

This item was submitted to Loughborough's Institutional Repository (<https://dspace.lboro.ac.uk/>) by the author and is made available under the following Creative Commons Licence conditions.



CC creative commons
COMMONS DEED

Attribution-NonCommercial-NoDerivs 2.5

You are free:

- to copy, distribute, display, and perform the work

Under the following conditions:

 **Attribution.** You must attribute the work in the manner specified by the author or licensor.

 **Noncommercial.** You may not use this work for commercial purposes.

 **No Derivative Works.** You may not alter, transform, or build upon this work.

- For any reuse or distribution, you must make clear to others the license terms of this work.
- Any of these conditions can be waived if you get permission from the copyright holder.

Your fair use and other rights are in no way affected by the above.

This is a human-readable summary of the [Legal Code \(the full license\)](#).

[Disclaimer](#) 

For the full text of this licence, please go to:
<http://creativecommons.org/licenses/by-nc-nd/2.5/>

The biomechanics of twisting somersaults. Part IV: Partitioning performances using the tilt angle

M. R. YEADON*

Sports Biomechanics Laboratory, Department of Physical Education and Sports Science,
Loughborough University, Ashby Road, Loughborough LE11 3TU, UK
and Human Performance Laboratory, University of Calgary, Canada

Abstract

A method is presented for determining the contributions made by contact and aerial twisting techniques in filmed performances of twisting somersaults. An 11-segment simulation model is used to determine the effects of removing asymmetries about the sagittal plane. Tilt contributions are determined for four competitive movements performed by an elite trampolinist. It is found that even in movements in which the twist is evident at takeoff, aerial techniques make a greater contribution than contact techniques.

Keywords: Twist, somersault, model, simulation, biomechanics.

Introduction

In Parts II and III of this series, various contact and aerial techniques were shown to be theoretically capable of producing twist. The question arises as to which of these techniques are actually used by elite competitors.

Investigations into twisting somersaults may be experimental, theoretical or analytical. An experimental study can demonstrate that something is possible. Bartee and Dowell (1982) showed that it is possible to produce twist in a somersault without starting the twist during contact with the diving board. A theoretical study can do the same but with more detail on technique. Pike (1980) showed that it is possible to produce a full twist in a dive by means of asymmetrical arm movements during the aerial phase. If the area of interest is the techniques normally used in elite performances of twisting somersaults, neither of these methods is suitable.

In order to determine the contributions made by the various twisting techniques to actual performances of twisting somersaults, the movements should be filmed and analysed from a mechanical point of view. While there have been a number of cinematographical studies (McCormick, 1954; Wiley, 1964; Winter, 1966; Mood, 1968; Bangerter and Leigh, 1968; Borms et al., 1973; Seidel, 1976; Van Gheluwe and Duquet, 1977; Al-Haroun, 1980), none of them employed a quantitative mechanical analysis to arrive at a conclusion. The only study which provides a mechanical analysis of filmed performances of twisting somersaults is that of Van Gheluwe (1981). In his study, a 6-segment simulation model was evaluated using film data of three full twisting somersaults to define the relative segmental movements, and then compare the simulation values of somersault, tilt and twist with the corresponding film values. Two modifications of each performance were obtained by restricting movements at the hips and shoulders. The resulting simulations showed that the removal of hip rotation reduced the amounts of twist only slightly, whereas the removal of arm movement resulted in little twist. It was concluded that the twist in the three performances was produced primarily by the asymmetrical arm movement during flight.

This method of using the final twist angle of a simulation as a measure of the twist corresponding to a particular technique gives twist values whose sum is greater than the actual twist. The reason for this may be that movements which stop the twist in the unmodified simulation can have different

*Address all correspondence to M. R. Yeadon, Department of Physical Education and Sports Science, Loughborough University, Ashby Road, Loughborough LE11 3TU, UK.

effects in the modified simulations. As a consequence, the twist values obtained cannot be considered to be contributions since they are not additive. In this paper, a method is presented for determining the contributions made by contact and aerial twisting techniques. The results are presented for four elite performances of competitive trampoline movements.

Method

In Part I, the twist rate $\dot{\psi}$ of a rod was described by equation (23):

$$\dot{\psi} = (h/C - h/A) \sin \theta \quad (1)$$

where h is the angular momentum, A is the moment of inertia about a transverse axis, C is the moment of inertia about the longitudinal axis and θ is the angle of tilt. This equation may be used to approximate the motion of a human performing a twisting somersault in a fixed straight body configuration (Fig. 1). For small tilt angles $\sin \theta \approx \theta$ so that the tilt angle θ will be proportional to the twist rate $\dot{\psi}$ and may be used as a measure of the twist present. The contribution of contact techniques may be measured by the initial tilt angle t_i at takeoff between the longitudinal principal axis and the plane P perpendicular to the angular momentum vector \mathbf{h} . The subsequent increase in the tilt angle during flight will be a measure of the total contribution of aerial twisting techniques. The contributions of individual aerial techniques will be defined using modified simulations to isolate each technique. If the various aerial techniques are used at the same point in the movement, it may be expected that the sum of the individual contributions will be equal to the tilt angle in the actual performance.

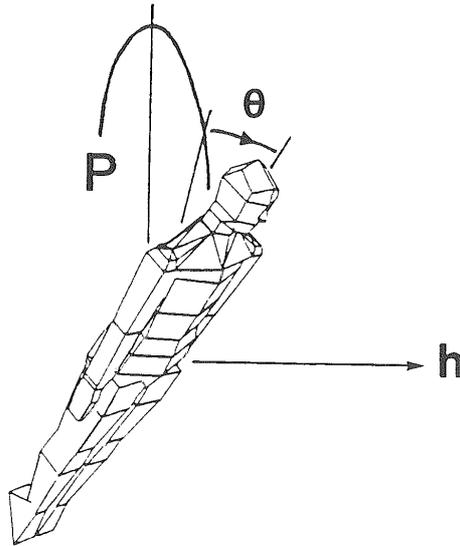


Figure 1: The tilt angle θ between the plane perpendicular to the angular momentum vector \mathbf{h} and the longitudinal axis of the body.

The procedure adopted is as follows. A twisting somersault is filmed using two cameras and angles describing the orientation and configuration of the body are calculated (Yeadon, 1990a). Segmental inertia parameters are calculated from a set of anthropometric measurements using the mathematical inertia model of Yeadon (1990b). The angular momentum of the filmed movement is calculated as the mean value of estimates obtained throughout the flight phase using the angle time histories and the inertia parameters as input to the 11-segment model of Yeadon (1990c). A simulation of the filmed movement is then produced using the angular momentum, initial orientation angles, configuration angle histories and segmental inertias as input to the model of Yeadon et al. (1990a). The time histories of the resulting somersault, tilt and twist angles are compared with the corresponding values from film in order to verify that the simulation is a reasonable approximation to the actual movement Yeadon et al.

(1990a). The configuration angles are then modified systematically to remove asymmetries of the arms, chest and hips about the sagittal plane. Arm asymmetries are removed by making the left arm mirror the filmed movement of the right arm or vice versa. Chest asymmetry is removed by restricting relative movement between the chest and thorax. Hip asymmetry is removed by only permitting movement parallel to the sagittal plane. The systematic removal of arm, chest and hip asymmetries provides 12 configuration sequences ranging from the filmed configuration to an entirely symmetrical configuration sequence.

In the simulation model, the axis corresponding to minimum moment of inertia is determined and the tilt angle between this axis and the plane perpendicular to the angular momentum vector is obtained. In the original unmodified simulation, the maximum value t_0 , of the tilt angle is recorded together with the time T at which it occurs. In each of the 11 modified simulations, the tilt angle at time T is recorded. Since arm asymmetries may be removed in two ways, the tilt values are averaged in these simulations. This leads to eight tilt values $t(a, c, h)$, where a , c and h each take the values 0 and 1 (Fig. 2). Let a , c and h denote the asymmetry in arm, chest and hip configurations, respectively, where a value of 0 denotes symmetry and a value of 1 denotes asymmetry.

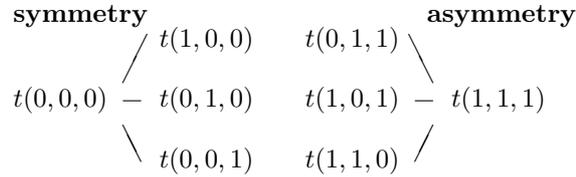


Figure 2: The eight tilt values $t(a, c, h)$ arising from simulations with varying amounts of arm, chest and hip asymmetry where 0 denotes symmetry and 1 denotes asymmetry.

$t(0,0,0)$ will be the tilt angle at time T in a simulation which has complete symmetry about the sagittal plane. The symmetry contribution will be defined as $t_s = t(0,0,0) - t_i$, where t_i is the initial tilt angle at takeoff; t_i is a measure of the tilt due to contact twist, while t_s is a measure of the additional tilt arising from nutation and symmetrical movements during flight.

The tilt associated with asymmetrical arm movement could be calculated either by comparison with a symmetrical simulation or the original asymmetrical simulation. The arm asymmetry contribution t_a is calculated as the average of $[t(1,0,0) - t(0,0,0)]$ and $[t(1,1,1) - t(0,1,1)]$, which correspond to the two comparisons.

The contributions corresponding to chest and hip asymmetry are calculated in a similar way as:

$$t_c = \frac{1}{2}[t(0,1,0) - t(0,0,0)] + \frac{1}{2}[t(1,1,1) - t(1,0,1)]$$

$$t_h = \frac{1}{2}[t(0,0,1) - t(0,0,0)] + \frac{1}{2}[t(1,1,1) - t(1,1,0)]$$

The tilt angle t_0 obtained in the original simulation may now be considered to have been partitioned into contributions arising from contact twist (t_i), symmetry (t_s), arm asymmetry (t_a), chest asymmetry (t_c) and hip asymmetry (t_h) providing that the sum of these contributions is close to t_0 .

Results

The method was applied to four filmed movements performed by an elite trampolinist. The first movement C1 was a double forward somersault with $1\frac{1}{2}$ twists in the second somersault (Fig. 3). The initial tilt angle was 0° showing that, as might be expected, there was little contribution from contact techniques. The tilt values associated with complete symmetry and with asymmetrical movements of the arms, chest and hips were 0° , 12° , 1° and 3° , respectively. It may be concluded that the twist arises from aerial techniques, primarily asymmetrical movement of the arms. In Fig. 3, it can be seen that there is some 4° of tilt after one somersault. This tilt arises from asymmetrical positioning of the arms

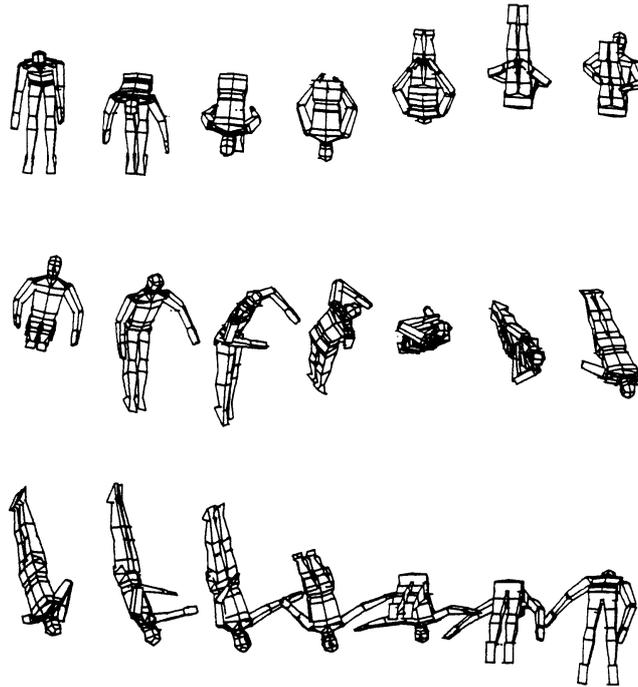


Figure 3: A double forward somersault with $1\frac{1}{2}$ twists in the second somersault.

while the body is piked and is moving in the wobbling mode. Whether this is a chance occurrence or is typical of the technique of this performer is unknown at present.

Figure 4 depicts a similar movement C2 in which the initial direction of somersault rotation is backwards. In the first three-quarters of a somersault, there is no twist, while in the remainder of the movement there is a full twist. Again, as might be expected, the initial tilt value is close to zero showing that contact techniques make little contribution. The tilt contributions from symmetry, arms, chest and hips are -2° , 22° , 1° and 0° , respectively, showing that the twist arises primarily from asymmetrical movements of the arms.

The third movement C3 comprised a backward somersault with one twist and was chosen since the twist is noticeable early in the somersault so that contact techniques might be expected to provide a major contribution (Fig. 5). In the symmetrical simulation, 9° of tilt were produced arising from contact and symmetry contributions. The tilt present at takeoff was only 3° which indicates that an additional 6° of tilt were obtained during flight using body configurations which were symmetrical about the sagittal plane. It can be seen from Fig. 5 that the arms move parallel to the sagittal plane at around the quarter twist position. If the total momentum is set to zero, the corresponding simulation shows that this arm movement produces 3° of tilt. The remaining 3° of the 6° symmetry contribution are a result of nutation. Thus of the 12° of tilt in the movement, only 3° are present at takeoff, the remaining 9° arising during the aerial phase with equal contributions of 3° from nutation, symmetrical arm movement and asymmetrical movements.

The fourth movement C4 comprised a double backward somersault with a half twist in the first somersault and $1\frac{1}{2}$ twists in the second somersault (Fig. 6). As in movement C3, the twist is evident in the early phase of the movement but the initial tilt angle is only 4° with the remainder of the total 17° of tilt arising during the aerial phase. The tilt for the symmetrical simulation is 16° , showing that the movement does not rely on asymmetry techniques. The additional 12° of tilt must arise from symmetrical arm movements, nutation in the twisting mode and oscillation in the wobbling mode.

For these four movements, the values listed in Table 1 may be considered to be contributions to the total tilt, since the total of the individual contributions lies within 1° of the tilt angle in the original simulation which was based on the film data.

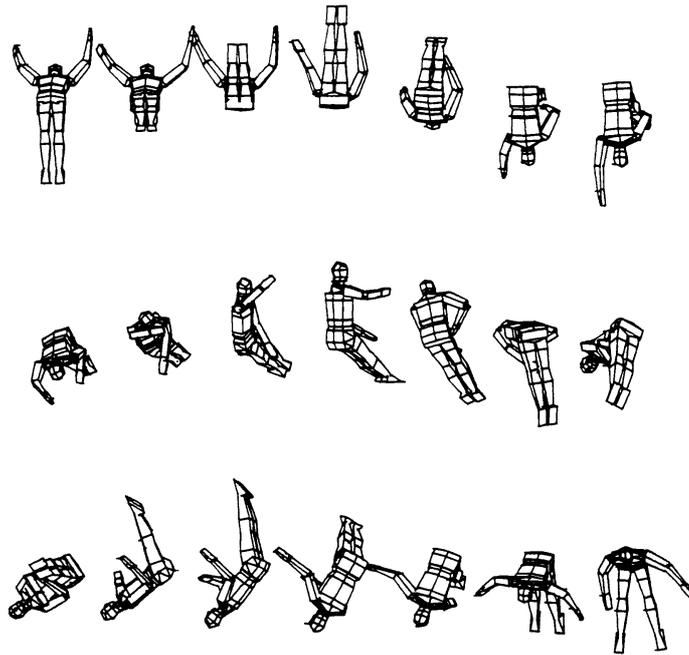


Figure 4: A double backward somersault with one twist in the second somersault.

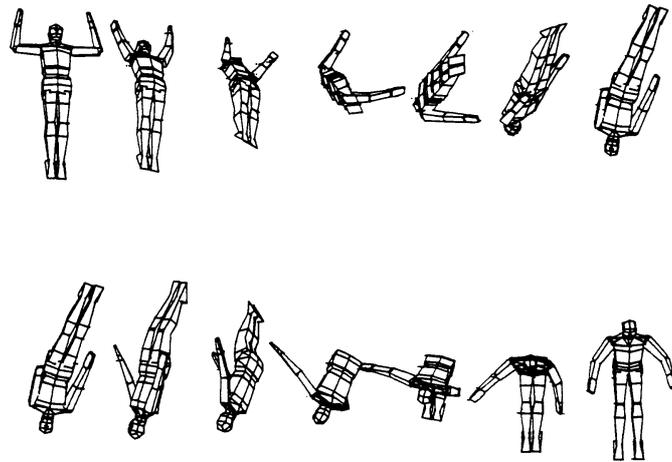


Figure 5: A backward somersault with one twist.

Discussion

A method has been presented for identifying and quantifying twisting techniques used in twisting somersaults. The quantification has been based upon the contributions to the angle of tilt between the longitudinal axis and the plane perpendicular to the angular momentum vector. This procedure has the advantage that the tilt angle is a measure of twisting potential in that it is not dependent upon the body configuration adopted, unlike measures such as twisting angular velocity. This means that the twisting technique used may be quantified separately from the effectiveness of the twisting position adopted, so that it is the initiation of twist that is being measured rather than the total performance. In order to quantify the effectiveness of body configuration, a measure such as the ratio of moments of inertia about the transverse and longitudinal axes may be used.

For the four movements analysed, the maximum tilt angle was partitioned into contributions from contact and aerial techniques such that the sum of the contributions was within 1° of the maximum tilt angle. This summation requirement must be satisfied if the term 'contributions' is to be used. The tilt

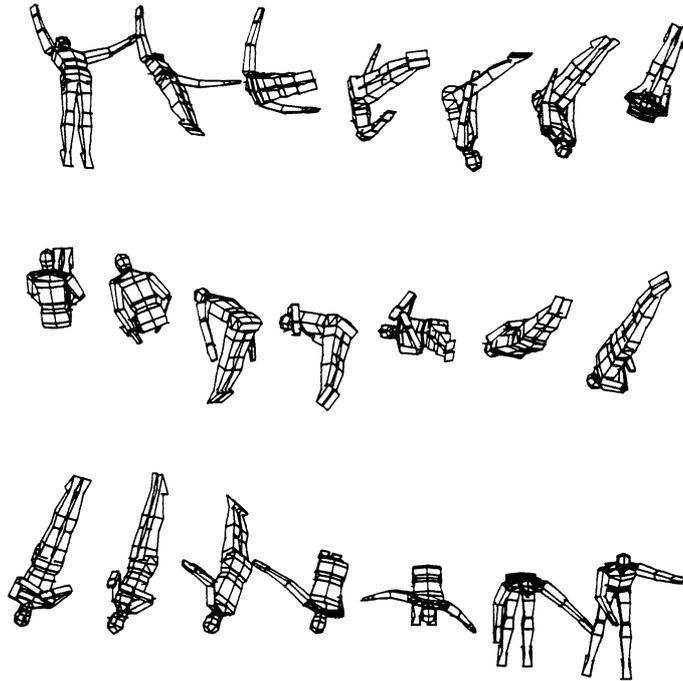


Figure 6: A double backward somersault with a half twist in the first somersault and $1\frac{1}{2}$ twists in the second somersault.

Table 1: Tilt contributions of four trampoline movements

| Movement | Initial | Symmetry | Asymmetries of: | | | Total | Actual |
|----------|---------|----------|-----------------|-------|------|-------|--------|
| | | | Arms | Chest | Hips | | |
| C1 | 0° | 0° | 12° | 1° | 3° | 16° | 16° |
| C2 | -1° | -2° | 22° | 1° | 0° | 20° | 21° |
| C3 | 3° | 6° | 2° | 0° | 1° | 12° | 12° |
| C4 | 4° | 12° | 4° | 0° | -4° | 17° | 17° |

angle was partitioned into contributions from contact techniques, symmetrical configurations, and asymmetries of arm, chest and hip movements. The tilt increase above the initial contact contribution arising from symmetrical configuration changes during flight is regarded as an aerial contribution, although it should be recognized that some initial tilt is necessary for there to be a symmetry contribution. The asymmetrical arm, chest and hip techniques, however, are capable of making contributions irrespective of whether there is a contact contribution. In each of the four movements analysed, contact techniques accounted for less than a quarter of the total tilt. It could be speculated that in other forms of twisting somersaults (such as diving, gymnastics, freestyle skiing), the majority of the tilt arises from aerial rather than contact techniques.

Since this initial study was conducted into twisting techniques used in trampolining, analyses of twisting technique have been made in a number of other sports. In diving it was found that contact contributions amounted to no more than one-sixth of the total tilt in forward, backward and reverse twisters, while arm and hip asymmetries were the major contributors Yeadon (1989b). In six performances of triple somersaults with three or four twists, two freestyle skiing competitors produced all their tilt during the contact phase, two produced all the tilt in the aerial phase and two had equal contributions from contact and aerial techniques (Yeadon, 1989a). For single somersaults with one twist from the high bar, contact contributions amounted to no more than 30% of the total tilt, the main contributors being arm and hip asymmetries (Yeadon et al., 1990b). In eight twisting double somersault dismounts

from the high bar, two competitors had contact contributions greater than half of the total tilt angle and there was evidence that the techniques used depended upon the distribution of twist between the two somersaults (Yeadon, 1991b).

In general, it seems that aerial twisting techniques are more prevalent than contact techniques. As discussed in Part II, this might be expected since the use of contact twist presents problems in landing the skill. The implications for coaching are that there are good reasons for learning aerial twisting techniques and reducing the dependence upon contact techniques. These techniques may be introduced using progressions based upon computer simulations of twisting dives (Yeadon, 1991a). While future research studies on the twisting techniques used by competitors in the various acrobatic sports will contribute to our knowledge of what elite athletes are actually doing, the question of what techniques they should be using will be answered by theoretical computer simulation studies similar to those discussed in Parts II and III of this series.

References

- Al-Haroun, M. R. (1980). *Three dimensional cinematographic analysis of selected full twisting movements in gymnastics*. PhD thesis, Indiana University.
- Bangerter, B. L. and Leigh, L. L. (1968). A comparison of twisting somersaults in diving and rebound tumbling. *Scholastic Coach*, 38:68–70, 111–112.
- Bartee, H. and Dowell, L. (1982). A cinematographical analysis of twisting about the longitudinal axis when performers are free of support. *Journal of Human Movement Studies*, 8:41–54.
- Borms, J., Duquet, W., and Hebbelinck, M. (1973). Biomechanical analysis of the full twist back somersault. In Cerquiglini, S., Venerando, A., and Wartenweiler, J., editors, *Biomechanics III*, pages pp. 429–433. Karger, Basel.
- McCormick, G. P. (1954). A kinesiological study of four divers executing the full twisting forward one and one-half somersault. Master's thesis, University of Southern California.
- Mood, D. P. (1968). A mechanical analysis of six twisting dives. Master's thesis, University of Iowa.
- Pike, N. L. (1980). *Computer simulation of a forward, full twisting dive in a layout position*. PhD thesis, Pennsylvania State University.
- Seidel, H. S. (1976). A comparative analysis of the layout back somersault and full twisting back somersault in tumbling. Master's thesis, Texas A&M University.
- Van Gheluwe, B. (1981). A biomechanical simulation model for airborne twist in backward somersaults. *Journal of Human Movement Studies*, 7:1–22.
- Van Gheluwe, B. and Duquet, W. (1977). A cinematographic evaluation of two twisting theories in the backward somersault. *Journal of Human Movement Studies*, 3:5–20.
- Wiley, J. F. (1964). A cinematographic and mechanical analysis of the backward somersault with double twist in tumbling. Master's thesis, Sacramento State College.
- Winter, F. W. (1966). A photographic analysis of selected twisting dives. Master's thesis, Springfield College.
- Yeadon, M. R. (1989a). Twisting techniques used in freestyle aerial skiing. *International Journal of Sport Biomechanics*, 5:275–284.
- Yeadon, M. R. (1989b). Twisting techniques used in springboard diving. In *Communication to the First IOC Congress on Sport Sciences, Colorado Springs*.
- Yeadon, M. R. (1990a). The simulation of aerial movement - I. The determination of orientation angles from film data. *Journal of Biomechanics*, 23:59–66.

- Yeadon, M. R. (1990b). The simulation of aerial movement - II. A mathematical inertia model of the human body. *Journal of Biomechanics*, 23:67-74.
- Yeadon, M. R. (1990c). The simulation of aerial movement - III. The determination of the angular momentum of the human body. *Journal of Biomechanics*, 23:75-83.
- Yeadon, M. R. (1991a). Coaching twisters. *Swimming Times*, 68(7):17-18.
- Yeadon, M. R. (1991b). Twisting double somersault dismounts from high bar. In *Communication to the XIIIth International Society of Biomechanics Congress*. Perth.
- Yeadon, M. R., Atha, J., and Hales, F. D. (1990a). The simulation of aerial movement - IV. A computer simulation model. *Journal of Biomechanics*, 23:85-89.
- Yeadon, M. R., Lee, S., and Kerwin, D. G. (1990b). Twisting techniques used in high bar dismounts. *International Journal of Sport Biomechanics*, 6:139-146.