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Twist limits for late twisting double somersaults on trampoline

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ABSTRACT

An angle-driven computer simulation model of aerial movement was used to determine the maximum amount of twist that could be produced in the second somersault of a double somersault on trampoline using asymmetrical movements of the arms and hips. Lower bounds were placed on the durations of arm and hip angle changes based on performances of a world trampoline champion whose inertia parameters were used in the simulations. The limiting movements were identified as the largest possible odd number of half twists for forward somersaulting takeoffs and even number of half twists for backward takeoffs. Simulations of these two limiting movements were found using simulated annealing optimisation to produce the required amounts of somersault, tilt and twist at landing after a flight time of 2.0 s. Additional optimisations were then run to seek solutions with the arms less adducted during the twisting phase. It was found that 3½ twists could be produced in the second somersault of a forward piked double somersault with arms abducted 8° from full adduction during the twisting phase and that three twists could be produced in the second somersault of a backward straight double somersault with arms fully adducted to the body. These two movements are at the limits of performance for elite trampolinists.

1. Introduction

Predicting limiting performances in a sport can be problematic when the limiting factors are primarily physiological. For example, quantifying the lowest possible 100 m sprint time is fraught with difficulty since the minimum time is more dependent upon the optimal physical attributes of an individual than inherent mechanical constraints. In contrast aerial movements are largely constrained by mechanical factors rather than by individual physical limitations. In addition the measure of sprint time is a continuous variable whereas the number of somersaults and twists are discrete measures. In double somersaults with twist the amount of twist will be a whole number of half twists. On trampoline double somersaults which initially rotate forward will have an odd number of half twists while those initially rotating backward will have an even number of half twists. As a consequence the final direction of somersault rotation is backward which allows viewing of the trampoline bed prior to landing and permits adjustments to be made at the end of the aerial phase and during the takeoff for the next movement.

In a double somersault twist may be confined to just one somersault or may occur in both somersaults. When there is twist in the first somersault there are typically contributions from both contact and aerial twisting techniques (Yeadon, 1993a, b, c, d). When there is no twist in the first somersault, aerial techniques are responsible for the production of twist during flight. This study will investigate the limits of aerial techniques for producing twist and will be confined to double somersaults with the twist in the second somersault since these movements must employ aerial twist and do not have a contact twist contribution.

Aerial twist in somersaults with multiple twists is a consequence of producing tilt of the longitudinal axis away from the vertical somersault axis using asymmetrical movements of the arms or hips (Yeadon, 1993c,d). The amount of tilt produced may be enhanced by the nutation effect in which the tilt angle increases during the first quarter twist if the arms are abducted away from the body (Yeadon, 1993a,c). For a recorded performance the computer simulation model of Yeadon et al. (1990) may be used to partition the production of tilt into contributions from contact and aerial techniques (Yeadon, 1993d).

In previous research on limiting movements using computer simulation models Hiley and Yeadon (2005) showed that it was theoretically possible to perform a triple straight backward somersault dismount from high bar, providing the release could be timed to within 28 ms. Brüggemann and Arampatzis (1993) determined that a quadruple tucked backward somersault dismount was pos-

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sible in principle. King and Yeadon (2004) found that large linear and angular approach velocities were key for maximising rotation in tumbling and that a straight triple somersault should be possible. A straight triple somersault has now been performed in tumbling competition. In gymnastics vaulting it was found that a handspring double somersault with 1½ twists and a handspring triple somersault tucked were limiting vaults (Hiley et al., 2015). A handspring triple tucked somersault vault has now been attempted in competition. In triple somersaults in the aerials event of freestyle skiing, six twists will be the limit according to Yeadon (2013).

The aim of this research study was to determine the twist limits for double somersaults with the twist in the second somersault. Since aerial twist may be produced using asymmetrical arm or asymmetrical hip movements it will be of interest to determine the individual tilt contributions for the limiting movements.

2. Methods

An angle-driven computer simulation model of aerial movement (Yeadon, 1990a; Yeadon et al., 1990) was used to determine the limits of asymmetrical arm and hip techniques for producing aerial twist in the second somersault of a double somersault using the segmental inertia parameters of a male world trampoline champion (Yeadon, 1990b). The model comprised 11 segments and required the initial angular momentum and body orientation as input together with the time histories of the joint angles. Elbow and knee flexion were not used and neither was relative movement of the shoulder girdle. As a consequence the model was reduced to six segments: chest + head, pelvis, two legs and two arms. Side flexion was shared between the hips and the spine as was hyperextension whereas forward flexion occurred solely at the hip joints for the first 90° of flexion and thereafter was shared between the hips and spine (Yeadon, 1990c). In addition the two legs moved together so that the six degrees of freedom at the hip joints and spine became two independent degrees of freedom. Constant angular momentum during flight was assumed and the equations of motion were solved numerically for whole body angular velocity from which somersault, tilt and twist angles were obtained by numerical integration. Somersault gave the whole body rotation about the (horizontal) angular momentum vector, tilt gave the angle between the longitudinal axis and the vertical plane perpendicular to the angular momentum vector, and twist gave the rotation about the longitudinal axis. The model was evaluated by comparing the twist angles from simulation with five performances of single and double somersaults with twist performed by the aforementioned world trampoline champion: differences were less than 0.04 revolutions of somersault and 0.12 revolutions of twist (Yeadon et al., 1990).

In multiple somersaults with multiple twists, the number of twists that can be achieved is limited by the time that the body can be extended in a straight position and so, in general, flight time and somersault momentum will be limiting factors. On trampoline flight time has an upper limit of around 2.0 s and it is possible to perform a triple straight somersault which will have 50% more angular momentum than a double straight somersault. As a consequence flight time was set at 2.0 s in this study and no specific constraints were needed to limit angular momentum.

The model was used to simulate the aerial phase of double somersaults in which twist was initiated at the end of the first somersault and stopped at the end of the second somersault using asymmetrical movements of the arms and hips to produce tilt away from the vertical somersault plane and subsequently to remove it. The maximum amounts of twist in the first 1.5 s during which tilt is produced and in the last 0.5 s during which tilt is removed were added together to determine a limiting movement with the maximum number of half twists. An optimised simulation was then found in which the target angles of somersault, tilt and twist were met. Details are given in the following paragraphs.

Seven constraints were imposed when producing a simulation: (a) at the 1.0 somersault position the twist was not more than 0.25 revolutions, (b) the final twist was an odd number of half twists for forward rotating takeoffs and was an even number of half twists when the initial direction of somersault was backward, (c) the final somersault angle gave a landing on the feet with the legs close to vertical, (d) the final tilt angle was zero, (e) arm abduction was restricted to be a maximum of 90° during the initiation of twist, (f) arm abduction angles were between 90° and 180° (hands higher than shoulders) and were symmetrical at the end of the simulation, (g) the time of flight was 2.0 s. Constraint (e) was used in order to follow current trampolining technique and to avoid sequential arm movements of large amplitude. Constraint (f) was used since the arms are typically raised overhead during landing.

Two cases were considered. In the first case asymmetrical hip movement was used to move from 60° forward flexion to 60° side flexion from a piked position in a forward rotating double somersault. In the second case asymmetrical hip movement was used to move from a straight position to 30° side flexion in a straight backward rotating double somersault.

Each change in joint angle was specified by the start and end angle values and the start and end times and was effected using a quintic function with zero velocity and acceleration at the endpoints (Hiley and Yeadon, 2003). Lower limits on the duration of arm and hip movements were based on times between angle turning points in recorded performances of twisting double somersaults by the world trampoline champion whose segmental inertias were used in simulations. For arm abduction through 180° a minimum duration of 0.30 s was imposed while 0.20 s was used for a 90° arm movement. For 90° hip flexion/extension a lower limit of 0.25 s was set and 0.20 s was used for a change from 60° hip flexion to 60° side flexion (a change in hula angle of 90°).

In order to maximise the amount of twist produced, the timings of the arm and hip movements were adjusted to maximise the amount of tilt achieved in the second somersault. After an initial side flexion with both arms abducted at 90°, one arm was adducted to the side of the body and as the quarter twist position was reached, the body was straightened and the other arm adducted to the body (Figs. 1 and 2). The majority of the twist then occurred during this twisting phase in a fixed body configuration. Finally the timings of the asymmetrical arm and hip movements, along with the value of the final common arm abduction angle, were used to remove the tilt and stop the twist prior to landing.

Simulations were first carried out manually to provide initial estimates of the required somersault angular momentum and timings of the arm and hip movements. Simulated annealing (Goffe et al., 1994) was then used to vary six parameters (comprising the start times and durations of hip movement from side flexion to straight body, and adduction of each arm from 90° to the side of the body) for the production of tilt and twist (typically using 40,000 simulations). Since there would be some trade-off between maximising tilt and maximising twist depending on the duration used for tilt production, the optimisation criterion was chosen to be that of maximising twist after 1.5 s without any attempt to remove the tilt. Since the arms were allowed to move through a greater range in the removal of tilt, it was expected that a greater angle of tilt could be coped with for tilt removal. This was verified by running optimisations of reverse simulations that started with the end of flight conditions at time 2.0 s in which tilt was produced by asymmetrical arm and hip movements (one angle and 8 timing parameters with typically 70,000 simulations) within the permitted ranges, using maximum twist after 0.5 s as the optimisation criterion. The amount of twist at 1.5 s in the first optimisation was added to the twist in the reverse simulation at 0.5 s from the second optimisation to provide an estimate of the maximum twist possible. These timings were used since the body was straight with arms adducted at this time. The maximum twist value was rounded down to the nearest number of half twists: an odd number of half twists for the forward rotating double somersault and an even number of half twists for the backward rotating double somersault.

Simulated annealing was then used to find complete performances in which the above twist values were achieved at 2.0 s along with zero tilt and the required somersault value using a score function that penalised deviations from the final target orientation angles. A total of 16 parameters (using typically 100,000 simulations) were used to vary the asymmetrical arm and hip movements which produced tilt (6 parameters) and removed tilt (9 parameters) along with a parameter to adjust the angular momentum value. Additional optimisations were then run to seek solu-

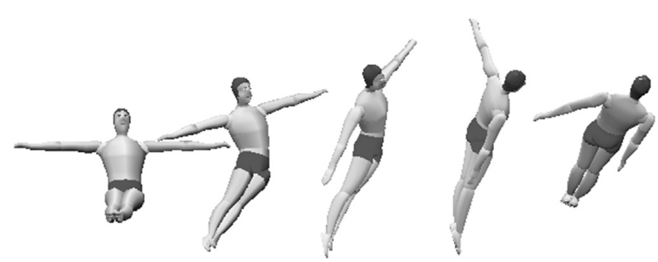

Fig. 1. Asymmetrical hip and arm movements used to produce tilt in a piked double forward somersault at the start of the second somersault (front view).

Fig. 2. Asymmetrical hip and arm movements used to produce tilt in a straight double backward somersault at the start of the second somersault (front view).