INTRA-LIMB JOINT CONFIGURATION CONTRIBUTIONS TO KNEE JOINT LOADING IN A SIMULATED LANDING TASK

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Causative insight into the link between important aspects of an athlete's kinematics and knee joint loading in potentially injurious landings remains limited. The aim of this simulation study was to develop insight into the intra-limb configuration contributions to sagittal plane knee joint loading in drop (0.46m) landings. Notably accentuated (up to a 1.53 $N.m.kg^{-1}$) peak knee joint extensor moments (M_ek) were incurred with increased ankle, knee and hip joint flexion across the landing phase. While the peak M_ek was alleviated with reduced ankle and knee joint flexion, a marginal, participant-specific effect was evident with a similarly reduced hip joint flexion. The extended use of customised simulations to understand the unique role of each lower-extremity joint in the kinematic chain was warranted to inform injury prevention strategies.

KEY WORDS: sagittal plane; lower-extremity, wobbling mass model; drop landing

INTRODUCTION: Overuse and traumatic knee injuries in the athletic population are common within sports involving challenging landing or impact tasks. Over the past 10 years, as much as a 50 % increase in anterior cruciate ligament injuries has been reported for athletic populations (Donnelly et al., 2012). Across diverse landing tasks, the knee joint consistently experiences enormous mechanical demands and high mechanical output (Zhang et al., 2000). Changes to an athlete's technique (kinematics) have been reported to beneficially reduce the joint and external loads experienced in potentially injurious movements (Salci et al., 2004; Gittoes et al., 2009; Donnelly et al., 2012; Janssen et al., 2012). Further empirical investigation has suggested that anatomical sites other than the knee, including the trunk, hip, and ankle, provide important contributions to knee injury risk (Griffin et al., 2006). Support for the important role of other joints in attenuating knee joint loading was provided by Zhang et al. (2000), who suggested a prominent role by the hip joint extensors in absorbing the high mechanical demands on the knee joint in particularly challenging landing tasks. Insight into the direct causative link between critical aspects of an athlete's kinematics and knee joint loading however, remains limited (Donnelly et al., 2012), and may in part be attributed to difficulties in controlling individual joint actions within the kinematic chain in traditional empirical studies. As advocated by Zang et al. (2000), more research into landing biomechanics is required to address the limited documented evidence that links changes in natural landing technique to changes in joint kinetics. The extended use of participant-specific simulation models, which are capable of quantifying the complex interaction between hip and knee joint kinematics and knee joint loading to better assess knee injury risk in sporting tasks has recently been supported (Donnelly et al., 2012).
The aim of this study was to subsequently use a simulation modelling approach to develop understanding of the unique and combined contributions of the ankle, knee and hip joint configuration profiles (joint angles) to sagittal plane knee joint loading during double-footed landings. Extended insight into the influence of the intra-limb kinematics on knee joint loading has the potential to provide important insights for the effective development of injury prevention strategies for athletic populations.

METHODS: Data collection and processing: A Cartesian Optoelectronic Dynamic Anthropometer (CODA 6.30B-CX1) motion analysis system was used to track (sample rate: 200 Hz) sagittal plane joint centre markers during drop landings (height 0.46 m) performed by two participants (Participant A: age 24 years, body mass 56.8 kg; Participant B: age 22 years, body mass 69.0 kg). Synchronous vertical (GFz) and horizontal (GFy) ground reaction forces (sample rate: 1000 Hz) were obtained using a Kistler 9287BA force plate. The South West Local Research Ethics Committee gave approval for the data collection and each participant provided written informed consent. Participant-specific anthropometric measurements and a component inertia model (Gittoes & Kerwin, 2006) were used to obtain customised inertia parameters. Sagittal plane foot orientation and ankle, knee and hip joint configurations (angles) were calculated as projections onto the y-z plane for the duration of each landing.

The simulation model: The dynamics simulation package AUTOLEV^{TM}3.4 (Online Dynamics, Inc.,USA) was used to derive the equations of motion for a planar wobbling mass simulation model (Figure 1; Gittoes & Kerwin, 2009; Gittoes et al., 2009). The ground contact model comprised vertical and horizontal non-linear spring-damper systems located at the forefoot and heel. A Runge-Kutta numerical integration algorithm comprising a variable step-length was used to advance the solutions for the differential equations of motion.

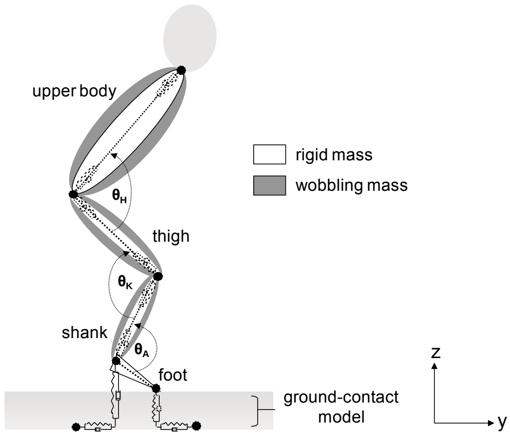


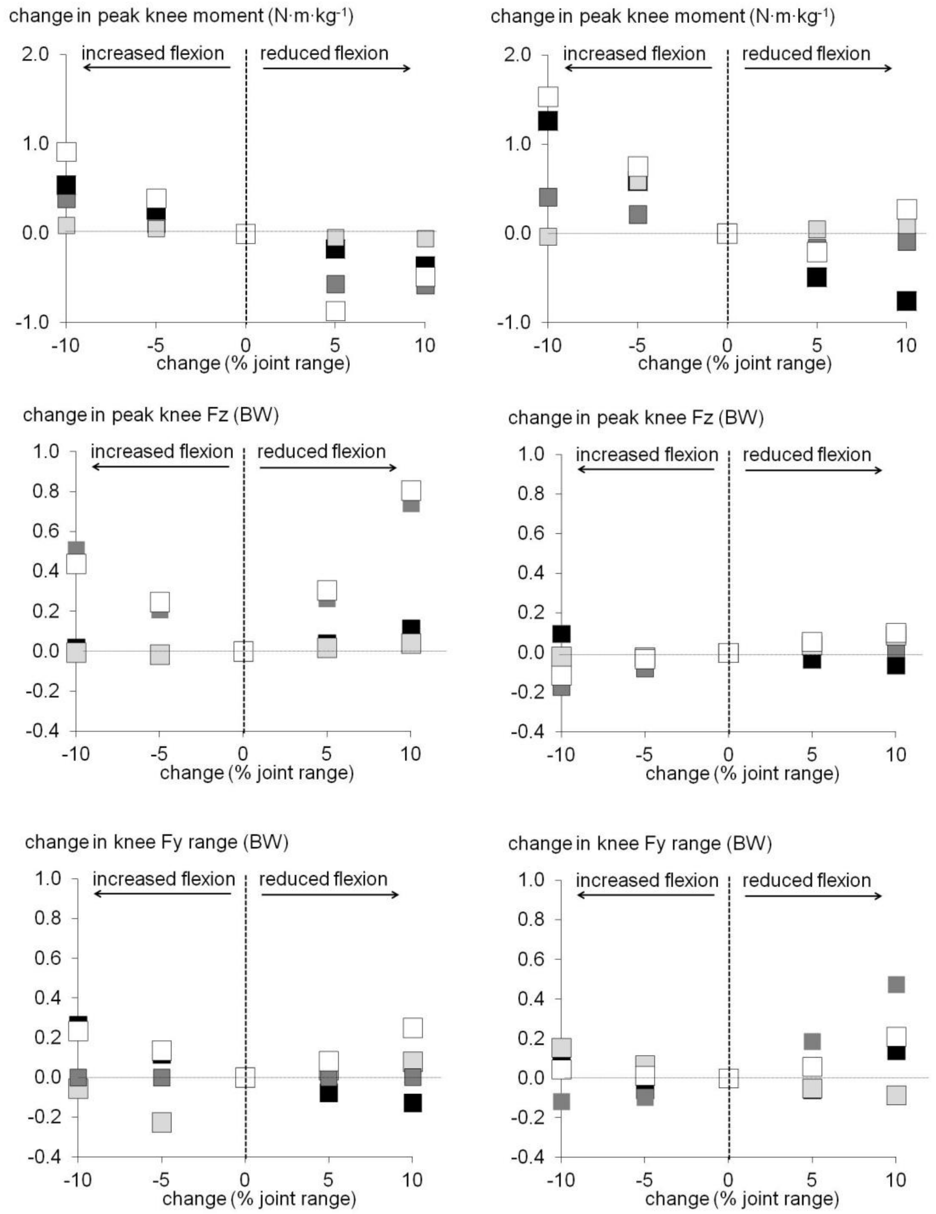
Figure 1: The four-segment wobbling mass model adapted from Gittoes et al. (2009).

Model evaluation and application: The model was evaluated for each landing by quantitatively comparing the measured and simulated GFz and GFy profiles. The evaluated landing was simulated using the trial-specific joint configuration profiles along with initial movement conditions. The evaluated simulated landing was defined as the self-selected movement for each participant. An optimisation procedure, which used an objective function comprising a weighted summation of the root mean squared (RMS) differences between measured and simulated GFz and GFy profiles, was employed to obtain modelled spring parameter estimates.

The self-selected joint configuration (angle) at each instant in time was independently perturbed by ± 5 % and ± 10 % of the joint angle range whilst the joint range of motion, velocities and accelerations were maintained. The initial conditions, inertia and spring parameters used in the evaluated landing were also maintained. A negative and positive offset increased and reduced the joint flexion, respectively. The influence of individually and simultaneously modifying the configurations on the peak knee joint extensor moment (M_ek) and vertical (Fz) and horizontal (Fy) knee joint constraining force were examined by comparing the evaluated and modified simulated values.

RESULTS: The simulation model replicated the measured GFz and GFy to within 0.26 BW and 0.07 BW, respectively for landings performed by the two participants. The maximum RMS difference between the measured and simulated GFz and GFy profile was 0.54 BW and 0.23 BW, respectively. As illustrated in Figure 2, independent and simultaneous increases in the ankle, knee and hip joint flexion across landing typically heightened (up to a 1.53 N.m.kg^{-1}) the peak M_ek and incurred participant and joint-specific knee joint Fz and Fy effects. A consistently attenuated peak M_ek was incurred with a reduced ankle dorisi-flexion (10% reduction: 0.58 N.m.kg^{-1} decline) and knee joint flexion (10% reduction: 0.76 N.m.kg^{-1}

decline) for Participants A and B, respectively. A reduced hip joint flexion had a marginal participant-specific effect on the peak M_{ek}, and incurred joint-specific responses in the peak knee Fz and range in knee Fy.



a) b)

Figure 2: Changes in the peak M_{ek}, peak knee Fz, range in knee Fy for the modified simulated landings of a) Participant A and b) Participant B with independent and simultaneous modifications to the self-selected ankle joint (dark grey), knee joint (black), hip joint (light grey) and all lower-extremity joints (white) configurations.

DISCUSSION: The simulation study evidenced a typically heightened peak M_{ek} with independently and simultaneously increased ankle, knee and hip joint flexion. The accentuated knee joint moments incurred with increased joint flexion contrasts traditional support for the use of greater degrees of lower-extremity flexion for load attenuation in landing (e.g. Salci et al., 2006). Increases in knee flexion have recently been reported to be clinically undesirable due to the associated accentuation of sagittal plane knee joint moments (Creaby et al., 2013). Soft tissue motion has been reported to have an important influence on lower-extremity loading in landing (Gittoes & Kerwin, 2009). A heightened knee joint loading with increased joint flexion may partially be incurred by a greater load

transmission through the joint due to increased soft tissue (wobbling mass) motion higher up the kinematic chain. Further investigation of the role of soft tissue motion in knee joint extensor loading is however, necessary to support the causative association to increased knee flexion. The notably attenuated peak M_{ek} incurred with reduced ankle joint dorsi-flexion (Participant A) and knee joint flexion (Participant B) supported the suggestion of Donnelly et al. (2012) that changes to an athlete's kinematic response can beneficially reduce joint loading in dynamic tasks. The configurations of other joints located in the kinematic chain (i.e. ankle joint) were accordingly found to provide important but performer-specific knee joint load attenuation contributions in the landing task. The participant-specific responses supported the potential use of self-selected and diverse compensatory mechanisms across the kinematic to protect the knee joint during dynamic landing tasks.
In opposition to traditional viewpoints, Janssen et al. (2012) provided support for the use of less joint flexion at the hip joint as an important injury prevention strategy in volleyball landings. Unlike Janssen et al. (2012), this study evidenced only a marginally reduced peak M_{ek} was with less hip joint flexion for one participant and a negligible response for the remaining participant. The limited role of the hip joint flexion on the peak M_{ek} suggested that the potentially high loading demands incurred by the prominent mass of the upper body may require substantial changes to the self-selected hip joint strategy or compensation by other joints in the kinematic chain. A reduced hip joint flexion further incurred opposing accentuations of the knee joint constraining forces for one participant, which demonstrated a need to simultaneously consider the knee joint moments and constraining forces imposed with modified techniques in potentially injurious landings.

CONCLUSION: Adjustments to self-selected kinematic responses of the lower-extremity joint configurations during dynamic landing tasks were found to provide important sagittal plane knee joint loading contributions. Participant- and joint-specific effects supported the extended use of customised simulations to understand the unique and complex role of each lower-extremity joint prior to the development of knee injury prevention strategies. Extended examination of the interaction of knee joint moment and constraining force responses were advocated in order to assist causative insight into potentially injurious landing tasks.

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