THE PHYSICAL DEMANDS OF GYMNASTIC-STYLE LANDINGS: UNDERSTANDING AND ALLEVIATING INHERENT PREDISPOSITION

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The research aims to develop insight into inherent mechanisms and regulatory strategies contributing to the physical demands of gymnastic-style landings. The use of a modelling approach to examine the interaction of: 1. a performer's physical profile and self-selected landing strategy and 2: local mass distribution and mass tuning effects on impact loading is presented. Strategy adjustments accommodating inherent physical profiles were found to be essential in ensuring effective load attenuation but were acknowledged as potentially incompatible with current constraints in gymnastic scoring systems. Mass tuning partially alleviated the loading effects of inherent local mass profiles and was considered achievable without substantial alterations in the regulatory movement patterns.

KEY WORDS: physical profile, mass tuning, landing strategy, simulation

INTRODUCTION: Biomechanical research has supported the notion that the large and rapid forces incurred in landings frequently performed in gymnastic routines impose a predisposition to musculoskeletal injury (Daly et al., 2001). As highlighted by Decker et al. (2003), it is generally accepted that the internal and external loads experienced in landing may be manipulated by the lower extremity kinematics or movement patterns used. Traditional laboratory-based studies have suggested regulatory control strategies such as the use of greater (Salci et al., 2004) and more rapid knee and hip flexion (Yu et al., 2006) to assist the execution of safe and efficient landing manoeuvres. In addition to control strategies, multiple inherent mechanisms have been considered influential in the impact loads experienced and the potential for lower extremity injury. Anatomical, neuromuscular and hormonal factors have been reviewed as traditional contributors to lower limb injury in sports performers (Boden et al., 2009). More recently, soft tissue mass properties (Liu & Nigg, 2000, Pain & Challis, 2006) and lower body stiffness (Butler et al., 2003) have been recognised as important contributors to the forces incurred during sport-related impacts.
Given the possibility of an inherent predisposition to excessive mechanical loading, Daly et al. (2001) highlighted recent discussions for rule changes to de-emphasise 'sticking' landing routines in the scoring of gymnastic dismounts. Allowing self-selected landing strategies may accommodate a conscious or instinctive compensation for inherent predispositions to the high physical demands incurred in landing. Gaining an insight into the contribution of inherent mechanisms to mechanical loading and the potential influence of regulatory strategies may be valuable for developing understanding of injury predisposition and in supporting customised landing responses in the scoring of gymnastic landings.
Due to control constraints associated with a traditional laboratory setting, the interactive and independent effects of inherent load attenuation and regulatory mechanisms such as landing strategy changes has been difficult to ascertain. Biomechanical modelling offers a contemporary alternative to traditional experimental investigation due to the ability to isolate and readily manipulate the mechanisms under investigation. The aim of this research was to subsequently gain an insight into inherent mechanisms and potentially modifiable strategies influencing the physical demands experienced in gymnastic-style landings using a contemporary biomechanical modelling approach.

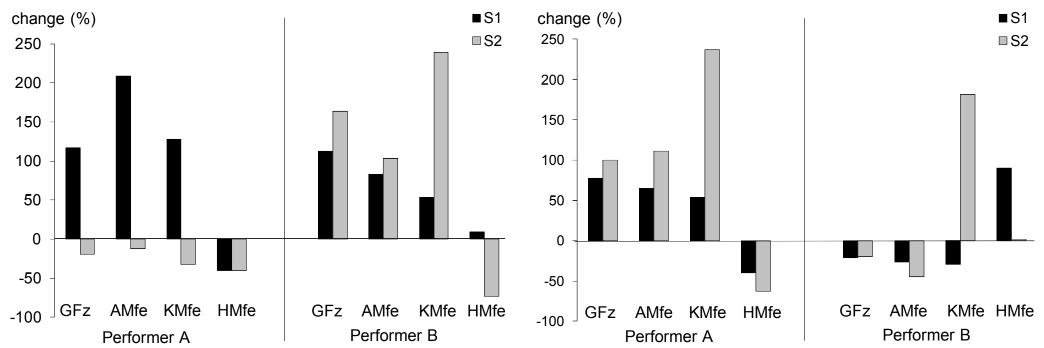
METHODS: A four-segment, non-rigid simulation model incorporating soft (wobbling) and rigid masses was developed and evaluated using the procedures presented by Gittoes et al. (2006). The evaluated simulation model was used to replicate customised, gymnastic-style drop landings (height 0.46m) for two female performers (A: body mass 56.8 kg; B: body mass 69.0 kg). The self-selected strategy used in the simulated landings was defined by performer-specific ankle, knee and hip joint kinematic profiles derived from actual landing performances. The visco-elastic properties of the foot-ground interface were represented using spring-damper systems that replicated the ground reaction forces incurred in the simulated landings. Customised visco-elastic properties representing the coupling between wobbling and rigid masses were used to represent mass tuning responses produced in the motions. The simulation model was subsequently employed to investigate mechanisms contributing to the physical demands incurred in the gymnastic-style drop landings.

Application 1- Influence of inherent physical profiles and landing strategy: Personalised whole body physical profiles derived using a component inertia model (Gittoes & Kerwin, 2006) were integrated with the non-rigid simulation model to produce motions executed using an independent performer's landing strategies. Secondly the personalised physical profiles were used to replicate landings executed with the performer's own self-selected and unselected landing strategies. Comparisons of the impact loads produced in the customised evaluated motion and the motions simulated using modified (independent performer and own unselected) landing strategies were subsequently made.

Application 2- Influence of inherent physical profiles and mass tuning: Personalised segmental wobbling and rigid mass distributions (Rm_p) and mass coupling (stiffness: k_{WR} and damping: c_{WR}) properties used in the customised evaluated motion were simultaneously modified by ±5% perturbations. Perturbations in the Rm_p were made in combination with k_{WR} and c_{WR} changes. A positive perturbation in the Rm_p, coupling k_{WR} and c_{WR} produced a larger segmental rigid mass distribution and increased coupling stiffness and damping, respectively. The maximum vertical ground reaction force (GFz) effects caused by simultaneous Rm_p and k_{WR} and c_{WR} modifications were compared to the maximum GFz changes reported in Gittoes & Kerwin (2009) as a consequence of independent Rm_p modifications (±5% perturbations).

RESULTS:

Effects of inherent physical profiles and landing strategy: The use of an independent performer's strategy incurred an attenuated maximum GFz, and ankle and knee joint flexion-extension moments than the self-selected strategy for one performer (B) and had inconsistent loading effects on the remaining performer (A) (Figure 1a). The use of an independent performer's strategies had the greatest effects on the maximum knee joint flexion-extension moment (113 ±93% mean difference from self-selected response) when compared to the GFz (103 ±60%) and ankle (102 ±81%) and hip (41 ±26%) joint flexion-extension moment.

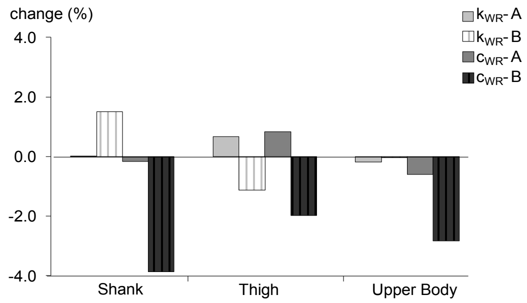


a. b.

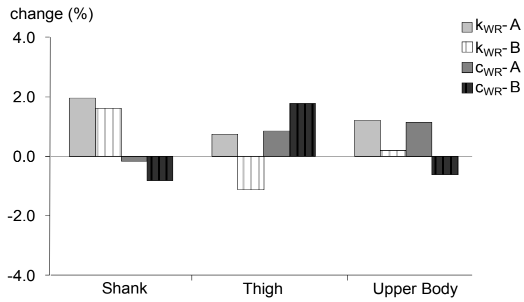
Figure 1: Change (%) in the maximum GFz and ankle (AMfe), knee (KMfe) and hip (HMfe) joint flexion-extension moment incurred using an (a) independent performer's and (b) the performer's own unselected landing strategies. [S1: strategy 1; S2: strategy 2]. Adapted from Gittoes & Kerwin (2008).

The use of a performer's own, unselected landing strategy incurred larger maximum GFz and ankle and knee joint flexion-extension moments for one performer (A) (Figure 1b) and typically attenuated effects for the corresponding measures of Performer B. A modulated personal strategy had the greatest effect on the maximum knee joint flexion-extension moment experienced (126 ±100% mean difference) but had relatively less effect on the impact loads (73 ±31% mean difference across all measures) compared to the use of another performer's strategy (90 ±29% mean difference).

Effects of inherent physical profiles and mass tuning: With reduced Rm_p, simultaneous c_{WR} increases typically produced larger changes in the maximum GFz experienced in the drop landings compared to simultaneous k_{WR} reductions (Figure 2). The notably attenuated maximum GFz incurred with independent upper body Rm_p reductions were further attenuated by increased c_{WR} by as much as 0.03 BW and 0.13 BW for landings performed by Perfomer A and B, respectively (Figure 2a).
The interaction of reduced Rm_p and k_{WR} had a relatively smaller but consistent effect (Figure 2b) on the maximum GFz compared to reduced Rm_p and increased c_{WR}, which produced idiosyncratic effects on the maximum GFz changes incurred with independent Rm_p modifications.



a.



b.

Figure 2: Interaction effects of Rm_p and k_{WR} and Rm_p and c_{WR} on GFz_{max}. (a) -5% perturbations in Rm_p and k_{WR}, and +5% in c_{WR}; (b) +5% perturbations in Rm_p and c_{WR}, and -5% in k_{WR}. Maximum GFz changes are reported relative to the maximum GFz changes incurred with corresponding independent Rm_p modifications. Adapted from Gittoes & Kerwin (2009).

DISCUSSION: An inherent predisposition to large and rapid mechanical loads in gymnastic-style landings potentially exists. The interactive contributions of a performer's inherent physical profile and regulatory control mechanisms to impact loading was investigated and may support alleviated constraints in the scoring of gymnastic dismounts. The simulation modelling approach used successfully allowed an examination of the isolated effects of the inherent and modifiable mechanisms under investigation.
The heightened impact loads experienced when using another performer's strategy or an unselected personal strategy suggested instinctive or conscious customisation of landing strategies to an inherent, whole-body physical profile and movement conditions. The greater impact load sensitivity in the landings simulated with another performer's strategy compared to the unselected personal strategy, further suggested strategies customised to inherent physical profiles may be prioritised over adjustments to diverse landing manoeuvres for effective impact load attenuation.
The whole body mechanism of landing strategy selection was found to be capable of influencing the maximum GFz incurred by a predisposing physical profile by as much as 103%. However, localised mass tuning adjustments were also found to provide a notable but smaller contribution to impact loading (up to a 3.9% change in maximum GFz). As highlighted in Gittoes and Kerwin (2009), reductions in the damping between soft (wobbling) and rigid masses were found to positively interact with lower, local rigid mass proportions, particularly in the upper body, to help further attenuate the impact loads experienced during the simulated landings. Liu and Nigg (2000) previously supported the notion that through muscle tuning, mass coupling properties may interact with inherent mass distributions in the body to control the impact forces incurred in less dynamic running ground contact phases. Without modifications to the kinematic landing strategy employed, mass tuning achieved by

developing and modulating neuromuscular responses may provide an alternative mechanism for alleviating the high impact loads naturally incurred by a performer's physical profile.

CONCLUSION: Considering the likely maintenance of a scoring system for gymnastic dismounting that requires constrained movement patterns, achievable modifications in mass tuning may alleviate the physical demands experienced in gymnastic-style landings without substantial alterations in the movement patterns produced. However, accommodating self-selected landing strategies that adjust to diverse physical profiles and movement conditions in the scoring system may provide substantially greater protection benefits for performers executing the potentially injurious manoeuvres.

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