# LOWER LIMB MUSCULOSKELETAL STIFFNESS CAN PREDICT OVERUSE INJURIES IN HIGH LEVEL ADOLESCENT FEMALE ATHLETES.

**Mark Moresi[1 2], Elizabeth Bradshaw[1], David Greene[1] and Geraldine Naughton[1]**

**Centre of Physical Activity Across the Lifespan (CoPAAL), Australian Catholic University, Australia[1]**

**New South Wales Institute of Sport, Sydney, Australia[2]**

The purpose of this study was to investigate whether measures of lower limb musculoskeletal stiffness (MSS) can prospectively predict overuse injuries in adolescent female athletes. Thirty-nine athletes from high-impact sports (gymnastics and track & field) completed a series of repeat jumps on force plates at baseline and 12 months later. Sport-related injuries were tracked using a self-report questionnaire. Receiver operating characteristic (ROC) curves established the predictive ability and appropriate cut-off value of baseline MSS measures. Logistic regression based on the ROC findings showed measures of MSS were able to correctly categorise 77% ($p<0.01$) of the prospective overuse injuries and non-injuries reported. It was concluded that measures of lower limb MSS are good predictors of overuse injury in females involved in high- impact sports.

**KEY WORDS:** repeat jumps, gymnastics, track and field.

**INTRODUCTION:** Investigation into the underlying mechanisms of sport-related injuries is vital for injury prevention. For the high level adolescent female athlete, sports participation has the potential for many positives outcomes. However, the increased demands of sports participation at a critical time of growth may place the adolescent female athlete at increased risk of injury (Purnell, Shirley, Nicholson & Adams, 2010). Injury rates for adolescent athletes involved in high impact sports indicate a high number of musculoskeletal injuries (Sands, Shultz, & Newman, 1993; Zemper, 2005). Although increases in training volume are associated with increased injury risk in adolescent athletes, it is suggested the magnitude of loading (i.e training intensity) may be more critical in overuse type injuries (Edwards, Taylor, Rudolphi, Gillette & Derrick, 2010).

Measures of lower limb musculoskeletal stiffness (MSS) seek to quantify the compliance or resistance of the musculoskeletal system during ground impact. As a measure of impact-musculoskeletal system interaction, MSS may provide some insight into the possible link between musculoskeletal loading and potential injury risk in high impact athletes. MSS has previously been linked to lower limb injuries in athletic populations (Butler, Crowell & Davis, 2003). Higher levels of MSS may increase the impact forces and loading rates experienced, and subsequently increase musculoskeletal injury risk (Butler et al., 2003). Retrospective research into injury and MSS in gymnasts suggests an optimal range of stiffness above which potential musculoskeletal stress and injury may occur (Bradshaw, Le Rossignol, Williams & Lorenzen, 2006).

Although there appears to be a link between MSS and injury, limited prospective support is available to date. A recent study into leg and musculotendinous stiffness of the hamstrings in Australian rules footballers, supports MSS as a potential risk factor in acute hamstring injuries (Watsford, Murphy, McLachlan, Bryant, Cameron, Crossley & Makdissi, 2010).

The purpose of the present study was to prospectively investigate whether measures of MSS can predict overuse injuries in high level adolescent female athletes. It was hypothesized that greater levels of lower limb MSS at baseline testing would successfully predict the incidence of lower limb overuse injury in adolescent female athletes involved in high impact sports (gymnastics and track and field).

**METHODS:** Thirty-nine national level adolescent female athletes from two high-impact sporting populations (17 gymnasts and 22 track and field athletes: 9 sprinters, 8 jumpers, 1 middle distance and 4 distance runners) completed fifteen contacts of continuous bent-knee (CJb) and continuous straight-leg (CJs) repeat jump tasks with one foot placed on each of two portable force plates (Kistler, 9286A, Switzerland). All jumps were performed at a self-selected jump frequency. Following removal of the first and last contacts as atypical, measures of vertical lower limb MSS ($k_{vert}$) were calculated from the combined force plate data and averaged across all remaining contacts for each trial. MSS measures were standardised to a body mass of 56.43 kg and jump frequencies of 1.40 Hz (CJb) and 1.78Hz (CJs) using residual calculations based on linear regression analysis for each participant group.

In addition to MSS measures, information on typical training hours, injury history (previous 2 years) and musculoskeletal injuries sustained during the 0-6 months and 6-12 month post-testing periods were obtained via self-report questionnaire. An injury was defined as any physical problem that occurred as a direct result of participation in their chosen sport resulting in a missed or modified subsequent training session or competition (Kirialanis, Malliou, Beneka & Giannakopoulos, 2003). A sub-sample (n=10) of participant injury reports were cross-checked with athlete parents and coaches and were positively verified. Only sport-related, overuse lower limb injuries were included in subsequent data analysis. Common chronic injury problems such as Severs disease were also classified as overuse injuries (Christopher & Congeni, 2002). Due to the large difference in average training hours between the two participant groups, training hours z-scores relative to the specific cohort were calculated for further statistical analysis.

Receiver operating characteristic (ROC) curves were calculated using the Statistical Package for Social Sciences (SPSS, v17.0) to assess the ability of MSS measures to successfully predict overuse injury and identify any associated critical threshold value. Subsequent logistic regression analysis was conducted for athletes above or below the threshold identified by ROC analysis to establish the ability of MSS measures to accurately classify injured or non-injured athletes prospectively.

**RESULTS:** A large number of high impact athletes experienced a sport-related lower limb injury across the 12 month tracking period (88% of gymnasts and 64% of track and field athletes). Of these injuries, nearly 77% of gymnasts and 41% of track and field athletes experienced a lower limb injury classified as overuse in nature (Table 1).

**Table 1: Participant descriptives (mean ±SD) and 12-month prospective lower limb injuries (number of athletes injured with the percentage of the group in brackets).**

| Athlete Group | n | Age (y) | Height (m) | Mass (kg) | Training hrs | # of Injuries | New Injury | Recurrent Injury | Overuse Injury |
|---|---|---|---|---|---|---|---|---|---|
| Gymnastics | 17 | 13.5 ±1.5 | 145.6 ±8.2 | 38.1 ±6.7 | 33.6 ±1.9 | 15 (88%) | 12 (71%) | 3 (18%) | 13 (77%) |
| Track and Field | 22 | 15.5 ±1.1 | 169.1 ±7.0 | 58.0 ±5.2 | 7.8 ±3.1 | 14 (64%) | 9 (41%) | 5 (23%) | 9 (41%) |
| Total | 39 | --- | --- | --- | --- | 34 (41%) | 23 (28%) | 11 (33%) | 24 (29%) |

Following standardisation to body mass and jump frequency, similar measures of lower MSS were displayed by both participant groups during the CJb and CJs tasks. For the CJb task gymnasts had an average $k_{vert}$ of 8.22 ±4.37 kN/m (standardised value: 14.00 kN/m) with track and field athletes averaging 13.43 ±8.00 kN/m (standardised value: 14.44 kN/m). Average lower limb $k_{vert}$ measures of 20.35 ±7.85 kN/m (standardised value: 24.16 kN/m) and 23.04 ±8.32 kN/m (standardised value: 25.52 kN/m) during the CJs task were obtained for the gymnast and track and field athletes, respectively.

Receiver operating characteristic (ROC) curve analysis indicated increased $k_{vert}$ was able to predict overuse injuries and non injuries during the CJs task (Area=0.762, $p<0.01$, Cutoff

value=23.05 kN/m). Although increased $k_{vert}$ measures during the CJb appeared to show a similar ability, the area under the curve did not reach significance (Area=0.666, p >0.05, Cutoff value=12.80 kN/m). Training hours did not predict overuse injury (Area=0.591, p >0.05).

Logistic regression results indicated increased $k_{vert}$ during the CJs task was able to correctly predict approximately 77% of athlete outcomes (Figure 1). Based on the calculated odds ratio, an athlete with a $k_{vert}$ measure above the calculated threshold has an increased likelihood of overuse injury of approximately 11.05 times.

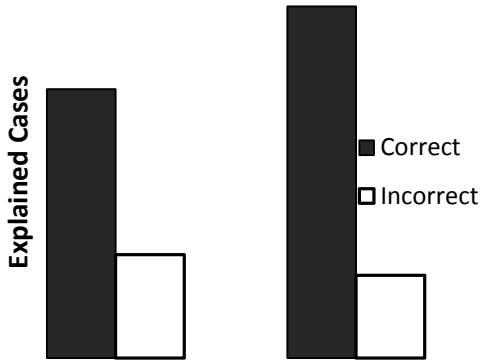


**Figure 1: Correct and incorrect prediction of overuse injuries using vertical stiffness ($k_{vert}$) measures from the straight-leg repeat jump (CJs) task.**

**DISCUSSION:** The results of the present study supported the hypothesis that increased measures of lower limb MSS could prospectively predict overuse injuries in high level adolescent athletes from high impact sports.

Previous research would suggest increased MSS results in greater forces and loading rates, increasing the stress applied to the musculoskeletal system (Butler et al., 2003). Although the underlying mechanisms require further exploration, the results of the present study suggest that higher MSS is associated with a greater risk of overuse injury in the high impact adolescent athlete. The prospective nature of the present study adds further weight to the links between lower limb MSS and stress-related injuries. It is postulated that increased MSS in the high impact adolescent athlete, increases the general impact magnitude and subsequent training load experienced potentially progressively overloading the musculoskeletal system.

The inability of training hours to successfully discriminate overuse injuries would suggest that for the high level adolescent athlete, overuse injury is more concerned with the magnitude of the loading than the volume. However, the large variation in training hours between the athlete groups made it difficult to compare the impact of training hours on potential injury. Unfortunately, small numbers in each participant group meant within group analysis was untenable. In addition to differences in self-reported training hours between athlete groups, the actual training volume and intensity may not be accurately represented by the surrogate "loading" estimate of training hours. Although previous research suggests training volume is related to injury in adolescent athletes (Loud, Gordon, Micheli & Field, 2005), at high level competition where training volumes are already increased, it may be that the magnitude of loading becomes more critical. Future research into more accurate measures that combine objective measures of training volume and measures of MSS may provide better injury prediction models for high-impact athletes.

The high incidence of self-reported injuries in the present study supports previous research indicating high level participation in high impact sports can come with an inherent increase in injury risk for the adolescent athlete (Sands et al., 1993; Zemper, 2005). These results continue to reinforce the need for further research to identify potential injury mechanisms and more importantly establish injury prevention strategies for these athletes at such a critical period in their athletic career.

Although MSS measures appear effective in their ability to prospectively discriminate adolescent female athletes who experience overuse injuries, injury risk prediction is based on baseline MSS measures. Potential longitudinal changes to MSS may have influenced the results of the present study. In addition, although care was taken to maintain the integrity of the logistic regression model, the present results may be influenced by the small case numbers and relatively high proportion of injuries in the present cohort. Although previous injury was considered in the present study and not believed to be largely influential based on the number of new injuries indicated in the injury results, previous injury and other underlying injury mechanisms must be considered in evaluating the results of the present study.

**CONCLUSION:** Increased lower limb MSS measures, as measured during self-paced repeat jump tasks, were related to an increased incidence of overuse injury in adolescent female athletes involved in high level gymnastics and track and field. Athlete screening for measures of MSS may allow 'at risk' athletes to be identified and potential athlete monitoring or intervention programs to be implemented.

**REFERENCES:**

Bradshaw, E.J., Le Rossignol, P., Williams, M. & Lorenzen, C. (2006). Novel insights on lower limb musculoskeletal health and performance in pre-adolescent and adolescent gymnasts. In *Proceedings of the 24th International Symposium on Biomechanics in Sport.* University of Salzburg, Salzburg.

Butler, R.J., Crowell, H.P. & Davis, I.M. (2003). Lower extremity stiffness: Implications for performance and injury. *Clinical Biomechanics, 18,* 511-517.

Christopher, N. & Congeni, J. (2002). Overuse injuries in the pediatric athlete: evaluation, initial management, and strategies for prevention. *Clinical Pediatric Emergency Medicine, 3,* 118-128.

Edwards, W.B., Taylor, D., Rudolphi, T.J., Gillette, J.C. & Derrick, T.R. (2010). Effects of running speed on a probabilistic stress fracture model. *Clinical Biomechanics, 25,* 372-377.

Kirialanis, P., Malliou, P., Beneka, A. & Giannakopoulos, K. (2003). Occurence of acute lower limb injuries in artistic gymnasts in relation to event and exercise phase. *British Journal of Sports Medicine, 37,* 137-139.

Loud, K.J., Gordon, C.M., Micheli, L.J. & Field, A.E. (2005). Correlates of stress fractures among preadolescent and adolescent girls. *Pediatrics, 115(4),* 399-406.

Purnell, M., Shirley, D., Nicholson, L. & Adams, R. (2010). Acrobatic gymnastics injury: occurrence, site and training risk factors. *Physical Therapy in Sport, 11,* 40-46.

Sands, W.A., Shultz, B.B. & Newman, A.P. (1993). Women's gymnastics injuries. A 5-year study. *The American Journal of Sports Medicine, 21(2),* 271-276.

Watsford, M.L., Murphy, A.J., McLachlan, K.A., Bryant, A.L., Cameron, M.L., Crossley, K.M. & Makdissi, M. (2010). A prospective study of the relationship between lower body stiffness and hamstring injury in professional Australian rules footballers. *The American Journal of Sports Medicine, 38(10),* 2058-2064.

Zemper, E.D. (2005). Track and field injuries. *Medicine and Sport Science, 48,* 138-151.

*Acknowledgement:* This research was supported by the New South Wales Sporting Injuries Committee and an Australian Research Council Industry Linkage grant (LP0776456).