SKIPP FROM HEAD TO TOES: SPORTS KINESIOLOGY, INJURY PREVENTION AND PERFORMANCE - CONCUSSION TO ACHILLES INJURY BIOMECHANICS

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Understanding injury mechanisms and risk factors, and introducing interventions to reduce inappropriate forces, are key to being a successful sports injury biomechanist. Monitoring rugby players' head impacts with triaxial accelerometers in behind-the-ear patches and instrumented mouthguards has shown that the size and frequency of impacts in rugby were greater than most other sports. Assessment of lower limb stiffness in elite triathletes has shown the association with Achilles tendon injury risk.Visual feedback training in rowers has changed biomechanics and reducedinjury risk. Monitoring load in gymnastics is important to reduce injury risk. Translation of SKIPP knowledge into SportSmart and its derivative programmes has provided practical information for coaches and athletes, helped change attitudes and behaviours towards injury prevention and reduce injuries.

KEY WORDS:rowing; netball; rugby; cycling; stiffness; accelerometry

INTRODUCTION: Sports injuries are frequent, particularly knee and ankle injuries in rugby, league, football and netball. Even in minority sports such as gymnastics the incidence and cost of injury is too high. Our analysis of 13,111 gymnastics injury entitlement claims in New Zealand between 2005 and 2010 (Gianotti, 2010)showed the most frequent body sites injured were the ankle, knee, foot, upper and lower arm and hand/wrist. The most expensive body sites to treat were the neck vertebrae, knee and ankle. Acute injuries are usually well documented, however incidence and cost of overuse injuries is often less clear.Understanding the mechanisms of injury and risk factors, and introducing interventions to reduce inappropriate forces, are the keys to being a successful injury biomechanist. Internal and external risk factors when combined with the mechanism (inciting events) of injury may make a gymnast more prone to injury(Hume, Bradshaw, & Bruggeman, 2013). Large impact forces, in combination with poor lower limb geometry during landings result in injuries predominantly to lower limbs. Loading frequency and total loading time in combination with loading amplitude arekey determinants of the mechanical stimulus in gymnastics(Bruggeman & Hume, 2013). Sports biomechanists have a role in preventing injury whilst improving performance. It is a balancing act as recommendations to reduce injury risk may also reduce performance.

AIM &METHODS: The aim of this invited paper is therefore to outline examples of SKIPP research from 2000 to 2014that have resulted in advancement of theory and practical application in sports injury biomechanics and injury prevention.

RESULTS: Concussion is frequent in contact sports and can results in serious outcomes. The IRB/NZRU/AUT RugbyHealth study reported long term health outcomes for 485 retired players, many of whom had sustained multiple concussions. Ex-rugby players had a greater proportion of injuries during sport including concussions, and arthritis and alcohol use concerns currently. Ex-rugby players reported a wider range of health issues than non-contact sport players. There were more neuro-cognitive deficits in retired elite rugby players and community rugby players than non-contact sport players. Retired players who sustained three or more concussions had greater deficits in neuro-cognition, psychomotor speed, visual memory, and motor speed than those who reported no previous concussions.Elite retired rugby players had better balance than community rugby players and non-contact sport players. Players with no self-reported concussion had better balance than retired players with one to three self-reported concussions.Corticomotor and intracortical brain excitability was intact in elite and community level rugby players in comparison to non-contact sport players.

There were no clear differences in any corticomotor excitability measures among groups with or without previous concussion.

Impacts in rugby have been implicated as a risk factor for concussion injury in rugby. At rucks, and in scrums and mauls, players collide with each other over and over again, often with large force.We monitored38 rugby players' head impacts with triaxial accelerometers in behind-the-ear X2Biosystemspatches and instrumented mouthguards, and their concussions. The size and frequency of the impacts in rugby were greater than in most sports previously studied(King, Hume, Brughelli, & Gissane, 2014). During aseason of19 games, 20,687 impacts greater than 10g were recorded, average 22g, maximum 164.9g, in one team. Players suffered an average of 77 head impacts per game, or 1,379 per player per season, more than previous studies had found in American high school football (16-29 per game, 520-625 per season) and American college football (9-13 per session, 414-1400 impacts per season). Impacts had an higher average force (22g) than had previously been found in youth football (15g), but were similar to those found in high school football (21-26g), some college football (18-27g), and lower than those found in girls' soccer (25- 63g), some college football (32g) and professional American football (60g). Previous analyses of American football teams had established an injury tolerance level for concussion of 95g or 5500 rad/s². We recorded 181 impacts greater than 95g, and 4452 greater than 5500 rad/s², although the relevance of those numbers is unclear, given differences between codes. The two concussions observed occurred following impacts <95g, demonstrative of the indistinct relationship between impact force and injury.

Rugby union generates the greatest proportion of total injury claims at 18% and claim costs at 17% to ACC. New Zealand (NZ) Rugby Union and ACC developed RugbySmart with the aim of eliminating serious injuries from rugby. Within NZ, RugbySmart is compulsory for coaches and referees in tackle grade rugby. Over 8,000 coaches and 2,000 referees are accredited each year. RugbySmart was introduced in 2001 with a corresponding decrease in the number of severe spine-neck injury claimswhen comparing the number of serious injuries from 1995 to 2004(Quarrie, Gianotti, Hopkins, & Hume, 2007). Dental injuries have also reduced since the introduction of RugbySmart which targets the use of mouth guards and correct tackling technique(Gianotti, Quarrie, & Hume, 2009). Evaluation of the effect of a new scrum law on neck and back injuries in rugby union also showed decreased injuries (Gianotti, Hume, Hopkins, Harawira, & Truman, 2008).

Back injuries and rib stress fractures are frequent in rowing. Correct technique is important given high training loads. Rowing and kayak biomechanics analysis using instrumentation and feedback systems have helped improve performance and reduce injury**.** Whilst coaches are predominately focused on what biomechanical variables are the most important for improving performance(McDonnell, Hume, & Nolte, 2013; Soper & Hume, 2004), what variables may be predictors for injury risk are also important.Some technology first used with rowing in 2001 was the Goggles Training System that allowed real time feedback of video and sound to the rower. We identifiedimmediate and training effects of visual feedback on lumbo-pelvic angle during 1-min of on-water rowing. Eight NZ rowers completed pre and post-training testing of four 1-minrowing trials at 28 strokes per minute with combinations of goggles on or off and instruction from national coach Dick Tonks or not. The Goggles Training System significantly reduced lumbo-pelvic angle for some rowers and supported the system use as a tool for improving rowing technique and preventing injury(Hume, Soper, & Zeinstra, 2003). The effect of foot-stretcher angle on rowing performance was not known, yet theoretically, horizontal forces should increase as the foot-stretcher angle increases or gets steeper. In the lab we tested how changes in foot stretcher angle affected rowing performance time, mean power output, mean stroke rate and mean handle excursion for ten elite rowers over 500 m. Changing foot-stretcher angle influenced performance resulting in use of optimal foot stretcher angles in training and competition(Hume, Soper, Reid, & Tong, 2005).Rowing NZestablishedthe use of a new boat instrumentation system to allow real-time collection of oar pin forces, oar angles and boat velocity. Reliability and validity have been reported (Coker, 2010).A 0.8% improvement equates to ~3.3 s improvement in total race time and can bethe difference between medaling or not.Small changes in technique that can improve boat velocity with each stroke can make a large difference to the performance outcome.The technology allows valid sensitive measures of elite rowing technique on-water.Our recent studies used a novel foot-stretcher witha rigid wedge shoe fixed at a pivot around the heel, allowing contact of the whole foot surface to the foot-plate throughout the entire stroke.Performanceover 500-m improved with the novel foot-stretcher, and comfort ratings were good.

Incorrect bicycle configuration may predispose athletes to injury and reduce cycling performance. A 5% change in saddle height affected knee joint kinematics by 35% and moments by 16%. Patellofemoral compressive force seems to be inversely related to saddle height but the effects on tibiofemoral forces are uncertain. Changes less than 4% of trochanteric length do not seem to affect injury risk or performance. Given conflicting evidence for effects of saddle height changes on performance and lower limb injury risk in cycling, we suggested the saddle height may be set using the knee flexion angle method (25-30°) to reduce the risk of knee injuries and to minimize oxygen uptake(Bini, Hume, & Croft, 2011).

Functional screening of rugby players using isokinetic dynamometry, balance and cutting movement assessment may help identify risk of ACL or hamstrings injury.Rugby sidestepping mechanics have been implicated as a risk factor for knee injury in rugby(Brown, Brughelli, & Hume, 2014). Three-dimensional kinematics and kinetics of lower limbs of 18 rugby players were recorded during maximal effort 45° sidestepping manoeuvres with and without a ball. Sidestepping with a ball resulted in greater knee adductor moments during weight acceptance than without a ball. The implications are that sidestepping with a ball may result in greater knee injury risk. Biomechanics evaluation for athletes in sport therefore need to include the implement/ball to ensure accurate understanding of movement patterns.

Wedetermined whether lower limb joint coupling variability during unanticipated change of direction movement tasks performed by netballers was associated with subsequent injury(Maulder, 2011).Twelve elite female netballers performed at maximal effort five successful trials of three unanticipated (visual stimulus) change of direction tasks: a left leg plant and 180° turn, a straight ahead run (left or right foot placement), and a right leg plant and 180° turn.Joint coupling variability was calculated as the standard deviation of coupling angles across five trials as a percentage of stance. Injuries, requiring professional treatment and missed game and/or training time,were prospectively followed for six months of the competitive netball season.Five of the 12 (42%) netballers sustained a lower limb injury. There were smaller joint coupling variability magnitudes in injured netballers.High joint coupling variability appeared beneficial for reducing injury risk.To help reduce injury risk, intervention programmes designed for female netballers should focus on developing a large repertoire of coupling strategies for use during unanticipated movement tasks.

Lower extremity stiffness has been implicated as a risk factor for Achilles injury in triathletes(Lorimer & Hume, 2014). In a one year prospective study of 75 triathletes,those who developed a new or reoccurring injury had higher leg and knee to ankle stiffness ratio compared to controls. Increasing running pace was associated with increases in knee (ES=0.61) and ankle stiffness (1.11). Transitioning from cycling caused an increase in ankle stiffness (0.55) but a decrease in knee stiffness (-0.38). Individual responses are likely to be important when assessing injury risk.Stiffness may be a potential screening tool for athletes.

Repetitive loading is a key component of pathophysiology of common running injuries such as bony stress injuries.Peak tibial acceleration has been linked with tibial stress fractures in runners. Sensors on a runners' lower limbs can capture impact loading. Runners with high-risk of tibial stress fracture will participate in an intervention study that evaluates the effectiveness of real-time visual feedback to alter biomechanics in runners.

Translation of SKIPP knowledge into practical information for coaches, athletes and administrators can help change attitudes and behaviours and help reduce injury risk. The NZ SportSmart 10-point plan for injury prevention, and sport specific adaptions (e.g. RugbySmart, NetballSmart), have incorporated best practice from scientific evidence of injury prevention strategies into education programmes. The use of biomechanics information in the technique, environment, screening, warm-up and conditioning points in particular have been useful to help reduce injury risk.Coaches were identified as key to injury prevention given their ability to influence the behaviour of players, so research attemptsto answer coaches' questions to ensure the injury prevention and performance content stays relevant. As new knowledge in each area has been gained the various on-line and written resources for SportSmart and the associated RugbySmart, NetballSmart etc are updated.The success of the SportSmart injury prevention model was the subject of an editorial in the British Journal of Sports Medicine in 2008 where Dr John Orchard stated that it was time for other nations to follow New Zealand's success. Since this time BokSmart for rugby has been introduced in South Africa, with an evaluation of its implementation by James Brown showing a positive effect.

CONCLUSION: Understanding mechanisms of injury and risk factors, and introducing interventions to reduce inappropriate forces, are key to being a successful sports injury biomechanist. Translation of SKIPP knowledge into SportSmart and its derivative programmes has provided practical information for coaches and athletes, has helped change attitudes and behaviours towards injury prevention and has helped reduce injuries.Further research is needed on real time feedback and analyses of forces on athletes during training and games.

REFERENCES:

Bini, R.R., Hume, P.A., & Croft, J.L. (2011). Effects of bicycle saddle height on knee injury risk and cycling performance. *Sports Medicine, 41*(6), 463-476.

Brown, S.R., Brughelli, M., & Hume, P.A. (2014). Knee mechanics during planned and unplanned sidestepping: A systematic review and meta-analysis. *Sports Medicine, 44*, 1573-1588. doi: 10.1007/s40279-014-0225-3

Bruggeman, G.P., & Hume, P.A. (2013). Biomechanics related to injury in gymnastics. In D.J. Caine, K. Russell & L. Lim (Eds.), *Handbook of Sports Medicine and Science, Gymnastics* (pp. 200): Wiley-Blackwell.

Coker, J. (2010). *Using a boat instrumentation system to measure and improve elite rowing technique and set-up for on-water rowing performance.* PhD PhD, AUT University, Auckland.

Gianotti, S.M., Hume, P.A., Hopkins, W.G., Harawira, J., & Truman, R. (2008). Interim evaluation of the effect of a new scrum law on neck and back injuries in rugby union. *British Journal of Sports Medicine, 42*(6), 427-430.

Gianotti, S.M., Quarrie, K.L., & Hume, P.A. (2009). Evaluation of RugbySmart: A rugby union community injury prevention programme. *Journal of Science and Medicine in Sport, 12*, 371-379.

Hume, P.A., Bradshaw, E., & Bruggeman, G.P. (2013). Biomechanical approaches to injury mechanisms and risk factors. In D.J. Caine, K. Russell & L. Lim (Eds.), *Handbook of Sports Medicine and Science, Gymnastics* (pp. 200): Wiley-Blackwell.

Hume, P.A., Soper, C.S., Reid, D., & Tong, R. (2005). Foot-stretcher angle does affect rowing ergometer performance. *Successful Coaching UK, 21*(April), 4.

Hume, P.A., Soper, C.S., & Zeinstra, J. (2003). The effectiveness of visual feedback on changing rowing technique. *New Zealand Coach, 1*(4), 6-9.

King, D., Hume, P.A., Brughelli, M., & Gissane, C. (2014). Instrumented mouthguard acceleration analyses for head impacts in amateur rugby union players over a season of matches. *American Journal of Sports Medicine*. doi: 10.1177/0363546514560876

Lorimer, A., & Hume, P.A. (2014). Achilles tendon injury risk factors associated with running: A systematic review. *Sports Medicine, 44*, 1459–1472. doi: 10.1007/s40279-014-0209-3

Maulder, P. (2011). *The association of joint coupling variability and muscle stiffness with lower limb injury occurrence: Biomechanical musculoskeletal markers of lower limb function and health* PhD.

McDonnell, L.K., Hume, P.A., & Nolte, V. (2013). A deterministic model based on evidence for the associations between kinematic variables and sprint kayak performance. *Sport Biomechanics, 12*(3), 205-220. doi: 10.1080/14763141.2012.760106

Quarrie, K.L., Gianotti, S., Hopkins, W.G., & Hume, P.A. (2007). Effect of nationwide injury prevention programme on serious spinal injuries in New Zealand rugby union. *British Medical Journal, 334*, 1150-1153.

Soper, C., & Hume, P.A. (2004). Towards an ideal rowing technique for performance: The contributions from biomechanics. *Sports Medicine, 34*(12), 825-848.

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