Interactions of the Gymnast and Spring Floor

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Fig. 1

The exciting gymnastics you see on television is formally known as artistic gymnastics. Artistic gymnastics involves competition for men and women on several apparatuses, six for men and four for women. Men and women share vaulting and floor exercise apparatuses. Vaulting involves a single skill performed over a 'tongue-shaped' raised surface called a table. Floor exercise is contested on a large 12m square matted and carpeted area that is raised by fiberglass-laminate panels on springs (Figure 1). Gymnasts use the springs to fly higher and farther while reducing the harshness of take-offs and landings. Impact forces in gymnastics tumbling can exceed the published limits for bone, ligament, and tendon in the associated lower leg structures (1, 2), and exceed 14 times body weight – per foot (8). The floor exercise apparatus also results in a large proportion of gymnastics injuries (3).

One of the most devastating injuries in floor exercise tumbling is a ruptured Achilles tendon. Tendon ruptures occur most frequently during tumbling take-offs and somewhat less so during landings. Figure 2 shows the acute angle of ankle dorsiflexion

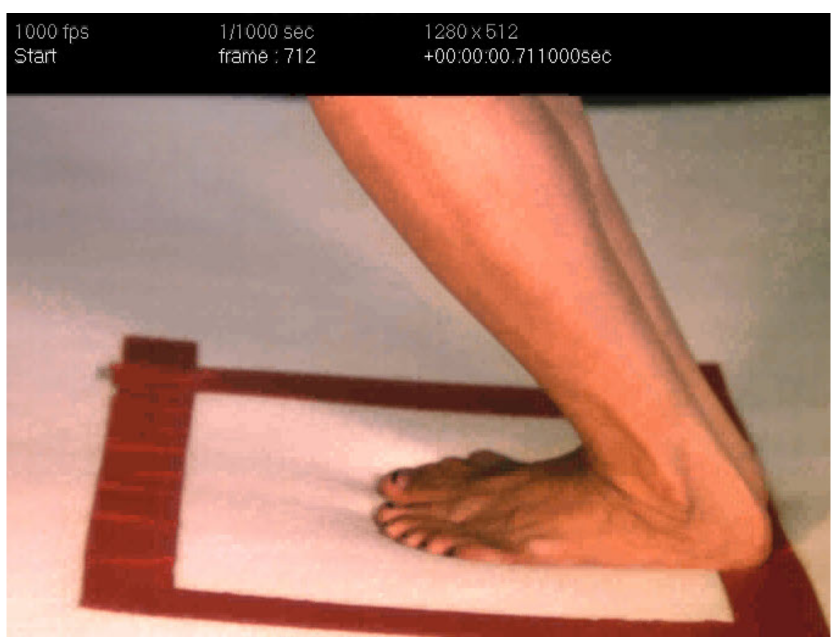


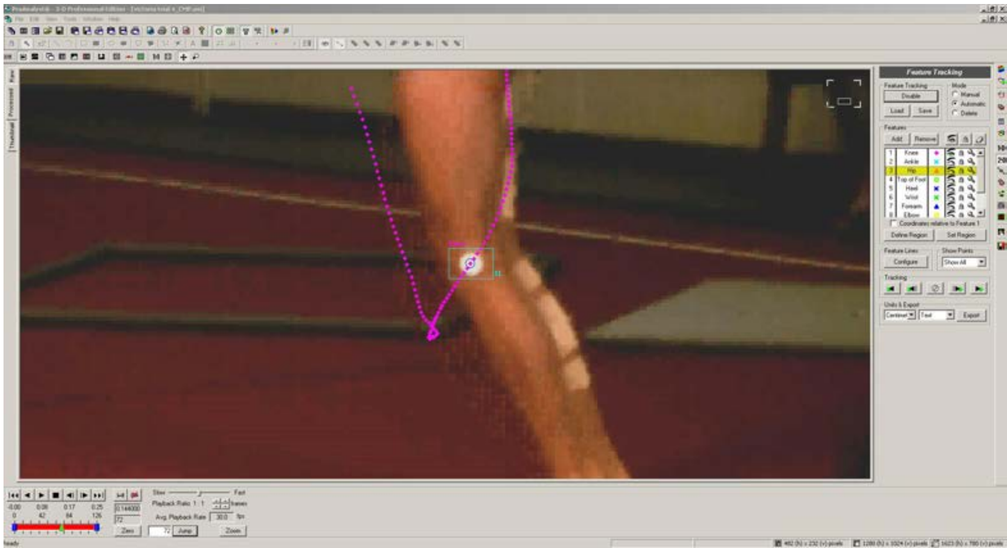
Fig. 2

captured from high-speed video at 1000 fps. This ankle position occurs in less than 60ms of total take-off duration that is less than about 150ms. Concentrating ground reaction forces of a dozen or more times body weight in less than a tenth of a second requires skill, strength, power, and coordination. Moreover, this circumstance also requires a predictable elastic response of the floor exercise apparatus. Unfortunately, the musculoskeletal actions of the gymnast do not always synchronize with the elastic deflection and recoil properties of the spring floor (10).

Jumping activities, like a gymnastics take-off, exhibit an initial knee flexion action as the lower extremity contacts the floor absorbing the impact. The flexion continues smoothly until the downward portion of the jump is complete. The knee position angle may hesitate for a very brief period prior to extension actions that raise the gymnast into the following take-off. Although the actions described above are normal and common, however, observations show that many gymnasts flex and extend their knees twice during the tumbling take-off impact (Figure 3). I believe that the cause of this odd phenomenon is the asynchronous motion interactions of the spring floor and the gymnast. If the gymnast's take-off jumping actions do not match the natural frequency of the elastic stiffness of the tumbling surface, then the mismatch will result in wasted energy and poor transfer of muscle and connective tissue tensions to the supporting surface. Of course, the gymnast also suffers from the asynchrony with altered force and torque distributions throughout the lower extremity. Although breaking the tumbling surface panels is not unknown; the usual 'losers' in the battle to maintain the coupling of coordinated stiffness between gymnast and spring floor are the gymnast's legs. In short, the disparity may result in a ruptured Achilles tendon.

Videos of gymnastics take-offs were analyzed with the ProAnalyst(R) motion analysis software for biomechanics and sports analysis. The software provides easy determination of positions, velocities, accelerations and angles of the stressed body parts. Figure 3 shows a common pattern of motion from 500 frame per second video (Quantum

Fig. 3



Technologies), and screen images of the knee of a highly trained gymnast performing at the Olympic Training Center in Colorado Springs, CO, using ProAnalyst(R) motion analysis software from Xcitex Inc. (Woburn, MA). Following the examination of kinematic records of gymnasts' knee angles, many of the gymnasts showed a knee motion direction reversal. Instead of the knee of the gymnast continuing in the horizontal direction of the tumbling pass, the knee flexes forward relative to the gymnast (who is traveling backward). The knee reversal motion is indicative of a 'collapse' of the knees, likely due to impact forces and poorly applied muscle torques. However, the genesis of this collapse may lie in the stiffness characteristics of the spring floor. Our reasoning lies with the fact that even Olympic champions can show this odd jumping behavior making strength and skill not the only, or perhaps even the dominant factors.

How does the spring floor contribute to the incidence of two knee flexions? Work by Paine at the University of Utah on an earlier version of the spring floor showed that the spring floor's natural frequency response was about twice that of the gymnast's take-off actions (6, 7). Moreover, work by McNeal and colleagues (4, 5), again at the University of Utah, found a number of extraneous spring floor vibrations during the gymnast's take-off actions along with electromyographic variations reflective of twisting versus non-twisting somersaults (Figure 4). Extraneous vibrations or asynchronous responses of a jumping surface, particularly when unexpected and unlearned, may spell disaster for a weakened Achilles tendon.

Unfortunately, the analysis of the potential contributions of the spring floor to Achilles tendon and other lower extremity injuries is staggeringly complex. The spring floor is not only influenced by the immediate take-off actions of the gymnast, but the entire floor is subject to vibrations induced by a series of impacts from the run-up and other preceding tumbling skills. Most frequently, the rearward tumbling take-off follows a run of several steps, a skill called a round-off, and a back handspring. Gymnasts come in all different sizes, shapes, and abilities. Moreover, the role of strength and power in tumbling cannot be overestimated and may be the most accessible countermeasure in the short-term. It is my hope that continued work will enlighten the gymnastics community on the potential contributions of the floor exercise apparatus to lower extremity injury.

Gymnastics has recognized that the elastic properties of the apparatuses may influence performance and safety (1, 2, 9, 11). The gymnastics vault board that is used for jumping following a run to the vault table, and modification of the vault board by adding and removing coil springs has been a coaching tactic for some time. Unlike the adjustable fulcrum in springboard diving, gymnastics has no corresponding technology to modify the stiffness of the spring floor. Gymnasts must adjust their neuromuscular system during a brief opportunity at the warm-up on the floor exercise apparatus. Gymnasts must essentially relearn their take-off actions in a matter of minutes, often prior to performing complex and potentially dangerous airborne skills. If the gymnast's neuromuscular system cannot adapt to the stiffness characteristics of the spring floor as presented, the gymnast's performance suffers and the route to injury is enhanced – particularly with the space-age skills that modern gymnasts perform. In competition, floor exercise apparatuses may be placed on undersurfaces such as a flexible platform (Olympic Games), floating wood floor (basketball gyms), carpet (hotel ballrooms), and concrete (conference/meeting facilities).

Given the potential serious nature of injuries to gymnasts, who are often upside-down during a fall, gymnastics apparatus behaviors should be maintained within a small range of performance properties. That youngsters are the most common participants in gymnastics should raise our concern and encourage continued research to understand spring floor and gymnast interaction properties.

References for this article can be found at http://bit.ly/P0GG3L

Fig. 4