Vault Injury Case Study:

The Sang Lan Vault - 1998 Goodwill Games

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The time from July 19th to August 2nd, 1998 saw approximately 1300 athletes from 60 countries compete in the fourth Goodwill Games in New York City. Perhaps one of the saddest and most highly covered aspects of these Games was the catastrophic injury suffered by then 17-year old, Sang Lan from China. Sang Lan had placed second in the vault in her country's national championships. She was a fine athlete - among the best in the world.

Her injury occurred during the warm-up for the vault event final. Since then, 17 years have passed and the nature of her tragic injury has not received scientific scrutiny. At the time of the accident, Mr. Jack Carter, then coach for the Parkettes National Training Center in Allentown, Pennsylvania (now at Carter's Gymnastics) videotaped the injury. In spite of considerable media pressure and some financial inducements, Mr. Carter said that he had erased the video (33). His motive was to avoid the media frenzy and the likely repeated coverage of the injury on national television (33). Mr. Carter provided me with a copy of the video in 2000 as a matter of scientific and medical interest. Information from analysis of the injury was presented to the International Society for Biomechanics in Sports 2002 (42), and the Anais do II Seminario and the Internacional de Ginastica Artistica e Rithmica de Competicao 2010 (38). At neither conference was the video given to anyone.

This injury and resulting questions go beyond a media frenzy for tragic newsworthy images. A forensic-like analysis of this incident may provide important information for the prevention of such injuries in the future. This incident happened to a well-trained, highly respected, and highly decorated young gymnast and established that skill and training alone may not be a failsafe for catastrophic injury. The continuous search for countermeasures that may reduce the incidence and severity of gymnastics injuries demands that injuries be investigated thoroughly and impartially. Any analysis of a vault begins with a phase break down. Vaulting is divided commonly into the run-up, hurdle, take-off, preflight, support, post-flight, and landing. These phases will be used in the following assessment of Sang Lan's performance.

Run-Up and Hurdle

Mr. Carter's video was captured perpendicular to the run-up, and the camera was panned from right to left following the gymnast as she ran. The run-up taping was begun slightly after the first step(s) and does not allow a full accounting of the number of steps for the run-up. The video began mid-stride with the athlete about to land on her right foot. Nine steps are visible from the beginning image to the hurdle step which occurred taking off from the right foot. Further analyses begin as the gymnast nears the vault board for the subsequent take-off.

Board Setting, Contact, and Take-off

Distances were scaled by using the dimensions of the vault board in the video image and video motion analysis software (KinoveaTM 0.8.15, 2006-2011, Joan Charmont & Contrib). The vault board is 120cm in length, 20cm high, and 60cm wide (10, 31). The distance from the forward edge of the vault board to the center of the vault horse base was approximately 150cm or six feet.

Figure 1 shows the athlete nearly in contact with the vault board at the end of the hurdle step. The athlete intends to perform a handspring- or forward entry-type preflight for a vault called a Layout Cuervo. The position of the feet in Figure 1 is relatively far forward on the vault board by common American practice. Importantly, Mr. Carter reports that this athlete repeatedly landed on the vault board near the area shown in Figure 2. Previous research has shown that the take-off position rarely has feet this far forward on the vault board - disregarding Yurchenko-type vaults (6, 25, 38, 41). Mr. Carter also noted in the media shortly after the injury that the feet were too far forward on the vault board (33).

Most coaches establish the vault board position by using a tape measure at the side of the runway. Other coaches "step-off" the board distance measuring in heel –to-toe paces from the vault horse base to the forward board base. Precise placement of the vault board is crucial for the gymnast's take-off (6, 38).

The gymnast's contact position on the vault board is extremely important. The vault board is not uniformly elastic. On handspring-type vaults, the optimal position for striking the top surface is approximately the midpoint (or slightly higher) on the sloping rear section (6, 25, 38, 41). Coaching experience indicates that the board distance shown in Figure 1 is quite far from the horse. The actual feet landing position indicates that the board should have been placed slightly more than 20cm (approximately one foot) closer to the horse. Searches for comparative images of measurable board position for this athlete failed. The only other reasonable explanation for the foot position on the vault board is that the athlete simply "over-ran" the board (33). In other words, the athlete's step distances were poorly calibrated for the board and horse position. Overrunning the vault board is possible and has occurred in the past as postulated by Mr. Carter (33). Thus, the athlete may have started her run approximately 20cm too close, she may have run with longer strides, the vault board may have been misplaced, or a combination of these factors.

The ability of a gymnast to regulate a handspring vault performance appears to be related to the positions of the vault board and the vault table (16) (the vault table was adopted later). Heinen and colleagues (16) varied the position of the vault board and table and found that gymnasts altered their performance in concert with the positions, but the nature of their technique alterations varied depending on actual apparatus placements (16). Figure 2 shows the athlete with feet contacting the vault board such that she is at the peak of the curved top surface, and her feet are on and passed the top surface board-line marker. Again, Mr. Carter indicates that the athlete landed near this area on all vaults.

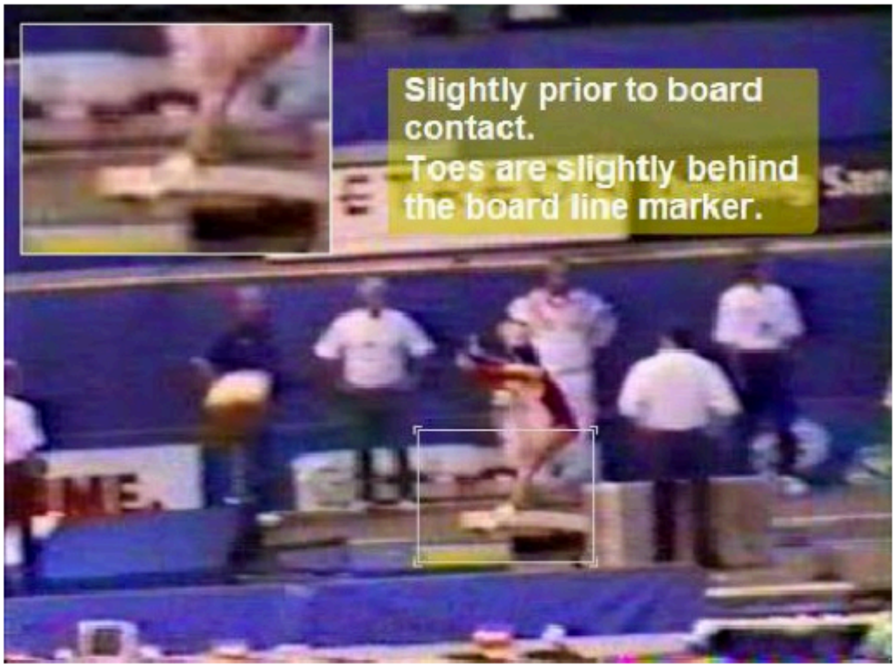

Figure 1. The athlete's feet are shown at or slightly before board contact. Note from the inset that the feet are positioned with the toes slightly behind the board-line marker.

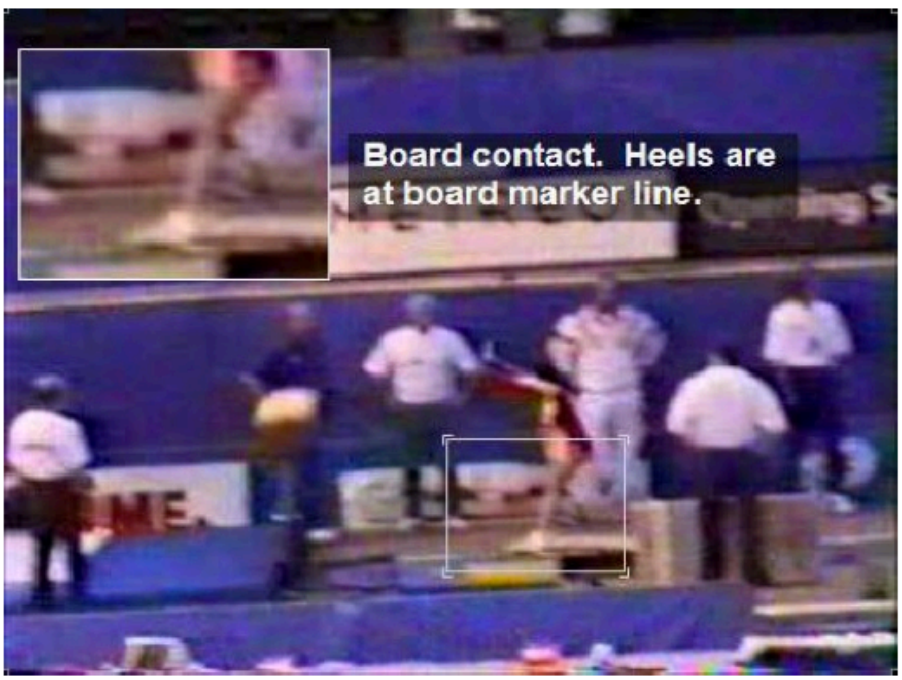

Figure 2. Initial board contact. The gymnast's feet are too far forward on the vault board top surface for an effective take-off.

Figure 3 is a crucial image, showing the gymnast's feet separating and sliding across the forward portion of the board top surface. The image clearly shows the gymnast's feet moving horizontally forward such that the left leg is preceding the right leg. Leg and foot position on this vault should be bilaterally symmetrical. The gymnast's position places her on the slight downward slope of the compressing vault board. The vault board's forward section is "softer" than the more rearward segments. The number of springs that effectively bear the take-off forces of the gymnast are reduced at the forward board segment. The softer, less stiff forward board segment will not support an explosive jumping action as effectively as the more rearward and stiffer areas. In addition, the natural elastic nature of the gymnast's legs and those of the vault board are mismatched in this situation (1, 2, 6, 11, 25, 38, 44, 45). The gymnast is expecting a stiffer take-off surface and her legs will be activated to handle this type of impact and explosive jump (2, 4, 12, 19, 26, 28).

Building from information shown in Figures 1, 2, and 3; Figure 4 shows this athlete in an earlier competition during her vaulting take-off. Although certainly not an ideal image, Figure 4 shows that the athlete strikes the board closer to the typical area, behind the crest of the board's top surface slope (6). The vault shown in Figure 4 was performed successfully and with virtuosity.

Figure 3. Feet are sliding across the forward segment of the vault board. Note that the feet and lower legs are separated with the left leg leading. This position is not appropriate for the type of vault being performed.

Figure 4. Sang Lan is performing the same vault at the International Team Championships. Note that her feet are well behind the vault board-line marker. https://www.youtube.com/watch?v=DQXRYVljy18

Preflight

Once the gymnast is in the air after the take-off from the vault board; the body will follow a trajectory that is completely determined by the forces present at departure from the vault board (39, 40). The leg position in Figure 5 emphasizes that the take-off was poor and that the gymnast departed from the forward vault board segment. The gymnast's body position was distorted during the preflight phase (Figure 6).

Figure 5. Initial board departure. Lower extremity positions continue to show leg separation.

Preflight trajectory and body positions are crucial for the subsequent hand support phase. If the body's posture is distorted from optimal, it is very difficult for the gymnast to recover and manage adequate technique in the following phases. We can infer from Figure 6 that the gymnast may have aborted her vault and is simply following the natural flight trajectory and body positions that resulted from the poor take-off. The gymnast was clearly in a poor body position during preflight, but head position indicated that she could see the horse and landing mat. In spite of possible visible orientation, the amount of time available to make corrections was staggeringly short. The approximate time from board departure to horse hand contact was 0.17 seconds. Simple reaction time for humans is approximately 0.18 seconds. Simple reaction time is often tested by seeing a light and pressing a button, certainly much less complex than dealing with a difficult vault. Of course, detecting a problem in a vault, planning a remedy, and executing the plan can take up to several seconds, a duration that is simply not available in this situation (24, 35, 46-49). If the gymnast was completely surprised by the poor take-off problems, it was unlikely she could have done anything to protect herself (35, 36). Combine the lack of time with inadequate and poorly directed take-off forces and the athlete becomes a simple projectile at the mercy of her perceptual-motor responses and the forces present at take-off.

Figure 6. Preflight position immediately prior to hand contact. The gymnast's head was in a position to see the horse and the landing mats.

Support

The hand support phase of the vault shows the seriousness of the poor take-off actions and body positions. In addition, these factors interacted to create an impossible technique problem with little chance of escape. Figure 7 shows the initial hand support body positions. Figure 8 shows the body positions at departure from the horse. The gymnast was still able to see the horse and landing mats in Figure 7, however in Figure 8 the gymnast's head was moved between her arms, and vision of important environmental cues was probably compromised. After the positions shown in Figure 8, unfortunately, the athlete had to rely on vestibular and somatosensory feedback rather than vision for spatial orientation (3, 5, 7-9, 14, 18, 27, 30, 34, 37).

Figure 7. Initial hand contact of the support phase. Note the body positions.

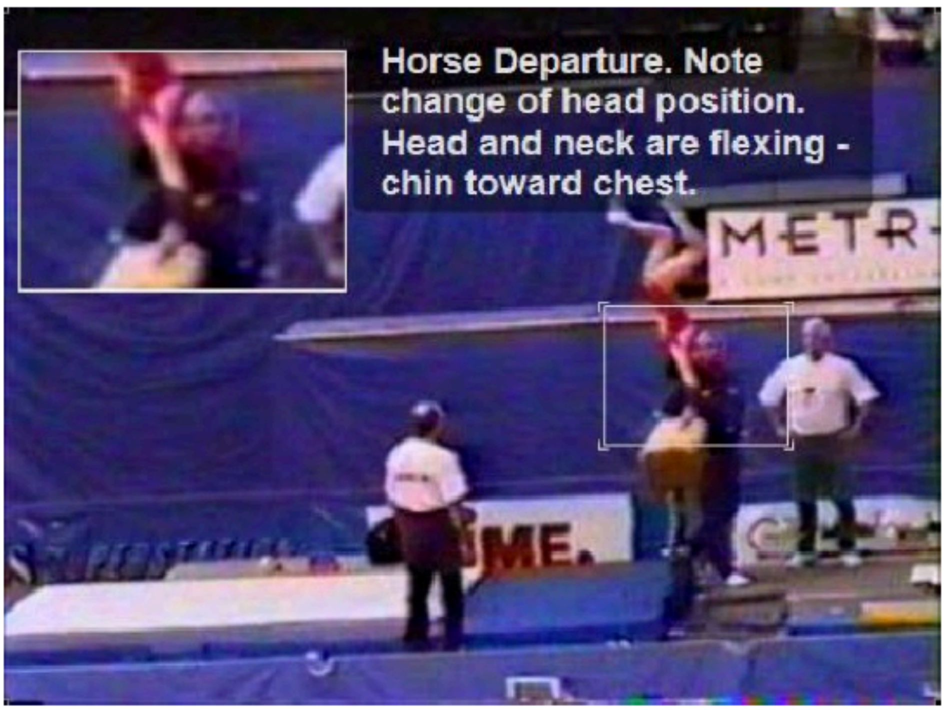

Figure 8. Departure from the horse. Note the distorted body position and the head between the arms with neck flexing.

Post Flight

Initial post-flight is shown in Figure 8. The athlete did not change her body position radically during the post flight indicating complete spatial disorientation. Work by Heinen and colleagues (14) on trampoline somersaults has shown that novice somersaulters close their eyes during portions of a backward somersault. The somersaulters closed their eyes when the head was moving rapidly rearward, and the only environmental cues in view were of little use to novices (i.e. the ceiling). Vision is an important part of skill regulation and is linked to specific skill performances and adaptations. There may be inherent differences in the use of vision between novices and experts, with novices more vision dependent (15). However, whenever a novel motion occurs such as a serious technical fault; the performer is immediately placed in the role of a novice. Although uncertain from an outside perspective, the athlete may not have used her vision effectively to establish her own protective countermeasures. Figure 9 shows the athlete at approximately the mid-flight peak of the trajectory. The body positions remained distorted, again indicating that the athlete was disoriented.

Figure 10 displays the last frame of the post flight. The positions indicate that the athlete would land directly on the apex of her head in the next frame. The actual head impact will not be shown because of the graphic nature of the landing. However, it is clear that any impact resulting from a position like that of Figure 10 would be injurious.

Figure 9. The athlete is at approximately mid-post flight. Her trajectory is low, and her body positions are poor.

Figure 10. The final moment before impact on the head. The hair may be touching, but the body is not yet accepting the forces of impact.

Countermeasures

Skill. Could the athlete have aborted the vault and performed some protective movement to avoid landing on the head? As noted by Mr. Carter (33), simply tucking tighter would probably have allowed the athlete to rotate slightly farther and by that land on her back instead of her head. However, the time available for making any corrective movements was extremely short. The time from board departure to the end of the post-flight was a mere 1.2 seconds. The entire post-flight phase lasted only 0.76 seconds. A corrective action requires the athlete to identify a problem, process the sensory information, determine a movement response, select the response, program the response, and finally execute the response. The Hick-Hyman Law indicates that choice reaction time (i.e. not simple reaction time) increases by approximately 0.15 seconds very time the number of response choices doubles (17, 22, 23, 35). A single reaction choice requires approximately 0.18 seconds. Under laboratory conditions, an athlete will exhaust available time after reaching a decision list of approximately eight possible choices. There are probably dozens of potential body positions, timings, and sequences within the universe of movement choices available to the athlete in this situation. Perceptual-motor overload is likely to occur in a somersaulting athlete, in a changing visual and sensory environment, dealing with the pressure to select correctly (13, 18, 29). As shown in images 8, 9, 10, the athlete does not appear to change body position during the entire post-flight. In essence, she is unable to establish a corrective action and follows her established trajectory and rotational momentum until she strikes the mat.

Vault Board Design. Were there countermeasures available in 1998 that could have prevented this injury? Overrunning the vault board during take-off has occurred in the past with several video examples available on YouTube™. Vault board designs have resisted innovations perhaps more than other gymnastics apparatuses. The primary vault board design changes have been in the spring or elastic aspects. The original all-wood construction has given way to metal, fiberglass, and varying numbers and types of springs. The vault board design in 1998 was well-tested and continues largely unchanged today. In 1998, the gymnastics community had not yet adopted the vault table (20, 21, 32, 43). In order to prevent a missed take-off by overrunning the vault board; the entire vault board would need to be larger and completely redesigned.

Vault Board Placement. As described above, the position of the vault board was probably too far from the horse. The image of vault board contact from an earlier competition (Figure 4) shows that this athlete had successfully performed her take-off from a position behind the crest of the top surface and considerably farther rearward than that shown in the Goodwill Games performance. Ultimately, the board placement was probably the single key issue in this mishap.

Spotting. Could a skilled and alert spotter have rescued the gymnast? Based on reaction time analyses and the duration of the vault, a spotter may have been able to intercede and prevent the gymnast from landing so badly. In spite of the vault's short duration, there is ample indication that the vault had failed from the moment the gymnast began her preflight. If a competent spotter was present, he/she could have taken actions to prevent the tragic landing. However, the athlete's previous performances were stable, and the need for a spotter was likely dubious. Finally, there is no guarantee that the spotter will intervene promptly and correctly (35, 36).

Conclusion

This case study demonstrates that placement of the vault board and the resulting destruction of an effective take-off were at the root of the performance problem that led to the tragic injury. If I am allowed to speculate, I believe the bulk of the evidence supports the faulty vault board placement. A board setting of approximately six feet is rather far from the horse. In addition, the size of the gymnast, her apparent lower extremity power, and the image in Figure 4 supports that the board was placed too far from the horse. This study amplifies the probable role of human error, the sensitive nature of vault board placement, and the potential tragic consequences of a single error in judgment – setting the vault board. A spotter may have been able to intercede and prevent or reduce the extent of injury, but the need for a spotter would have been obviated by a more optimal board position.

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