# OPTIMISED TUMBLING PERFORMANCES THAT ARE ROBUST TO PERTURBATIONS

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## INTRODUCTION

Determining optimum tumbling performance in artistic gymnastics has previously focused on maximising somersault rotation in simulations, with a double straight somersault being possible [1]. Gymnasts may develop their optimum performance in a different way, however, since their technique must have some robustness to perturbations. Therefore using an optimisation criterion that merely maximises somersault rotation in a simulation is unlikely to give a realistic solution. In particular there is no guarantee that such an optimum simulation will be robust to small perturbations of the touchdown conditions and the technique used. The aim of this paper is to determine the effect of incorporating perturbations of technique into the optimisation of simulated tumbling performance.

## METHODS

A planar five-segment model was developed with torque generators at each joint for simulating the foot contact phase in tumbling. The elastic properties of the interface between the feet and tumbling track were represented by horizontal and vertical massless damped linear springs (Figure 1).

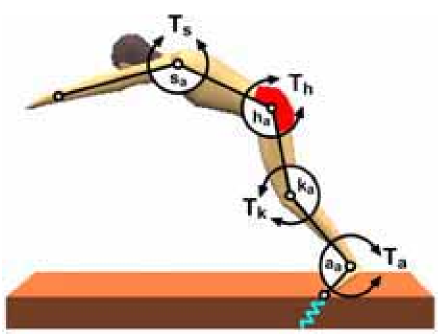


**Figure 1**: A five segment simulation model of the foot contact phase in tumbling.

The model was customised to an elite gymnast by determining subject-specific segmental inertia and joint torque parameters. Anthropometric measurements of an elite gymnast were taken and segmental inertia parameters were calculated using a mathematical model [2]. Torque measurements were taken during eccentric-concentric movements at the ankle, knee, hip and shoulder joints using an isovelocity dynamometer (KinCom 125E), with crank angular velocities ranging from 20°/s to 250°/s, in order to express torque as a function of joint angle and angular velocity [3].

A performance of a double layout somersault was used to provide initial conditions for simulations. Maximising rotation potential (angular momentum × flight time) subject to a flight time constraint (greater than the actual performance) produced sufficient somersault rotation for a double straight somersault [3]. This original optimised simulation was then perturbed by varying the initial conditions (body orientation ±3°, linear momentum ±3% and angular momentum ±3%), and the onset activation times (±20ms) of the knee and hip torque generators in order to determine its robustness to perturbations. Two modified optimisations were then carried out with the perturbations to the initial conditions and the onset activation times included in the optimisation procedure (lowest rotation potential score chosen for each combination of parameters and simulations with flight times less than that of the actual performance discarded).

## RESULTS AND DISCUSSION

The optimisation for robustness to perturbations of initial conditions had 4% less rotation potential than the original optimisation while the onset time optimisation had 3% less rotation. Perturbing the initial conditions for the original optimised simulation and the two robust optimisations resulted in maximum reductions in rotational potential of 5%, 5% and 5% respectively. Perturbing onset times to the torque generators resulted in reductions in rotation potential of 3%, 2% and 1% respectively. The flight times for the perturbed original optimisation were as much as 6% less than in the actual performance while the flight times for the perturbed robust optimisations were all greater than the actual flight time. In summary, including perturbations within the optimisation procedure resulted in simulations that had less rotation potential but were more robust (in terms of rotation potential and flight time) to perturbations than the original double straight optimum simulation.

## CONCLUSIONS

When maximising performance it is important that the robustness of the optimum simulation to perturbations is considered and is included in the formulation of the optimisation procedure used. Failure to do this can result in maximal solutions that are unrealistic and not achievable. In the development of such gymnastic skills it is likely that robustness and consistency are an inherent part of optimised performance. Considerations of robust and consistent performance may therefore have parallels in both motor learning and evolution.

## REFERENCES

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