 3) 50–75°. Verbal feedback was provided to the subjects during practice and data collection trials regarding