NOVEL INSIGHTS ON LOWER LIMB MUSCULOSKELETAL HEALTH AND PERFORMANCE IN PRE-ADOLESCENT AND ADOLESCENT GYMNASTS

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New analyses are presented from the data of Bradshaw and Le Rossignol (2004) to examine the relationship between musculoskeletal health, and physical and performance qualities, with measures of leg stiffness in a group of female gymnasts. A gymnasts leg stiffness can be assessed through continuous jump (straight & bent legged) series tests, as well as from rebound jumps. Although the observations are retrospective, the study revealed a potential safe zone for ankle extensor stiffness. The gymnast with low stiffness had previously suffered a landing ankle injury; whilst four gymnasts with high stiffness had histories of take-off ankle injuries. Aside from profiling physical performance qualities, biomechanical (kinetic) testing has the potential to also aid in the assessment and management of the athlete's functional musculoskeletal health (rehabilitation, injury risk).

KEY WORDS: gymnastics, leg, stiffness, performance, injury.

INTRODUCTION: Virtually every movement in gymnastics is associated with single or sequential impacts with a surface either proceeding and/or at its conclusion. The frequency and exact mechanics of the impact is largely determined by the requirement of a successful landing (descent) and the optimal musculotendinous activation that is required for launching the following movement (Funase et al, 2001). The stiffness of the leg serves dual purposes; first to cushion the impact, and secondly to provide elastic propulsion of the lower extremity. The lower extremity initiates and transfers energy along a kinetic sequence that propels the gymnast during running, hopping, and jumping-based movements on the floor, beam, and vaulting apparatus.

The overall spring stiffness of the leg(s) is achieved through adjustments to the stiffness and geometry of the ankle, knee, and hip joints. When running, leg stiffness is mainly influenced by changes in the knee joint action (increasing at faster velocities) with the stiffness of the ankle joint remaining relatively constant (Arampatzis et al, 1999). During hopping tasks the primary mechanism for adjusting leg stiffness is through biomechanical changes at the ankle joint (Farley & Morgenroth, 1999). The hip and knee joints are characteristically 'braced'. The countermovement is performed by plantar flexion, where the muscle fibres of the lower leg extensors act quasi isometrically, and like a catapult, the stored elastic energy is released from the Achilles tendon (Kawakami et al, 2002). Humans have been revealed to adjust their leg stiffness to also accommodate different surface compliances. The stiffness of the leg spring is increased by as much as 3.6-fold to accommodate decreases in surface stiffness such as when jumping on a sprung floor surface or landing onto a soft mat (Ferris & Farley, 1997). As a result of the adjustment to leg stiffness, the combined total stiffness of the leg and the surface is nearly the same on all surfaces encountered for a specific movement or task. This constant total stiffness makes it possible for the centre of mass mechanics to be extraordinarily similar on sporting surfaces with a wide range of material properties i.e. stiffness, resilience, compliance, hardness (Ferris & Farley, 1997).

In gymnastics tasks, maximal take-off body energy is achieved through variations in leg stiffness by controlling the pre-contact activation levels and through differing musculoskeletal recruitment patterns (Komi, 2000). Leg stiffness is strongly correlated with ground contact time; that is, faster and more explosive surface impacts are achieved through higher leg stiffness in, for example, accelerative sprinting and rebound jumps (e.g. Arampatzis et al, 2001). The control of leg stiffness in tasks such as hopping and rebound jumps can be influenced through verbal instructions by, for example, coaching the gymnast to jump as high and fast as possible with maximum effort (Arampatzis et al, 2001).

Increased stiffness appears to be beneficial to performance (Butler et al, 2003); however there also seems to be an optimal amount of stiffness for injury-free performance. Whilst

increased stiffness is generally beneficial to performance through the creation of force and power; in some movement tasks such as rebound jumps too much stiffness can be detrimental to performance and may lead to injury, especially when it exceeds the athlete's current trained threshold. In young male adults, Walshe and Wilson (1997) demonstrated that stiffer subjects had a reduced capacity to perform under higher eccentric loads during rebound jump tasks (rebound jump heights $\geq$ 80 cm). The authors suggested that the relatively greater forces transmitted from the skeletal system to the musculature units of the stiffer subjects, reduced their ability to attenuate the higher eccentric loads due to less effective contractile dynamics and greater levels of reflex induced inhibition.
Gymnastics involves moderate and high-intensity musculoskeletal loading which has many positive effects such as increased bone mass and reduced risk of osteoporosis later in life (Frederickson et al, 2005), but is also associated with soft tissue and bony injury, particularly to the lower limbs (Hutchinson & Swan, 2002). Recent data on female gymnasts revealed that the ankle was the anatomical location most frequently injured, with approximately 48% of these injuries occurring upon landing and 36% during take-off (Kirialanis et al, 2003). It is therefore feasible that the musculotendinous control of the lower extremity (leg & ankle extensor stiffness) adjustments may be related to the incidence of lower extremity injury in female gymnasts. The purpose of the current study was to explore the relationship between musculoskeletal injury, anthropometry, and physical performance qualities with measures of leg stiffness of female gymnasts.

METHOD: The methods and earlier examination of the data in relation to predictors of floor tumbling and vaulting ability are fully described in Bradshaw and Le Rossignol (2004). The current analyses, in addition to those previously reported, included an examination of the gymnasts leg stiffness from the bent legged jump series test (CJb_{Ref}) and ankle extensor stiffness from the straight legged jump series test (CJs) on the Quattro portable force platform (Kistler, Switzerland, 500 Hz). The formula for calculating stiffness was $\boldsymbol{k}_{vert} = \boldsymbol{F}_i/\Delta s$, where $\boldsymbol{F}_i$ is the vertical force at the point of eccentric-concentric transition during the take-off phase, and Δs is the change in vertical position of the centre of mass between the eccentric-concentric transition and take-off. This analysis was in response to initial observations of the gymnasts and subsequent conversations with the head coach that linked current (retrospective) injury patterns with measures of leg stiffness. Linear regression analysis in SPSS was utilised to examine the relationship between the anthropometric and physical performance measures with leg and ankle extensor stiffness. Individual and group Z-score profiles were calculated across all measures. The Z-score profiles were utilised to corroborate the mechanisms of injuries assessed retrospectively. Statistical significance was set at $p \leq 0.05$ for all analyses.

RESULTS AND DISCUSSION: Gymnastics movements involve three key phases; the landing, the eccentric (energy storage) to concentric (energy release) transition, and the take-off for the jump. In addition to the control of the landing phase, efficient transfer from eccentric to concentric actions require an appropriate level of leg stiffness. Insufficient leg stiffness during the landing phase or at the point of transition could result in an unwanted collapsing of lower limbs resulting in joint capsule or soft tissue injury. In contrast, excessive leg stiffness may result in excessive loading rates causing injury to the tendon or the attachments/bone. Retrospective observations of leg and ankle extensor stiffness in female gymnasts revealed that there may be an upper threshold for an appropriate level of leg stiffness (Figure 1a), and a safe zone (upper & lower threshold) for ankle extensor stiffness (Figure 1b). Only one gymnast in the study was treated for a knee injury. Interestingly, this gymnast (SC) had a total leg stiffness (6.84 kN/m) during the bent legged jumping test that was ~2.5 kN/m higher than the other gymnasts (Figure 1a). Five gymnasts in the group had sustained an ankle injury (Figure 1b). The gymnast (FC) who presented with noticeably lower ankle extensor stiffness (15.53 kN/m) had attained an ankle injury during landing within the previous year. Four gymnasts (MR, AN, SP, SM) with a markedly higher level of ankle extensor stiffness (31.94-47.91 kN/m) had been treated for ankle injuries that occurred during take-off. Due to the larger number of ankle injuries in the group, the ankle extensor stiffness was selected for further analysis.

a)

b)

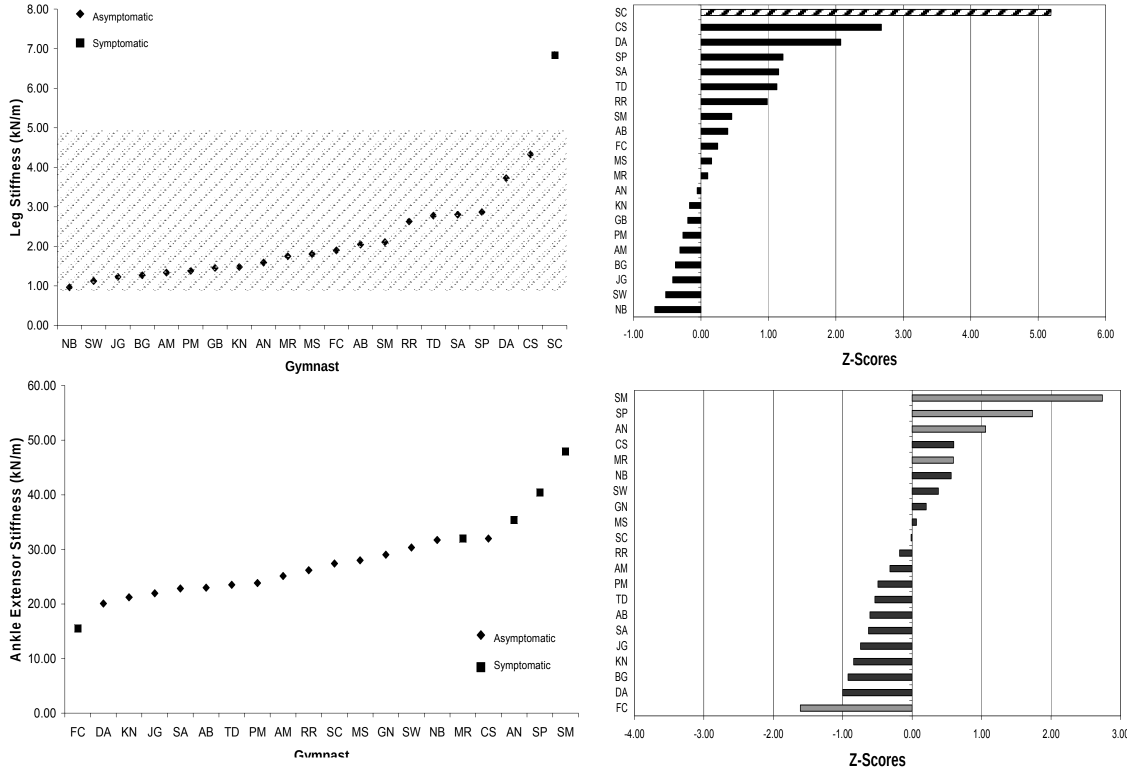

Figure 1. The individual leg (a-upper panel) and ankle extensor stiffness (b-lower panel) of the female gymnasts indicating a possible safe zone (shaded). The gymnasts who had previously suffered a knee or ankle injury that required medical attention are labelled as symptomatic on the scatter graph, and highlighted in diagonal lines (knee) or grey (ankle) on the Z-score profiles.

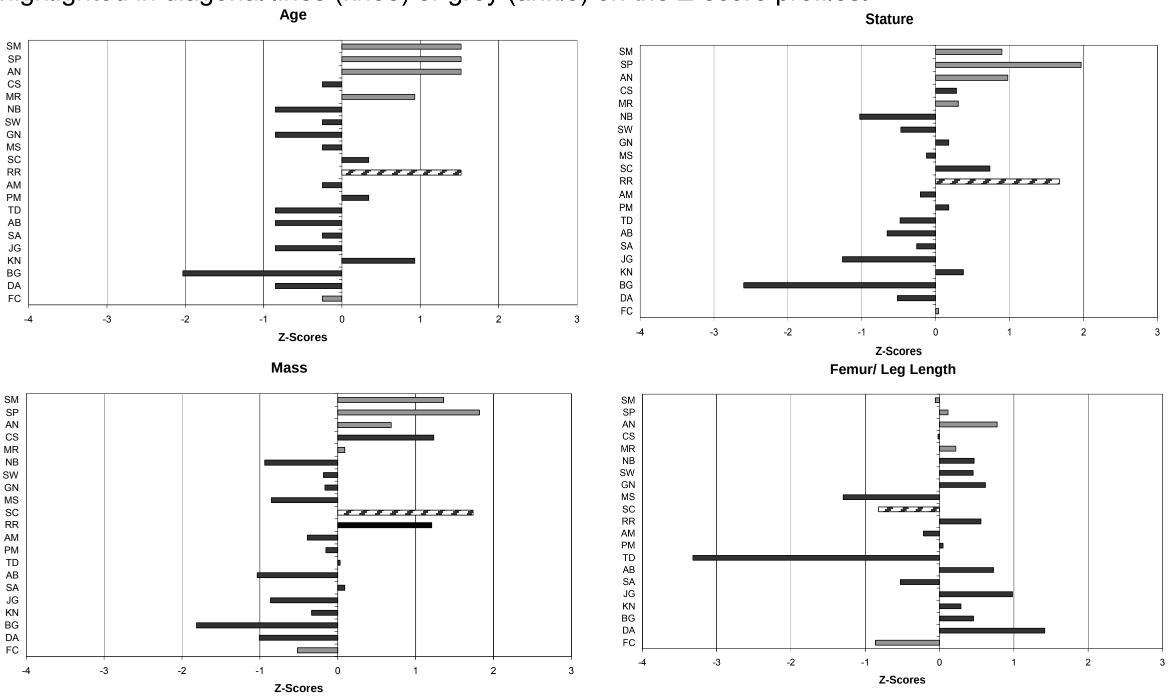

Figure 2. Selected group Z-Score profiles. The gymnasts are presented in order of ankle extensor stiffness from lowest (FC) to highest (SM). The Z-Scores for the five gymnasts who had previously suffered an ankle injury are shaded in grey. The gymnast (SC) with the knee injury is highlighted with diagonal lines.

The production of muscular power either through a concentric leg action (SJ: r=0.22, p=0.04) or a stretch-shortening action (CMJ: r=0.49, p=0.03) is higher in the gymnasts who have increased lower extremity stiffness (CJs). Therefore an appropriate amount of ankle extensor stiffness is required for superior jumping performance in gymnastics. The group Z-Score profiles for ankle extensor stiffness and selected measures are displayed in figure 2. The gymnasts with high ankle extensor stiffness were generally older, taller, and heavier than the other gymnasts, with an average to longer femur length in proportion to their overall leg length. Whereas, the gymnast with lower extensor stiffness was average in stature but lower in body mass. This gymnast also had a shorter femur in proportion to overall leg length, revealing that she had a longer tibia. No further clear patterns were revealed for the group profiles of the other measures or the individual Z-score profiles.

CONCLUSION: New medical and scientific avenues are available for managing the young female gymnast. Customized kinetic measures when used in combination with clinical tests and anthropometric measurements have the potential to help with the management of athletes. Measures of countermovement jump power could be utilized to more accurately determine the gymnasts readiness to return to modified training (e.g. >75% of power levels pre-injury) and then to guide the coach on when full training can resume (e.g. >95% of power levels pre-injury). Leg stiffness may reflect the effects of specific mechanisms of injury, but also exhibits potential for identifying gymnasts who are at risk of particular injuries. Gymnastics is a high impact sport where females are exposed daily to short- and long-term health risks. Individual anthropometry and biomechanics necessary for success in gymnastics can predispose the athlete to injury. The management of these young athletes, particularly in regards to the medical treatment of injuries, often compromises a full recovery in the quest to return to training and competition. In absence of individual objective assessment specific to the sport, the gymnast often experiences difficulties returning to previous performance levels, may drop out of the sport, become re-injured, and/or develop compensatory injuries that arise through altered biomechanics. Future research should track the anthropometric and physical performance qualities of gymnasts', in combination with records of skill development, musculoskeletal health (medical), and competition performance.

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