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The influence of touchdown conditions and contact phase technique on post-flight height in the straight handspring somersault vault

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ABSTRACT

In vaulting the gymnast must generate sufficient linear and angular momentum during the approach and table contact in order to complete the rotational requirements in the post-flight phase. This study investigated the effects of touchdown conditions and contact technique on peak post-flight height of a straight handspring somersault vault. A planar seven-segment torque-driven computer simulation model of the contact phase in vaulting was evaluated by varying joint torque activation time histories to match three performances of a straight handspring somersault vault by an elite gymnast. The closest matching simulation was used as a starting point to optimise peak post-flight height of the mass centre for a straight handspring somersault. It was found that optimising either the touchdown conditions or the contact technique increased post-flight height by 0.1 m whereas optimising both together increased post-flight height by 0.4 m above that of a simulation matching the recorded performance. Thus touchdown technique and contact technique make similar contributions to post-flight height in the straight handspring somersault vault. Increasing touchdown velocity and angular momentum lead to additional post-flight height although there was a critical value of vertical touchdown velocity beyond which post-flight height decreased.

1. Introduction

The mechanics of the table contact phase of gymnastics vaulting is dependent on the initial contact conditions and the technique used during the contact phase. Although there are numerous coaching publications on vaulting, there is no general consensus about the importance of table contact phase technique. Some authors hold the view that vaulting performance is primarily determined prior to table contact (Still, 1990) while others have suggested that the gymnast has the ability to change the outcome of the vault via table contact technique (Smith, 1982; Boone, 1976).

Takei (1988) used correlational analysis to show that a large pre-flight horizontal velocity is an important determinant of success in the tucked handspring somersault vault. Additionally Takei and Kim (1990) found that a large change in mass centre vertical velocity during contact was beneficial. While the horizontal pre-flight velocity is clearly an aspect of touchdown conditions, it is unclear whether the change in vertical velocity is a function of initial conditions or contact technique or both.

King et al. (1999) used a passive (no shoulder torque) two-segment simulation model to determine optimum touchdown conditions for a straight handspring somersault vault (which continues the pre-flight rotation, Fig. 1a) and a Hecht vault (which reverses the pre-flight rotation during contact, Fig. 1b). It was found that quite different touchdown conditions were required for the two vaults and were similar to those used in actual performances, indicating that initial conditions can have a profound effect. King and Yeadon (2005) subsequently used a five-segment torque-driven model to simulate the Hecht vault and found that shoulder torque during the contact phase had only a small effect on post-flight performance.

Koh et al. (2003) used a five-segment angle-driven simulation model with joint torque constraints to optimise the post-flight of a straight Yurchenko vault (backward entry, Fig. 1c). The optimum simulation had similar post-flight horizontal velocity to the actual performance but greater vertical velocity at takeoff resulting in greater peak height in post-flight. The optimal vault was achieved by modifying the initial conditions (after impact) and contact phase technique. The relative importance of these two contributors to improved performance in vaults that continue the pre-flight rotation (Fig. 1a and c) remains unknown. The straight handspring somersault vault (Fig. 1a) forms the basis of the 12 most difficult forward entry vaults seen in elite male competition (Fédération Internationale de Gymnastique (FIG), 2013).

The aims of this study were to investigate the effect on peak post-flight height of the straight handspring somersault vault

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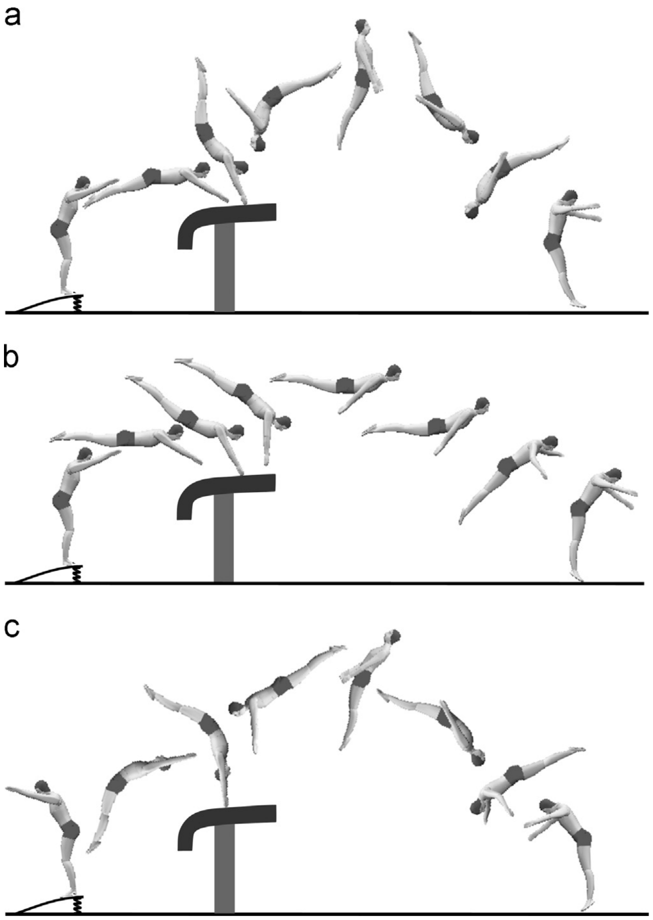

Fig. 1. The (a) straight handspring somersault, (b) Hecht and (c) straight Yurchencho somersault vaults.

arising from (a) initial conditions at touchdown and (b) joint torques during the contact phase (technique).

2. Methods

In order to investigate the effects of initial conditions and table contact technique on vaulting performance a torque-driven computer simulation model was developed. Section 2.1 describes data collection on an elite gymnast, the simulation model, the method of model evaluation, and the application of the model.

2.1. Data collection

An internationally competitive male gymnast (21 years, 69.9 kg, 1.73 m) gave informed consent to perform six straight handspring somersault vaults (Fig. 1a). Eighteen Vicon MX13 cameras, sampling at 480 Hz, were used to track the motion of markers attached to the gymnast and the vaulting table. An international Brevet judge assessed and ranked the performance of each vault, with the best three vaults selected for subsequent analysis. Details of the methods used to determine the kinematics of the performances are given in Jackson et al. (2011).

Gymnast-specific torque parameters were calculated from measurements taken from the gymnast during maximal voluntary contractions using a Con-trex isovelocity dynamometer. Data were obtained for extension and flexion of the wrist, shoulder, hip and knee at angular velocities ranging from $30^\circ\ \mathrm{s}^{-1}$ to $400^\circ\ \mathrm{s}^{-1}$. Torque surfaces were fit to the data based on the relationships between torque, angle and angular velocity as detailed in Forrester et al. (2011). Passive torque data were also obtained using the isovelocity dynamometer for shoulder flexion, wrist extension and hip extension. Exponential equations were fit to the passive torque–angle data for each joint (Reiner and Edrich, 1999; Esteki and Mansour, 1996).

Ninety-five anthropometric measurements were taken from the gymnast and gymnast-specific segmental inertia parameters were calculated using the model of Yeadon (1990a). The mass and dimensions of the vaulting table were measured and the inertial parameters calculated as in Jackson et al. (2011).

2.2. Simulation model

A two-dimensional torque-driven simulation model of gymnastics vaulting was developed using the software package Autolev$^{\mathrm{TM}}$. A planar model was used since non-twisting vaults are essentially symmetrical about the sagittal plane. The model simulated the interaction between a seven-segment gymnast and a single-segment vaulting table during the table contact phase of the vault.

The gymnast was modelled using seven rigid segments to represent the fingers, the palms, the arms, the head + upper trunk, the lower trunk, the thighs and the shanks (Fig. 2). A damped linear spring was used to represent shoulder retraction and protraction, whilst displacement of the glenohumeral joint centre was modelled as a cubic function of the shoulder angle as in Begon et al. (2008). A damped torsional spring was used to represent hand flexion/extension at the knuckles, whilst flexion/extension of the trunk was modelled as a function of the hip angle as in Yeadon (1990b). A non-linear, damped torsional spring allowed the table to rotate about its centre of rotation.

The interaction between the gymnast and the table was modelled as detailed in Jackson et al. (2011). The normal contact force was represented by spring-dampers situated at three points of contact: the fingertip, the knuckle and the base of the palm, while the tangential contact force was modelled using a two-state frictional force representation to allow for both static and dynamic friction.

The model was driven by torque generators, consisting of contractile and series elastic components, which acted to extend and flex the wrist, shoulder, hip and knee. The torque generators were defined based on the measured torque–angle–angular velocity relations and represented the maximum voluntary torques that the gymnast could produce.

To determine the applied torque the maximal torque was multiplied by an activation level lying between 0 and 1. A quintic function (Hiley and Yeadon, 2003) was used to ramp up/down the activation level. The extensors were allowed to ramp up from an initial level (<0.5) and ramp down towards the end of the simulation. In contrast the flexors were allowed to ramp down from an initial level and then ramp up towards the end of the simulation to prevent hyper-extension (King et al., 2009). The shoulder flexor was regarded as an extensor since it was responsible for increasing the shoulder joint angle and the shoulder extensor was regarded as a flexor. Seven parameters were required to specify the timing and level of activation for each torque generator (two start times, two ramp durations, three activation levels), giving a total of 56 parameters. In addition to the active torque generators, passive torque elements, based on the measured exponential torque–angle relations, were included at the wrist, shoulder and hip joints.

The model parameters (viscoelastic parameters of the shoulder, knuckle, table and contact springs and the static and kinetic coefficients of friction between the hands and the contact surface) were set to those determined in Jackson et al. (2011) apart from the damping parameter of the contact spring, which was increased to $10{,}000\ \mathrm{N\ m^{-1}\ s}$ to prevent the hands from 'bouncing' during the initial part of the table contact phase. The input to the torque-driven model comprised the initial conditions at contact (joint angles and velocities, upper trunk angle and velocity, mass centre position and velocity) together with the activation time histories of the torque generators. The output from the torque-driven model comprised the joint

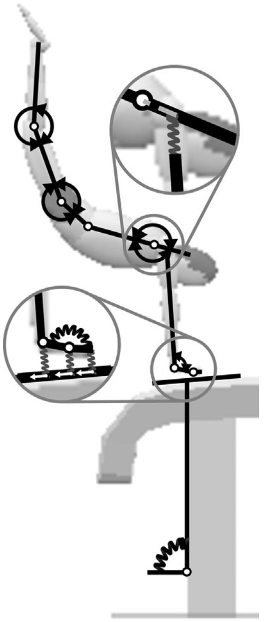

Fig. 2. Vaulting table contact phase simulation model.