A PILOT STUDY OF THE KNEE JOINT ACTION CONTRIBUTIONS TO LOADING IN LANDINGS PERFORMED BY FEMALES

Marianne Gittoes[1], Mark Brewin[2] and David Kerwin[1]

[1]Cardiff School of Sport, University of Wales Institute, Cardiff, United Kingdom
[2]Sport and Exercise Science Group, University of Bath, Bath, United Kingdom

Females are particularly susceptible to knee injuries in landing. This investigation aimed to gain further insight into the contributions of female knee joint actions to loading in landing. A wobbling mass model was used to simulate landings executed with a self-selected strategy. The selected knee actions were modified and the resulting loads were examined. A 0.05 s change in knee joint action timing substantially increased the peak vertical ground reaction force (GFz) by 1.55 BW. Conversely, a small reduction in peak GFz (0.06 BW) was produced using a 10 % more extended knee during the impact. The prominent influence the knee joint action timing had on loading may be attributed to the need to maintain coordinated and continuous load attenuation. Subject-specific modifications to landing strategies were found to achieve load reductions.

KEY WORDS: simulation, wobbling mass, self-selected strategies, impacts

INTRODUCTION: The rapid and excessive impact forces experienced in landings performed in sport have been associated with a high incidence of lower extremity injuries (Devita & Skelly, 1992). Compared to males, females involved in jumping and cutting sports are up to six times more likely to sustain a serious knee injury (Hewett, 2000) and have been found to land with a more extended knee joint and a more rapid knee angular velocity (Decker et al., 2003). Devita and Skelly (1992) suggested that increasing knee flexion at initial ground contact can notably reduce peak impact loading. However, insight into the role of the timing of the knee joint action in load attenuation has been limited.

Modifying the timing and configuration of the joint actions used by females may be beneficial in more effectively attenuating the loads experienced in landing. However, Decker et al. (2003) recently suggested that the more extended knee and greater peak knee angular velocities used by females was not necessarily accompanied by higher peak external loading compared to males adopting a more flexed knee and less rapid knee joint action. Rather, compensations for the more extended posture were apparent in the larger energy absorption produced in the ankle joints of females, which potentially stabilised the peak force, but increased the demand on the compensating joints. Further understanding of the contribution of the knee joint action to load attenuation in females may be achieved using a simulation model of landing, which unlike experimental investigations, allows a controlled and systematic manipulation of isolated components of joint actions. This study therefore aimed to use a customised simulation model of females landing to gain a further insight into the contribution of the timing and configuration of the knee joint action to the loads experienced.

METHODS: Data collection and processing: Two females (Subject A: age 24 years, body mass 56.8 kg; Subject B: age 22 years, body mass 69.0 kg) each performed four drop landings from a height of 0.46 m using self-selected strategies. The data collection session was ethically approved and the subject signed written informed consent. Subject-specific anthropometric data were collected according to the measurements detailed for the inertia model of Yeadon (1990) and were used as input into a component inertia model (Gittoes & Kerwin, 2006) to derive personalised inertia parameters. Ankle, knee, hip and shoulder joint centre coordinate data were obtained (sample rate: 200 Hz, capture time: 5 s), for one landing performed by each subject, using a Cartesian Optoelectronic Dynamic Anthropometer (CODA) 6.30B-CX1 motion analysis system. Smoothed continuous foot orientation and joint angle time histories and first and second derivatives were derived using the coordinate data and a quintic spline routine (Wood & Jennings, 1979). Synchronised vertical (GFz) and horizontal (GFy) ground reaction force data were measured using a Kistler

9287BA force plate (sample rate: 1000 Hz, capture time: 5 s). The impact phase of each landing was defined as the first 0.10 s following initial ground contact (GFz < 5N). Mass centre velocity changes were calculated from the GFz and GFy data using the trapezoid rule for integration.

Simulation model: The equations of motion for a planar, angle-driven wobbling mass model (Gittoes, Brewin & Kerwin, 2005) were generated in the dynamic simulation package, AUTOLEV^{TM}3.4 (Online Dynamics, Inc., USA). The four-segment model (Figure 1) comprised a rigid foot and shank, thigh and upper body segments comprising wobbling and rigid masses. Two linear damped springs connected segmental wobbling masses to rigid masses. The ground contact model comprised four non-linear, spring-damper systems: a vertical and horizontal system 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.

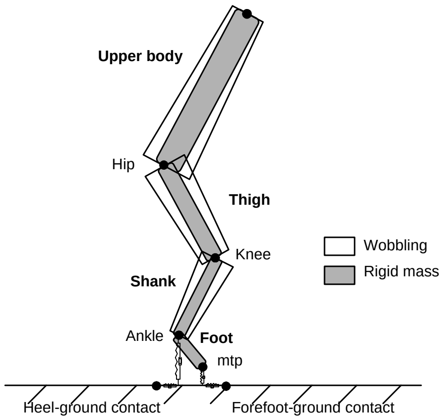

Figure 1: The four-segment wobbling mass model

Model evaluation & application: The trial-specific foot orientation, angular velocity and mass centre velocity at impact were used to initiate the simulated motion and the trial-specific ankle, knee and hip joint angle profiles were used to drive the model. Estimates for all modelled spring parameters were obtained using an optimisation procedure. An objective function comprising a weighted summation of the root mean squared (RMS) differences between simulated and actual GFz and GFy profiles was developed. The weighting was based on the mean ratio of the ranges in the GFz and GFy profiles of the eight experimental landing trials. A simulated annealing algorithm (Goffe, Ferrier & Rogers, 1994) varied the spring parameters in the optimisation procedure. The level of agreement between the optimised simulated landing and the actual performance indicated the model's accuracy.

The simulation model was used to investigate the influence of the knee joint action timings and configuration on the impact loads experienced by each female. The evaluated simulated motion was defined as the self-selected movement for each subject. Firstly, the self-selected knee joint angle time history was offset by ± 0.005 s and ± 0.010 s (5 % and 10 % of the impact phase duration) relative to the self-selected ankle and hip joint angle time histories whilst maintaining the self-selected movement impact velocity. A negative offset in the timing perturbations represented a delayed knee joint action (minimum knee flexion achieved later than in the self-selected action) and a positive offset produced a more rapid knee joint action (minimum knee flexion achieved earlier than in the self-selected action). Secondly, the knee joint configuration was progressively modified such that the magnitude of the knee joint angle at each instant in time was reduced by ± 5 % and ± 10 % of the self-selected knee joint angular range whilst maintaining the self-selected knee joint range of motion, velocities and accelerations. A negative and positive offset produced a more and less flexed knee respectively, than used in the self-selected movement.

The trial-specific initial conditions, ankle and hip joint angle time histories and inertia and spring parameters used in the self-selected movement were used in the simulations performed with the modified knee joint profiles. The influences of the timing and configuration of the knee joint action on the peak external and internal loads experienced in each landing were examined by comparing the self-selected and modified simulated landing values.

RESULTS: The simulation model reproduced the measured peak GFz to 5.0 % and 7.0 % and produced RMS differences between the measured and simulated GFz profiles of 10.4 % and 10.8 % of the measured force range for subjects A and B, respectively. The effects of modifying the self-selected knee joint actions on the peak impact forces experienced in landings performed by each female are illustrated in Figure 2. A 0 % perturbation represented the value obtained in the simulated, self-selected landing.

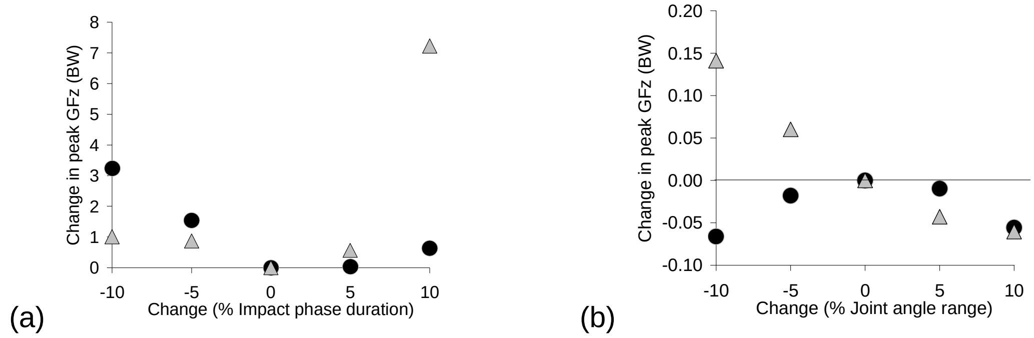

Figure 2: Influence of knee joint action timing (a) and configuration (b) on the magnitude of the peak GFz experienced in simulated landings performed by Subject A (●) and B (△).

Modifying the knee joint action timing substantially increased the peak GFz experienced by subjects A and B. The increases in peak GFz (A = 3.24 BW and B = 7.22 BW) were produced by incurring a 10 % more delayed or rapid knee joint action respectively, than used in the self-selected landing. The increased peak GFz experienced with the most rapid knee joint action was accompanied by notable increases in the peak vertical force (Fz) at the knee for Subject A (5.37 BW) and B (1.41 BW). Modifications to the timing of the knee joint action had contrasting effects on the time of peak GFz. The most delayed action produced a 0.005 s more extended time to peak GFz for Subject A and a 0.001 s more rapid time to peak GFz for Subject B.

As illustrated in Figure 2, modifying the knee joint configuration had less influence on the peak GFz compared to modifying the knee joint action timings. A 10 % more extended knee joint reduced peak GFz by up to 0.06 BW, which was accompanied by an increased (0.11 BW) and decreased (0.06 BW) peak knee Fz in Subject A and B, respectively. A 10 % more flexed knee contrastingly incurred a slight decrease (0.07 BW) and increase (0.14 BW) in the peak GFz experienced by Subject A and B, respectively. Modifications to the knee joint configuration produced minimal changes in the time of peak GFz.

DISCUSSION: The role of the knee joint action in load attenuation in females performing self-selected landing techniques was examined. Modifying the self-selected knee joint action timing substantially increased the peak GFz experienced by each female. The prominent effects on impact loading, incurred as a result of mistiming the knee joint action, may be explained by the independent contributions of the lower-extremity joints to load attenuation. Larger peak impact forces may be attributed to the failure to maintain load attenuation with an immediate knee action following the previously fully utilised ankle joint action. Conversely, a more rapid knee action may have enhanced load attenuation early in the impact phase due to the combined role of the ankle and knee but later inhibited attenuation due to the consequential delay in resuming load attenuation with the hip joint. The relative load attenuation contributions provided by all lower extremity joints may be examined in the future by investigating the influence of separately mistiming the ankle, knee and hip actions. This investigation was limited by the uncharacteristic force profiles produced for Subject B as a result of incurring a potentially unachievable 0.01 s more rapid knee joint action than used in the self-selected movement. The sensitivity of Subject B's technique to mistimed knee joint actions suggested that compared to Subject A's technique a narrower margin for error existed in initiating the knee joint action.

The minimal effect of the knee joint configuration on the forces reported in this investigation confirmed the suggestions of Decker et al. (2003) and Panzer et al. (1988) that modifying the knee joint angle in experimental landing trials produced negligible or slight changes respectively, in the peak GFz experienced. The advocated use of a more pronounced knee flexion in landing (Devita & Skelly, 1992) was questioned in this investigation. Although increasing knee flexion reduced external loading in Subject A, Subject B experienced greater external loading. Furthermore, the reduced peak GFz in Subject A was accompanied by an increased peak knee Fz which accentuated the knee joint demand and potentially increased the risk of injury in Subject A. This investigation therefore highlighted that recommendations for landing technique modifications, such as increased knee flexion, should be made on a subject-specific basis and should consider the resulting joint loads incurred.

CONCLUSION: Increasing knee flexion had the potential to reduce the loads experienced by females in landing. The effects of using greater knee flexion in landing were however neither consistent for the females investigated nor were they substantial. Rather, alternative adjustments to landing technique may be recommended for females such as modifying the knee joint action timing, which has been shown to have had a prominent influence on loading by ensuring a coordinated and sequential maintenance of load attenuation for the duration of the impact phase of landing.

REFERENCES:

Decker, M. J., Torry, M. R., Wyland, D. J., Sterett, W.I. & Steadman, J. R. (2003). Gender differences in lower extremity kinematics, kinetics and energy absorption during landings. *Clinical Biomechanics*, **18** (7), 662-669.

Devita, P. & Skelly, W. A. (1992). Effect of landing stiffness on joint kinetics and energetics in the lower-extremity. *Medicine and Science in Sports and Exercise*, **24** (1), 108-115.

Gittoes, M. J. R., Brewin, M. A. & Kerwin, D. G., (2005). Evaluation of a wobbling mass model simulating female impact landings. In Q. Wang (Ed.) *Proceedings of the XXII International Symposium on Biomechanics in Sports* (Volume 2, pp. 565-568). The China Institute of Sport Science, Beijing.

Gittoes, M. J. R. & Kerwin, D. G. (2006). Component inertia modelling of segmental wobbling and rigid masses. *Journal of Applied Biomechanics, 22 (2), 148-154*.

Goffe, W. L., Ferrier, G. D. & Rogers, J. (1994). Global optimization of statistical functions with simulated annealing. *Journal of Econometrics*, **60**, 65-69.

Hewett, T. E. (2000). Neuromuscular and hormonal factors associated with knee injuries in female athletes. *Sports Medicine*, **29** (5), 313-327.

Panzer, V. P., Wood, G. A., Bates, B. T. & Mason, B. R. (1988). *Lower extremity loads in landings of elite gymnasts (XI)*, 729-735: Free University Press.

Wood, G. A. & Jennings, L. S. (1979). On the use of spline functions for data smoothing. *Journal of Biomechanics*, **12**, 477-479.

Yeadon, M. R. (1990). The simulation of aerial movement 2. A mathematical inertia model of the human-body. *Journal of Biomechanics*, **23** (1), 67-7.