KINETIC AND KINEMATIC DIFFERENCES BETWEEN FORWARD AND BACKWARD FACING DROP LANDINGS IN COLLEGIATE LEVEL GYMNASTS.

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The purpose of this study was to determine any biomechanical differences between a forward and backward drop landing. Overall this study reported that landing in one direction was not inherently safer than the other direction. Gymnasts utilised different strategies dependent on the landing direction which may have strength and conditioning implications.

KEY WORDS: gymnastics, landing direction, injury.

INTRODUCTION: Prolonged exposure to large forces upon landing is one of the main contributors to injury of the lower extremity within gymnastics (Mills *et al.,* 2008). Given that many years of repetitive practice of skills is fundamental to the achievement of a high standard of performance within gymnastics, chronic exposure to these large forces is unavoidable and consequently injury is prevalent. Effective injury prevention strategies (altering joint flexion, strengthening of specific muscles groups etc) are therefore essential to the maintenance of gymnasts' health and levels of performance.
Studies investigating gymnastic landings have predominantly examined those in the forward direction (whole body centre of mass: horizontal velocity vector is in the same direction as a vector from anatomical posterior to anterior) with only a few considering backward facing landings (McNitt-Gray *et al.*, 2001; Panzer *et al.*, 1987). Such studies have found that gymnasts tend to experience peak vertical ground reaction force (PVGRF) of similar magnitudes (approximately 4 times body weight (BW)) when landing from backward and forward facing somersaults (McNitt-Gray *et al.*, 2001). However, the important kinematic variables that influence the impact force experienced during landing were not considered. Consequently complete kinetic and kinematic information with regard to backward facing landings is lacking and thus methods of possible injury prevention are unknown.
This study aims to identify any differences in the kinematics and kinetics of forward and backward facing drop landings, from the same height, in national collegiate level gymnasts. Based on previous research, it is hypothesised that there will be no kinematic or kinetic differences in relation to drop landing direction. If this hypothesis is rejected, the design and implementation of different strategies for each landing direction is required in order to minimise risk of injury both within training and competitive routines.

Methods: Eight healthy national collegiate female gymnasts volunteered to participate in this study. Participants' age (19.86 ± 1.55 years), height (162 ± 7cm), mass (58.26 ± 5.41kg), years of experience within gymnastics (13.75 ± 3.45 years) and hours spent training per week (8.50 ± 0.93 hours) were recorded and everyone provided signed informed consent. The experimental procedure received approval from the University Ethics committee.
A platform with a drop height of 0.67m was centrally aligned with the force plate (Kistler, 9281) on which gymnasts would land on a 0.10m thick mat (1.98m x 1.98m, Continental Sports) constructed of dx30 poly foam with a fire retardant polyvinyl chloride cover, as specified within the "code of points".
Two cameras (Canon MD101), both set at a sampling rate of 50Hz with a shutter speed of 1/250s, were secured and horizontally levelled on their respective tripods on either side of the platform, perpendicular to the line of action. Cameras were positioned to allow the right side of the gymnast to be viewed for both conditions and then calibrated using a two dimensional 'L' shaped frame (2m: x axis – horizontal, 2m: y axis – vertical). Skin markers were placed on the following anatomical landmarks on the right side of the body using a marker pen; acromion process, greater trochanter, lateral condyle of the knee, lateral malleolus and the lateral aspect of the 5th metatarsal.

The force plate (1000 Hz; y- vertical axis, x- horizontal axis) was calibrated for each individual by instructing the participant to stand stationary on the mat above the force plate, immediately prior to execution of the first landing in the forward and backward directions. Each participant performed four forward and backward facing landings in a randomised order with a one minute interval in-between each one to prevent fatigue. All jumps were performed by stepping off the platform with the arms folded across their chests as a way to control the contribution of the arm action between participants (Pain & Challis, 2006). Landings were performed by contacting the mat with both feet simultaneously and bringing the velocity of the centre of gravity (COG) to zero.

Kinematic and kinetic data collection were synchronised to the time of initial contact using a force triggered LED, positioned in the field of view of each camera. Time of contact was identified by the video field in which the LED illuminated within the kinematic data and the first consistent increase in vertical force within the kinetic data (McNitt-Gray *et al.,* 1993).

All landing trials were analysed using Ariel Performance Analysis System (APAS) (Ariel Dynamics Inc, Trabuco Canion, USA) motion analysis software. Each landing was trimmed to start ten frames before initial contact with the landing mat and end fifteen frames after the minimum COG position. Following digitisation the raw spatial coordinates were smoothed using a digital Butterworth filter with a cut-off frequency of 6Hz.

PVGRF of each landing task was identified and converted to BW to account for any differences in weight. Peak ankle, knee and hip joint angular velocity (JAV) were obtained from APAS by defining the segments as follows; shank relative to the foot, thigh relative to the shank and trunk relative to the thigh, respectively. Landing phase duration was identified as the time from initial contact to the minimum vertical position of the whole body COG, as used by McNitt-Gray (1991). Leg stiffness was determined as the ratio of change in vertical GRF to the vertical displacement of the whole body COG between initial contact and PVGRF, derived from Hughes and Watkins (2008), with the absolute values used for analysis.

Means of each variable for the four trials in each direction were calculated. Data were tested for normality using Shapiro-Wilk tests and if normal repeated measures *t*-tests ($p < 0.05$) were carried out. Effect size data were interpreted using the scale of 0.1 to 0.3 as small, 0.3 to 0.5 as moderate, 0.5 to 0.7 as large and 0.7 to 0.9 as very large.

Results: PVGRF was not significantly different between the forward and backward facing landings ($t(7) = 1.849$; $p = 0.107$) and the effect size showed a large effect ($r = 0.57$). Table 1 illustrates mean PVGRF values and standard deviations.

	Backward Facing Landings	Forwards Facing Landings
PVGRF (BW)	5.29 ± 0.50	4.99 ± 0.63
Peak Hip JAV (rad/s)*****	-8.48 ± 0.72	-7.70 ±0.88
Time to Peak Hip JAV (s)	0.16 ± 0.01	0.14 ± 0.01
Peak Knee JAV (rad/s)*****	-9.60 ± 0.54	-10.52 ± 0.69
Time to Peak Knee JAV (s)	0.14 ± 0.01	0.13 ± 0.01
Peak Ankle JAV (rad/s)*****	-16.93 ± 1.59	-14.47 ± 1.25
Time to Peak Ankle JAV (s)	0.10 ± 0.01	0.10 ± 0.01
Landing Phase Duration (s)	0.23 ± 0.08	0.29 ± 0.08
Leg Stiffness ($N \cdot m^{-1}$)	23.5 ± 3.35	24.37 ± 3.90

Table 1. Forward and backward facing kinematic and kinetic results (mean ± standard deviation). ***** Significant difference between the forward and backward facing landings.

Maximum ankle and hip JAV were found to be significantly larger for backward facing landings than forward ones ($z = -2.521$; $p = 0.012$, $t(7) = -2.903$; $p = 0.023$ respectively). The effect size between the landing directions showed a large effect for ankle JAV ($r = 0.63$) and a very large effect for hip JAV ($r = 0.74$). Maximum knee JAV was significantly greater when landing in the forward direction compared to the backward direction ($t(7) = 4.908$; $p = 0.002$) and the effect size was very large ($r = 0.88$).

Maximum JAV was greatest in magnitude and occurred earliest at the ankle joint, followed by the knee and then the hip joint during both the landing directions (Table 1).
Landing phase duration was not found to differ significantly between forward and backward facing landings although the difference approached significance ($t(7) = -2.269$; $p = 0.058$) and the effect size was large ($r = 0.65$). Leg stiffness was not found to differ significantly between the landing directions ($t(7) = -1.163$; $p = 0.283$) and the effect size was medium ($r = 0.40$).

Discussion

This study found ankle, knee and hip joint peak angular velocity to be the only variables to differ between landings in the forward and backward direction. Specifically it was found that peak angular velocity of the ankle and hip joints were greater when landing in the backward compared to the forward direction, whereas peak angular velocity of the knee joint was greater when landing in the forward direction relative to backwards drop landing. These findings indicate that 'landing direction' acts like a task constraint, resulting in the gymnasts organising a specific landing strategy depending on whether they are landing from a forwards or backwards drop jump. This is in agreement with Mills *et al.* (2009) who also reported that gymnasts modified their landing strategy according to the landing direction when performing somersaults. One suggestion for this altered landing strategy may be due to postural control as a consequence of differing centre of mass trajectories (anteriorly/posteriorly) (Cortes *et al.,* 2007) when performing a front and backwards drop landing. Consequently gymnasts adjust the landing strategy so that they may successfully land the drop jump in a balanced manner.
As the leg muscles control the landing movement, this study indicates that the hip and ankle extensors are activated to a greater extent when landing from a backwards drop jump compared to a forwards landing; whereas the knee extensors (quadriceps) are activated more when landing from a forwards drop landing compared to a backwards landing. Although EMG analysis is needed to support this assumption, it is predicted that through the repetitive nature of landing activities within gymnastics, stress may be placed on specific muscle groups depending on the landing direction. Consequently coaches should incorporate varying landing directions within practices so to avoid overloading muscle groups that could eventually result in injury. Moreover coaches may find it beneficial to reduce the direction of landing that increases possible stress of the previously injured joint in an attempt to avoid further injury.
The finding that peak angular velocity was greatest in magnitude and occurred earliest at the ankle followed by the knee and hip joint during both the forward and backward facing landings is in accordance with McNitt-Gray (1991). Such findings suggest that gymnasts consistently utilise invariant temporal characteristics (McNitt-Gray, 1991) independent of landing direction to absorb the force experienced. This is suggested to place the ankle joint at the greatest risk of injury during landings in both directions given the associated increase in joint loading rate with increased JAV (McClay *et al.*, 1994). However, such patterns appear beneficial for the more proximal joints. Coaches are encouraged to consider emphasising strength training of the surrounding muscles of the ankle joint, irrespective of the direction of landings executed during routines, as this joint is under a greater amount of stress than the knee and hip joints during both forward and backward facing landings. This is proposed to aid the resistance of the ankle joint to the greater angular velocity experienced upon landing and consequently reduce the loading rate of this joint, contributing to injury prevention.
The finding that forward and backward facing landings do not differ with respect to the PVGRF experienced corresponds with McNitt-Gray *et al.* (2001), who reported forward and backward facing somersaults to possess similar PVGRF. This indicates that a different landing strategy is employed to dissipate the impact forces similarly. Additionally, the range of PVGRF values reported within the current study correspond with those obtained by McNitt-Gray *et al.* (1993) when investigating landings in the forward direction onto a soft or stiff mat from a drop height of 0.69m, comparable to that used within the current study

(0.67m). Based on the current findings and those of McNitt-Gray *et al.* (2001) it appears that gymnasts are at no overall greater risk of injury when landing in the forward direction compared to the backward direction with regard to the impact force experienced. This is supported by the finding that forward and backward facing landings do not differ with respect to the landing phase duration, which also corresponds with results of previous research concerning landings in the forward direction (McNitt-Gray, 1991; McNitt-Gray *et al.*, 1993). However Mills *et al.* (2009) noted that although participants could minimise the GRF through changes in muscle activation via an altered landing strategy, this could result in greater internal loading and hence the possibility of risk. It is therefore suggested that GRF may not be the most appropriate measure to assess risk of injury during landing activities, but in the future should include internal loading forces.

It was found that leg stiffness does not differ when landing in the forward or backward direction which also supports the notion that one landing direction is not inherently safer than the other, meaning the lower extremity is not exposed to a greater risk of injury (Williams et al., 2004). The current leg stiffness values are lower than those obtained by Hughes & Watkins (2008). This may be attributed to the greater drop height used within this study and the fact that leg stiffness decreases as drop height is increased (Wang, 2009). Due to the different methods used to calculate leg stiffness across similar studies, it is difficult to compare research findings to the current results. However, it appears that gymnasts use similar leg stiffness irrespective of landing direction.

Conclusion: The current study has shown gymnasts utilise different strategies when landing from a forward and backwards drop landing. It is suggested that one landing direction is not inherently safer than the other but that coaches should be aware of these different strategies and the potential risk of injury as a gymnast continually lands from only one direction. To gain a more in-depth understanding of the differences between these two landing strategies, joint moment and joint power analysis is required.

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