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Full Length Article

The limits of aerial techniques for producing twist in forward 1½ somersault dives

M.R. Yeadon*, M.J. Hiley

School of Sport, Exercise and Health Sciences, Loughborough University, Loughborough LE11 3TU, UK

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ABSTRACT

An angle-driven computer simulation model of aerial movement was used to determine the maximum amount of twist that can be produced in a forward 1½ somersault dive from a three-metre springboard using various aerial twisting techniques. The segmental inertia parameters of an elite springboard diver were used in the simulations and lower bounds were placed on the durations of arm and hip angle changes based on recorded performances of twisting somersaults. A limiting dive was identified as that producing the largest possible whole number of twists. Simulations of the limiting dives were found using simulated annealing optimisation to produce the required amounts of somersault, tilt and twist after a flight time of 1.5 s. Additional optimisations were then run to seek solutions with the arms less adducted during the twisting phase. It was found that the upper limits ranged from two to five twists with arm abduction ranges lying between 6° and 17°. Similar results were obtained when the inertia parameters of two other springboard divers were used.

1. Introduction

According to rule D8.4.6 for judging dives: “In dives with twist, the twisting shall not be manifestly done from the springboard or platform” (FINA, 2017). Historically this rule lead to controversy as to whether it was possible to twist in flight without starting the twist during the board contact phase. While it was accepted that aerial twist could be produced by counter-rotation of the hips (Eaves, 1969; Rackham, 1960), there was a problem in that a cycle of counter-rotation could produce a half twist but the method could not account for the continuous twisting that was seen in diving. Commenting upon the descriptions of twisting dives given by Barrow (1959a), (1959b), Orner (1959) stated that when twist is not taken from the diving board it can only be produced by counter-rotation and that “any postulated technique, in which the diver leaves the board without angular momentum about the desired axis of rotation and then has him 'Spinning', is faulty”. Barrow (1959c) replied to Orner and showed how the total angular momentum could be resolved about tilted body axes. This was insufficient for Eaves (1960) who observed: “Mr. Barrow offers no mechanism whereby the body is tilted… and the only feasible mechanism is a series of rapid rotations of the arms across the front of the body in the opposite direction to the tilt. It can be shown that this cannot be done quickly enough to be effective…” Rackham (1958) also held the same view but reversed his position after experiments in which divers produced such a twist (Rackham, 1970) and agreed with Travis, 1968 that asymmetrical arm movements could product twist in a somersault. Frolich (1979) and Pike (1980) subsequently showed that it is theoretically possible to convert a plain somersault into a twisting somersault by tilting the twist axis out of the vertical somersault plane by means of asymmetrical arm movements. Frolich (1980) observed that in addition to arm movements any relative movement of body segments that produces tilt will result in twist. Rackham (1970) and Batterman (1974) proposed a torsion of the

* Corresponding author at: School of Sport, Exercise and Health Sciences, Loughborough University, Ashby Road, Loughborough, Leicestershire LE11 3TU, UK.
E-mail address: M.R.Yeadon@lboro.ac.uk (M.R. Yeadon).

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upper body in the direction of twist when in the piked position, causing the legs to swing in the opposite direction so that when the body extends it will be tilted.

Yeadon (1993a), (1993b), (1993c), (1993d) used a rigid body model of aerial movement together with an 11-segment computer simulation model to investigate contact and aerial twisting techniques by considering contributions to the tilt angle. In an analysis of eight reverse 1½ somersault dives with 2½ twists it was found that aerial asymmetries of arms, chest and hips as well as contact techniques all made contributions to the tilt angle (Yeadon, 1993e). While dives that rotate backwards typically show an early twist, indicating the presence of contact twist, forward somersaulting dives often exhibit no twist until well after takeoff. The question arises as to the twist limits of aerial twisting techniques. Since the twist rate increases with the tilt angle (Yeadon, 1993a; Mikl & Rye, 2016), the twist limits will depend upon how much tilt can be produced.

Yeadon (2013) used computer simulation to investigate the capabilities of various aerial twisting techniques for producing twist in triple somersaults in the aerials event of freestyle skiing. It was concluded that six twists should be possible. Yeadon and Hiley (2017) found that three twists is the limit for twist in the second somersault of a straight backward double somersault on trampoline and that 3½ twists is the limit for twist in the second somersault of a piked forward double somersault. The aim of the present research study is to determine the limits of aerial twisting techniques comprising asymmetrical movements of arms, hips and chest in forward rotating 1½ somersault dives with twist.

2. Methods

An angle-driven computer simulation model of aerial movement (Yeadon, 1990a; Yeadon, Atha, & Hales, 1990) was used to determine the limits of asymmetrical arm, hip and chest techniques for producing aerial twist in a forward 1½ somersault dive. The segmental inertia parameters of a male international springboard diver (height 1.79 m, mass 69.7 kg) were calculated from anthropometric measurements (Yeadon, 1990b) and were used in the simulations. 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. For the majority of simulations elbow and knee flexion were not used. As a consequence the model was effectively reduced to seven segments: upper trunk + head, lower trunk, 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 lower spine became two independent degrees of freedom. The model was modified so that the locations of the shoulder centres within the upper trunk segment were a function of the angle between arm and upper trunk as in Begon, Wieber, and Yeadon (2008).

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 has been evaluated by comparing the twist angles from simulation with those in performances of trampolining (Yeadon et al., 1990), springboard diving (Yeadon, 1993e), freestyle skiing (Yeadon, 1989), rings dismounts (Yeadon, 1994), high bar dismounts (Yeadon, 1997), and tumbling (Yeadon & Kerwin, 1999).

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 and so, in general, flight time and somersault momentum will be limiting factors. For dives from the three-metre springboard flight time has an upper limit of around 1.5 s and it is possible to perform a triple twisting forward 2½ somersault which will have more angular momentum than a forward 1½ somersault dive in the straight position. As a consequence flight time was set at 1.5 s in this study and no specific constraints were needed to limit angular momentum.

The model was used to simulate the aerial phase of forward 1½ somersaults in which twist was initiated during the first 0.75 s and was stopped during the following 0.75 s using asymmetrical movements of the arms, hips and chest to produce tilt and subsequently to remove it. The maximum amounts of twist in the first 0.75 s during which tilt is produced and in the last 0.75 s during which tilt is removed were added together to determine a limiting movement with the maximum whole number of twists. An optimised simulation was then found in which the target angles of somersault, tilt and twist were met. Four cases of asymmetrical arm movement were considered and one case for each of asymmetrical hip and asymmetrical chest movement. Details are given in the following paragraphs.

Five constraints were imposed when producing an optimised simulation: (a) the final twist angle was a whole number of revolutions, (b) the final somersault angle (trunk 25° short of vertical) was appropriate for hands, hips and feet to have the same water entry point for a three-metre springboard dive, (c) the shoulder and hip angles at entry (150° and 155°) were fixed at values consistent with (b), (d) the final tilt angle was zero, (e) the time of flight was 1.5 s.

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 & 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 on trampoline as in Yeadon and Hiley (2017). 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 hip flexion to 60° side flexion (a change in hula angle of 90°). A lower limit of 0.20 s was imposed on a 90° torsion of the upper trunk relative to the lower trunk and pelvis segment (chest asymmetry). The corresponding maximum angular velocities were 19.6 s^{-1} (arm), 11.8 s^{-1} (hip), 14.7 s^{-1} (hula) and 14.7 s^{-1} (chest).

In the first case of asymmetrical arm movement, the left arm was raised sideways through 90° while the right arm was lowered

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