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Angular Momentum in Multiple Rotation Nontwisting Platform Dives

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A study was undertaken to investigate the changes in total body angular momentum about a transverse axis through the center of mass that occurred as the rotational requirement in the four categories of nontwisting platform dives was increased. Three skilled subjects were filmed performing dives in the pike position, with increases in rotation in each of the four categories. Angular momentum was calculated from the initiation of the dive until the diver reached the peak of his trajectory after takeoff. In all categories of dives, the constant, flight phase total body angular momentum increased as a function of rotational requirement. Increases in the angular momentum at takeoff due to increases in the rotational requirement ranged from a factor of 3.61 times in the forward category of dives to 1.52 times in the inward category. It was found that the remote contribution of angular momentum contributed from 81 to 89% of the total body angular momentum. The trunk accounted for 80 to 90% of the local contribution. In all categories of dives except the forward 1/2 pike somersault, the remote percent contribution of the arms was the largest of all segments, ranging from 38 to 74% of the total angular momentum.

Very little quantitative research is available to help the coach and diver understand the mechanics of platform diving. Recently, divers have been performing increasingly more difficult dives and, as a result, injuries have become more numerous and serious. It is crucial that the diver and coach understand the sensitive balance between linear and angular momentum at takeoff. Upon takeoff, the diver must achieve sufficient linear momentum to ensure the necessary height and distance to travel safely away from the platform, while generating sufficient

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angular momentum to complete the required number of rotations about the transverse axis. After departure from the diving platform, the diver is subject to no external forces or moments apart from gravity. Once in the flight phase, the diver cannot alter his or her total body angular momentum (Hg). Angular velocity can only be changed by altering the moment of inertia about a transverse axis through the center of mass (CM). When performing a front somersaulting dive, the divers can decrease their mass moment of inertia from approximately 15 kg-m^2 to 6.5 kg-m^2, by changing their body position from layout to pike (Hay, 1985).

Since angular momentum is conserved, this reduction in moment of inertia results in a proportional increase in total body angular velocity. When performing a dive in the pike position, reductions in moment of inertia are limited and, as a result, it is essential that the diver attain the necessary angular momentum during takeoff.

The mechanics of platform diving have not been investigated to any great degree. Unlike springboard diving, the platform provides almost no elastic energy to enhance the diver's momentum. Several studies have been reported, however, pertaining to rotations attained in springboard diving (Batterman, 1968; Fairbanks, 1963). In most cases, it was felt that body lean at takeoff determined the number of rotations in the dive. Stroup and Bushnell (1969) reviewed the nature of rotation and translation in diving. They concluded that angular momentum was related to both angle of lean at takeoff and the direction of force application. Golden (1984) found that body lean at takeoff increased according to the number of rotations being performed.

Miller and Munro (1984) reported that the height obtained in springboard diving was predominantly due to the action of the lower extremities as they accelerated the trunk upward. Miller (1983) studied the torques about the CM produced by the springboard reaction force components during the takeoff of nontwisting dives. The vertical reaction forces were found to be consistent with the somersault direction. She also reported that performances could be differentiated based upon the magnitude and direction of the horizontal reaction forces. More recently, Miller and Munro (1985a, 1985b) reported a temporal and joint position analysis and a linear and angular momentum analysis of Greg Louganis' springboard takeoff. They reported that increasing the required number of rotations resulted in a subsequent increase in angular momentum.

Hamill, Golden, Ricard, and Williams (1985) investigated the kinematics and kinetics of platform dive takeoffs. During the takeoff it was found that platform divers imparted a maximum ground reaction force at takeoff, and these forces were found to be invariant as the rotational requirement increased. The kinematics of the dives indicated that the divers increased their total body angular velocity at takeoff by modifying the trunk angle and concomitantly increasing the angular velocity of the large trunk mass.

The purpose of this study was to investigate the changes in angular momentum that occurred as a result of increasing the required number of somersaulting rotations in forward, backward, reverse, and inward dives performed in the pike position. Also of principal interest were the individual body segment contributions to the total body angular momentum obtained prior to takeoff from the diving platform.

Methods

Three young, healthy, male collegiate divers served as subjects in this study after signing informed consent forms in accordance with university policy. The subjects were highly skilled (one national, one international, and one Olympic) platform divers. Individual subject data are presented in Table 1.

Table 1

Subject Characteristics

Subject	Height (m)	Weight (kg)	Caliber
1	1.78	70.5	National
2	1.68	62.7	Olympic
3	1.75	74.5	International

A 16-mm LoCam camera equipped with a Canon 15-150-mm zoom lens was positioned normal to the movement plane at a height of 1 m above and 1 m in front of the diving tower takeoff area. The focal point of the lens was positioned 25 m from the movement plane. A 100-Hz pulsed signal applied to an internal LED timing light enabled the framing rate of 80 fps to be accurately verified. The camera shutter was set at 120/360 degrees, resulting in an exposure time of 1/240s.

Each subject was required to perform three trials in each category of dives in the pike position. In the forward dives, the subjects were required to complete dives with 1/2, 1 1/2, and 2 1/2 rotations. Concerning the inward dives, because of their difficulty the subjects were only required to complete dives with 1/2 and 1 1/2 rotations. For the back and reverse dives, subjects completed dives with 1/2, 1, and 2 rotations. Each dive was evaluated by a national-caliber coach as to its success, and the highest scoring dive for each diver in each group was chosen for analysis.

Subjects were given as much time as they needed to warm-up and practice the criterion dives. They were also given as much time as required between dives so that fatigue would not be a factor. For the forward dives, the camera was started as the subject began the next-to-last approach step. For the other categories of dives, which had a less distinct beginning, the camera was started during a verbal countdown by the investigator and prior to the initiation of the dive.

Data reduction from the high-speed film was accomplished using a Vanguard Motion Analyzer in conjunction with a Numonics 1224 digitizer interfaced to an Apple II+ microcomputer equipped with a PDQII 32-bit co-processor. For the forward dives, five frames prior to diving platform contact until the peak of the diver's trajectory of the diver's CM were digitized. However, for the other categories of dives, digitizing began when the diver began unweighting and continued until the peak of the trajectory of his CM was reached. Unweighting was determined by the downward movement of the diver's CM caused by knee flexion in preparation for takeoff. Coordinates of background references and eight body segment endpoints were identified and digitized for the analysis. The data were then smoothed using a low-pass digital filter with a cutoff level of 6 Hz in order to minimize measurement error.

The angular momentum about the CM was determined as described by Hay, Wilson, Dapena, and Woodworth (1977). The divers were assumed to be adequately represented by a two-dimensional, seven-segment, rigid-link system. Segments included in the model were the feet, shanks, thighs, trunk, head-neck, upper arms, and forearm-hands. The angular momentum of the diver was computed by summing the local and remote contributions of each segment. The local term consisted of the product of the segment's moment of inertia about a transverse axis through the CM (I) and the angular velocity of the segment (w). The remote term was the product of the segment mass (m), the distance from the segment center of mass to the body CM squared (d^2), and the angular velocity of the line connecting the segment CM and the total body CM (w'). The total angular momentum of a given segment is then $Hg = Iw + md^2w'$. The total body Hg was then calculated as the sum of all segmental contributions. The direction of the angular momentum vector was defined by the right hand rule. Counterclockwise (CCW) was considered to be positive and clockwise (CW) was negative.

Results

Total Angular Momentum

The mean angular momentum values at takeoff for all dives are presented in Table 2. When normalized for standing height and mass using the normalizing procedure of Hinrichs, Cavanagh, and Williams (1983), the coefficient of variation with each rotation requirement and category never exceeded 10%. It was clear, therefore, that there was consistency in the Hg values across subjects. Thus, the values presented in the remainder of the paper will be the mean absolute values of the three subjects.

In each case, the Hg about the transverse axis increased with each subsequent increase in rotation. The largest magnitude of Hg was observed in the forward 2 1/2 somersault dive with a mean value of 72.44 $kg\text{-}m^2/s$. The largest increase in Hg as a function of rotation was also seen in the forward dives. This magnitude of the Hg in the forward category of dives probably results from the fact that this is the only category in which the divers use a running approach. In the transition from the forward 1/2 somersault to the 2 1/2 somersault, Hg was increased 3.61 times. The smallest increases in angular momentum were seen in the reverse dives, where the mean Hg of the 2-rotation somersault dive was 1.67 times greater than the 1/2 somersault dive.

An example of typical angular momentum–time curves (Subject 2) representing forward dives with 1/2, 1 1/2, and 2 1/2 rotations is presented in Figure 1. Positive values indicate CCW angular momentum and, if the diver's body is rigid, this indicates CCW angular rotation. This positive phase from 0 to .22 s represents landing from the hurdle and the compression phase of the 1/2 rotation dive takeoff.

Table 2

Mean Angular Momentum Values at Takeoff[a]

		Total Hg		Local Hg			Remote Hg		
		M	*SD*	*M*	*SD*	% of total	*M*	*SD*	% of total
Forward	1/2	−20.08	4.35	−2.66	0.69	13.25	−17.42	3.69	86.75
	1 1/2	−50.89	6.32	−5.65	0.21	10.93	−45.25	6.27	88.92
	2 1/2	−72.44	5.41	−10.24	0.73	14.14	−62.19	5.02	85.85
Inward	1/2	29.53	4.58	4.06	0.96	13.75	25.47	5.49	86.25
	1 1/2	44.76	3.55	8.98	1.39	20.06	35.77	3.91	79.92
Back	1/2	−22.43	2.65	−3.75	0.57	16.72	−18.67	2.12	83.24
	1	−38.18	0.87	−5.86	0.69	15.37	−32.27	1.17	84.63
	2	−53.15	3.58	−9.15	0.62	17.22	−43.99	3.73	82.77
Reverse	1/2	23.60	1.54	4.24	0.66	17.97	19.35	1.06	81.99
	1	28.97	2.34	5.28	0.98	18.23	23.68	1.40	81.74
	2	39.46	3.04	6.79	0.30	17.21	32.66	2.84	82.77

Hg: kg - m^2/s

[a]3 subjects

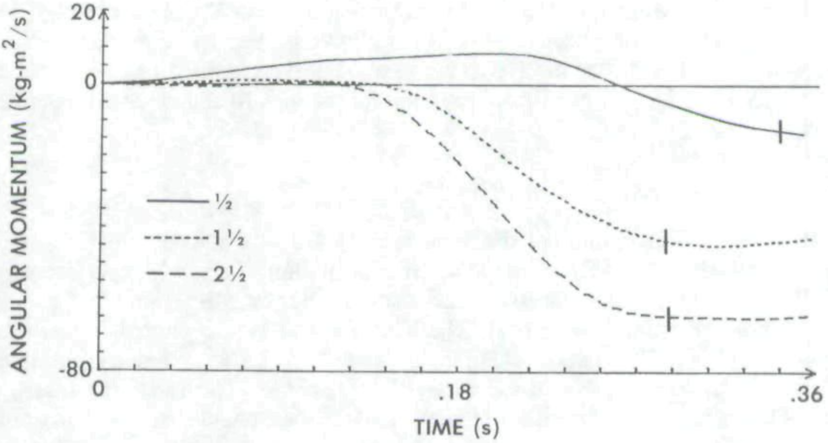

Figure 1 — Angular momentum profiles (Subject 2) of forward category of dives with 1/2, 1 1/2, 2 1/2 rotations (takeoff marked with a vertical line).

At approximately .22 s the diver begins the repulsion phase of takeoff, and the reaction force that is developed causes the angular momentum vector to decrease and eventually become negative. In the 1/2 rotation dive the takeoff occurs at .35s, where the angular momentum reaches a constant value of -17.75 kg-m²/s. In the 1 1/2 and 2 1/2 rotation dives, the diver has a small positive Hg during the landing from the hurdle and compression phases, which decreases to become negative during repulsion, peaking at -46.69 kg-m²/s in the 1 1/2 rotation and at -65.38 kg-m²/s in the 2 1/2 rotation dive.

A graphical representation of angular momentum–time profiles for the back dives (Subject 3) is presented in Figure 2. Hg remained slightly negative

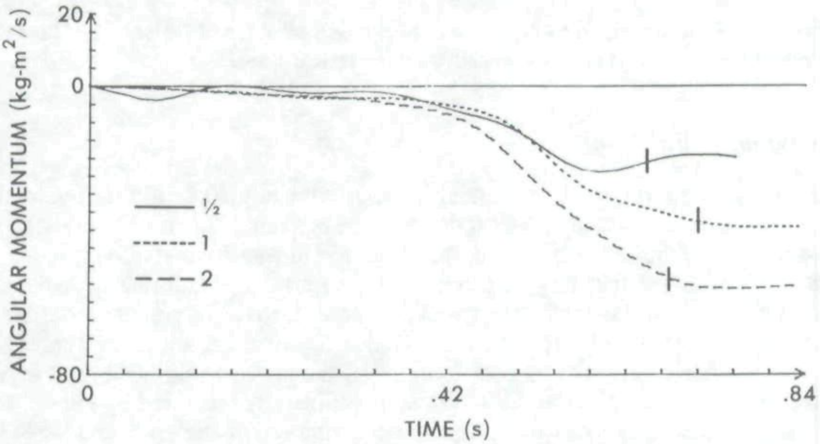

Figure 2 — Angular momentum profiles (Subject 3) of back category of dives with 1/2, 1, 2 rotations (takeoff marked with a vertical line).

for approximately .45 s in all three dives. During this time the diver is unweighting and slowly rotating backward (CW). Following the unweighting, the diver exerts a force that causes the Hg to increase negatively until it reaches a maximum at takeoff. Similar profiles were found for the inward and reverse sequences of dives.

Local and Remote Contributions

In all cases, the magnitude of the local term of Hg was considerably less than the remote term (Table 2). A graphical representation of a single dive (forward 2 1/2) by Subject 2 showing the relationship of the total Hg, remote Hg, and local Hg is presented in Figure 3. The local term of Hg accounted for a mean maximum of 20.06% of the total Hg in the inward 1 1/2 dive to a mean minimum of 10.93% of the total Hg in the forward 1 1/2 dives. The relatively massive trunk-head segment accounted for 80 to 90% of the local angular momentum term.

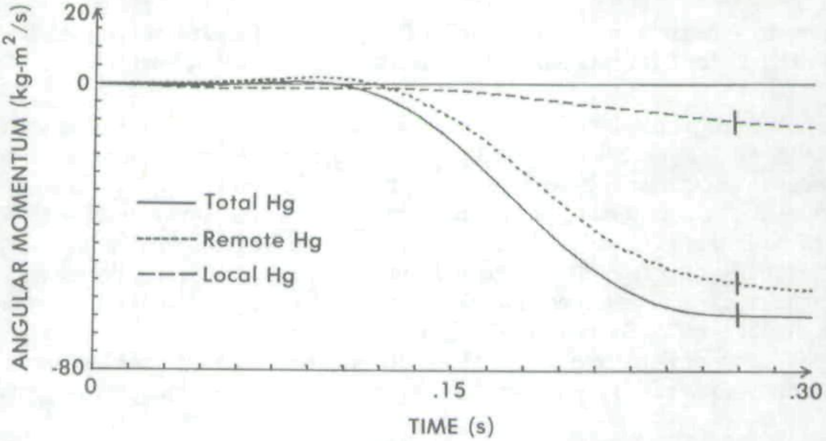

Figure 3 — Relationship of total Hg, remote Hg, and local Hg of forward 2 1/2 rotation dive of Subject 2 (takeoff marked with a vertical line).

Segmental Contributions

Since the remote term of Hg accounted for approximately 80 to 90% of the total Hg, further discussion will focus on the remote segmental Hg contributions. To further elucidate these contributions, the remote term was divided into three segments: legs (foot, shank, thigh), trunk-head, and arms (arm, forearm, hands). Each of these segmental components was then considered as its percent contribution to the remote term of Hg obtained at takeoff and is presented in Table 3. The relationship of the remote contributions of the arms, trunk-head, and legs for one dive (Subject 2, forward 2 1/2) is graphically represented in Figure 4.

It should be noted that the maximum contribution of the arms and legs to the remote term of Hg (and to the total Hg) was generally achieved at takeoff. The maximum contribution of the arms was found to precede takeoff in only 2 of the 33 dives analyzed. This was never the case for the legs, as the maximum con-

Table 3

Mean Percent Values for Remote Segmental Angular Momenta[a]

		% Remote Hg	% Remote arms	% Remote trunk	% Remote legs
Forward	1/2	86.75	17.20	18.62	50.93
	1 1/2	88.92	46.23	11.32	31.37
	2 1/2	85.85	40.63	16.22	29.00
Inward	1/2	86.25	56.33	10.82	19.10
	1 1/2	79.25	38.27	18.98	22.67
Back	1/2	83.24	68.07	3.80	11.37
	1	84.63	49.00	7.43	28.20
	2	82.77	41.17	10.50	31.10
Reverse	1/2	81.99	74.27	2.39	5.33
	1	81.74	61.10	5.37	15.27
	2	82.77	50.00	8.37	24.40

[a]3 subjects

Note: segmental percentages are portions of remote Hg.

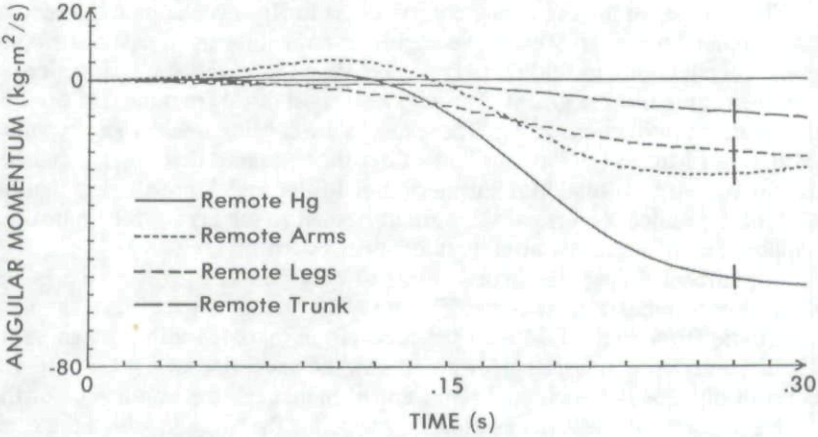

Figure 4 — Contributions of trunk-head and upper and lower extremities to remote Hg in forward 2 1/2 rotation dive of Subject 2 (takeoff marked with a vertical line).

tribution for the legs was coincident with takeoff. In addition, the contribution of the trunk-head to the remote Hg was never more than 18% of the total Hg.

In the transition from the forward 1/2 to the forward 1 1/2 rotation dives, the percent remote contribution of the arms increased while the percent remote contribution of the legs decreased. In the 1/2 rotation dive, the legs accounted for 50.93% of the remote term. The divers met the demand for greater rotation in the forward 1 1/2 and 2 1/2 dives by increasing the remote contribution from the arms to 46.23% and 40.63%, respectively.

Unlike the forward dives, for the inward, back, and reverse dives the percent remote contribution from arms decreased as the rotational requirement increased. In the initial rotational requirement the arms dominated, but by the final rotational requirement the contribution of the legs to the remote Hg became more evident. It should be noted, however, that in the inward, back, and reverse dives the percent of the remote Hg for the arms was always greater than that of the legs.

Discussion

During takeoff the divers must create a sufficient moment about their CM in order to increase their total body Hg and successfully complete the dive. The angular momentum generated at takeoff was found to increase as a function of increasing the required number of rotations in the dive. The magnitude of Hg generated at takeoff varied little from subject to subject. In all subjects, Hg increased with each increase in somersaulting rotation. Miller and Munro (1985b) reported that Hg for the forward 3.5 somersault pike dive was four times greater than Hg for the forward layout dive. In the present study, Hg increased from the initial rotational requirement to the final rotational requirement by a factor of 3.61 times in the forward category, 1.52 times in the inward category, 2.37 times in the back category, and 1.67 times in the reverse category.

The analysis of the segmental contributions to Hg revealed that the remote terms accounted for about 80% of the angular momentum. In all cases, the body segment contributions to the total Hg at takeoff were in the same direction as the rotation of the trunk segment. The segments most distal from the CM provided the greatest contributions to Hg. These results are consistent with those reported by Miller and Munro (1985b). In that study, the remote terms contributed between 80 and 90% of total Hg. Furthermore, Miller and Munro found that 30 to 43% of the remote contributions were attributed to the arms, thus indicating the importance of the arms at takeoff in springboard diving.

In platform diving, the arms appear to play an even greater role in the development of angular momentum. The remote term due to the arms was found to contribute from 17% to 74% of the total Hg at takeoff, with a mean value of 49.30% over all conditions. However, with the exception of the forward 1/2 somersault dive, as the rotational requirement increased, the dominance of the arms in generating Hg was not as great. Perhaps for the dives in which the rotational requirement was perfunctory for this caliber of divers the remote Hg developed by the arms was sufficient to complete the rotation. However, as the rotational requirement became more severe it was necessary to increase the remote contribution of the legs, sacrificing a small amount from the arms. But it must be pointed out that the remote Hg of the arms appeared to contribute greatly to the success of a multiple rotation platform dive.

In an earlier study, Miller and Munro (1984) reported approximate segmental contribution values to height achieved in springboard diving. The arms were found to account for only 10% of the diver's vertical acceleration. However, more recently Miller and Munro (1985b) identified the arms as having an important role (46%) in the development of angular momentum. The present investigation also demonstrated that the arms are of considerable importance in the generation of rotation in platform diving, particularly in the low rotation dives. At takeoff the diver must partition the momentum obtained such that distance, height, and rotation are optimized. As divers attempt increasingly more difficult dives, this partitioning of momentum becomes even more critical in order to ensure the diver's safety. Based upon the results of the present study, it appears that coaches should observe the diver's arm action at takeoff to optimize the outcome of the dive.

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