OPTIMAL TECHNIQUE, VARIABILITY, CONTROL, AND SKILLED PERFORMANCE

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Optimisation is often used in an attempt to explain technique adopted in skilled sport performance. This might take the form of minimising joint torques in an expectation that the optimum simulated technique will resemble the actual performance. If a suitable optimisation criterion can be identified then this may give some insight into the adopted technique. In all human movement there is inherent variation so that no two performances are exactly the same. As a consequence skilled technique needs to be successful in a noisy environment and so optimised technique also needs to be robust to the inherent variation in coordination. In movements in which there is sufficient time for feedback control to operate it is to be expected that there will be greater variation in technique in those phases that adjustments are made. It is also to be expected that there will be little variation in technique for those phases where accurate coordination is crucial to the success of the movement. The aspect that often governs elite technique is that of achieving consistent success rather than some biomechanical measure of movement.

KEY WORDS: simulation, optimisation, motor control, variability

INTRODUCTION: Biomechanics is often used to try to explain the techniques adopted by skilled sports competitors. While a biomechanical analysis can often provide important insights, other aspects of technique such as variability and control are important determinants and should also be considered.

OPTIMISATION: Optimisation is often used in an attempt to explain technique adopted in skilled sport performance. Prior to a dismount on high bar an accelerated giant circle is used. The traditional giant circle in which the body remains extended at the highest point has been superseded by a scooped giant circle in which the body flexes at the highest point and hyperextends at the lowest point of the circle (Figure 1). An attempt to explain this change in terms of ability to produce more angular momentum failed (Hiley and Yeadon, 2003a). The change was accounted for by considering the margin for error in timing the release (Hiley and Yeadon, 2003b). The scooped technique exhibited larger release windows for successful dismounts.

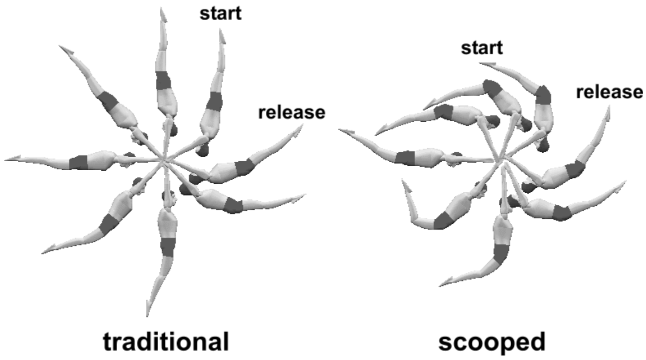

Figure 1. The two techniques (traditional and scooped) used by elite gymnasts during accelerated backward giant circles prior to a double layout somersault dismount (Hiley and Yeadon, 2003a, b).

In order to maximise the angular momentum of a dismount a constraint of a sufficiently large release window was imposed within the optimisation (Hiley and Yeadon, 2005). This resulted in a triple piked somersault dismount or a double twisting triple somersault (Figure 2).

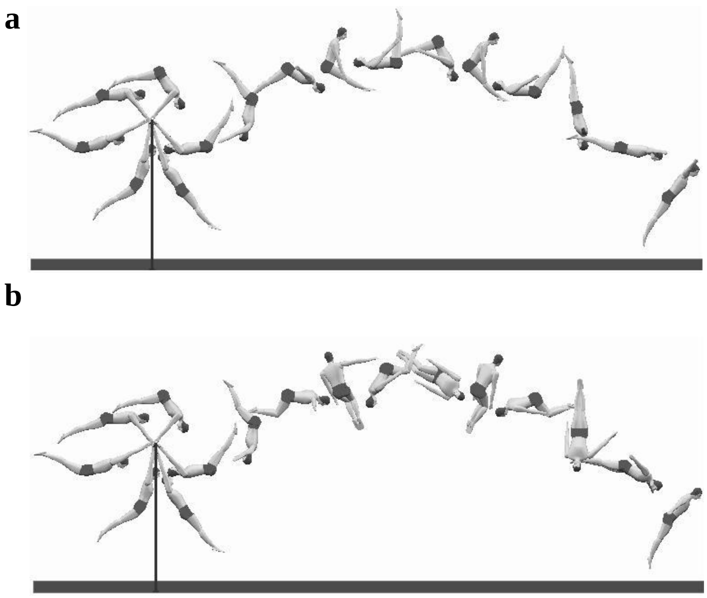

Figure 2. Limiting dismounts using optimised giant circles with full strength: (a) triple piked somersault, (b) triple somersault with two twists (Hiley and Yeadon, 2005).

Optimisation criteria such as minimisation of joint torque are often used to attempt to account for techniques adopted by elite gymnasts. Often, however, the gymnast is using maximum effort within the constraints of his strength. As a consequence other criteria are often more appropriate. For an undersomersault on parallel bars torque minimisation results in a technique similar to that used by beginners while the technique of elite gymnasts can be characterised as having a vertical velocity at hand release (Figure 3).

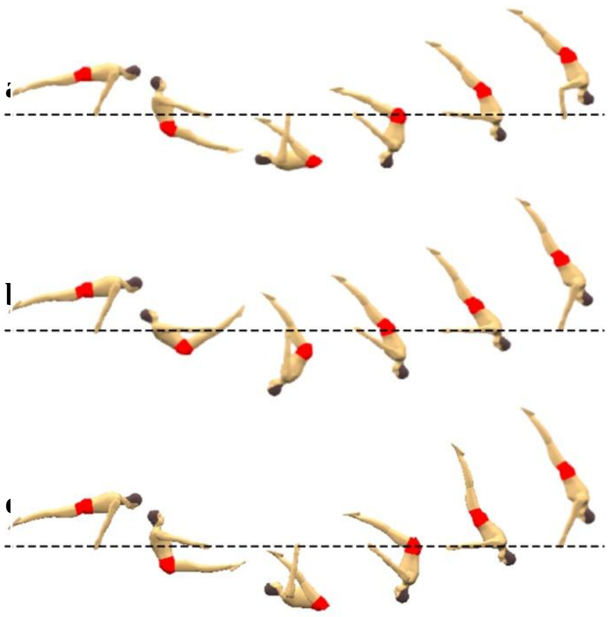

Figure 3. Graphical sequences of (a) recorded performance, and optimum simulations (b) minimising joint torques and (c) producing vertical mass centre path (Hiley and Yeadon, 2012a).

VARIABILITY: In all sports activities there is inherent variation so that no two performances are exactly the same. As a consequence skilled technique needs to be successful in a noisy environment and so optimised technique needs to be robust to the inherent variation in coordination. It is necessary to determine the level of variability in order to conduct such optimisations studies. This was investigated for regular and accelerated giant circles on high bar (Figure 4).

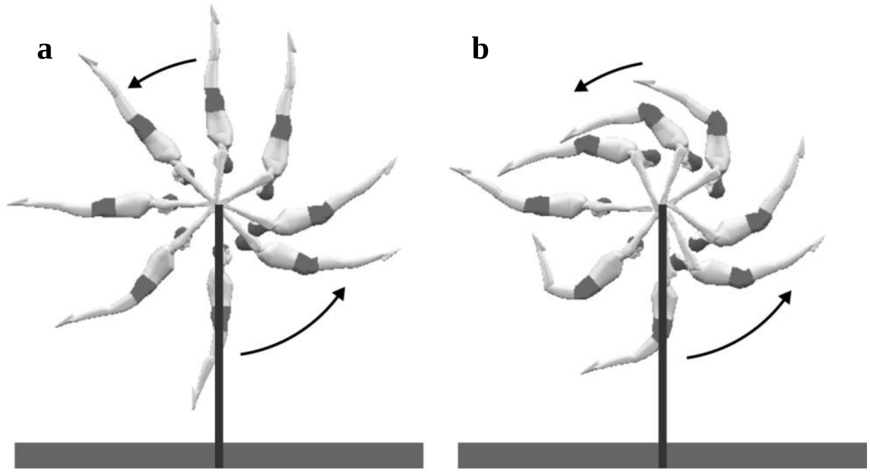

Figure 4. Two types of backward giant circles performed on the high bar: (a) the regular giant circle and (b) accelerated giant circles.

The variation in joint angles and timing was determined at four key points within each type of giant circle (Figure 5). For the regular giant circles (1) and (2) were considered to be mechanically important while for the accelerated circles (3) and (4) were important. In the regular giant circles the hip showed small variation (6 ms SD) at the mechanically important points and large variation (130 ms SD) elsewhere. This may be explained by the gymnast making feedback adjustments near the highest point. In the accelerated circles the corresponding values were 7 ms and 12 ms indicating that there was less possibility for adjustment.

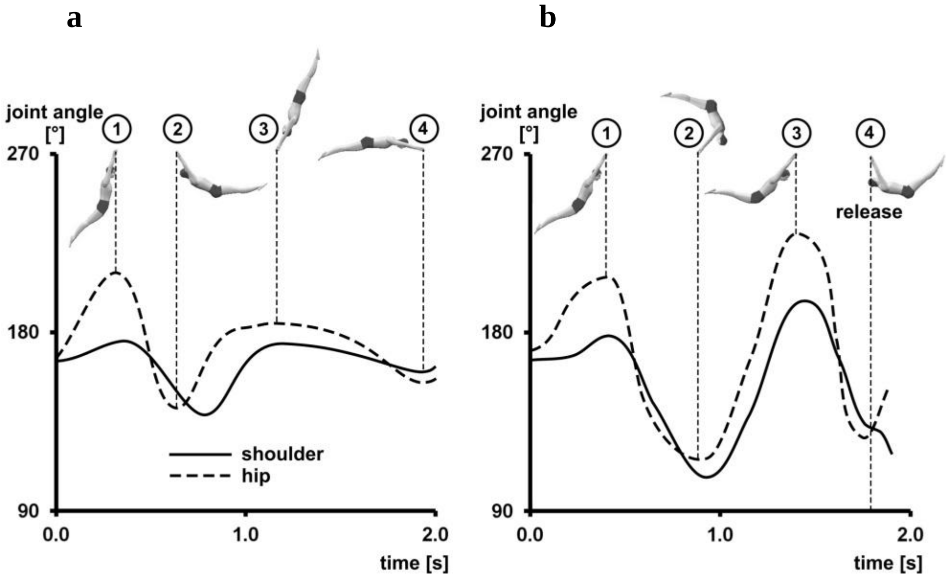

Figure 5. Time histories of the hip and shoulder angles for (a) regular and (b) accelerated giant circles, with graphics to show the gymnast orientation (Hiley et al., 2013).

In the piked triple somersault dismount shown in Figure 2a it was found that when the timing of the actions at the hip and shoulder joints of the optimum giant circle simulation were perturbed by 30 ms, the resulting simulation could no longer meet the criteria for sufficient aerial rotation and release window. Since it is to be expected that a gymnast's technique can cope with small errors in timing for consistent performance, a requirement of robustness to timing perturbations should be included within the optimisation process. When the technique in the backward giant circle was optimised to be robust to 30 ms perturbations it was found that sufficient linear and angular momentum for a triple piked dismount could be achieved with a realistic release window (Figure 6).

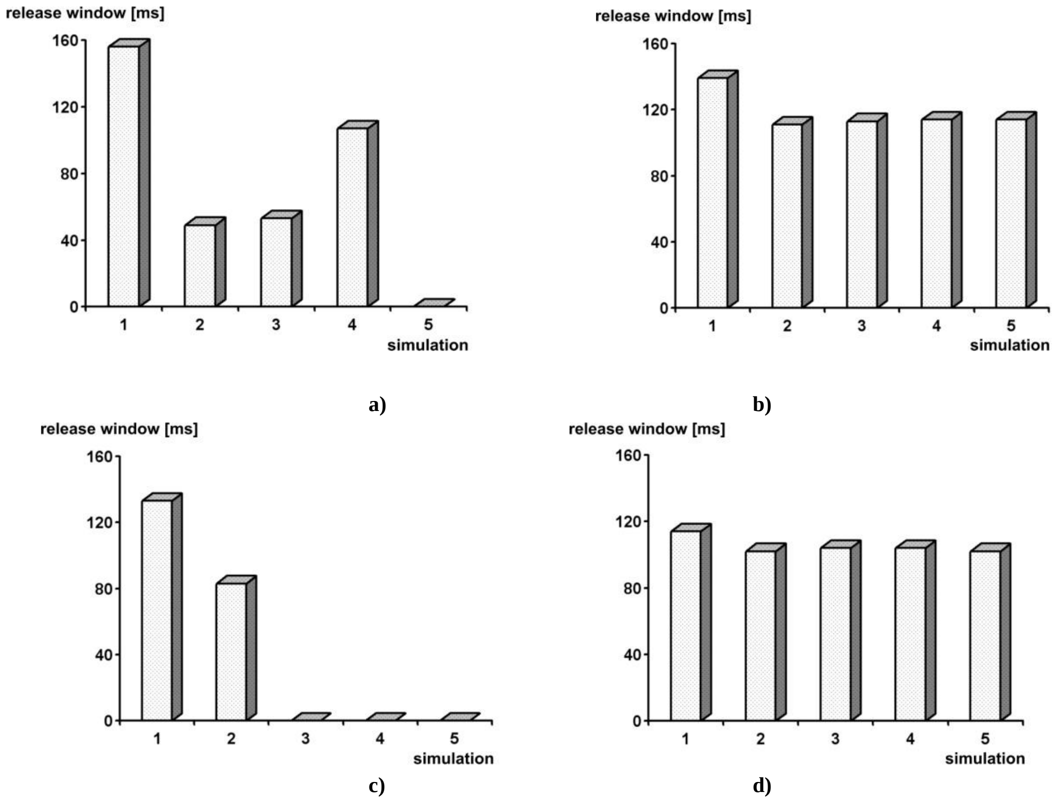

Figure 6. The size of release window when the (a) maximised and (b) robust to 30 ms simulations are perturbed by 30 ms using five different perturbation combinations – [1] the unperturbed simulation, [2] shoulder and hip actions early, [3] shoulder and hip actions late, [4] shoulder early with hip late, and [5] shoulder late with hip early. Charts (c) and (d) are the equivalent data for reduced strength robust to 20 ms and then perturbed by 20 ms (Hiley and Yeadon, 2008).

In the Tkatchev skill the high bar is released while the gymnast travels backwards over the bar and rotates forwards for the regrasp (Figure 7). The SD coordination accuracy for repeated attempts by a gymnast was 2.3^{o} and 12 ms for hip and shoulder angles at four key instants. Optimised technique for successful recatch robust to such variation was determined using 1000 perturbed variants for each simulation within the optimisation. This resulted in 69% success compared with the gymnast's 17% success. When strength was increased by 25% and variability decreased by 25% the success rate improved to 91%.

The gymnast could not have improved his success by timing the release differently since all the release windows were small. The optimised technique used a later extension of the hips just before release (Figure 8). There was comparable variation in technique between gymnast performance and variants of the optimum simulation (Figure 8).

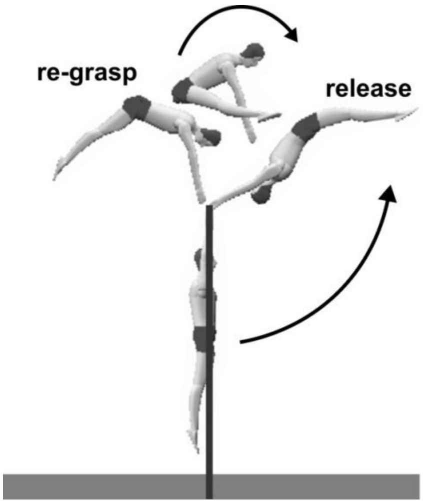

Figure 7. The Tkatchev release and regrasp on high bar.

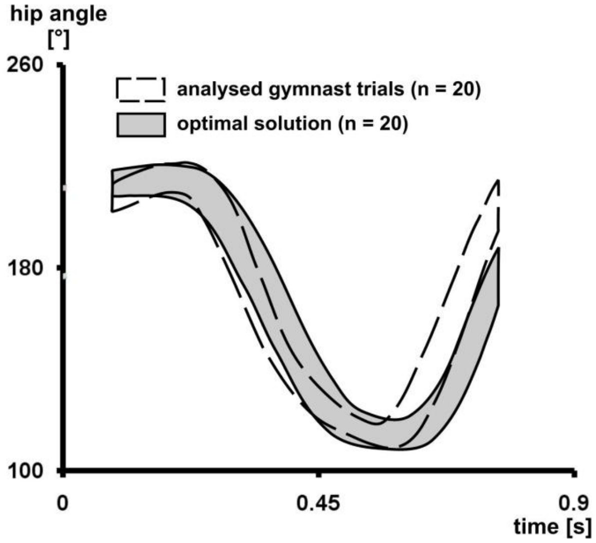

Figure 8. Envelopes containing the hip joint angle time histories obtained from (a) the 20 gymnast performances and (b) 20 perturbed simulations based on the optimal solution (standard deviations, 12 ms and 2.3°, Hiley and Yeadon, 2012b).

The upstart is a fundamental skill in gymnastics which is used to transfer a gymnast from a swing beneath the bar to a position above the bar (Figure 9).

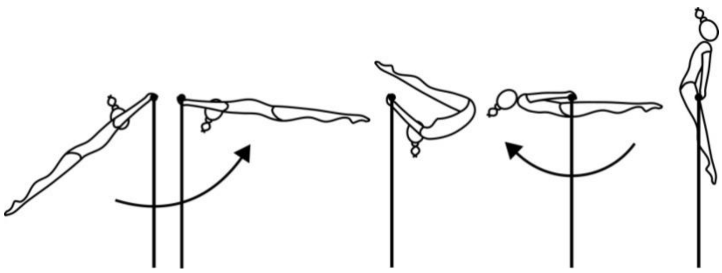

Figure 9. The upstart (adapted from the FIG Code of Points, 2009).

Technique (joint angle histories) used in the upstart was optimised under three different criteria: minimising joint torque, minimising joint torque change, and maximising success in the presence of movement variability. The two optimisations based on minimising joint torque diverged from the gymnast's technique. However, the technique based on maximising the number of successful performances in a noisy environment remained close to the gymnast's technique (Figure 10). It is concluded that the underlying strategy used in the upstart is not based on minimisation of joint torque; rather, it is based on ensuring success in the task despite the inherent variability in technique. Gymnasts develop techniques that are able to cope with the level of kinematic variability present in their movements.

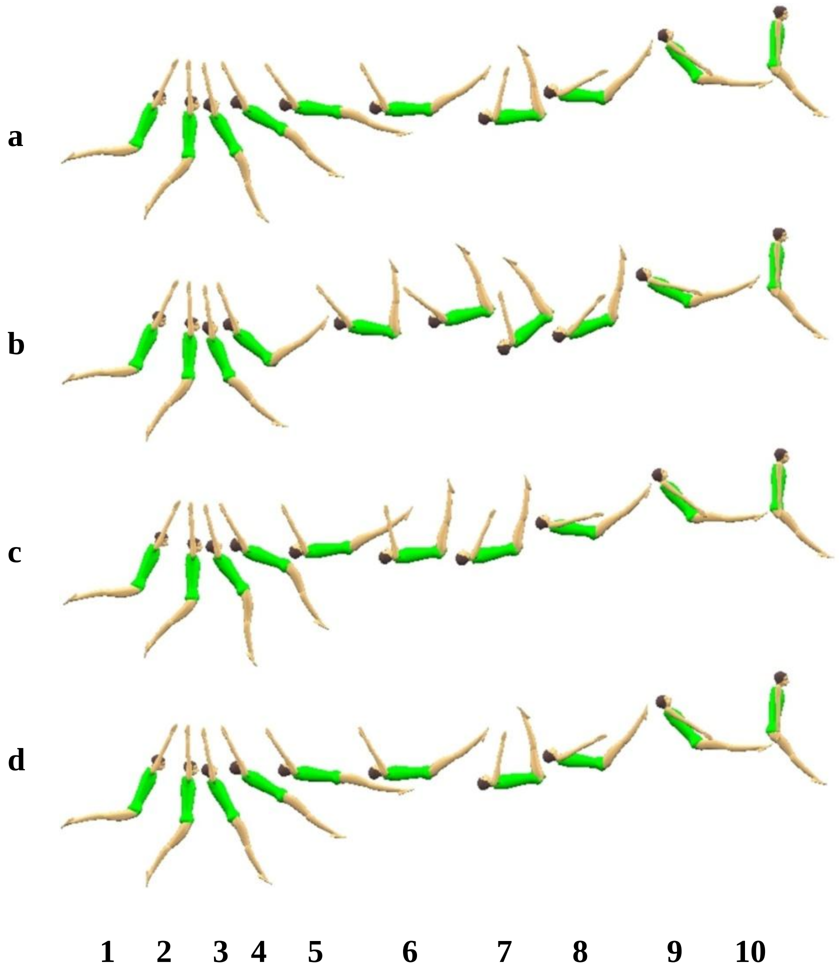

Figure 10. Graphics sequences of: (a) the matching simulation of the recorded performance and the optimal solutions for (b) minimising torque, (c) minimising torque change and (d) maximising success (Hiley and Yeadon, 2013).

CONTROL: Many sports movements are only possible because the athlete makes continual adjustments. For example in a hand balance a gymnast must continually correct for movement of the mass centre. In movements with a flight phase the athlete will make adjustments towards the end of flight in order to achieve an appropriate landing. In a double straight somersault failure to make such corrections will lead to an unwanted half twist due to inherent slight asymmetries in initial conditions or body configuration (Figure 11).

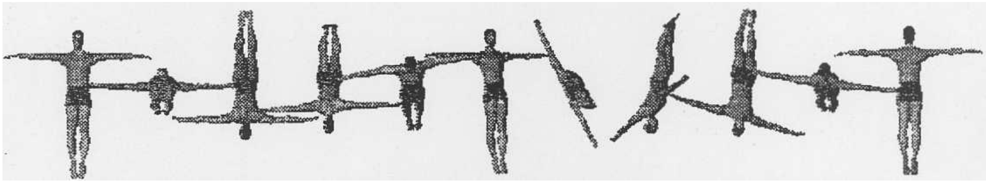

Figure 11. A rigid configuration with only 1◦ of asymmetry in arm abduction angles produces almost a half twist after two somersaults in the straight position.

To prevent the build-up of twist, small asymmetrical arm movements may be used based on twist angular velocity and acceleration information provided by the inner ear balance mechanisms. So long as the feedback time delay in the control system is less than 0.25 somersaults such control can prevent the build-up of twist (Figure 12). This technique can also be used to control twist towards the end of a twisting somersault (Yeadon, 2002). Indeed it is likely that gymnasts first learn this method of control in single somersaults with twist and so control is in place when the first double straight somersault (without twist) is attempted.

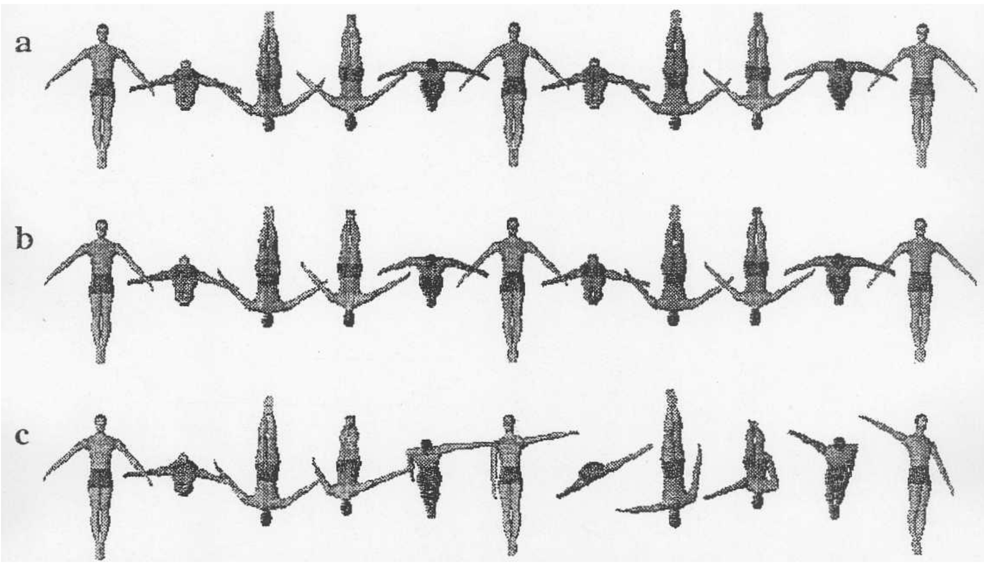

Figure 12. Proportional plus derivative control in straight double somersaults with feedback delays of (a) 0.02, (b) 0.12, and (c) 0.24 somersaults (Yeadon, 2000).

In order to make adjustments during the aerial phase of a gymnastics movement it is of advantage to obtain good visual information on the progress of the twist and somersault throughout the aerial phase. This can be achieved by adjusting head position so that the landing area can be viewed throughout the skill. Such head movement can be learned in a virtual environment by adjusting the gymnast view of a simulated aerial movement in real-time based on the user's head movement (Figure 13).

After a few minutes of using the virtual viewing system to learn the appropriate head movement for viewing during a full twisting double somersault simulation, the gymnast learned to apply the same head movement strategy to high bar dismounts and was successful in learning to view during a full twisting double somersault dismount on the same day (Figure 14).

Figure 13. Use of a virtual environment to learn the head movements required for viewing (Yeadon and Knight, 2012).

Figure 14. A full twisting double somersault dismount from high bar whilst viewing the landing area throughout.

CONCLUSION: Sports movements are learned and refined in an environment of constraints comprising strength, flexibility, anatomical limits, coordination precision as well as the mechanical constraints of the particular movement. In movements in which there is sufficient time for feedback control to operate it is to be expected that there will be greater variation in technique in those phases that adjustments are made. It is also to be expected that there will be little variation in technique for those phases where accurate coordination is crucial to the success of the movement. The aspect that often governs elite technique is that of achieving consistent success rather than some biomechanical measure of movement.

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