Limiting factors in tumbling

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Introduction

Tumblers routinely perform double layout somersaults or triple tucked somersaults but few, if any, can execute a triple layout somersault. If a tumbler is able to complete a double layout somersault, the question arises as to what should be changed in order to produce a triple layout somersault. The aim of this study was to investigate whether an increase in approach speed without a concurrent increase in strength would permit a triple layout somersault to be completed.

Methods

A planar five segment model was developed to simulate the foot contact phase in tumbling takeoffs. The model comprised rigid foot, shank, thigh, trunk + head and arm + hand segments with two damped linear springs to represent the elasticity of the tumbling track / gymnast interface (Figure 1). Torque generators were included at the ankle, knee, hip and shoulder joints in order to allow each joint to open actively during the takeoff. Input to the simulation model comprised the motion of the system just prior to the initial contact of the model with the tumbling track and the activation timings to each torque generator. The output from the model comprised the motion of the system at the instant of takeoff. The postflight performance of the model was then determined using a simulation model of the aerial phase (Yeadon, 1990). The simulation model was customised to one elite male gymnast by determining subject specific segmental inertial parameters (Yeadon 1990), and strength parameters (King et al., 1999). In addition stiffness and damping parameters for the tumbling track / gymnast interface were determined through optimisation using an independent tumbling trial. The tumbling model was evaluated by comparing a simulation of a double layout somersault with the actual performance by the gymnast. For the optimisation of the postflight performance a score was used which equalled the product of angular momentum and vertical velocity of the mass centre at takeoff (rotation potential). This performance score was maximised for the same initial preflight conditions as the double layout by varying the activation timings to the four torque generators. Subsequently another optimisation was carried out in which the horizontal approach velocity was allowed to be up to 50% greater than in the double layout somersault.

Figure 1: The five segment simulation model of tumbling. Four torque generators open the ankle, knee, hip and shoulder joints (TA, TK, TH, TS) and two springs allow for horizontal and vertical movement of the tumbling track.
Results & Discussion

For the evaluation of the simulation model good agreement was found between the actual double layout and the simulation with the same initial conditions. At takeoff from the tumbling track there was a 5% difference in the mass centre velocity, a 5% difference in the angular momentum, and the average difference in the segment angles was 6° (third graphic in each sequence of Figure 2).

![actual performance](image1)

![simulation](image2)

Figure 2: (a) Actual double layout somersault, (b) simulated double layout somersault

Optimising the postflight performance (with the same approach characteristics as the double layout somersault) produced a simulation with 6% more rotation potential than the simulation of the actual performance. Combining this result with the evaluation indicates that the strength parameters used in the simulation model are realistic since it is to be expected that the gymnast is operating close to optimum.
With a 50% increase in horizontal velocity (7.2 m.s\(^{-1}\)) and the same strength parameters, optimising the postflight performance allowed a triple layout somersault to be produced (Figure 3). This simulation has 48% more rotation potential than the actual double layout.

**Figure 3**: Simulation of a triple layout somersault

It may be concluded that the limiting factor to tumbling performance is not the strength of the gymnast, but the ability to produce sufficient horizontal approach velocity at touchdown.

**References**
