FUNCTIONAL VARIABILITY IN A WHOLE BODY CO-ORDINATED MOVEMENT

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Gymnasts flex at the hips in the lower part and extend in the upper part of the giant circle. In order to perform a sequence of circles at even tempo, any variation in angular velocity at the end of the flexion phase needs to be reduced by the end of the extension phase. The aim of this study was to determine the nature and contribution of such adjustments. A computer simulation model of a gymnast on high bar was used to investigate strategies of (a) fixed timing of the extension phase (feedforward control) and (b) stretched timing (feedforward and feedback control). For three elite gymnasts fixed timing reduced the angular velocity variation by 36% and stretched timing by 63%. The mean reduction for the actual gymnast techniques was 61%. It was concluded that both feedforward and feedback control strategies are used by gymnasts for controlling such movements.

KEYWORDS: gymnastics, technique, computer simulation, control

INTRODUCTION: When a gymnast performs regular giant circles on the high bar (Figure 1) the aim is to swing with as little deviation in body form as possible. The gymnast and bar are a mechanical system, where muscular actions at the hip and shoulder can input or dissipate energy (Bauer, 1983). As the gymnast passes beneath the bar the hip and shoulder angles are closed increasing both the potential and kinetic energy. As the gymnast passes through the upper part of the circle, opening the hip and shoulder angles increases the potential energy but decreases the kinetic energy. By varying the timing and amount of extension the gymnast can control the energy within the system and thus regulate the speed of rotation.

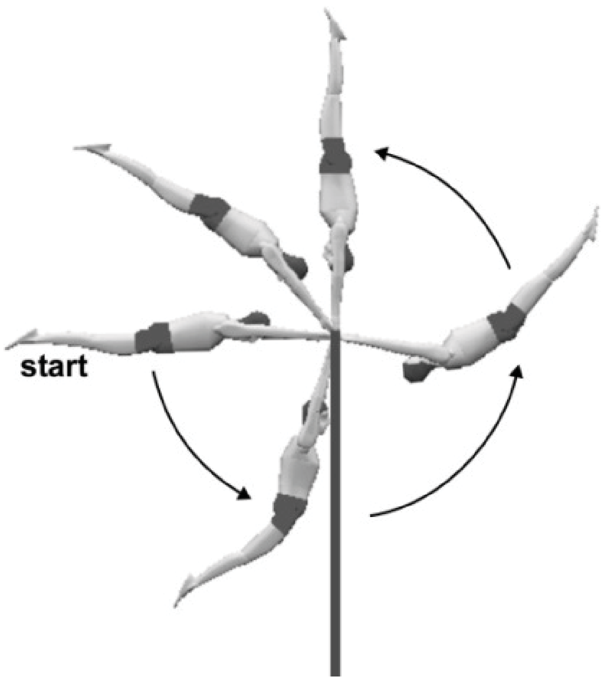

Figure 1. Giant circle starting at a rotation angle of 90° past the vertical.

Movement variability is often reported to have a functional role, which is referred to as the flexibility or adaptability of the system to external variability (Preatoni et al., 2013). Hiley et al. (2013) found that gymnasts' technique was more variable through the upper part compared to the lower part of the circle. An increase in movement variability associated with a gymnast making feedback corrections (Jagacinski & Flach, 2003) would fall under the

definition of functional variability since the adjustments have the function of controlling the pace of the giant circle. However, in order to maintain low variability in the outcome of the movement each feedback correction must still be performed with accuracy (Yeadon and Hiley, 2014).
The aim of the study was to determine the nature and contribution of technique and adjustments to the control of pace during consecutive regular giant circles. This comprises the contributions of feedback control (closed loop) and feedforward control (open loop).

METHODS: Data Collection: Three elite male gymnasts (age 21 ± 3 years, mass 69.8 ± 1.6 kg, height 1.72 ± 0.03 m) who competed internationally gave informed consent to participate in the study which was approved by the university's ethics committee. The gymnasts performed 10 consecutive giant circles, performed with even tempo and good form. All trials were captured using 15 Vicon MX13 cameras operating at 300 Hz.
Data Processing: Joint angles were calculated from the joint centre coordinates. The whole body centre of mass location was determined using subject-specific inertia data (Yeadon, 1990). The rotation angle was defined as the angle made by the line joining the gymnast's centre of mass to the bar location with the upward vertical. For each giant circle the whole body angular velocity at key rotation angles were noted; end of the closing of the hip and shoulder angle (approx 290°), end of the giant circle (450°). The mean and standard deviation of the angular velocity at both instants were calculated. The actions beneath the bar resulted in variability in the whole body angular velocity at the start of the upper part of the circle. By the time the gymnast had reached the end of the circle the variability had been reduced.
Simulation model: A planar four-segment angle-driven model of a gymnast (comprising arm, torso, thigh and lower leg segments) and bar was used (Hiley & Yeadon, 2003a). The bar and the gymnast's shoulder structure were modelled as damped linear springs. Model parameters comprised segmental inertia datal, stiffness and damping coefficients of the bar and shoulder springs, and the torso lengthening parameter were calculated using matching simulations (Hiley & Yeadon, 2003b).
Control Strategies: Two control strategies were tested. The first maintained the average technique of each gymnast which was akin to a feedforward strategy, where the gymnast makes no changes to the planned timings of the extension and flexion through the upper part of the circle. Ten simulations were run for each gymnast where the initial whole body angular velocity at the start of the upper part of the circle was replaced by the values obtained from the ten trials. The whole body angular velocity at the end of each circle (450°) was recorded. The second strategy assumed that through the upper part of the circle the gymnast attempts to complete the extension (opening of the hip and shoulder angles) at the same rotation angle in each trial. For a given initial angular velocity, the timing of the extension was adjusted so that it was completed at the same rotation angle as the average technique. For each simulation the whole body angular velocity at the end of the circle was recorded.

RESULTS: Both control strategies were able to reduce the standard deviation of the angular velocity at the end of the simulation in comparison to the start (Table 1). For all but one of the three gymnasts the stretched timing (feedback) strategy was most effective at reducing the standard deviation. On average for the three gymnasts, fixed timing (feedforward) reduced the angular velocity variation by 36% whereas stretched timing (feedforward plus feedback) reduced the variation by 63%. The mean reduction for the actual gymnast techniques was 61%.

Table 1

Comparison of angular velocity variation (°/s) at 450° for (a) gymnast performances, (b) fixed timing simulations, (c) stretched timing simulations

	recorded		simulation	
gymnast	recorded 290°	recorded 450°	fixed timing 450°	stretched timing 450°
1	212.8 ± 7.4	209.6 ± 2.3	206.3 ± 2.3	206.9 ± 2.5
2	217.2 ± 3.1	220.5 ± 1.4	216.4 ± 3.0	216.7 ± 1.5
3	215.1 ± 5.2	209.6 ± 2.2	208.4 ± 3.4	210.3 ± 1.5

Note : Mean and standard deviation have been reported

DISCUSSION: When considering the energy in the system during the upper part of the circle, since the gymnast starts and ends each circle in approximately the same configuration the change in energy due to gravity will be the same irrespective of initial angular velocity. However, when the gymnast extends the kinetic energy will decrease. If the model is rotating faster the loss of kinetic energy is greater and if the model is rotating slower the loss is less, thus reducing the difference in whole body angular velocity at the end of the circle. This explains why both the fixed and stretched timing strategies were able to reduce the variation in angular velocity.

For all three gymnasts the recorded variability in angular velocity at the end of the giant circles lay close to or between the values obtained from the two control strategies (Table 1). This would suggest that the gymnasts were using a combination of the two strategies. It may be that the gymnasts were employing the stretched timing strategy with the shoulder and a fixed timing strategy with the hip angle. If they were, it might be expected that these movements would not be performed with the same precision as those performed beneath the bar, leading to more variation during the upper part of the circle compared to the lower part, as found by Hiley et al., (2014). Indeed, it has been shown that humans are less able to judge movement time at slower movement speeds (Newell et al., 1979). Since the gymnast is rotating relatively slowly through the upper part of the circle it may be difficult to replicate the low timing variability seen earlier in the circle, i.e. the increased movement variability arises from a combination of slower rotation speed and feedback control.

CONCLUSION: Elite gymnasts control the pace of regular giant circles using a combination of feedforward and feedback techniques. On average the additional contribution provided by feedback control is the same magnitude as that provided by feedforward control. It may be concluded that both feedforward and feedback techniques make substantial contributions to the regulation of tempo/pace in performances of consecutive regular giant circles. Therefore, the increased variability through the upper part of the circle plays a functional role as the gymnast makes feedback adjustments, and so may be described as functional variability.

REFERENCES:

Bauer, W.L. (1983). *Swinging as a way of increasing the mechanical energy in gymnastic manoeuvres*. In H. Matsui and K. Kobayashi (Eds.), Biomechanics VIII-B. Champaign, IL: Human Kinetics. pp. 801-806.

Hiley, M.J., & Yeadon, M.R. (2003a). Optimum technique for generating angular momentum in accelerated backward giant circles prior to a dismount. *Journal of Applied Biomechanics*, 19, 119-130.

Hiley, M.J., & Yeadon, M.R. (2003b). The margin for error when releasing the high bar for dismounts. *Journal of Biomechanics*, 36, 313-319.

Hiley, M.J., Zuevsky, V.V., & Yeadon, M.R. (2013). Is skilled technique characterised by high or low variability? – An analysis of high bar giant circles. *Human Movement Science*, 31, 171-180.

Jagacinski, R.J. & Flach, J.M. (2003). *Control theory for humans: Quantitative approaches to modeling performance*. Mahwah, NJ: Erlbaum.

Newell, K.M., Hoshizaki, L.E.F., Carlton, M.J., & Halbert, J.A. (1979). Movement time and velocity as determinants of movement timing accuracy. *Journal of Motor Behavior*, 11, 49-58.

Preatoni, E., Hamill, J., Harrison, A.J., Hayes, K., Van Emmerik, R.E.A., Wilson, C., & Rodano, R. (2013). Movement variability and skills monitoring in sports. *Sports Biomechanics*, 12, 69-92,

Yeadon, M.R., & Hiley, M.J. (2014). The control of twisting somersaults. *Journal of Biomechanics*, 47, 1340-1347.

Yeadon, M.R. (1990). The simulation of aerial movement - II. A mathematical inertia model of the human body. *Journal of Biomechanics*, 23, 67-74.