OPTIMISATION OF THE FELGE TO HANDSTAND ON PARALLEL BARS

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The felge, or undersomersault, to handstand on parallel bars has become an important skill in Men's Artistic Gymnastics as it forms the basis of many complex variations. To receive no deductions from the judges, the felge must be performed without demonstrating the use of strength to achieve the final handstand position. Two male gymnasts each performed nine trials of the felge from handstand to handstand while data were recorded using an automatic motion capture system. The highest and lowest scoring trials of each gymnast, as determined by four international judges, were chosen for further analysis. The technique used by each gymnast was optimised using a computer simulation model so that the final handstand position could be achieved with straight arms. Two separate optimisations found different techniques identified in the coaching literature that are used by gymnasts. Although the stoop stalder technique used by the two gymnasts was found to be more demanding than the clear circle technique in terms of the strength required, it offered the potential for more consistent performance and future developments in skill complexity.

KEY WORDS: gymnastics, simulation, technique, undersomersault

INTRODUCTION: In the new Code of Points (Fédération Internationale de Gymnastique (FIG), 2006) the felge, or undersomersault, on parallel bars has become an important skill in Men's Artistic Gymnastics as it forms the basis for many variations of the skill. Although the basic skill is performed to support, it is the felge from handstand to handstand (Figure1a) that provides the basis for the more complex variations. From the handstand position the gymnast lowers the body by closing the shoulder angle and allowing the shoulders to move forwards relative to the hands (Figure 1b). The gymnast then rotates backwards about the point of contact with the bars and circles below the bar. Release occurs shortly after the gymnast's mass centre has passed above the level of the bars (Figure 1b). The gymnast re-grasps the bars before reaching the handstand position. In order to receive no deductions from the judges, the gymnast must perform the felge without demonstrating the use of strength to achieve the final handstand position.

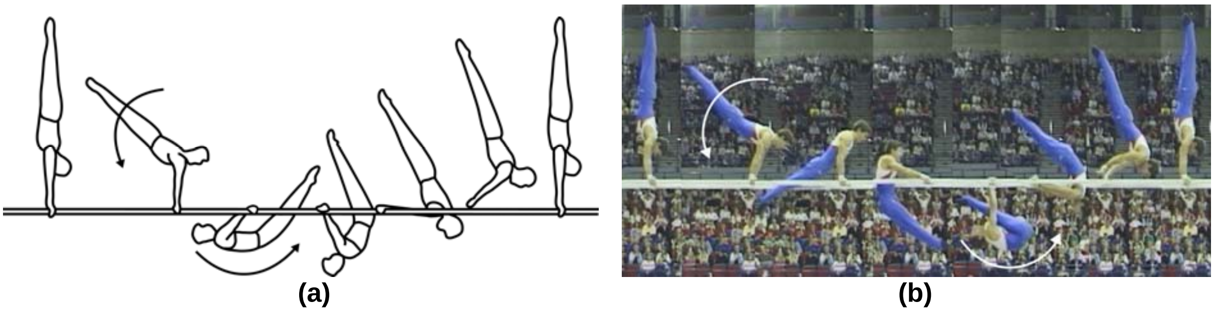

Figure 1. The felge from hand stand to handstand using (a) the "clear circle" (adapted from the FIG Code of Points, 2006) and (b) the "stoop stalder" technique.

The technique depicted in the Code of Points (FIG, 2006), Figure 1a, closely resembles a backward clear circle to handstand as performed on the high bar. During this technique the gymnast maintains quite an extended hip angle throughout the majority of the circle, in particular whilst the gymnast is below the bars (Figure 1a). It has been recommended that this technique is used during the initial stages of learning the felge (Davis, 2005). However, the technique used by many senior gymnasts more closely resembles a "stoop stalder" (Davis, 2005). As the gymnast passes beneath the bars a deep pike position is adopted from which the gymnast rapidly extends passing through release and into the final handstand position (Figure 1b).

The aim of the present study was to optimise the existing technique of gymnasts performing the felge from handstand to handstand so that the final position could be achieved with straight arms. The optimisations would be used to gain an insight into which of the two techniques described above is the most appropriate.

METHODS: Data collection: Two senior male gymnasts competing at national level (gymnast 1: mass 61.2 kg, height 1.65 m; gymnast 2: mass 63.5 kg, height 1.75 m) each performed 9 trials of the felge from handstand to handstand. All trials were captured using 13 Vicon M2 cameras operating at 100 Hz. In addition all trials were recorded with a standard 50 Hz digital video camcorder (Panasonic NV-GS200EB). Three-dimensional marker coordinates were reconstructed from which arm orientation and joint configuration angles were calculated. A set of 95 anthropometric measurements were taken on each gymnast and inertia parameters were calculated using the model of Yeadon (1990b). Four judges with international accreditation (FIG) scored each felge from the video recordings. The highest and lowest scoring trials of each gymnast were chosen for further analysis. None of the chosen trials achieved the final handstand position with straight arms.

Matching Process: A four segment model including damped linear springs at the shoulder and hands for the elastic structures of the gymnast and high bar was used (Hiley and Yeadon, 2003). The simulation model was angle driven using joint angle time histories in the form of Fourier series, which were matched to the recorded angle data during a matching procedure. During the matching optimisation the bar and gymnast spring parameters were allowed to vary together with the initial orientation and angular momentum of the model. The optimisation was required to produce a close match between the recorded and simulated rotation angles, bar displacements, joint angle time histories and absolute linear and angular momentum at release. Each simulation started once the angular velocity of the arm segment was in the positive direction (anti-clockwise).

Optimisation: The cost function was based on minimising the peak joint torques at the hip and shoulder joints whilst seeking an acceptable felge through the use of appropriate penalties. Joint torque limits were obtained from the matching simulations. The simulations started from the same point as in the matching process and finished once the torso segment had rotated 40° past the vertical. The cost function was calculated from when the torso segment reached the vertical through to 40° past the vertical. The value returned to the optimisation was the lowest value of the cost function during this period. The optimum technique was required to produce sufficient vertical velocity at release to achieve a mass centre height in flight of at least 90% of the final handstand position measured above the bars. The simulation incurred penalties if the horizontal velocity and normalised angular momentum at release exceeded the range obtained from the analysis of the 18 trials and values reported for high scoring performances (Takei and Dunn,1996). A further penalty was imposed for excessive hip flexion angles at release from the bars as this was likely to result in poor body configurations on re-grasping the bars (Takei and Dunn, 1996). The optimisations were run twice: the first set of four optimisations with no limits placed on the joint angle time histories (other than those described above) and the second set where they were constrained to produce a stoop stalder technique – this was achieved by creating a penalty for flexing too early in the felge and not producing the characteristic deep pike position.

RESULTS: Over the approximate 270° rotation of the four matching simulations the model was able to reproduce the whole body rotation angle to within 2° root mean squared (rms) difference and the displacements of the bar to within 0.005 m rms difference (Figure 2). The matches between the measured joint angle time histories and those determined using Fourier series were close with an average rms difference of 4°. The simulation model matched the mass centre velocity at release to within1%.

In the first set of optimisations where the joint angle time histories were not constrained the model was able to achieve the appropriate vertical velocity at release whilst satisfying the criteria for a successful performance. At release the model had a higher mass centre position and vertical velocity than in the actual performances. The peak hip and shoulder joint torques from the optimisations did not exceed either of the limits. The technique in the first set of optimised simulations differed from the gymnasts' technique (Figure 3b). In the optimisations where the joint angle time histories were encouraged to produce a technique similar to the gymnasts' own technique the model was still able to achieve the appropriate vertical velocity at release whilst satisfying the criteria for a successful performance (Figure 3c). However, the peak joint torques were higher than those obtained from the first set of optimisations.

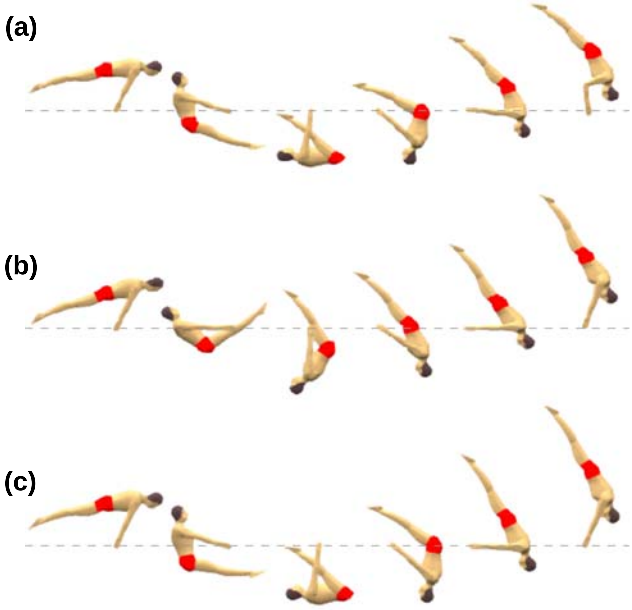

Figure 2. Graphical sequences of the (a) gymnast's technique, (b) optimised technique and (c) constrained optimised technique.

DISCUSSION: In all four cases the first set of optimisations was able to improve the gymnasts' performances with the mass centre able to reach over 90% of handstand height in the flight phase. The improvement was achieved through a combination of increased vertical velocity and an increase in mass centre height at release. The higher mass centre location and more extended body configuration at release have been shown to be desirable from a judging perspective (Takei and Dunn, 1996). However, the optimised technique differed from the stoop stalder technique and more closely represented the clear circle technique. When the optimisation used a constraint to encourage a stoop stalder technique the second set of optimal solutions was still able to achieve the required increase in vertical velocity at release. The increased vertical velocity at release was produced predominantly by a more rapid extension of the hip angle.

Both sets of optimisations were able to achieve the improved performance whilst staying within the joint torque limits defined by the gymnasts' actual performances. When choosing which technique to use, it was found that in terms of peak joint torque the stoop stalder was more demanding of the gymnast. This explains why in the early stages of learning, the clear circle technique is adopted, as recommended by Davis (2005). Why then is the stoop stalder technique adopted by the majority of senior gymnasts?

The path of the mass centre during the optimal felges is shown in Figure 3. In the optimisations encouraged to produce the stoop stalder the path of the mass centre is flatter and more vertical as the gymnast approaches release. This has two advantages: firstly the direction of the mass centre velocity changes less near to release, when compared to the clear circle technique, and this should lead to a more consistent performance, when compared to the clear circle technique. Secondly, the felge to handstand forms the basis of more complex skills: typically the felge to handstand with either a half or full twist. In these skills there is not a flight phase as such, rather the gymnast makes hand changes whilst the force on the bars is low. Having a vertical mass centre velocity while the body is twisting reduces the task complexity of the hand changes (i.e. less correction for non-vertical alignment).

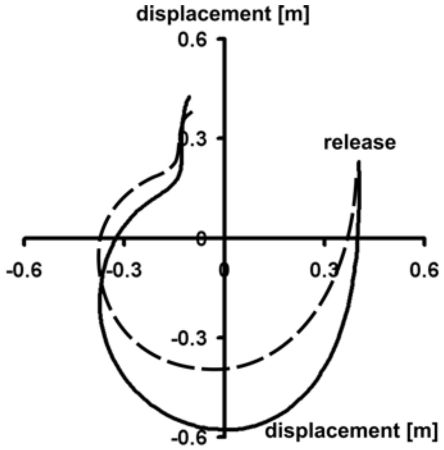

Figure 3. Path of the mass centre during the optimised (dashed line) and constrained optimised (solid line) felge to handstand.

CONCLUSION: It was found that both good and poor performances of the felge from handstand to handstand could be improved. The technique used by the gymnasts could be improved by extending the hip angle more rapidly and over a larger range. The minimisation of joint torque resulted in a global optimum similar to the clear circle technique. Since the strength requirements of the clear circle are lower than those of the stoop stalder the clear circle is more appropriate for the early stages of development as suggested by Davis (2005). Although the optimum technique that closely resembled the technique used by the gymnasts was found to be more demanding in terms of the strength required, it does offer the potential for more consistent performance and future developments in skill complexity.

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