TWIST LIMITS OF LATE TWISTING DOUBLE SOMERSAULTS ON TRAMPOLINE

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The aim of this research study was to determine the twist limits for double somersaults on trampoline with the twist in the second somersault. An angle-driven computer simulation model of aerial movement was used to determine the maximum number of half twists that could be produced in a double somersault using asymmetrical movements of the arms and hips. Simulations of 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. 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 3 twists could be produced in the second somersault of a backward straight double somersault with arms fully adducted.

KEY WORDS: computer simulation, aerial movements, technique

INTRODUCTION: In trampolining an elite competition routine comprises 10 sequential multiple somersaults with multiple twists. The score for a routine is based on execution, difficulty and time of flight. The difficulty component increases with the number of somersaults and twists. The time of flight for a skill can be as much as two seconds, corresponding to a jump height of five metres. The staple movement used in competitive routines is the double somersault with twist. Twist may be initiated prior to takeoff or may be produced during the aerial phase using asymmetrical movements of the arms and hips (Yeadon, 1993). For twists initiated after takeoff the angular momentum for the twist comes from the somersault momentum generated during takeoff. In this study the twisting limits of double somersaults with twist in the second somersault were investigated.

METHODS: A computer simulation model of aerial movement (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. 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. Side flexion was shared between the hips and the spine as was hyperextension whereas forward flexion occurred solely at the hip joints (Yeadon, 1990). 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 equation of motion was solved numerically for whole body angular velocity from which somersault, tilt and twist angles were obtained by numerical integration. Somersault gave the 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 a world trampoline champion: differences were less than 0.12 revolutions of twist (Yeadon et al., 1990).

Various sequences of asymmetrical arm and hip movements were used to produce tilt away from the vertical somersault plane using the simulation model. 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. 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 / adduction 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.
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. 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.
The following constraints were used 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) arm abduction was restricted to be a maximum of 90° during the initiation of twist, (d) arm abduction angles were between 90° and 180° (hands higher than shoulders) and were symmetrical at the end of the simulation, (e) the time of flight was 2.0 s. 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.
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 arm and hip timing parameters for the production of tilt and twist. 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 in which tilt was produced by asymmetrical arm and hip movements (9 parameters) 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 produced at 0.5 s (occurring during the last 0.5 s) in 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. A total of 16 parameters 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 initial angular momentum value. Additional optimisations were then run to seek solutions with the arms less adducted during the twisting phase, increasing the arm abduction angle by one degree at a time until the target orientation angles failed to be met.

RESULTS: For the forward rotating double somersault the amounts of twist that could be produced during the tilt production and tilt removal phases were 2.70 revolutions and 1.10 revolutions (Table 1). As a consequence the first limiting movement which used asymmetrical hip movement with wide arms that were adducted sequentially (Figure 1) was able to produce 3½ twists in the second somersault of a piked double forward somersault. A solution was found with the arms abducted 4° away from rather than adducted 4° towards the midline of the body in the twisting phase (Figure 2). This trampoline movement is known as an Adolf-out fliffus and although it has been performed on trampoline, appreciable twist typically occurs in the first somersault.

For the backward rotating double somersault the amounts of twist that could be produced during the tilt production and tilt removal phases were 2.02 revolutions and 1.03 revolutions (Table 1). As a consequence the second limiting movement which also used asymmetrical hip movement with wide arms that were adducted sequentially (Figure 3) was able to produce 3 twists in the second somersault of a straight double backward somersault (Figure 4). No other solution was found with the arms less adducted than the 4° that placed them close to the body during the twisting phase. While two twists have been produced in the second somersault of a double backward straight somersault, three twists have yet to be achieved.

Table 1
Maximum twist in tilt production phase and tilt removal phase

	max tilt	twist 1.5s	twist 0.5s	total twist
forward	23.9°	2.70 rev	1.10 rev	3.5 rev
backward	19.0°	2.02 rev	1.03 rev	3.0 rev

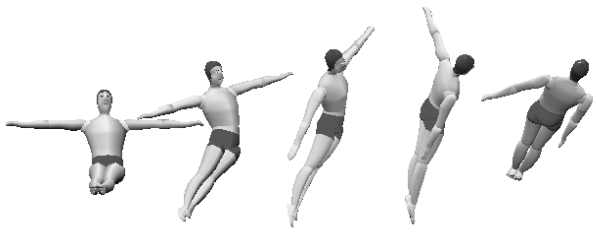

Figure 1: Asymmetrical hip and arm movements used to produce tilt in a piked double forward somersault at the start of the second somersault (front view).

Figure 2: 3½ twists in the second somersault of a piked double forward somersault (side view).

Figure 3: Asymmetrical hip and arm movements used to produce tilt in a straight double backward somersault at the start of the second somersault (front view).

Figure 4: Three twists in the second somersault of a straight double backward somersault (side view).

DISCUSSION: The extent to which the various assumptions affect the results of this study will now be considered. In the straight double backward somersault the amount of side flexion during tilt production and removal was restricted to 30^{o}. If more flexion than this were to be used it would detract from the expected extended body configuration and although it would make the twist easier to achieve it would not change the limiting movement. The arm position used in the initiation of twist was restricted to 90^{o} of arm abduction in order to represent typical trampolining technique used in a straight double somersault with twist. If the requirement of a symmetrical arm configuration at landing were to be relaxed, this would make the removal of tilt easier but would not change the limiting movements. The same would be true for a relaxation in meeting precisely the target somersault, tilt and twist angles at landing.

CONCLUSION: It may be concluded that on trampoline the limiting movements for late twisting double somersaults are 3½ twists in a forward piked double somersault and 3 twists in a backward straight double somersault with the twist occurring in the second somersault in each case. Both movements make use of a side arch with wide arms which are adducted sequentially to produce the tilt and ensuing twist and this has implications for coaching.

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