Effect of Ability on Twisting Techniques in Forward Somersaults on the Trampoline

Ross H. Sanders

This study was designed to investigate the effect of ability on technique in the forward somersault with half twist (Barani) and the forward somersault with one and one half twists (Rudi) on the trampoline. Eleven trampolinists ranging in ability from elite (national representative) to early intermediate (regional representative) were analyzed using three-dimensional analysis techniques. Cumulative twist angle, rate of twist, angle of tilt of the twist axis, chest rotation, hip angle, and hip lateral flexion angle were measured. Characteristics of the arm actions were also assessed using an internal frame of reference. To generate twist in the Baranis, trampolinists tilted the axis between $5^\circ$ and $14^\circ$; the amount of tilt was inversely related to ability ($p < .05$). In the Rudis, subjects tilted the axis between $15^\circ$ and $23^\circ$ using more asymmetrical arm actions and larger and more rapid hip extensions, hip lateral flexions, and chest rotations than in the Baranis. The timing and magnitude of the actions differed among the subjects and were related to ability.

Twist rotation in acrobatic activities may be produced by applying torques about the twist axis prior to takeoff from a supporting surface (Eaves, 1960; Rackham, 1960). This may be termed “contact twist” (Yeadon, 1993b). These torques may be generated by rotations of the head, arms, and shoulders (Aaron, 1977), the upper body (Batterman, 1974), or the legs (Smith, 1980).

Twist rotation may also be produced in somersaulting skills by tilting the longitudinal axis away from the vertical plane corresponding to the somersault plane. This does not require initial twist angular momentum and may be called “aerial twist” (Yeadon, 1993c). When the axis is tilted, a component of the initial angular momentum is in the direction of the longitudinal axis of the body and produces twist (Batterman, 1974). Tilt may be produced by an asymmetrical action of the arms (Frohlich, 1979). Van Gheluwe (1981) showed that this method is a particularly effective means of producing tilt and thereby twist rotation. Van Gheluwe also showed that “hula” actions of the hips can also produce twist. Yeadon and Atha (1983) showed that if a somersaulting gymnast performs such

Ross H. Sanders is with the School of Physical Education, University of Otago, Dunedin, New Zealand.
a movement in conjunction with an extension from a pike, a large tilt angle and fast rate of twist rotation are achieved by this action alone. Recent simulation studies by Yeadon (1993c) have established that during a somersault, tilt may be produced using asymmetrical movements of the arms, chest, or hips. The effectiveness of the movements is dependent on body configuration, somersault direction (forward or backward), and timing of the movements.

The question arises whether acrobats should use contact twist or asymmetrical movements once airborne to produce twist. Aerial twist leads to more balanced landings because the performer can complete the skill with the long axis in the vertical plane and without twist. In both contact and aerial twists, the twist may be stopped by reducing to zero the angle between the long axis and the plane perpendicular to the angular momentum vector.

To stop the twist and prepare for landing, the performer can change from a straight position to a pike position. This will cause a change from the “twisting mode” to the “wobbling mode” (Yeadon 1993a). In the twisting mode, the longitudinal axis remains tilted and the twist angle continues to increase. In the wobbling mode, the angle with respect to the plane perpendicular to the angular momentum vector oscillates. By extending from the pike at the time when this angle is zero, the performer can complete the skill with a zero rate of twist rotation. If no contact twist is used, the angular momentum vector is horizontal, and the performer can exit the skill with the long axis in the vertical plane and with a zero rate of twist rotation. If contact twist is used, the angular momentum vector is not horizontal. Therefore, it is not possible to have both the longitudinal axis in the vertical plane and a zero rate of twist rotation at landing. A compromise is necessary so the performer is upright enough to maintain balance and so the rate of twist rotation is small.

Yeadon (1993d) has indicated that elite performers of twisting rotations in various activities use only small contributions from contact twist and that twist is predominantly produced by aerial techniques. In trampolining it is particularly important to have a balanced position at landing (i.e., a small angle between the long axis and vertical plane) and to have a small rate of twist. This assists in regaining control leading into the next skill in the routine.

It may be expected that elite performance is characterized by landings in which the longitudinal axis has a small angle with respect to the vertical plane and in which the rate of twist is slow. This may mean that with increasing skill, performers become more efficient at generating twist using aerial techniques and minimize the use of contact twist. To date there has been a lack of data describing differences in technique related to ability. This knowledge is required to understand the learning process of these complex tasks, thereby enabling accelerated learning through increased awareness and improved coaching.

This study was designed to investigate the effect of ability on technique in the forward somersault with half twist (Barani) and the forward somersault with one and one half twists (Rudi).

**Method**

**Subjects**

Eleven New Zealand trampolinists ranging in ability from elite at international level to early intermediate were analyzed. Prior to analysis, subjects were ranked
by a national trampolining judge and coach who was familiar with the trampolinists’ form having observed their development in the sport for at least 3 years. The judge also observed all the trials recorded on videotape during data collection to qualitatively assess performances. The subjects were identified as S1 to S11 in order of ability, with S1 being the best. Subjects S8 to S11 were capable of performing Baranis but not Rudis. There was an unskewed distribution of abilities within the range from S1 to S11. The subjects ranged in age from 11 to 22 years. Although the group consisted of 6 males and 5 females, there was no gender bias with respect to ability ranking. Further, it was considered that none of the subjects had physical attributes that would limit their potential to attain elite standard. For this reason, the inhomogeneity of the sample in terms of sex, age, height, and mass was considered not to affect the validity of the study. The subjects’ ranking, age, sex, height, and mass are shown in Table 1.

Prior to filming, subjects were marked with retro-reflective tape so that the joint centers were clearly visible. This aided subsequent digitizing to determine body orientation throughout the flight phase of each trial. The body landmarks were the vertex of the head, both shoulders, elbows, wrists, hips, knees, and ankles. All subjects except S5 performed five trials of Baranis. The most skilled subjects \((n = 7)\) also performed five trials of Rudis. Subjects were instructed to bounce to the height they would normally achieve before commencing the skill. They then commenced the skill on the count of “three” as called by their coach in time with the bounces.

**Data Collection**

The trampolinists were filmed simultaneously by two phase-locked Photosonics high-speed 16 mm cine cameras. Each camera was positioned 30 m from the center of the trampoline and 4 m above the trampoline, as shown in Figure 1. To optimize the accuracy of the three-dimensional analysis, the camera axes

<table>
<thead>
<tr>
<th>Subject/rank</th>
<th>Age (years)</th>
<th>Sex</th>
<th>Height (m)</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>19</td>
<td>M</td>
<td>1.74</td>
<td>70</td>
</tr>
<tr>
<td>S2</td>
<td>15</td>
<td>F</td>
<td>1.57</td>
<td>52</td>
</tr>
<tr>
<td>S3</td>
<td>16</td>
<td>M</td>
<td>1.69</td>
<td>62</td>
</tr>
<tr>
<td>S4</td>
<td>14</td>
<td>M</td>
<td>1.66</td>
<td>58</td>
</tr>
<tr>
<td>S5</td>
<td>22</td>
<td>F</td>
<td>1.56</td>
<td>60</td>
</tr>
<tr>
<td>S6</td>
<td>19</td>
<td>F</td>
<td>1.69</td>
<td>64</td>
</tr>
<tr>
<td>S7</td>
<td>16</td>
<td>M</td>
<td>1.69</td>
<td>63</td>
</tr>
<tr>
<td>S8</td>
<td>11</td>
<td>M</td>
<td>1.38</td>
<td>19</td>
</tr>
<tr>
<td>S9</td>
<td>17</td>
<td>F</td>
<td>1.54</td>
<td>50</td>
</tr>
<tr>
<td>S10</td>
<td>12</td>
<td>M</td>
<td>1.43</td>
<td>37</td>
</tr>
<tr>
<td>S11</td>
<td>11</td>
<td>F</td>
<td>1.39</td>
<td>29</td>
</tr>
</tbody>
</table>
were at approximately 90° in accordance with the recommendations of Shapiro (1978). Each camera was fitted with an Angenieux 12–120 m zoom lens that was adjusted so that the whole trampoline, the three-dimensional calibration frame, and a space 5 m above the trampoline and 1 m below the trampoline bed were in view.

The three-dimensional calibration frame was recorded prior to positioning the trampoline so that all calibration markers were visible. These markers were white table tennis balls suspended at known heights by four plumb lines of nylon cord that passed through the center of the table tennis balls. The distances between the plumb lines and markers were determined to within 5 mm.

The cameras were set to operate at 100 frames per second to ensure that the instants of takeoff and landing were accurately identified and that a detailed
record of the movement throughout the flight phase (from the instant of last contact with the trampoline at the start of the skill to the instant of contact with the trampoline bed at the completion of the skill) was obtained. Markings on the film from light-emitting diodes flashing at 10 Hz internal to each camera were subsequently used to determine the actual framing rate. A video camera recorded the trampolinists from prior to last contact with the trampoline at the start of the skill to after landing. This allowed qualitative assessment of each trampolinist’s form to supplement the quantitative analysis based on the digitized high-speed cine film.

Analysis

The known three-dimensional coordinates of the calibration frame, the two-dimensional coordinates of the calibration frame digitized from the film taken by each camera, and the coordinates of the body landmarks digitized from each film frame of each camera comprised the input to a direct linear transformation (DLT) computer program (Marzan & Karara, 1975) to determine the three-dimensional coordinates of the body landmarks. These were determined for the period corresponding to 10 frames prior to last contact with the trampoline leading into the skill to 10 frames after landing on the trampoline after completing the skill. The three-dimensional coordinates were smoothed with a second-order Butterworth recursive low-pass digital filter with a cutoff frequency of 6 Hz. This filter passed through the data in both directions to avoid phase-shifting the data.

A mathematical model, presented in the appendix, was developed and coded into a FORTRAN computer program to determine the angle of twist, angle of tilt (defined as the angle between the longitudinal axis and the vertical plane parallel to the sides of the trampoline), chest rotation with respect to the hips, hip angle, and hip lateral flexion angle (Figure 2). Angular velocities were derived from these angle-time records by differentiating with respect to time using a standard central difference formula (Wood, 1982). To assess the use of asymmetrical arm movements, stick figures of the subject viewed from an internal reference frame were produced. The z axis of this frame was parallel to the line joining the midpoint of the shoulders to the midpoint of the hips, the x axis was perpendicular to the line joining the shoulders and z axis, and the y axis was perpendicular to the z and x axes. One view of the subject was the projection onto the yz plane as if viewing the subject from the front. This enabled arm abduction and adduction to be clearly seen. The second view was the projection onto the xz plane as if viewing the subject from the side. This showed flexion and extension of the arms.

To compare timing aspects of performance among individuals, variables were also expressed in terms of percentiles of the flight phase. This permitted valid comparisons of movement patterns and the timing of events despite differences in the duration of flight.

For each variable, means of each subject’s five trials were determined and used as the scores for further analysis and reporting. A Pearson rank order correlation was applied to the data within skill types (Barani or Rudi) with ability as the ranked variable. To compare variables across skill types, paired t tests were applied to the data of the 6 subjects who performed both Baranis and Rudis...
Angles measured to describe the orientation of trampolinists’ angle of twist, angle of tilt, chest rotation, hip angle, and hip lateral flexion.

(S5 chose to perform Rudis only and was therefore omitted from this statistical procedure).

Reliability of each variable was estimated by determining the 95% confidence intervals of the true mean of eight repeated digitizations of one trial of a typical Rudi by S1. The maximum 95% confidence interval over the period of flight was used as the measure of reliability for each variable. The same procedure was applied to the five trials of each subject for the Baranis and Rudis to provide an estimate of the within-subject variability. The maximum of the 95% confidence intervals of the true means of all subjects is reported as an indication of within-subject variability for each variable.
Results and Discussion

Reliability and Within-Subject Variability

Reliability and within-subject variability are presented in Table 2. The reliability of each variable reflects the effects of errors in digitizing and errors in calibration of the three-dimensional space. Average root mean square error for the calculated positions (resultant of maximum x, y, and z root mean square errors) of the markers on the calibration frame was 0.012 m.

Calculations of chest rotation were found to be sensitive to error (varying by up to 7°). Therefore, the quantitative measurements of chest rotation were supplemented by qualitative assessment of chest rotation by observing the cine and video footage.

The patterns for tilt angle were consistent within subjects. For the bulk of flight, the 95% confidence intervals of the true mean were within 3° for both Baranis and Rudis, with the most elite subjects varying considerably less. Although the shapes of the tilt angle profiles were similar within subjects, tilt angles during the time of rapid change (near landing at approximately 80% of flight) were more variable (up to 8°) than during periods of slow change. This was due to the exaggerated effect of small differences in the time that the rapid change in tilt began. Final twist angles calculated by integrating the twist angular velocity varied within subjects by less than 10° in the Baranis and 17° in the Rudis. Hip angles were very consistent within subjects in terms of the pattern of movement; maximum and minimum hip angles varied by less than 3°. However, there was greater variability during the period of rapid change (up to 12° for both Baranis and Rudis) due mainly to the effect of small differences in the times of initiation of rapid flexions or extensions. Variability in hip lateral flexion was similar to the variability in hip angles; that is, patterns were consistent within subjects. There was less than 3° variability during the periods of slow change in hip lateral flexion angle and less than 11° during periods of rapid change. For all the

<table>
<thead>
<tr>
<th>Variable</th>
<th>Reliability</th>
<th>Within-subject variability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period of flight (s)</td>
<td>0.02</td>
<td>0.06</td>
</tr>
<tr>
<td>Initial twist</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Cumulative twist</td>
<td>5</td>
<td>17</td>
</tr>
<tr>
<td>Twist velocity (°/s)</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Tilt angle</td>
<td>1</td>
<td>3°</td>
</tr>
<tr>
<td>Hip angle</td>
<td>2.5</td>
<td>3°</td>
</tr>
<tr>
<td>Hip lateral flexion</td>
<td>3</td>
<td>3°</td>
</tr>
<tr>
<td>Chest rotation</td>
<td>7</td>
<td>15</td>
</tr>
</tbody>
</table>

Note. Values are measured in degrees unless otherwise noted.

*These values are the 95% confidence intervals for the bulk of the period of flight. Higher values occurred during the short periods of rapid change.
variables measured, the more elite subjects tended to have less variability than
the less skilled subjects, although, this trend did not reach statistical significance
\((p < .05)\) for any variable.

**Time of Flight and Height Achieved**

The time of flight ranged from 0.83 s to 1.39 s, and the maximum height of the
center of gravity with respect to the height at last contact ranged from 0.84 m
to 2.37 m. There was a strong correlation (significant at \(p < .05\)) between ability
and height achieved for the Baranis \((r = .75)\) and the Rudis \((r = .74)\). The
correlations between ability and height achieved after normalizing by standing
height were also strong for the Baranis \((r = .70)\) and the Rudis \((r = .76)\).

**Twist**

In the Baranis, all trampolinists except S9 (13°) and S10 (12°) had little twist
rotation at last contact. However, the rates of twist rotation of S9 and S10 at last
contact were small and suggested that contact twist had not been used. The two
most skilled trampolinists, S1 (−5°) and S2 (−4°), had small amounts of rotation
counter to the twist direction at last contact. This tendency for the more skilled
trampolinists to have less of the twist completed at last contact was significant
at the \(p < .05\) level \((r = .71)\).

The twist rate at last contact was less than 20°/s for all but 4 subjects \((S2,
125°/s; S4, 51°/s; S8, 143°/s; and S11, 81°/s)\). Three subjects \((S7, S9, S10)\) had
small, negative rates of rotation \((-10°/s, -20°/s, and -20°/s, respectively)\) \((negative\)
meaning in the opposite direction to the eventual twisting direction of the
Barani). When interpreting the relative contribution of contact twist, one needs
to bear in mind that at last contact there was some hip flexion, arm flexion, and
arm abduction. After the subject extended the hips and brought the arms closer
to the long axis, the rate of twist would increase due to a reduced moment of
inertia. However, because twist rates at last contact were so small for most
subjects, it would appear that these subjects made minimal use of contact twist
to perform the Baranis. Conversely, it is likely that S2, S4, S8, and S11 used
some contact twist.

Maximum twist rates averaged 313°/s \((SD = 114)\), with one subject \((S10)\)
twisting much faster than the other subjects \((614°/s)\). The absolute rates of twist
at landing were generally less than 50°/s. However, S4 (114°/s), S8 (174°/s),
and S11 (102°/s) had twist rates at landing above 100°/s. The fact that these
subjects had higher twist rates at landing as well as at last contact than other
subjects was further evidence that they used some contact twist. In the case of
S11, the large twist rate at landing was also due to not removing the tilt.

The twist rate at last contact for the Rudis \((mean = 200°/s, SD = 139°/s)\)
was significantly greater \((p < .01)\) than for the Baranis \((mean = 41°/s, SD =
57°/s)\). This reflected a tendency to commence the twist prior to last contact and
to use some contact twist. However, 2 of the most elite subjects, S1 and S3, had
much smaller rates of twist at last contact \((68°/s, and 35°/s, respectively)\) than
the group mean. This indicated that they were able to perform the necessary
rotations with minimal use of contact twist.

The maximum rates of twist in the Rudis \((mean = 864°/s, SD = 189°/s)\)
were much greater than those of the Baranis (mean = 313°/s, SD = 114°/s), indicating that subjects needed to generate a much faster rate of twist than in the Baranis to successfully complete the Rudis. The twist rates at landing (mean = 77°/s) were slow compared to the maximum twist rate. For S2 and S7, this was despite the fact that twist rates at last contact were large. This indicated that subjects were able to slow the twist rotation prior to landing. However, twist rates at landing for the Rudis were generally greater, although not significant at \( p = .05 \), than those of the Baranis. Further study with a greater number of subjects is required to establish whether twist rates at landing are actually greater in Rudis than in Baranis.

Figures 3a and 3b show the cumulative twist for the period of flight for the Baranis and Rudis of S1 and S7, respectively. These subjects represent the extremes in ability of those subjects who performed both Baranis and Rudis. The stick figures show the orientations of the trampolinists at 0, 20, 40, 60, 80, and 100% of the period of flight of a typical Barani and Rudi.

The elite subject (S1) had very little twist at last contact, and the rate of twist (indicated by the slope of the angle–time graph) did not increase markedly until midway through the hip extension. This is particularly noticeable in the Rudis. The twisting rotation was slowed at around 70% of flight and stopped prior to landing. The symmetry of the graph about 50% of flight was typical of elite performance, and both the start and finish of the skill appeared unbrushed. This pattern was similar for both Baranis and Rudis, indicating consistent timing across the two skills.

The less skilled subject (S7) had very different twisting patterns for the Baranis and Rudis. In the Baranis, the twisting motion was established much later than in the Rudis and later than the Baranis of S1. Most of the twisting motion was performed in the second half of flight. These features are also evident in the stick figures.

In the Rudis, S7 had performed 14° of twist at last contact and was twisting rapidly at last contact (328°/s). Clearly, S7 used considerable contact twist in the Rudis (notice also the large amount of chest rotation at last contact evident in the stick figure). In contrast to the timing of twist in the Baranis, most of the twist rotation was completed prior to 60% of flight and the rate of twist was very fast (maximum = 1,066°/s). This was much faster than S1’s maximum rate of twist (643°/s).

**Angle of Tilt**

With the exception of S4 (6°), all trampolinists had small angles of tilt (less than 4°) at last contact in the Baranis. This indicated a balanced takeoff posture. The maximum angle of tilt achieved during flight ranged from 5° to 14° and was significantly related to ability (\( r = -.66, p < .05 \)). The most skilled subject achieved the required twist rotation with only 5° of tilt and little contact twist. All trampolinists except the two least skilled, S10 (8°) and S11 (12°), reduced the inclination to close to zero at landing.

In the Rudis, all subjects except S3 had small angles of tilt at last contact. This subject started with 7° of tilt counter to the direction that generates twist in the desired direction. Between 15° and 23° of tilt was attained in the Rudis. As with the Baranis, there was a trend toward greater maximum tilt with decreas-
ing ability. However, this trend did not reach statistical significance at $p = .05$ ($r = .572$), and further investigation is required to establish whether there is a relationship between tilt and ability in Rudis. The most skilled subject had the smallest maximum inclination ($15^\circ$). All trampolinists had close to zero inclination at landing.

Figures 4a and 4b show the tilt angles of the most elite subject (S1) and the less skilled subject (S7). In both the Baranis and Rudis, S1 increased tilt angle from the time of last contact. The angle of tilt closely corresponded to the twist rate generated, with the fast twist rates corresponding to the period of large tilt.

The differences in timing of the twist between the Baranis and Rudis of S7 were reflected in the patterns of tilt. In both the Baranis and Rudis, S7
commenced with tilting motion opposite to the direction that produces twist in the desired direction. In the Baranis, tilt in the desired direction was not generated until 30% of flight. This caused a late start to the twisting motion. The tilt was removed late in the flight period, and this contributed to the appearance of being rushed in the preparation for landing. In the Rudis, the tendency to tilt in the wrong direction was quickly reversed by the combined effect of the contact twist and asymmetrical actions after last contact. The tilt angle increased very rapidly, attaining a maximum at 49% of flight. In contrast to S1, S7 was still removing tilt at a fast rate at the time of landing. This contributed to an appearance of a more rushed and less controlled landing than that of S1.

**Chest Rotation**

Most subjects had very little chest rotation at last contact in the Baranis, although some chest rotation after last contact was evident. However, S2, S4, S8, and S11 commenced chest rotation prior to last contact. Because torques about the long axis are generated from the trampoline in response to rotation of the chest, this was further evidence that some contact twist was used by these subjects.
Figure 4 — Angle of tilt for the period of flight for the Baranis and Rudis of (a) the most elite subject (S1) and (b) the seventh-ranked subject (S7).
In the Rudis, chest rotation was used during and after last contact as a means of generating tilt and twist. The chest rotation tended to be performed rapidly around the time of last contact, with the shoulders leading the hips in the direction of intended twist. In the case of the more elite trampolinists, the rotation was performed after last contact. The most skilled trampolinist (S1) was able to complete the necessary twist rotations in the Rudi with only a small amount of chest rotation (maximum of 25°). In contrast, it appeared that the less experienced trampolinists had larger and more vigorous (performed at a greater rate) chest rotations. Maximum chest rotations were in the order of 60°.

Hip Angle

Hip angles at last contact in the Baranis ranged from 161° (S10) to 124° (S8). This corresponded to hip flexion of 19° and 56°, respectively. The more able trampolinists had between 29° and 39° of hip flexion. The more skilled trampolinists (S1, S2, and S3) established a slightly hyperextended body position prior to the middle of the flight. Of the remaining subjects, some (S5, S7, S8, S9, and S11) adopted an extended or slightly hyperextended position, while others (S4, S6, and S10) did not fully extend in the Baranis. All trampolinists flexed in preparation for landing, and this coincided with slowing the twist rotation. The skilled trampolinists generally used about 40° of hip flexion to stop the twist and then extended to between 27° and 33° at the time of landing.

In the Rudis, the trampolinists had hip angles at last contact between 33° and 40° with the exception of the least skilled subject, S7 (48°). These were similar to the hip angles in the Baranis. At the time of maximum hip extension all subjects except S7 were more extended in the Rudis than Baranis and the extension was performed more rapidly. Significantly ($p < .05$) greater hip flexion was used to stop the twist in the Rudis (mean = 50°) than in the Baranis (mean = 37°). However, the amount of flexion at landing was similar (mean = 30°). Because of the greater hip flexion achieved prior to landing, the hip flexions and extensions were performed faster in the Rudis than Baranis.

Figures 5a and 5b show the hip flexions of S1 and S7, respectively, and reflect differences related to ability. The Rudis of S1 were similar to the Baranis in terms of the temporal pattern. However, there was more flexion following last contact and in preparation for landing. Also, the rates of flexion and extension were considerably greater in the Rudis than Baranis. Extension from the pike position was synchronous with a rapid increase in tilt and twist rate. The greatest tilt and twist rate occurred when the body was fully extended.

The hip angle pattern of the less skilled subject (S7) was very different in the Rudis than the Baranis. In particular, he extended sooner after last contact and much more rapidly in the Rudis than the Baranis. The late extension in the Baranis appeared to be a contributing factor in the late development of tilt and twist.

Hip Lateral Flexion

Trampolinists tended to flex first to one side then the other during the flight. For a trampolinist twisting to the left, the first lateral flexion was to the right and the second was to the left. The first lateral flexion occurred during the time of
Figure 5 — Hip angle for the period of flight for the Baranis and Rudis of (a) the most elite subject (S1) and (b) the seventh-ranked subject (S7).
extension from the pike after last contact. The second occurred in conjunction with hip flexion to stop the twist in the second half of flight. The first lateral flexions were greater \( p < .05 \) in the Rudis (mean = 27.7°, SD = 6.5°) than Baranis (mean = 17.9°, SD = 13.0°). The second lateral flexions were also larger \( p < .05 \) in the Rudis (mean = 23.8°, SD = 7.7°) than the Baranis (mean = 17.7°, SD = 5.2°). The flexions tended to be performed more rapidly in the Rudis than Baranis. Thus, it is possible that hip lateral flexions were utilized as part of a hula action that contributed to generating and removing tilt to control the twist rate.

In the Baranis, the timing of the first hip lateral flexion was quite variable. The time of attaining the maximum ranged from 5% of the flight phase (S11) to 51% of the flight phase (S1). The timing of the second maximum ranged from 65% (S3) to 93% (S6). In the Rudis, the timing of the first hip lateral flexion was less variable than in the Baranis, with the time of the maximum ranging from 7% of the flight phase (S7) to 24% of the flight phase (S1). The timing of the second maximum ranged from 54% (S2) to 81% (S6). The first hip lateral flexion was completed earlier \( p < .05 \) with decreasing ability in both the Baranis \( r = .67 \) and Rudis \( r = .74 \). This indicated that the less skilled performers tended to rush these actions at the start of the skill.

The more highly skilled performances were characterized by a slow rate of change of lateral flexion near the time of landing. That is, the trampolinist had established a stable posture prior to landing. Poorer performances were characterized by rapid lateral flexions up to the time of landing, indicating less control and rushing to complete the skill.

Arm Flexion and Abduction

Figures 6a and 6b show the side view (external frame) and the front and side upper body views (internal reference frame) of a typical Barani of the most skilled trampolinist (S1) and a less skilled subject (S7), respectively.

In the Baranis, similar arm movement patterns were apparent among the trampolins. The arms were generally moved down to the sides after last contact, then raised in preparation for landing. The pattern of arm flexion and extension tended to be very similar for right and left sides. However, there was some asymmetry apparent in the patterns of abduction, with one arm being more abducted than the other, particularly as the arms were being lowered early in the flight. Figure 6a shows that for the elite subject (S1), who was twisting to the left, the left arm commenced the airborne phase in a more abducted position than the right. Because the right arm swung further after takeoff than the left arm, the body tilted to the left and caused twist rotation to the left. The less skilled subject (S7) showed a more pronounced asymmetry as the arms were swung down and across the body from right to left. As with S1, this action caused the body to tilt to the left, thereby generating twist to the left. However, the action occurred later than that of S1.

Whereas S1 held his arms by his sides while performing the bulk of the twist, thereby reducing the moment of inertia about the longitudinal axis and achieving an adequate twist rate with minimal tilt, S7 continually moved his arms. There was also a more pronounced asymmetry for S7 than S1 when preparing to land and at the time of landing.
All trampolinists used an arm action in Rudis that was very different from that used in Baranis. Although there was considerable variability in the patterns of arm movement among trampolinists, there was always considerable asymmetry of movement of right and left arms. This asymmetry occurred following last contact and was clearly designed to contribute to the production of tilt. Since all subjects used a different action in the Rudis than Baranis, and since this action was more vigorous and had greater asymmetry, it is likely that trampolinists relied strongly on arm action to produce the required tilt and twist rate in the Rudis.

The asymmetrical movement generally involved one arm being in a higher
position than the other. In some cases one arm was raised vigorously while the other was lowered. In other cases, a circling movement or "wrap" was performed that culminated in the arms being adducted across the body at different levels.

**Summary and Conclusions**

In this study, the effect of ability on technique in performing forward somersaults with half twists (Baranis) and forward somersaults with one and one half twists (Rudis) was investigated.

There were differences in technique in the Baranis that were related to the subjects' abilities. With increasing skill, trampolinists performed the Baranis with less tilt. The skilled subjects also performed hip lateral flexions in a less rushed manner than the less skilled subjects.

The Rudis were much more demanding for the trampolinists, and this was manifested in substantial changes in technique from that used to perform Baranis. The maximum rates of twist in the Rudis were much greater than those of the Baranis, indicating that subjects needed to generate a much faster rate of twist to successfully complete the Rudis. Although the twist rates at last contact and chest rotations indicated that some contact twist was used (with the possible exception of S1 and S3), all subjects were able to land with small angles of tilt. The twist rates at landing were generally larger than in the Baranis (this did not reach statistical significance at $p = .05$).

Maximum tilt angles in the Rudis were between 15° and 23°. There was a trend toward greater maximum tilt with decreasing ability. To produce the additional tilt, the arm action was changed from a relatively slow and almost symmetrical action in the Baranis to a distinctly asymmetrical and vigorous action in the Rudis. Hip extensions after last contact were greater and were performed more vigorously in the Rudis than in the Baranis. Similarly, hip lateral flexions were larger in magnitude and were performed more rapidly in the Rudis than in the Baranis, and the magnitude and rate of chest rotation increased.

Less skilled subjects had vigorous chest rotations prior to last contact, whereas the more elite trampolinists rotated the chest after last contact. The first hip lateral flexion in the Rudis was completed earlier with decreasing ability. This indicated that the less skilled performers tended to rush these actions at the start of the skill.

**References**


Marzan, G.T., & Karara, H.M. (1975). A computer program for direct linear transformation solution of the collinearity condition, and some applications of it. In *Symposium on*


Appendix

Mathematical Model

Twist Axis. To simplify the analysis, the axis of twist rotation (z) was assumed to be a line joining the midpoint of the shoulders and the midpoint of the ankles.

Angle of Twist. The angle of twist shows how much of the twist has been performed at any particular time during the flight phase. Because the plane of motion in which twist occurred was constantly changing, twist angle with respect to the position at takeoff was estimated by integrating the average angular velocity about the twist axis with respect to time.

$$\Theta_t = \Theta_0 + \int_0^t \omega_{av} \, dt,$$

where $\Theta_t$ is the cumulative twist angle achieved at time $t = T$, $\Theta_0$ is the rotation at the time of last contact with the trampoline, and $\omega_{av}$ is the average of the hip ($\omega_h$) and shoulder ($\omega_s$) angular velocity vectors projected onto the twist (z axis):

$$\omega_{av} = [(\omega_h + \omega_s)/2] \cdot \mathbf{L},$$

where $\mathbf{L}$ is the unit vector representing the twist axis of rotation.

The idea of averaging the shoulder and hip angular velocities has also been applied by Kwon, Fortney, and Shin (1990). This method acknowledges the fact that the rate of rotation of either the hips or shoulders does not necessarily reflect the rotation of the whole body mass about the twist axis. Averaging the shoulder and hip angular velocities
minimizes the error due to different body parts rotating at different rates. Shoulder angular velocity was given by

$$\omega_s = \frac{\dot{S} \times S}{||S||^2}$$

where $\omega_s$ is the angular velocity of the shoulder, and $S$ is the position vector of the right shoulder with respect to the left.

An identical procedure was used to calculate the hip angular velocity ($\omega_h$) using the hip position vector ($H$), where $H$ is the position vector of the right hip with respect to the left.

To estimate the starting angular position $\Theta_0$, the shoulder ($S$) and hip ($H$) vectors were projected onto the XY plane (horizontal plane in the external reference frame) at the time of last contact with the trampoline, and the angle of those projections made with the Y axis (across the trampoline) was determined as

$$\Theta_s = \tan^{-1}[S_x/S_y]$$
$$\Theta_h = \tan^{-1}[H_x/H_y].$$

The starting angular position was then given as

$$\Theta_0 = (\Theta_s + \Theta_h)/2.$$

There were small errors in twist angle due to the actual axis of twist rotation being slightly different from the line through the midpoints of the shoulders and ankles. This resulted in the cumulative twist angle slightly underestimating the actual twist completed. However, this error was always less than 20° after approximately 540° of actual twist rotation; that is, the error was less than 4%. Rates of twist rotation were also underestimated by less than 4%.

**Angle of Tilt.** The angle of tilt ($\Theta$) was regarded as the angle between the twist axis of the trampolinist (as defined previously) and the vertical plane parallel to the sides of the trampoline (the YZ plane):

$$\Theta = \sin^{-1}|L(y)|/|L|,$$

where $L(y)$ is the y component of the position vector $L$ representing the axis of twist rotation.

**Chest Rotation.** Chest rotation was defined as the angle between the normals to the shoulder and hip planes. The normal to the shoulder plane was given as the cross-product of the shoulder ($S$) and hip–shoulder ($HS$) vectors:

$$SN = (S \times HS).$$

The normal to the hip plane was given as the cross-product of the hip ($H$) and hip–shoulder vectors:

$$HN = (H \times HS),$$

where $SN$ is the normal to the shoulder ($S$) and hip–shoulder ($HS$) vectors, and $HN$ is the normal to the hip ($H$) and hip–shoulder vectors. The hip–shoulder vector was the position of the midpoint of the hips with respect to the midpoint of the shoulders.

**Hip Angle.** Hip angle was used to describe the flexion and extension occurring in
the plane that contains the hip–shoulder vector and the normal (HN) to the hip–shoulder vector and the hip vector (Figure 7). Hip angle was given as

$$\Theta_{\text{hip}} = 90 + \tan^{-1}\left(|\text{AJ}|/|\text{JH}|\right),$$

where $|\text{AJ}|$ is the length of the component of the hip–ankle vector (HA) in the direction of HS. This was given by

$$|\text{AJ}| = \text{HA} \cdot \text{HS}/|\text{HS}|.$$

$|\text{JH}|$ is the length of the component of HA in the direction of HN. This was given by

$$|\text{JH}| = \text{HA} \cdot \text{HN}/|\text{HN}|.$$

Hip angle was 180° when the trampolinist was straight, greater than 180° when the trampolinist was hyperextended, and less than 180° when the trampolinist was flexed (pike). The quantity of hip flexion was given as 180° – hip angle and hip extension as hip angle – 180°.

**Hip Lateral Flexion.** Hip lateral flexion angle was used to describe the flexion and extension occurring in the plane that contains the hip–shoulder vector and the hip vector (Figure 8). A vector (HF) was defined as a reference. This was perpendicular to HN and HS given as

$$\text{HF} = \text{HN} \times \text{HS}.$$  

Hip lateral flexion angle was calculated as

$$\Theta_{\text{hip}} = \tan^{-1}\left(|\text{HC}|/|\text{HD}|\right),$$

where $|\text{HC}|$ is the length of the component of the hip–ankle vector (HA) in the direction of HF. This was given by

$$|\text{HC}| = \text{HA} \cdot \text{HF}/|\text{HF}|.$$

$|\text{HD}|$ is the length of the component of HA in the direction of HS. This was given by

$$|\text{HD}| = \text{HA} \cdot \text{HS}/|\text{HS}|.$$

Hip lateral flexion angle was greater than zero when the hips were flexed to the right and less than zero when the hips were flexed to the left.
Figure 8 — Schematic representation of the vectors used to define the hip lateral flexion angle.

*Arm Flexion and Arm Abduction.* To show arm abduction and flexion, an internal reference frame was established. The \( z \) axis of this reference frame was in the direction of the hip–shoulder vector \( \text{HS} \). The \( y \) axis was in the direction of the normal to the shoulder (\( S \)) and hip–shoulder (\( \text{HS} \)) vectors. The \( x \) axis was normal to both the \( y \) and \( z \) axes given by the cross-product of \( y \) and \( z \):

\[
x = y \times z.
\]

The coordinates of the vertex, shoulders, elbows, wrists, and hips were transformed to the internal reference frame. Stick figures depicting views from the front and right sides were then produced.

---

**Acknowledgments**

This research was conducted for the New Zealand Trampoline Association and was supported by a grant from the New Zealand Sports Science and Technology Board. I am grateful to Anne Isaac, PhD, for her assistance in organizing subjects and judging their performances.