Angular Momentum Requirements of the Twisting and Nontwisting Forward 1 1/2 Somersault Dive

Ross H. Sanders and Barry D. Wilson

This study investigated the in-flight rotation of elite 3m springboard divers by determining the angular momentum requirement about the transverse axis through the divers center of gravity (somersault axis) required to perform a forward 1 1/2 somersault with and without twist. Three elite male divers competing in the 1982 Commonwealth Games were filmed using high-speed cinematography while performing the forward 1 1/2 somersault in the pike position and the forward 1 1/2 somersault with one twist in a free position. The film was digitized to provide a kinematic description of each dive. An inclined axis technique appeared to be the predominant means of producing twist after takeoff from the board. The angular momentum about the somersault axis after takeoff was greater for the forward 1 1/2 somersault with twist than the forward 1 1/2 somersault without twist for all three divers. The difference in angular momentum between the two dives of each diver ranged from 6% to 19%. The most observable difference between the dives during the preflight phases was the degree of hip flexion at takeoff. There was more hip flexion at takeoff in 5132D than 103B for all three divers. This difference ranged from 9° to 18° (mean = 14°).

During the final approach step, hurdle, and takeoff phases of a dive, the linear and angular momentum required to successfully complete the dive are established. Aside from having sufficient linear momentum to clear the board and to gain height, the diver's concern is to leave the board with angular momentum of appropriate magnitude and direction to enable successful completion of the dive. Therefore, much research into springboard diving has been analysis prior to takeoff (Golden, 1981; Miller, 1974, 1981a, 1981b, 1983, 1984; Miller & Munro, 1984, 1985a, 1985b).

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There is a dearth of literature pertaining to methods employed by spring-board divers to produce rotation about the longitudinal axis through the body's center of gravity (twist axis). Basically, twist may be generated by establishing rotation through the action of torques while in contact with the springboard or by changing the body's orientation through muscular action while in flight. If divers initiate twist from the board, the angular momentum vector is not parallel to the somersault axis. Consequently, rotations other than somersaults occur throughout the entire flight (Frohlich, 1980). The twist rotation generated in this way, observable from the moment of takeoff to water entry, is undesirable from an aesthetic point of view.

Several means of initiating twist in the air have been documented. The cat twist involves bending the body so that the upper and lower body are aligned along two axes and alternately rotating each half about its own longitudinal axis (Hay, 1985). Van Gheluwe and Duquet (1977) described a conical or hula method of twisting as an alternative explanation of the cat twist phenomenon. This involves rotation and counter rotation of the body about the twist axis. In practice, a rotation of the hips in one direction results in rotation of the whole body in the opposite direction, conserving zero angular momentum about the twist axis. A third means of producing twist in flight is to incline the body's somersault axis so that it is not parallel to the initial angular momentum vector. When the axis is thus inclined, vector components of the initial angular momentum vector cause rotation about the inclined somersault axis of the body and the twist axis of the body (Frohlich, 1980). The diver may achieve the inclined position by rotating the arms about an anteroposterior axis (Figure 1).

Figure 1 — Resolution of the angular momentum vector to perform an inclined axis twist. Adapted from Biomechanics: A Qualitative Approach for Studying Human Movement (p. 349) by Kreighbaum and Barthels, 1981, Minneapolis: Burgess.
Regardless of the method employed to produce twists, the body is in a more extended position than the pike position while the twist is being performed. Consequently, the moment of inertia with respect to the axis of somersault rotation is greater for the twisting dive than for the nontwisting dive during this period. Thus, it was hypothesized that divers would require more somersaulting angular momentum to perform the twisting dive than the nontwisting dive.

In previous studies three methods have been used to determine the angular momentum about the somersault axis. In the "quasi-rigid" method used by Miller (1970), the angular momentum is computed by finding the product of the body's moment of inertia and the angle through which the quasi-rigid body rotates with respect to time. The moment of inertia of the whole body is calculated using a segmental model and the parallel axis theorem. A second method involves the direct measurement of forces from which change in angular momentum may be determined through integration of torques with respect to time. This technique was used by Ramey (1973). A linked segment approach was developed by Hay and Wilson (1978). This method sums the local and remote angular momenta of each of the 14 body segments. The angular velocity of the segment about its own axis and about the body's axis must be determined over a number of film frames. In their study of eight gymnasts executing a forward dive somersault, Wilson and Hay (1976) found that the quasi-rigid method and the linked segment method yielded similar angular momentum values while the method of integrating torques obtained by direct force measurement provided less consistent results.

The purpose of this study was to investigate the in-flight rotation of elite 3m springboard divers by determining the angular momentum requirement about the somersault axis for a diver performing a forward 1 1/2 somersault with and without twist.

Procedures

Data Collection

Three male divers (S1, S2, S3) competing at the 1982 Commonwealth Games were filmed and the films were subsequently analyzed. Each diver performed a forward 1 1/2 somersault in the pike position (103B) and a forward 1 1/2 somersault with one twist in a free position (5132D) during the course of the competition.

A photosonics high-speed cine camera fitted with a 10mm Angenieux lens was used at a distance of approximately 22m from the subject. The camera was positioned level with the end of the springboard and with the optical axis perpendicular to the plane of motion. The film framing rate was 97 frames per second (fps) in all dives. A linear scale was filmed in the plane of motion at the divers' takeoff point to facilitate scaling procedures prior to digitizing.

Twenty segment endpoints were digitized to define a 14-segment body model: head and neck, right arm, left arm, right forearm, left forearm, right hand, left hand, trunk, right thigh, left thigh, right shank, left shank, right foot, and left foot. The endpoints were digitized according to the anatomical landmarks of Dempster and Gaughran (1967). Every frame within the hurdle and takeoff phases was digitized. Every sixth frame of the flight phase was digitized to facilitate the qualitative analysis of twisting techniques used.

In order to determine the techniques employed by the divers to produce twist, each dive was qualitatively analyzed in slow and stopped motion. These
data were supplemented by a still film sequence of Stephen Foley (S1) performing a forward 1 1/2 somersault with one twist during a practice session (4/8/75). A Canon F1 35mm camera fitted with a 135mm lens and a motor drive was positioned on a fixed tripod so that the lens was 1.5m above the water and directly in line with the plane of motion. The camera was panned in a vertical plane to maximize image size and operated at approximately 5 fps.

The digitized data of the hurdle and takeoff phases of the dive were used to calculate whole-body centers of gravity (CG) based on Dempster’s (1955) segment masses for median subjects (living subject data) and mass center locations from Dempster’s (1955) cadaver data.

**Data Smoothing**

Random digitizer error was removed by fitting a parabola to the coordinates of the CG during the hurdle phase using a least squares criterion. The mathematical relationships used for this purpose are shown below:

\[
y = u_v t + 1/2at^2 \\
x = u_h t
\]

where \(y\) is the vertical CG displacement, \(x\) is the horizontal CG displacement, \(u_v\) is the initial vertical velocity, \(u_h\) is the initial horizontal velocity, \(t\) is time, and \(a\) is the acceleration due to gravity (9.81 m \cdot s^{-1}). Initial horizontal velocity was determined by averaging the horizontal displacement over time between successive frames during the hurdle (approximately 35 sample intervals).

The mean initial vertical velocity was found by averaging the initial velocity calculation determined for each data point in the first half of the data set using the relationship:

\[
s = u_v t + 1/2at^2
\]

rearranging and substituting \(t = t_{n+N/2} - t_n\)

\[u_n = (s - 1/2a (t_{n+N/2} - t_n)^2)/(t_{n+N/2} - t_n)\]

where \(s\) is the vertical displacement between the points \(n\) and \(n + N/2\) (\(N\) is the number of data points in the hurdle phase, if \(N\) is odd then \(N = N - 1\)).

The initial vertical velocity found for each point \((U_n)\) was adjusted to the starting time using the following relationship:

\[U_1 = \sum_{n=1}^{N/2} (u_n + a [t_n - t_1])/N/2\]

Thus, the initial vertical velocity at the starting point \((U_1)\) was taken as the mean of the calculated initial vertical velocities. This was then used to determine successive displacements from the first data point. The first data point, used as a reference for the parabola, was then adjusted so that the parabola minimized the sum of the squares of the differences of the fitted data points from the original data points, indicating the parabola of best fit.

The coordinates of the CG during the takeoff phase were filtered using a recursive Second Order Butterworth digital filter with a cutoff frequency of
4Hz. The vertical coordinates of the metatarsal-phalangeal (MP) joint and the horizontal coordinate of the midpoint between the ankle and big toe were filtered in the same manner.

**Methods of Calculation**

Selected temporal and kinematic variables were calculated from this smoothed digitized film record:

- **Hurdle length**: the horizontal displacement of the CG from the instant of hurdle takeoff to hurdle landing (meters);
- **Time period of hurdle**: the number of frame intervals in the hurdle phase multiplied by the inverse of the frame rate (1/97 seconds = 0.01031s);
- **Time period of takeoff**: the number of frame intervals from hurdle landing to takeoff multiplied by 0.01031s;
- **Springboard depression**: the maximum vertical displacement of the MP joint (meters);
- **Angle of lean at hurdle landing**: angle of the diver’s CG to MP joint from vertical at the instant of hurdle landing (degrees);
- **Angle of lean at maximal springboard depression**: angle of the diver’s CG to MP joint from vertical at the instant of maximal springboard depression (degrees);
- **Angle of lean at takeoff**: angle of the diver’s CG to MP joint from vertical at the instant of takeoff (degrees);
- **Hip flexion**: the supplement of the angle made by the lines joining the vertex and knee to the hip joint at the instant of takeoff (degrees);
- **Entry angle**: angle of the diver’s vertex to ankle from left horizontal at the instant the hands broke the water (degrees);
- **Horizontal velocity at takeoff**: horizontal displacement of the CG during flight divided by the period of flight (m/s).

Horizontal and vertical components of velocity, force, and torque at instants corresponding to each film frame were derived from the smoothed CG data using central difference formulae. Torques were calculated using the assumption that the vertical reaction forces acted through a point midway between the ankle and distal extremity of the big toe while the line of action of the horizontal component of the reaction force was assumed to pass through the diver’s metatarsal-phalangeal joint. Angular impulse (equivalent to change in angular momentum) was determined by integrating the functions of an interpolating spline of torques for the takeoff phase.

In this study the angular momentum about the somersault axis developed during the takeoff phase (from the instant of landing from the hurdle to the instant of takeoff from the board) was determined in two ways. For both methods it was assumed the diver’s somersault axis was perpendicular to the plane of motion (and to the film plane) during the hurdle and during the periods in which no twist was occurring. In the first, change in angular momentum was calculated by integrating torques over the period of the takeoff phase. However, rather than directly measuring the forces from which torques could be calculated, these were derived from the CG displacement data using an “inverse dynamics” approach.
That is, forces and torques were calculated through differentiation of displacement data. The second method used for angular momentum calculation assumed the quasi-rigid body position. Sample intervals of .06s (6 film frames) were selected on the basis of best adherence to the quasi-rigid assumption during the hurdle and flight phase (immediately prior to water entry) enabling the calculation of initial and final angular momentum.

The first and last frames defining the sample interval were each digitized five times and the coordinates were entered into a validated FORTRAN program to calculate mean moment of inertia. This program calculated moment of inertia by summing the transfer terms and local terms of each of the 14 body segments. The transfer term for each segment was obtained by multiplying the mass of each segment by the square of the distance of its center of gravity from the whole body center of gravity. The mean moment of inertia data of Chandler, Clauser, McConville, Reynolds, and Young (1975) was used for the values of the local term of each segment. Digitized coordinate data of the ankle and vertex (five trials of each sample) were entered into a validated FORTRAN program. This program applied the arctangent function to the coordinate data to determine the mean angle to the right horizontal of the line joining the vertex of the head to the ankle. The angular velocity was calculated as the difference between the angles for the first and last frame of the sample multiplied by the time interval (.062s).

Estimates of Measurement Errors

Reliability trials were conducted for S1 (3 trials) to determine the variability of the parameters determined by differentiation. The following error estimates were based on these trials:

- Vertical velocity at takeoff  $\pm 0.35 \text{ m s}^{-1}$
- Horizontal springboard reaction force  $\pm 125 \text{ N}$
- Vertical springboard reaction force  $\pm 250 \text{ N}$
- Resultant torque  $\pm 40 \text{ N} \cdot \text{m}$

The error associated with the calculation of other variables is somewhat smaller than with those quantified through differentiation techniques. Estimates of error associated with these parameters are:

- Durations  $\pm 0.01 \text{ sec.}$
- Hurdle length  $\pm 0.015 \text{ m}$
- Maximal springboard depression  $\pm 0.02 \text{ m}$
- Angle of hip flexion  $\pm 3^\circ$
- Angle of lean  $\pm 2^\circ$
- Horizontal and vertical velocity during the hurdle  $\pm 1 \text{ m s}^{-1}$
- Horizontal velocity at takeoff  $\pm 0.15 \text{ m s}^{-1}$
- Angular momentum (quasi-rigid approach)  $\pm 10 \text{ kg m}^2 \text{ s}^{-1}$
- Angular momentum (quasi-rigid approach) reliability  $\pm 1 \text{ kg m}^2 \text{ s}^{-1}$

Because of the small number of subjects and trials, no statistical tests were applied to the results. Data are presented for each subject.
Results and Discussion

Method of Twisting

Qualitative analysis of the high-speed film in slow and stopped motion suggested there was little rotation about the twist axis of all three divers prior to their initiating the twisting rotation in the air. This indicates that any component of the angular momentum vector producing twist rotation was very small and that the somersault axis of the diver was aligned closely to the angular momentum vector. Thus, it can be concluded that very little if any twist was generated through the action of torques from the board. An arm action, which was essentially a rotation about an anteroposterior axis, was common to all divers. This caused a counter rotation of the body about the anteroposterior axis through the diver’s center of gravity (cartwheel axis). As a result, the body rotated about the twist axis as well as the somersault axis in keeping with the inclined axis technique. It appears this was the primary means of producing twist. It is not clear whether the hula or cat twist methods contributed to the twisting rotation.

The degree of hip flexion immediately prior to initiation of the twist varied considerably among divers. Because there was substantial hip flexion in all cases, it is possible that the movement was initiated by a two-axis technique and that a degree of hip flexion was required. However, qualitative analysis of the film in slow and stopped motion indicates that these contributions were very small. Further, unlike the gymnasts studied by Van Gheluwe and Duquet (1977) who were found to initiate twist with a catting action and to continue it with a hula action, the straight body position attained during the twist and inclined axis indicates that the inclined axis technique was the predominant means of generating twist.

The rate of rotation about the twist axis compared to that about the somersault axis for a diver utilizing the inclined axis technique was estimated for S1 by applying the formula presented by Frolich (1980). Santschi, Dubois, and Omoto (1963) moment of inertia data for a subject in the standing position were used. With the axis inclined at 25° (based on the orientation evident in Figure 2), the

Figure 2 — Diver inclined at 25 degrees to the original axis.
rate of twist rotation gained is approximately four times greater than the original somersault rotation for a subject in a standing position. Therefore it appears the inclined axis technique is a highly effective way of generating twist, and that supplementation by two-axis techniques may not be necessary providing that sufficient angular momentum about the somersault axis is generated prior to takeoff. This supports the findings of Pike (1980). Using a computer simulation of the forward, full twisting dive in layout position, Pike found that an inclination of 0.18 rad (approximately 10°) was sufficient to enable a diver to successfully complete the dive without supplementation by torques from the board or by two-axis techniques. Indeed, use of a two-axis technique may militate against a high rate of rotation about the twist axis due to the greater moment of inertia about this axis than when the body is in a straight position.

The bulk of the twisting rotation occurred while the divers were fully extended (no flexion at the hips), and the cessation of twist coincided with the rotation of the arms about an anteroposterior axis tending to realign the axis of somersault rotation with the angular momentum vector. From qualitative analysis of both the cine film and the still sequence, it appears as though the action of unwrapping the arms was sufficient to realign the somersault axis with the angular momentum vector. Thus, the twist component of the angular momentum vector was very small at the time of entry.

All three divers assumed a pike position once the twist was almost completed. This pike position reduced the moment of inertia about the somersault axis, enabling the diver to complete the somersault rotation with enough time to extend for entry.

While the twist rotation was being performed, the rotation about the somersault axis slowed. This was indicated most clearly in the dive of S1, who exhibited similar orientations in both dives, enabling temporal comparisons to be made. The twist was completed within a period in which half a rotation about the somersault axis occurred (0.65 s). The equivalent rotation about the somersault axis during the corresponding phase of the nontwisting dive was completed in approximately 0.2 s less (0.43 s) than in the twisting dive. There are two reasons for the difference in the rate of rotation. First, there was an increased moment of inertia about the somersault axis resulting from an extended body position in the twisting dive compared to the piked position of the nontwisting dive. Second, a reduction in angular momentum about the somersault axis occurred due to resolution of the angular momentum vector into angular momentum about the somersault axis and twist axis when the axis was inclined away from the original axis of rotation.

Development of Angular Momentum

The quasi-rigid method of quantifying angular momentum indicated that slightly more angular momentum about the somersault axis was generated from the spring-board to perform the forward 1 1/2 somersault with the twist than the forward 1 1/2 somersault without twist. From the figures presented in Table 1, it is evident there was an increase of approximately 6% for S1, 8% for S2, and 19% for S3 to perform the twisting dive compared to the nontwisting dive. Thus the angular momentum about the somersault axis was increased to perform the twisting dive compared to the nontwisting dive. Miller (1981a) used a linked segment method to calculate angular momentum of a male diver performing a 3 1/2 for-
ward tuck somersault. The angular momentum for this diver was calculated as $-39.32 \, \text{kg} \cdot \text{m}^2 \cdot \text{s}^{-1}$ (weight = 575 N). Miller (1981b) reported an angular momentum of $-44 \, \text{kg} \cdot \text{m}^2 \cdot \text{s}^{-1}$ for a female diver (mass 62 kg) performing a forward 2 1/2 pike somersault. The angular momentum for a female diver (mass 47 kg) performing the same dive was reported as $25-27 \, \text{kg} \cdot \text{m}^2 \cdot \text{s}^{-1}$.

The change in angular momentum integrated from torques determined by the inverse dynamics method was found to be highly variable. Reliability studies based on three repeated digitizations of one trial of S1 displayed a maximum variation of $\pm 15 \, \text{kg} \cdot \text{m}^2 \cdot \text{s}^{-1}$. Three factors contributing to this variability are readily apparent. First, the reaction force values are determined by double differentiation of CG displacement data. In this process small errors in the digitized displacement data may give rise to quite large errors in force values. Second, accurate calculation of torques is dependent upon the accuracy of locating the CG and the line of action of the springboard reaction forces. The horizontal component of the latter was assumed to act through the metatarsal-phalangeal joint throughout the whole of the takeoff phase. The vertical component was assumed to act through the point midway between the ankle and distal extremity of the big toe. This assumption may be erroneous. Third, a small image size due to the necessity of filming the entire dive contributed to larger than usual errors in locating segment endpoints.

The contribution of the angular momentum acquired prior to hurdle flight was very minor. The largest absolute value of $4.6 \, \text{kg} \cdot \text{m}^2 \cdot \text{s}^{-1}$ was measured using the quasi-rigid approach in the hurdle phase of the pike dive of S2 and was counter to the desired direction of rotation. Similarly, Miller and Munro (1985b) reported a very small total body angular momentum at the beginning of the takeoff phase for a range of forward and reverse dives of Greg Louganis (1 to 2 kg $\cdot \text{m}^2 \cdot \text{s}^{-1}$).

**Force Data**

Vertical reaction forces, horizontal reaction forces, and torque histories of the three divers displayed similar trends. Those of the best diver, S1, are displayed in Figures 3, 4, and 5.
The horizontal reaction forces displayed a predictable pattern in all dives studied. This included a period of negative frictional forces for the first part of the takeoff phase, checking the horizontal linear momentum developed prior to the hurdle flight. The horizontal velocity figures presented in Table 2 indicate that for S1 and S2 the horizontal linear momentum on landing from the hurdle was greater for the twisting dive than for the nontwisting dive. This appears to have contributed to the development of the desired angular momentum. Negative horizontal reaction forces in the dives of S1 and S2 during the first 100 m after landing from the hurdle caused the center of gravity to pass in front of the line of action of the vertical force sooner for the forward 1 1/2 somersault with twist than for the forward 1 1/2 somersault without twist. In all dives, the horizontal reaction forces then became positive during the middle period of the takeoff phase (see Figure 3). The magnitude of the horizontal reaction forces during this peri-
Figure 4 — Torque histories of the horizontal and vertical force components and resultant torque of S1 during the takeoff phase of the nontwisting dive (103B).

Figure 5 — Torque histories of the horizontal and vertical force components and resultant torque of S1 during the takeoff phase of the twisting dive (5132D).
Table 2
Hurdle and Takeoff Velocities

<table>
<thead>
<tr>
<th>Diver/Dive</th>
<th>Dive score</th>
<th>Velocity (m/s)</th>
<th>Horizontal</th>
<th>Vertical</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hurdle</td>
<td>Takeoff</td>
</tr>
<tr>
<td>S_1</td>
<td>103B</td>
<td>7.5</td>
<td>0.9</td>
<td>1.2</td>
</tr>
<tr>
<td>WT = 756N</td>
<td>5132D</td>
<td>7.6</td>
<td>1.0</td>
<td>1.2</td>
</tr>
<tr>
<td>S_2</td>
<td>103B</td>
<td>6.5</td>
<td>0.6</td>
<td>0.9</td>
</tr>
<tr>
<td>WT = 600N</td>
<td>5132D</td>
<td>7.1</td>
<td>0.6</td>
<td>1.1</td>
</tr>
<tr>
<td>S_3</td>
<td>103B</td>
<td>5.8</td>
<td>0.6</td>
<td>1.0</td>
</tr>
<tr>
<td>WT = 662N</td>
<td>5132D</td>
<td>6.1</td>
<td>0.6</td>
<td>0.9</td>
</tr>
<tr>
<td>M 103B</td>
<td>6.6</td>
<td>0.7</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>M 5132D</td>
<td>6.9</td>
<td>0.7</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>M MILLER</td>
<td>7.5</td>
<td>0.6</td>
<td>1.0</td>
<td></td>
</tr>
</tbody>
</table>

*Average of middle five scores of seven judges. Does not take into account the degree of difficulty.

**Based on a group of six male divers performing forward and reverse dives.

...modulated the effects of the torques due to the vertical force component (see Figures 4 and 5).

The reduction in magnitude of the horizontal reaction forces in the last 100 m of the takeoff phase coincided with the period in which the bulk of the required angular momentum was being developed. Miller (1981a) reported that negative horizontal forces act at the end of the takeoff phase, contributing to final somersaulting angular momentum and reducing horizontal velocity. Similar results were obtained for all three nontwisting dives in this study. With regard to the twisting dive, only the horizontal reaction forces of S1 became negative during the final period of the takeoff phase. The horizontal reaction forces of S2 and S3 during the corresponding period remained positive, producing a torque counter to the direction of rotation. However, these forces and the resulting torques were very small and diminished markedly during the last 100 m of the takeoff phase.

No conclusions regarding the direction of the horizontal reaction forces at takeoff in 5132D can be drawn due to the recognized inaccuracies of the inverse dynamics approach and the small number of subjects. In agreement with the findings of Miller (1983) and Golden (1981), it appears the timing and magnitude of the horizontal reaction forces are the major determinants of the resultant angular momentum.

Kinematic Data

Kinematic variables quantified in this study show considerable agreement with those of Miller (1984). These are presented in Tables 2 and 3. It is apparent that
the net horizontal impulse for the takeoff phase is positive (i.e., there is an increase in the horizontal velocity of the diver’s CG from hurdle landing to takeoff), tending to produce rotation that is counter to the desired direction of rotation. This supports the conclusion that it is primarily the timing of the horizontal reaction forces rather than the total horizontal impulse over the takeoff period which affects the development of angular momentum.

**Body Orientation Data**

In the kinematic and temporal analysis of the hurdle and takeoff phases of the dives, very little difference in body actions or their timing was apparent. The angle of lean values (Table 4) indicate that the divers may have been leaning slightly more forward in the twisting dive than in the nontwisting dive at the time of maximal springboard depression. But this cannot be stated with certainty, due to the unknown magnitude of errors associated with the calculation of CG and the estimation of the line of action of the vertical reaction forces. However, this factor could be partly responsible for the development of more angular momentum about the somersault axis in the twisting dive than in the nontwisting dive due to the increased moment arm of the vertical reaction forces (see also Golden, 1981).

The major observable difference between twisting and nontwisting dives was the increased angle of hip flexion at takeoff in the twisting dive (Table 4). The difference in hip flexion between the two dives was 18° for S1, 9° for S2, and 13° for S3. The increase in hip flexion to perform a twisting dive compared to a nontwisting dive of the same number of rotations about the somersault axis parallels to a considerable extent the increase in hip flexion to perform a 105B
Table 4
Orientation of the Divers

<table>
<thead>
<tr>
<th>Diver/Dive</th>
<th>Hurdle landing</th>
<th>Max. springboard depression</th>
<th>Takeoff</th>
<th>Angle at entry (degrees)</th>
<th>Hip flexion (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1 103B</td>
<td>−10</td>
<td>4</td>
<td>20</td>
<td>70</td>
<td>34</td>
</tr>
<tr>
<td>5132D</td>
<td>−8</td>
<td>6</td>
<td>20</td>
<td>72</td>
<td>52</td>
</tr>
<tr>
<td>S2 103B</td>
<td>−3</td>
<td>5</td>
<td>24</td>
<td>82</td>
<td>42</td>
</tr>
<tr>
<td>5132D</td>
<td>−4.5</td>
<td>7</td>
<td>25</td>
<td>75</td>
<td>53</td>
</tr>
<tr>
<td>S3 103B</td>
<td>−5</td>
<td>5</td>
<td>18</td>
<td>80</td>
<td>30</td>
</tr>
<tr>
<td>5132D</td>
<td>−3</td>
<td>7</td>
<td>26</td>
<td>70</td>
<td>43</td>
</tr>
</tbody>
</table>

compared to a 103B of approximately 19° as observed by Golden (1981). Thus, it may be that the addition of a twist to a dive places demands upon the diver prior to takeoff similar to those imposed by the addition of another somersault.

Summary and Conclusions

The method all three divers used to produce rotation about the twist axis was predominantly the inclined axis technique. Whether this technique was supplemented by the hula or cat twisting techniques could not be empirically determined in this study. Qualitative analysis strongly suggests that the contribution of two-axis techniques was minor in comparison to that of the inclined axis technique.

The hypothesis that divers require greater angular momentum about the somersault axis to perform a twisting dive compared to the corresponding non-twisting dive was supported. However, the increase in angular momentum showed that the increase was relatively small for S1 (6%) and S2 (8%). The less skilled diver, S3, substantially (19%) increased angular momentum to perform the dive.

The most observable difference between the twisting and non-twisting dives during the takeoff phase was the degree of hip flexion at takeoff. Rotation about the somersault axis was slower for the period of the flight during which the twist was performed than in the corresponding phase of the non-twisting dive. This was partly due to the increased moment of inertia about the somersault axis while the body was extended to perform the twist and partly to the resolution of the angular momentum vector. The magnitude of the effects of each factor warrants further research.

All three divers completed the twist rotation during approximately one third of the flight. Therefore, the remaining period in which the diver could complete the rotation about the somersault axis and prepare for entry may have been sufficient to permit comfortable completion of the dive without large increases in angular momentum compared to the non-twisting dive. For this reason it is suggested that future research compare the angular momentum requirements of twisting and non-twisting dives in which more than 1 1/2 rotations about the somersault axis are performed.
References


