OPTIMUM TECHNIQUE FOR MAXIMISING FORWARD SOMERSAULT ROTATION IN TRAMPOLINING

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The purpose of this study was to investigate the optimal technique to produce somersault rotation in forwards rotating somersaulting skills. A 7-segment planar, torque-driven simulation model of a trampolinist was developed. The trampoline was represented by horizontal and vertical force-displacement relationships. The model was evaluated using recorded performances of three forward somersaulting skills. Optimised takeoff technique produced an increase of 9% in rotation potential using a more open shoulder angle and a greater initial horizontal velocity.

KEY WORDS: trampolining, takeoff, simulation, model, optimisation, torque-driven.

INTRODUCTION: During each contact phase in trampolining, the trampolinist must create the required linear and angular momenta to enable themselves to have sufficient flight time and angular velocity to complete the desired skill in the subsequent flight phase. In order to achieve maximum rotation a trampolinist must have both a large vertical velocity and possess a large amount of angular momentum at takeoff (King & Yeadon, 2004). The generation of both linear and angular momenta are dependent on the vertical reaction force acting on a trampolinist (Vaughan, 1980), and it has been shown that the production of vertical linear momentum and angular momentum require opposing movement strategies; the production of vertical linear momentum requires a straight body position (Cheng & Hubbard, 2004) whereas the creation of forwards rotation requires a piked position at takeoff (Lephart, 1972). The inter-related nature of the two primary factors in the production of somersault rotation makes the identification of an optimal technique a complex problem. This study aims to investigate the optimal technique to produce maximum forward somersault rotation through the simulation of the trampoline contact phase.

METHODS: A planar seven-segment computer simulation model of a trampolinist with eight torque generators (four extensor, four flexor) was developed to investigate the mechanics of the contact phase in trampolining. Segments represented the head and trunk, upper arm, lower arm, thigh, shank, and a two-segment foot. The foot-trampoline interface was modelled as linear horizontal and non-linear vertical force-displacement relationships acting at the heel, metatarsal-phalangeal (MTP) joint and toe. The total reaction force was distributed between three points on the foot based on the relative depressions of each point.

The movements of the ankle, knee, hip, and shoulder joint were driven by pairs of torque generators representing the extensors and flexors. The movements of the elbow were driven by joint angle time histories calculated from 3D automatic motion capture of trampoline performances. The MTP joint was driven by two angle-displacement relationships that governed the MTP joint angle in the depression and recoil phases of the contact.

The torque generators represented the properties of muscle and tendon as a rotational muscle-tendon complex comprising a contractile element and a series elastic element. The torque exerted about a joint was calculated as the product of an activation level and the maximum voluntary torque as defined by a nine parameter, torque-angle-angular velocity function (King *et al.*, 2006; Yeadon *et al.*, 2006).

Input to the simulation model comprised the initial orientation and joint angles and angular velocities, the initial position and velocity of the centre of mass, and the parameters governing the activation profile of each torque generator. The output of the model consisted

of the orientation and joint angle time histories, and the linear and angular momenta of the trampolinist throughout the movement and at takeoff.

The simulation model was customised to an elite trampolinist by determining subject-specific segmental inertia parameters (Yeadon, 1990) and scaling the parameters governing isometric strength of each pair of torque generators to appropriate effective strength levels (King *et al.*,2009) from torque parameters measured from a gymnast and a triple jumper.

The simulation model was evaluated against three recorded performances of forward somersaults with varying amounts of rotation; a single straight somersault (F_1), a piked 1¾ somersault (F_2), and a piked triffus (F_3). Simulated annealing was used to minimise a cost function whilst varying sixty parameters comprising 56 parameters governing the joint activation profiles and four allowing adjustments to the initial orientation angle, horizontal and vertical velocity of the centre of mass, and shoulder angular velocity. The cost function was an RMS score given to each simulation quantifying the differences between the recorded performances and simulation in four areas: orientation and joint angles throughout the contact phase, orientation and joint angles at takeoff, duration of the contact phase, and the movement outcomes of horizontal and vertical linear momentum and angular momentum at takeoff. The components of the cost function were weighted so that one degree difference was equivalent to 1% difference in the measures of duration and momentum (Yeadon & King, 2002).

The simulation model was used to investigate optimal technique to maximise rotation potential in forward rotating somersaults. Rotational potential is a normalised product of angular momentum and flight time and is expressed as the number of somersaults the trampolinist would be capable of completing in a straight position. The optimisation procedure varied 57 parameters: 56 joint activation parameters and one parameter allowing adjustment to the initial horizontal velocity. Rotation potential was maximised whilst permitting travel (in the preceding and subsequent flight phases) up to a total of half the length of the jumping zone (1.075 m) and the full length of the jumping zone (2.15 m). Penalties were imposed on the simulations if they utilised joint movements beyond the limits of ranges of motion observed in the recorded performances or exceeded the permitted allowance of horizontal travel.

RESULTS & DISCUSSION: The simulation model was capable of providing a close match to the recorded performances of the trampolinist. On average the simulation model was able to match the performance to within 4.4%, with the individual trials matched to 3.2%, 4.8% and 5.3% for F_1, F_2, and F_3 respectively. The individual component scores are presented in Table 1.

Table 1
Cost function component scores resulting evaluation procedure

	S_{RMS}	S_{ABS}	S_1	S_2	S_3	S_4	RMS (%)
F_1	2.7	1.5	0.2	1.3	0.2	0.0	3.2
F_2	4.1	1.2	1.4	2.8	0.1	3.0	4.8
F_3	4.9	1.2	1.7	2.2	1.2	0.6	5.3
Mean	3.9	1.3	1.1	2.1	0.5	1.2	4.4

S_1 – average RMS difference in orientation and configuration angles during contact (°), S_2 - average difference in orientation and configuration angles at takeoff (°), S_3 - percentage difference in horizontal linear momentum (%), S_4 - percentage difference vertical linear momentum (%), S_5 - percentage difference angular momentum (%), S_6 - percentage difference contact duration (%)

The level of agreement shown between the simulated and recorded performances was sufficient to allow investigation of optimum takeoff technique.

The piked triffus skill (F_3) performed by the trampolinist had a rotation potential of 1.74 straight somersaults, whilst travelling a total distance of 1.88 m. The optimum simulations produced an increase of 9% in rotation potential when permitted to travel 2.15 m (*1L*) and a

reduction of 2% when limited to a total travel of 1.075 m (*0.5L*). The simulation model was capable of producing 1.71 and 1.89 straight somersaults when permitted to travel half and the full length of the jumping zone respectively. The *0.5L* solution achieved this in a longer flight time of 1.47 s compared to 1.42 s for *1L*. Figure 1 shows the optimal takeoff techniques alongside the technique used to perform F$_3$ in the evaluation of the simulation model.

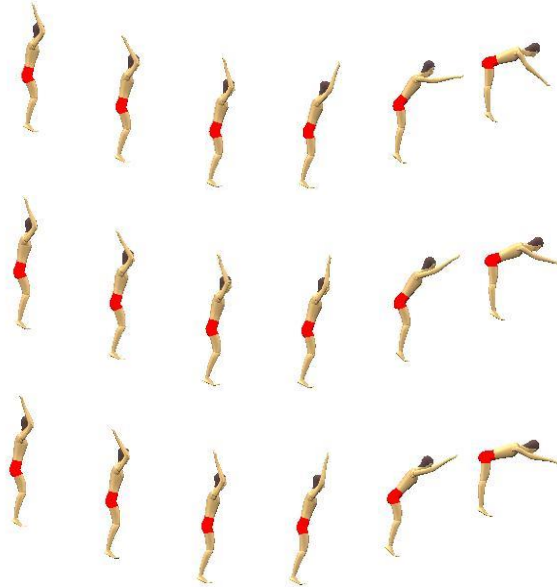**Figure 1: Comparison of torque-driven simulation of F$_3$ (top) and optimal technique to produce rotation potential for 0.5L (middle) and 1L (bottom).**

The optimal techniques show greater flexion of the shoulders at takeoff, helping to produce angular momentum by moving the mass centre forward and increasing the moment arm of the vertical reaction force. During the recoil phase, the knee and hip both display greater flexion with *1L* showing greater forward rotation with the hip in front of the ankle throughout.

The optimal techniques for *0.5L* and *1L* produced 1.00 m and 2.06 m of horizontal travel respectively, compared with 1.89 m for the recorded movement. The 47% decrease in horizontal travel for *0.5L* was the result of a 4% increase in the travel in the preceding flight phase and an 87% decrease in the horizontal travel during the subsequent flight phase. *1L* had a greater initial horizontal velocity, travelling 1.21 m before contact and 0.84 m afterwards. The initial horizontal velocity caused the model to rotate over the feet throughout the contact phase, promoting the production of angular momentum.

The differences in the optimal techniques were caused by differences in the activation profiles of the hip extensors and flexors, the knee extensors, and the ankle dorsi flexors, as well as a different horizontal velocity of the centre of mass at the beginning of the contact phase. The remaining joint torque activation profiles showed no significant differences between the two optimal techniques. The optimal solution for *0.5L* decreased the initial horizontal velocity by 0.06 ms^{-1} whilst the solution for *1L* increased the velocity by 0.10 ms^{-1}. Figure 2 shows the differences in the activation profiles. In *1L*, both the knee and hip extensors show a greater level of initial activation and a lesser maximum activation level in *1L* than *0.5L*. The knee uses very similar activation timings but the hip extensor activation both increases to the maximum and decreases earlier than in *0.5L*. Both the hip flexor and dorsi flexor activation follow similar shapes but the activation of both is greater throughout in *1L* and the difference constantly increases during the recoil phase.
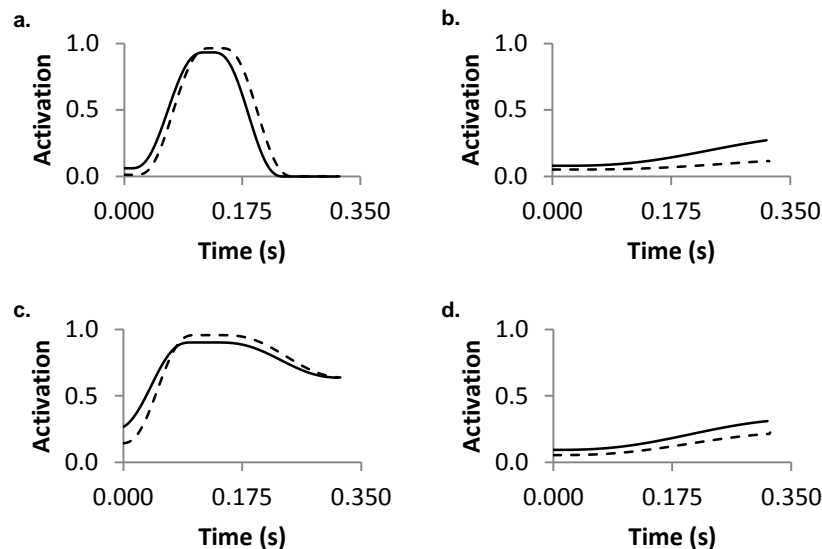
Figure 2: Activation profiles of (a) hip extensor (b) hip flexor (c) knee extensor (d) dorsi flexor

CONCLUSION: Optimal takeoff technique for maximal forward somersault rotation in trampolining was determined using a simulation model. The model utilised greater horizontal velocity of the centre of mass and greater flexion of the hips and shoulder to increase the moment arm of the vertical reaction force during the recoil phase. The larger moment arm enabled the increased production of angular momentum. A trade-off between flight time and angular momentum was seen but maintaining shoulder flexion helped to increase both of these. This knowledge can inform coaching practice through a better understanding of the use of the arms in forward somersaults.

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