SENSITIVITY OF IMPACT LOADING TO LANDING STRATEGY AND PHYSICAL PROFILES IN DROP LANDING

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This study aimed to gain an insight into the sensitivity of loading in drop landings to the selected strategy and physical profile of the performer. A wobbling mass model was used to simulate landings executed by two performers. Each performer's physical profile was used to produce simulated motions employing the performer's self-selected strategy and in landings replicated using another performer's strategy. Impact loads were sensitive to changes in the strategy and physical profile of the performer. Changing the strategy altered the peak vertical ground reaction force (GFz) by up to 2.55 bodyweights (BW) and modifying the physical profile similarly changed the peak GFz by 2.52 BW. The execution of a strategy customized to a performer's physical profile is potentially beneficial for reducing loading but may not fully alleviate the effects of a predisposing physical profile.

KEY WORDS: simulation, lower extremity, joint kinetics.

INTRODUCTION:

Human landings requires a lower body control strategy that effectively and safely dissipates the large and rapid reaction forces experienced upon ground impact. The attenuation of impact forces experienced in potentially injurious landings performed in sport, such as during the dismount phase in gymnastic routines, is particularly challenging to a performer due to the associated high impact velocities. During impact tasks (e.g. running and landing), performers have been found to self-select load attenuation strategies, which are differentiated between conditions or performers by the magnitude and timing of the joint actions used (McNitt-Gray, 1991) or the muscle tuning responses produced (Boyer & Nigg, 2004).

An individual's preferred landing strategy may in part, be influenced by the nature of their inherent physical profile. Limb inertial properties have previously been found to influence the mechanical demands and performance outcome of running (Dellanini et al., 2003). Although, the kinematics of a lower body control strategy may be modified to alleviate impact loading (Zhang, Bates & Dufek, 2000) a performer may remain susceptible to large and rapid impact loads due to their inherent physical profile. However, a limited insight into the contribution of an individual's physical profile and the associated self-selected landing strategy to load attenuation in potentially injurious landings exists, which may be attributed to experimental constraints in controlling each factor.

Gaining insight into a performer's preferred strategy and the affect of their physical profile on impact loading has the potential to further understanding of customized lower body control strategies used to reduce the potentially injurious demands of landing. Simulation modelling provides a beneficial approach for manipulating and isolating the effects of intrinsic musculo-skeletal factors and modifiable control strategies associated with task-specific movements. The aim of this study was to use a simulation modelling approach to develop understanding of the sensitivity of loading in potentially injurious landings to an individual's selected landing strategy and physical profile.

METHOD:

A four-segment, angle-driven simulation model (Gittoes, Brewin & Kerwin, 2006) incorporating wobbling and rigid masses (Figure 1) replicated the impact phase (100 ms) of drop landings (height: 0.46m) executed by two performers (A: body mass 56.8 kg; B: body mass 69.0 kg). A Cartesian Optoelectronic Dynamic Anthropometer (CODA 6.30B-CX1) motion analysis system was used to obtain coordinate data for the right metatarsophalangeal (mtp), ankle, knee, hip and shoulder joint centres (sample rate: 200 Hz) and synchronized (sample rate: 1000 Hz) ground reaction force profiles were obtained using a Kistler 9287BA force plate for each landing performance.

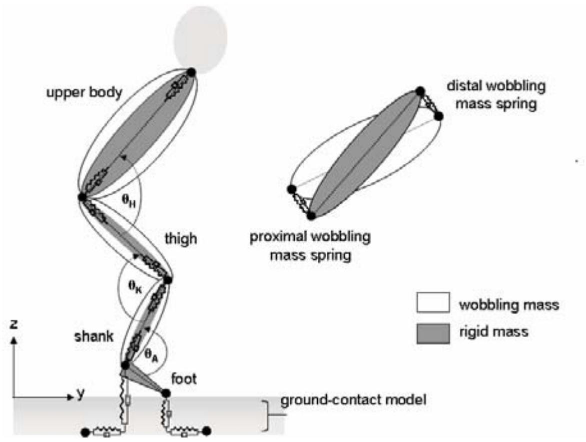
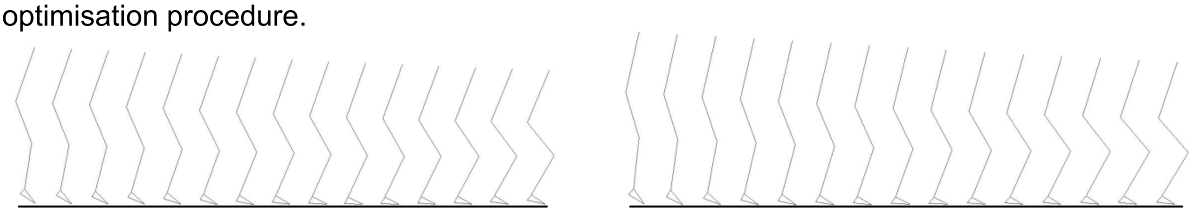


Figure 1: The Four-Segment Wobbling Mass Simulation Model.

The self-selected strategies used in the simulated motions were defined by hip, knee and ankle joint angle profiles derived from the joint centre coordinate data of the respective actual landing performance and are illustrated for each performer in the schematics presented in Figure 2. Performance-specific mass coupling responses (visco-elastic properties between wobbling and rigid masses), which were used to partially represent the muscle tuning responses produced in the respective landing were derived for each simulated motion using an optimisation procedure. The optimisation procedure aimed to minimise the difference between the simulated and actual ground reaction force time histories of corresponding landing performances. A simulated annealing algorithm (Goffe, Ferrier & Rogers, 1994) was used to vary the spring parameters in the optimisation procedure
Performer-specific inertia parameters, required to represent the physical profile of each individual, were obtained using a component inertia model (Gittoes & Kerwin, 2006) and used in the simulated motions. Visco-elastic properties representing the foot-ground interface completed the physical profile and were approximated for each trial within the optimisation procedure.



(a) (b)

Figure 2: Graphical Sequence of the Hip, Knee and Ankle Joint Angle Profiles of the Self-Selected Strategies used by Performer A (a) and Performer B (b).

The simulation model successfully replicated the measured vertical ground reaction force (GFz) profile to 10.4% and 7.0% and the peak GFz to 5.0% and -1.2% of the actual landing trials of Performer A and Performer B, respectively. The performer-specific physical profiles were subsequently used in modified motions replicated using the other performer's strategy. The peak GFz, average peak GFz loading rate and ankle, knee and hip extensor moments produced in the self-selected landing and landing performed using the other performer's strategy were compared to examine the affect of landing strategy on impact loading. The effects incurred by the physical profile were assessed by comparing impact loading in landings using the same strategy but simulated using different physical profiles.

RESULTS:

As illustrated in Table 1, the peak GFz and joint kinetics were sensitive to changes in the landing strategy and physical profile. Changing the strategy influenced the peak GFz by up to 2.55 BW and the knee moment by up to 2.4 $N \cdot m \cdot kg^{-1}$ while modifying the inertia profile incurred a slightly smaller change of up to 2.52 BW in the peak GFz and a 1.2 $N \cdot m \cdot kg^{-1}$ perturbation in the peak knee moment.

Table 1 External and Joint Kinetics of the Personalized[a] and Modified[b] Landing Performances

Kinetic Variable		Physical Profile	
	Strategy	A	B
Peak GFz (BW)	A	4.87	7.39
	B	3.92	4.84
Average Peak GFz Loading Rate ($BW \cdot s^{-1}$)	A	70	112
	B	65	58
Peak Ankle Moment ($N \cdot m \cdot kg^{-1}$)	A	5.5	6.0
	B	4.9	3.2
Peak Knee Moment ($N \cdot m \cdot kg^{-1}$)	A	5.6	6.8
	B	3.8	4.4
Peak Hip Moment ($N \cdot m \cdot kg^{-1}$)	A	10.5	4.8
	B	6.4	4.4

[a] Strategy A using A's Physical Profile, Strategy B using B's Physical Profile; [b] Strategy A using B's Physical Profile, Strategy B using A's Physical Profile

The relatively larger peak GFz and average peak GFz loading rate experienced when using Performer A's landing strategy was associated with larger peak joint moments than experienced when using Performer B's strategy. Using an unselected strategy incurred performer-specific responses to load attenuation. Compared to the personalized landing, Performer B experienced a 2.55 BW increase in the peak GFz using Performer A's strategy while Performer A was benefited by a 0.95 BW peak GFz reduction using Performer B's strategy.

For the same strategy, the performer's physical profile also had a notable affect on the peak loads experienced. Performer B's profile incurred larger peak GFz (strategy A: 2.52 BW, strategy B: 0.92 BW), GFz loading rate and ankle and knee joint moments than Performer A's profile for a maintained landing strategy.

DISCUSSION:

A simulation modelling approach was used to investigate the independent contributions of landing strategy and inherent physical profiles to load attenuation during drop landings. Separately changing the strategy and physical profile typically had substantial and similar contributions to external and joint loading. For one performer, adopting another performer's strategy produced notably reduced loads than experienced using their preferred strategy. This investigation provided support for previous suggestions from experimental studies (Zhang, Dufek & Bates, 2000) that strategy changes are beneficial in achieving notably reduced impact loads in landing.

The simulated loads were also sensitive to changes in the physical profile of each performer. Dellanini et al. (2005) previously reported increased internal work during dynamic movements due to subject-specific, localized changes in the inertia properties of limbs. Increased physical demands on the body with changes in physical profiling were similarly found in this investigation but the effects of physical variations between performers on the resulting demands experienced were further highlighted. Performer B's physical profile was predisposing to larger peak impact loads than Performer A's which suggested that a performer may be intrinsically more susceptible to excessive loading than their counterparts due to their innate physical profile. The reduced impact loads experienced by each performer when adopting Performer B's strategy further suggested that although predisposed to greater loads than Performer A, Performer B accommodated their inherent susceptibility by initiating a more successful load attenuation strategy than Performer A. Customisation of the landing strategy to the performer's physical profile may therefore be considered important and beneficial for reducing impact loading in potentially injurious landings. However, the similar sensitivity of the impact loads to strategy and physical profiles suggested that individuals may have a valuable but constrained ability, due to their inherent physical profile, to reduce the physical demands of landing through voluntary manipulation of their technique and muscle tuning response.

CONCLUSION:

Landing strategies, which are customized to the physical profile of a performer are beneficial for reducing impact loading in landing but may not fully alleviate the effects of a predisposing physical profile. Future insight into the contribution of numerous landing strategies to impact loading can provide further understanding of preferred, customized lower body control strategies used to reduce the physical demands of potentially injurious landings.

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