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High Bar Release in Triple Somersault Dismounts

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The release from the high bar was analyzed for six performances of triple backward somersaults. All 6 gymnasts released the bar with their mass centers below the level of the bar. The mean horizontal velocity of the mass center away from the bar was $1.2 \text{ m} \cdot \text{s}^{-1}$. This horizontal velocity was partitioned into contributions from the tangential and radial motions of the mass center relative to the bar and the movement of the bar relative to its neutral position. It was found that the tangential motion was the major contributor although the radial motion produced substantial positive contributions and the bar movement gave large negative contributions in two cases.

In men's artistic gymnastics, a competitive high bar routine comprises a series of circling movements culminating in a somersaulting dismount. At elite levels of competition multiple somersaults with or without twists are common. At the instant of bar release, the gymnast's trajectory becomes parabolic with the initial direction of motion being determined by the tangent to the arc described by the gymnast's center of mass. Observation of gymnasts performing multiple backward somersault dismounts, together with data from previously published studies, indicates that during triple somersault dismounts some gymnasts appear to release with their mass centers higher than 2.55 m, the regulation bar height above the landing surface. Kerwin, Yeadon, and Lee (1990) reported a range of 2.46 m to 2.76 m for the height of the mass center at release for triple somersault dismounts performed during the 1988 Seoul Olympic finals, while Okamoto, Sakurai, Ikegami, and Yabe (1989) found a range of 2.52 m to 2.68 m at two international gymnastics competitions.

Of the nine dismounts analyzed in these two studies, seven appeared to have their mass centers above bar height at release. If a simple rigid rod model of a gymnast is used, as in Smith (1982), horizontal motion away from the bar after such a release would not be possible. In this paper the release heights for six triple somersault dismounts are analyzed to determine whether gymnasts

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release above or below the level of the bar. In addition, mechanisms employed by gymnasts to produce horizontal travel away from the bar following release are examined.

Methods

Data Collection

During the 1988 Seoul Olympic Games, all high bar dismounts were recorded using two 1PL Photosonics 16-mm cine-film cameras running at 70 Hz. The cameras were positioned 40 m from the apparatus and 11 m above the landing surface. One camera was located to the side of the apparatus in the vertical plane containing the high bar, and the other was in the perpendicular vertical plane through one of the supporting uprights. The field of view for each camera was approximately 8 m wide. Prior to the competition 35-mm slides of the seven members of the Canadian team were taken providing front and side views from which anthropometric data could be obtained on a variety of gymnast physiques for the purposes of calculating segmental and whole body mass center locations.

Data Analysis

Six triple somersault dismounts were selected on the basis of having a well-controlled landing. This resulted in one competitor each from Canada, China, the GDR, Italy, the USA, and the USSR. Identification of the instant of release is crucial to the analysis. In studies of the flight phase of dismounts (Kerwin et al., 1990; Yeadon et al., 1990) it is essential for the mechanical analysis that contact with the apparatus has been lost. Frames are thus sought in which clear space between the gymnast's hands and the bar can be observed. However, some time may have elapsed from the effective release point. The loss of tension caused by the gymnast releasing the grip on the bar, enabling the bar to revert to its equilibrium position, would be a more appropriate definition of the moment of release. The *release frame* was therefore identified as the first frame in which a change in the distance between the gymnast's wrists and the bar could be observed.

The last frame of bar contact plus 10 frames on either side in each sequence were selected for analysis. These 21 frames were digitized twice by the same operator from each camera view using a high-resolution digitizing tablet (TDS HR48). The 15 points digitized from each image were wrist, elbow, shoulder, hip, knee, and ankle on each side of the body; the midpoint of that portion of the high bar between the hands; and two control points on the high bar uprights. The resulting data sets were synchronized by determining rays from each camera to the mean position of the 12 digitized body landmarks for the first and last three frames from each camera. The method described in Yeadon (1989) was used to determine the time of the second and penultimate frame from one camera in terms of the time scale of the other camera.

The three-dimensional coordinates of the 12 body landmarks, the bar center, and the whole body center of mass location were obtained using the reconstruction technique of Yeadon (1989). Quintic splines (Wood & Jennings, 1979) were used to calculate two independent estimates of each required velocity from the repeated digitization of each view. These two values were used to give a mean

velocity together with an estimate of error. Segmental inertia values were obtained by digitizing 35-mm slide images of the seven Canadian team members and using the model of Yeadon (1990a). The inertia set for Competitor 110 was available since he was one of the Canadian team members who had been measured prior to the competition. For the remaining five competitors, all seven inertia sets were used to calculate the angular momentum over the whole aerial phase of the dismount using the method of Yeadon (1990b). For each competitor the inertia set that gave the smallest variance in the calculated angular momentum was selected as the most appropriate for the subsequent analysis as in Kerwin et al. (1990).

Body angle was defined as the angle between the horizontal and the perpendicular from the mass center to the bar. A positive value indicated that the mass center was above bar level. To estimate the contributions to the horizontal velocity of the mass center in flight, the horizontal velocity of the mass center just prior to release was partitioned into three components. These comprised the horizontal components of the velocity of the bar relative to its neutral position, the radial velocity of the mass center relative to the bar due to alterations in body configuration, and the tangential velocity of the mass center resulting from the rotation about the bar.

Results and Discussion

The horizontal field of view of the available film was approximately 8 m wide since the recordings were originally made for the analysis of the whole of the high bar dismounts. As a consequence the accuracy with which body points could be located was not as high as could be achieved with a field of view specifically chosen for the release. An estimate of the error associated with the manual digitization of body landmarks was obtained using the repeated digitization values. The mean digitization errors (reliability) of the body landmarks for each dismount ranged from 0.005 m to 0.007 m. The mean digitization errors for the locations of the bar and the mass center of the body were 0.002 m and 0.003 m, respectively. An estimate of the propagated synchronization error arising from the digitization was also obtained using the repeated digitization values. The synchronization error estimates ranged from 0.001 s to 0.003 s for the six dismounts. Estimates of error in the calculated velocities were obtained by using two independent velocity estimates from the repeated digitizations; these error estimates ranged from $0.03 \text{ m} \cdot \text{s}^{-1}$ to $0.12 \text{ m} \cdot \text{s}^{-1}$ with a mean value of $0.07 \text{ m} \cdot \text{s}^{-1}$.

When a gymnast is approaching release the velocity of his or her mass center is almost the opposite of the velocity of the hands relative to the mass center. The same is true during the early part of the flight phase, and so the velocity of the hands is close to zero at this time. This can be seen in Figure 1, which shows that just after release the hands remain close to the bar.

Close inspection of the film confirmed that waiting for clear space to appear between a gymnast's hands and the bar resulted in an error of typically two frames (0.029 s) in the identification of release. The instant of effective release was identified using the change in the distance between the bar and the wrists. The body angles for the frames surrounding release have been summarized in Table 1 with positive values indicating that the mass center is above bar level.

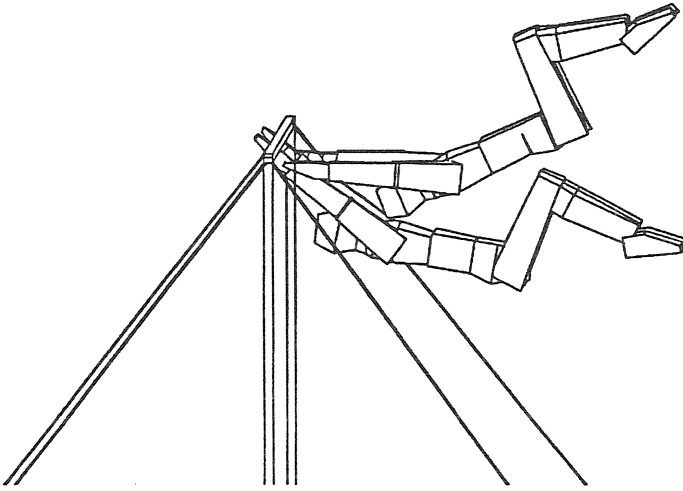


Figure 1 — Images showing that during the approach to release the velocity of the hands is close to zero and that immediately after release the hands remain close to the bar.

Table 1
Body Angle at Release (in degrees)

| Gymnast | Frame -2 | Frame -1 | Frame +1 | Frame +2 |
|---------------------|----------|----------|-----------|----------|
| Early release group | | | | |
| 110 | -20 | -15 | -11 | -7 |
| 149 | -22 | -16 | -9 | -3 |
| 202 | -19 | -14 | -9 | -5 |
| | | | (Release) | |
| Late release group | | | | |
| 161 | -12 | -7 | -2 | +3 |
| 120 | -11 | -6 | -1 | +3 |
| 193 | -12 | -6 | -1 | +4 |

Note. Body angle is defined as the angle between the horizontal and the perpendicular from the gymnast's mass center to the bar with positive values indicating that the gymnast's mass center is above the bar level.

The last frame prior to effective release has been numbered Frame -1, and the first frame after effective release has been numbered Frame +1.

The six gymnasts were divided into two groups, early release and late release. The body angle at effective release was calculated as the mean value of the body angles at Frames -1 and +1. Competitors numbered 110, 149, and 202 were regarded as the early release group, having body angles at effective release

lower than -10° . Competitors 161, 120, and 193 were classed as the late release group, with body angles at effective release above -5° . Use of repeated digitization enabled the reliability of these body angles to be established at $\pm 1^\circ$. The objectivity of the data was checked when a second independent operator digitized selected sequences, and the variation in the calculated body angles was found to be less than 1° .

The gymnasts' horizontal components of mass center velocity in flight were found to range from $0.9 \text{ m} \cdot \text{s}^{-1}$ to $1.5 \text{ m} \cdot \text{s}^{-1}$. These data have been summarized in Table 2 along with the contributions to horizontal velocity arising from the gymnasts' preparatory actions during the upswing to release, with positive values indicating travel away from the bar.

The expected contribution to the horizontal component of mass center velocity arising from the tangential velocity of mass center relative to the bar is apparent. Competitor 110 with a release angle of about -13° obtained a contribution of $1.5 \text{ m} \cdot \text{s}^{-1}$ from this factor, while Competitor 193, at the other end of the release angle range (-3° to -4°), produced only $0.6 \text{ m} \cdot \text{s}^{-1}$ from this source. It can be seen from Table 2 that the tangential contributions from the late release group are all smaller than those from the early release group.

Theoretical considerations of the actions made by gymnasts prior to release indicated that at least two other contributory factors were worthy of consideration. The deflection of the bar combined with the circling action of the gymnast around the bar offered the potential to transfer energy from the bar. However, the greatest deflection occurred near to the point when the gymnast passed directly beneath the bar. On the upswing the bar tended to return to its neutral position and so any contribution to the subsequent motion of the gymnast might be expected to detract from horizontal flight velocity. The gymnasts were in fact faced with the problem of negating this bar contribution rather than capitalizing on positive benefits. The data in Table 2 under "Bar velocity" indicate that the late release group suffered less from this effect, with two gymnasts obtaining small positive

Table 2
Contributions to Horizontal Velocity of the Mass Center (in $\text{m} \cdot \text{s}^{-1}$)

| Gymnast | Tangential velocity | Radial velocity | Bar velocity | Resultant velocity |
|---------------------|---------------------|-----------------|--------------|--------------------|
| Early release group | | | | |
| 110 | 1.5 | 0.5 | -1.0 | 1.0 |
| 149 | 1.7 | -0.3 | -0.2 | 1.3 |
| 202 | 1.4 | 0.8 | -0.9 | 1.3 |
| Late release group | | | | |
| 161 | 0.7 | 0.4 | -0.2 | 0.9 |
| 120 | 0.6 | 0.6 | 0.1 | 1.3 |
| 193 | 0.6 | 0.6 | 0.3 | 1.5 |
| Mean | 1.1 | 0.4 | -0.3 | 1.2 |

contributions. One of the early release group did not appear to suffer too greatly from this factor with a negative contribution of $0.2 \text{ m} \cdot \text{s}^{-1}$, but Competitors 110 and 202 had to cope with large negative contributions of $1.0 \text{ m} \cdot \text{s}^{-1}$ and $0.9 \text{ m} \cdot \text{s}^{-1}$.

Another possible contributory factor was that arising from the radial motion of the mass center relative to the bar arising from body shape changes during the upswing to release. The radial contributions to horizontal release velocity were positive for five of the six gymnasts, indicating that the distance from bar to mass center was increasing at release. Although the body becomes increasingly flexed at the hips during the upswing the angle between the upper arm and trunk decreases during the early part of the upswing but typically increases just prior to release. The hip, shoulder, and wrist angles are shown in Figure 2.

Another factor affecting this contribution is the action of the wrists immediately prior to release. If the wrists are straightening from a previously flexed position there will be a positive contribution to the radial velocity. Figure 3 shows the time histories of the hip, shoulder, and wrist angles for Competitor 193 up to the moment of release.

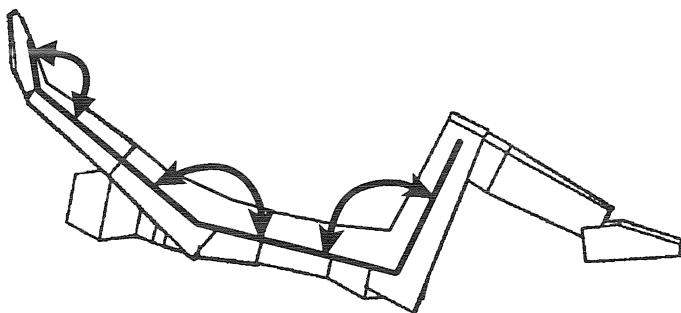


Figure 2 — Image showing the angles at hip, shoulder, and wrist.

Summary and Conclusions

The apparent anomaly arising from previously published research that gymnasts travel away from the apparatus in the high bar triple somersault dismount while appearing to release with their mass centers above bar level was examined. The instant of effective release was defined as the first observation of bar recoil with respect to the gymnasts' wrists rather than the more conventionally adopted observation of clear space between the bar and the gymnasts' hands. This important distinction meant that release had begun up to two frames prior to the time that contact was clearly lost. With this new definition, values for the body angles at triple somersault release ranged from -13° to -3.5° , confirming that none of the six competitors who were analyzed released the bar with their mass centers above bar level. Also the linear horizontal flight velocity component was found to be similar for all six gymnasts and therefore did not depend solely on the body angle at release.

Two other factors were considered that theoretically could have contributed

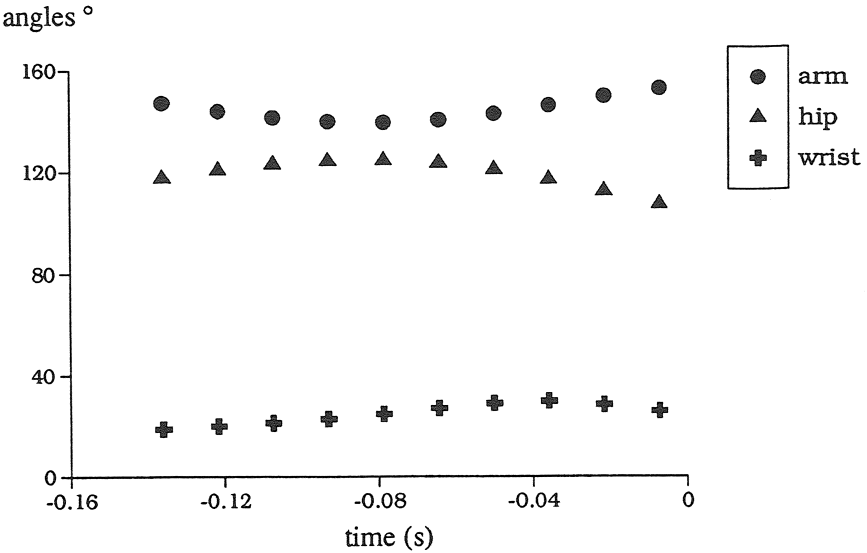


Figure 3 — Time histories of the hip, shoulder, and wrist angles for Competitor 193 up to the moment of release. Release occurs in the interval between time -0.007 and $+0.007$ s.

to the horizontal flight velocity. Contributions from the motion of the bar were negative for the early release group and large for two of these three gymnasts. For the late release group the bar contributions were small and in two cases were positive. This suggests that it is necessary to wait in order that the oscillatory movement of the bar can be used to positive advantage. However, the bar motion will also depend upon the timing of body movements during the final giant circle and so may vary with technique. The radial contributions to the horizontal release velocity were positive for five of the six gymnasts. The hip flexion evident prior to release will produce a negative radial contribution, whereas shoulder extension will produce movement away from the bar. Since this shoulder extension was evident in only the final few film frames before release there is a case for using framing rates higher than 70 Hz in order to study configuration changes immediately prior to release.

This study was based on only six elite gymnasts, and the excessive field of view of the available film material was less than ideal. In future studies the accuracy with which velocity contributions may be calculated could be increased by using a small field of view and a high camera framing rate.

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