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## INVESTIGATING OPTIMAL TECHNIQUE IN A NOISY ENVIRONMENT

<sup>1,2</sup>M.J. Hiley and <sup>1</sup>M.R. Yeadon

<sup>1</sup>School of Sport, Exercise & Health Sciences, Loughborough University, UK

<sup>2</sup>Corresponding Author; email: [m.j.hiley@lboro.ac.uk](mailto:m.j.hiley@lboro.ac.uk), web: [www.lboro.ac.uk](http://www.lboro.ac.uk)

### SUMMARY

The aim of the study was to optimize the technique in the backward giant circle prior to a dismount from the high bar using various optimization criteria to determine which best characterized the technique adopted by a gymnast. Ten gymnast trials were captured and used to determine the level of kinematic variability in the gymnast's joint angle time histories. A computer simulation model of a gymnast and high bar was used to optimize the giant circles under three different criteria: minimizing joint torques, maximizing the release window and maximizing success in the presence of kinematic variability. Optimizations to find local (i.e. a solution close to the gymnast's technique) and global solutions were performed using the three criteria starting from the gymnast's technique. All global solutions diverged from the gymnast's technique. However, the local optimum for maximizing success in a noisy environment had a success rate comparable with the global optimum (98% vs. 99%, respectively). It is concluded that the gymnast's technique was characterized by maximizing success at the task despite operating in a noisy environment.

### INTRODUCTION

Minimising effort (joint torques) or energy has been used to describe the underlying technique of everyday activities such as walking [1,2]. When optimizing sporting movements, minimising joint torque has also been used with varying degrees of success [3,4,5]. Alternatively, it has been proposed [6] that maximising the likelihood of success at a task, despite the presence of noise within the motor system, was a more plausible explanation of technique in human movement. Therefore, does an optimization criterion based on maximising the likelihood of success in a noisy environment provide a better characterization of the technique adopted by athletes than criteria based on minimizing joint torque or maximizing some biomechanical descriptor of performance?

### METHODS

One male gymnast (age 24 years, mass 70 kg, height 1.73 m) who competed internationally gave informed consent to participate in the study which was approved by the University's Ethical Advisory Committee. The gymnast performed 10 double layout somersault dismounts from the high bar (Figure 1) which were recorded using an automatic motion capture system. Only the data for the last 1.5 giant circles and the aerial phase of the dismount were analysed

(Figure 1). The level of noise within the gymnast's joint angle time histories was determined from the repeated trials [7]. The release window (time when gymnast has appropriate linear and angular momentum for a successful dismount [8]) was determined for each trial.



**Figure 1.** Double layout dismount with preceding 1.5 giant circles.

Six optimizations were performed to determine which criterion best characterized the technique used in the giant circles prior to release using a simulation model of a gymnast and high bar [9]. The procedure used a combination of simulated annealing and genetic optimization. The optimization algorithms manipulated a mean set of joint angle time histories at the shoulder, hip and knee obtained from the 10 recorded performances. All joint angle histories were constrained using joint torque limits determined from isovelocity dynamometer measurements on the gymnast [10].

The optimizations were performed in two sets: (a) one where the bounds placed on the joint angle time history parameters were set close to the mean values of the 10 performances to determine whether the gymnast's technique occupied a local optimum and (b) one where the bounds were set wide in order to find a global optimum. Within each of the two sets of optimizations described above three optimization criteria were used. The first criterion was based on minimizing the joint torque at the shoulder and hip throughout the simulation. The simulation was also required to produce a release window within the mean of the 10 trials  $\pm 3$  SD to ensure that a double layout somersault was possible. The second criterion was based on maximizing the size of the release window. The third criterion was based on maximizing the number of successful simulations despite operating in a "noisy" environment. A successful simulation

was one which produced a release window within the mean of the 10 trials  $\pm$  3 SD and did not exceed the strength limits. During the third optimization, the parameters defining the joint angle histories of the shoulder and hip were randomly perturbed to the level of the lowest kinematic variability measured in the gymnast performances. Normally distributed perturbations were added using a random number generator. For each set of joint angle parameters produced by the optimization algorithm, 500 randomly perturbed simulations were performed. Simulations were given a score of 1 for a successful simulation and 0 for an unsuccessful simulation.

The root mean squared difference between the mean recorded and optimal joint angle time histories were calculated for both the shoulder, hip and knee angles for each of the six solutions. In addition, percentage success was assessed for each of the six optimal solutions using 500 randomly perturbed simulations.

## RESULTS AND DISCUSSION

In the first set of optimizations used to see if the gymnast's technique occupied a local optimum the first solution was able to reduce the joint torques at the shoulder and hip from a combined average of 209 Nm to 159 Nm. The second optimization was able to increase the size of the release window from a maximum of 71 ms in the gymnast trials to 124 ms. Over the 500 simulations used in each step of the third optimization the solution produced 98% success despite the presence of noise in the joint angle time histories. In the second set of optimizations used to find global solutions: the joint torque criterion was able to reduce the combined average torques at the shoulder and hip to 100 Nm, the release window criterion increased the window to 156 ms and the success criterion produced 99% success.

The root mean squared (RMS) differences of the joint angle histories between the average recorded trial and the optimal solutions were all smaller for the local solutions compared to the global solutions (Table 1). The success of the six solutions ranged from 36% to 99% (Table 1).

**Table 1:** Root mean squared differences between the joint angle time histories of the optimal solutions and the average histories from the recorded trials

Optimization / Criterion	Shoulder [°]	Hip [°]	Knee [°]	Success [%]
<b>Local</b>				
Min torque	7	4	5	36
Max window	4	6	5	72
Max success	4	6	4	98
<b>Global</b>				
Min torque	22	26	11	42
Max window	12	16	9	60
Max success	6	9	5	99

In the case of minimizing joint torques, the local and global solutions reduced the average joint torques by 25% and 52% respectively, suggesting that the gymnast's technique was not characterized by this criterion. When maximizing the

release window, the local solution was able to increase the window by 75% and the global by nearly 120%. Since large increases in release window were possible close to the gymnast's technique and that even larger increases could be obtained further from the gymnast's technique (Table 1) it suggests that the gymnast was not attempting to maximize his release window. When maximizing success in the presence of noise the local solution, close to the gymnast's technique, was able to produce a 98% success rate, whilst the global optimization produced only a small improvement over the local optimum with a 99% success rate. Moreover the global solution for maximizing success deviated from the gymnast's technique by considerably less than the other two global solutions (Table 1). It therefore appears that the gymnast's technique has the characteristic of maximizing success.

All six optimal solutions were tested to see how robust they were (Table 1, success). Although it would be expected that the optimal solutions for maximizing success would perform better on this aspect than the others, the results demonstrate that, unless coping with the noise resulting from the motor system is taken into consideration, solutions are not automatically robust to kinematic variability (Table 1). Therefore, coping with noise should be included in optimization scores if human like solutions are to be found.

## CONCLUSIONS

Ultimately, optimizing for success determines the solution space defined by the constraints placed on the system. If the task is complex it might be that the solution space is so small that it effectively defines the gymnast's technique.

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