# THE MEN'S HANDSPRING FRONT ONE AND A HALF SOMERSAULT VAULT: RELATIONSHIP OF EARLY PHASE TO POSTFLIGHT

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Men's Olympic gymnastics today is comprised of six events. Listed in order of Olympic competition they are: floor exercise, pommel horse, Roman rings, vaulting horse, parallel bars, and horizontal bar. In five of these events a routine is required by the International Gymnastics Federation (FIG) to consist of 11 moves. The exception is vaulting. This event consists of only one jump over the vaulting horse for which a maximum score of 10 points can be awarded. This one skill is rated at the same value as 11 skills on any other apparatus. Ten points can be won or lost on this one skill. It is possible to see zero awarded for an unsuccessful vault. In this light, the importance of vaulting can be seen.

One of the difficult vaults of the past, which has become a basic vault today, is the handspring vault. This vault is, however, rarely seen in modern high-level competition since it has a maximum score of 9.0. It does, however, form the basis of the most common of the more difficult vaults performed today.

At the 1970 World Gymnastics Championships, a Japanese gymnast, Tsukahara, performed a revolutionary new vault, which was later given his name. He added a somersault to the final airborne phase of the vault. This was the first time that had been done. This vault began the revolution in vaulting technique. Since that time, somersaults and twists have been added to the postflight of all the basic vaults.

The two most common families of vaults seen at high level competition today must definitely be the Tsukahara (round-off backward 1½ somersault) and the handspring front 1½ somersault, Figure I shows an example of this vault. This study covers the

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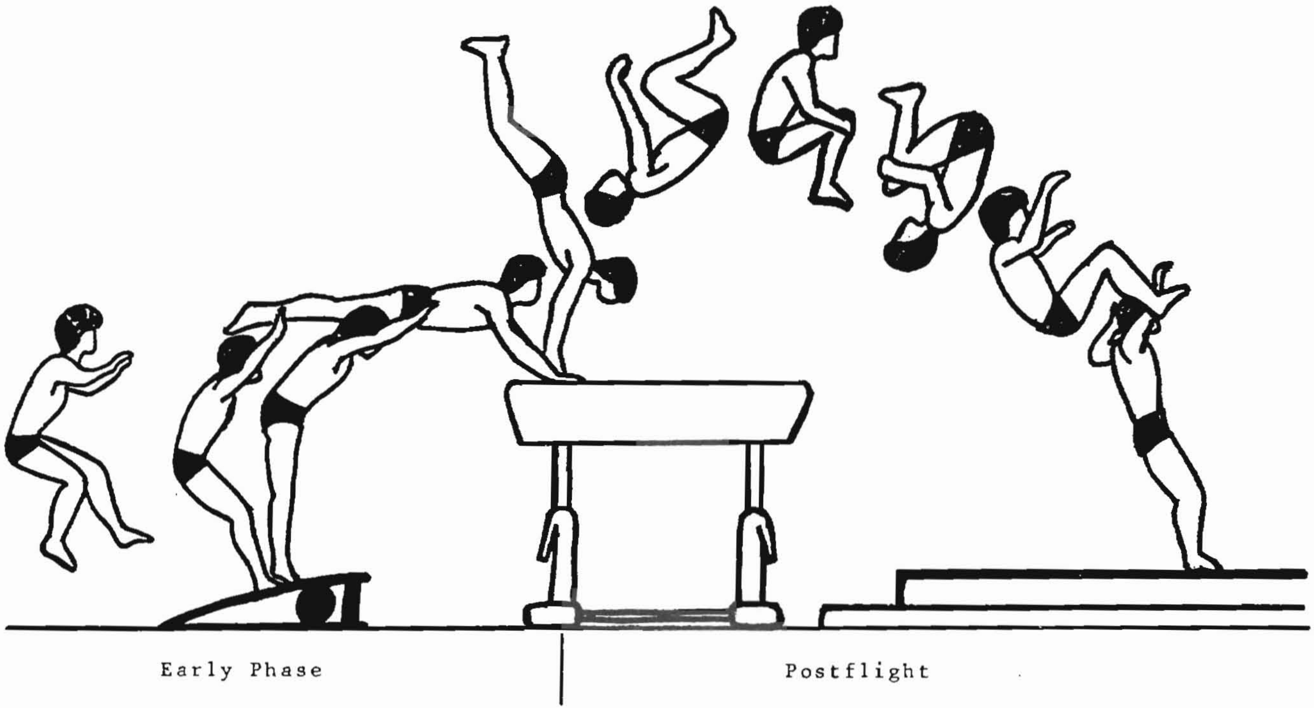



Figure 1. The Handspring Front 1½ Somersault: An Example

handspring front 1½ somersault.

The biomechanics of gymnastics has received relatively little study compared to other major sports. Within this realm, though, vaulting has received much attention. The basic vault, the handspring, has been extensively studied. Ferriter (1964), Cianfarani (1974), Dainis (1979), Brüggemann (1979) and Brüggemann and Nissinen (1981), have all done studies on this vault. Dainis (1981) broke the vault down, phase by phase and produced the first mathematical model of the handspring.

The handspring front 1½ somersault, however, has not been so extensively studied, and, in fact, some of the studies done lacked sound scientific methods. Whitmore (1975) studied six handspring front 1½ somersaults done by male college gymnasts. Direct tracings from the films were used to calculate displacements and velocities and no data smoothing was used. Borrmann (1978, p. 184) diagrams the handspring front 1½ somersault and shows the center of gravity to come down onto the horse. Bajin (1979) studied the push-off phase of the handspring front 1½ somersault. He found that the 4 world-class gymnasts studied did not reach a completely stretched phase before leaving the horse. The push-off also depended on the position of horse contact.

The purpose of this study was to identify the main factors in the early phase of the handspring front 1½ somersault, that affect the three main postflight variables. The early phase is the phase up until the the hands loose contact with the horse and the postflight is from then on. The three main postflight variables are, the distance of the landing from the end of the horse, the height of the postflight and the angular velocity on leaving the horse. These three variables were chosen because; height and distance of the postflight are the two main criteria judged in a competition and the angular velocity on leaving the horse is that which allows (or does not allow) the gymnast to complete the 1½ somersault.

## EXPERIMENTAL PROCEDURES

A group of eight male gymnasts were used for the study. Seven of these gymnasts were from the Arizona State University competitive gymnasitcs team and the other was a former Australian Olympian. A prerequisite for all subjects was the capability of successfully completing the handspring 1½ somersault vault with a score of 9.0 or higher.

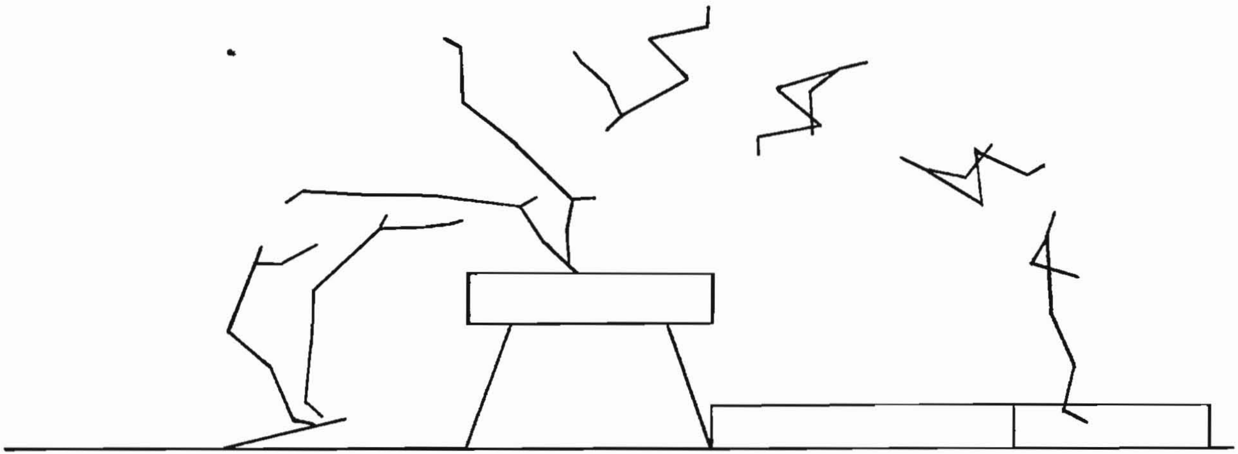
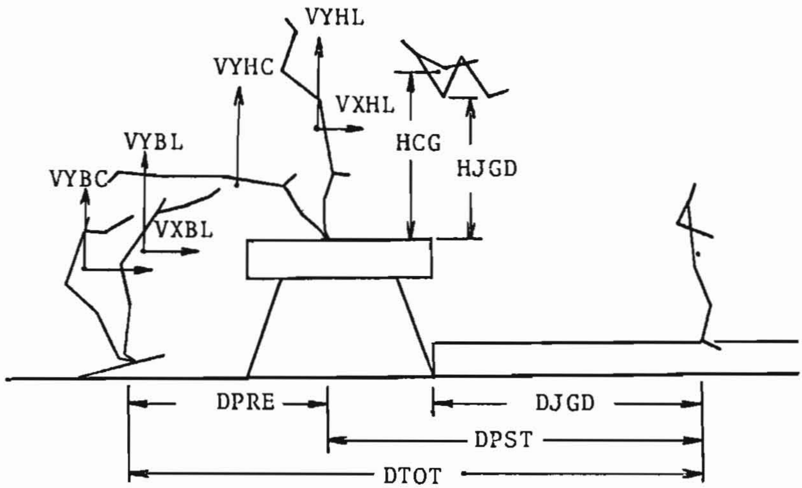


Figure 2. The Handspring Front Somersault: Stick Figure Diagram.




DISPLACEMENTS (Meters)

HCG - Maximum height of center of gravity (CG) in post flight
HJGD - Height from top of horse to hip. The judged height
DPRE - Distance of preflight, ankle to wrist
DPST - Distance of post flight, wrist to ankle
DTOT - Total length of vault. DPRE + DPST
DJGD - Distance from end of horse to landing. The judged distance

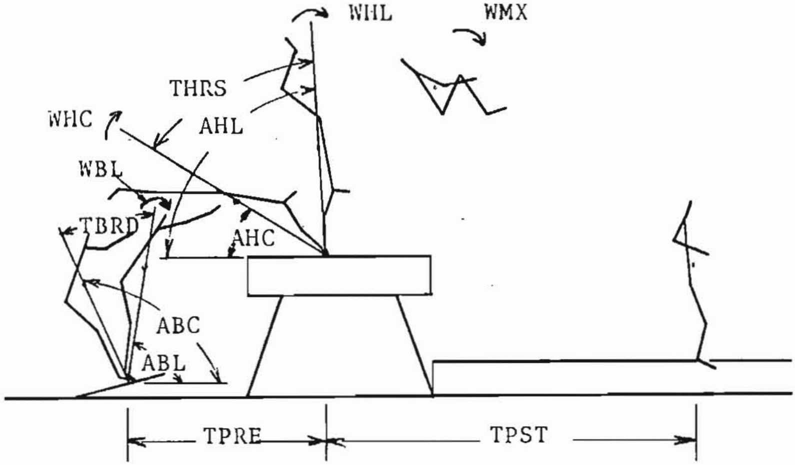
HORIZONTAL VELOCITIES (Meters/Second )

VXBC - Horizontal velocity of CG on board contact
VXBL - Horizontal velocity of CG on leaving the board
VXBDL - Change in horizontal velocity of CG on the board.
VXHL - Horizontal velocity of CG when wrists first leave the horse
VXHDL - Change in horizontal velocity of CG on the horse.

VERTICAL VELOCITIES (Meters/Second )

VYBC - Vertical Veloctiy of CG on board contact
VYBL - Vertical Velocity of CG on leaving the board
VYBDL - Change in vertical velocity of CG on the board.
VYHC - Vertical Velocity of CG on horse contact
VYHL - Vertical Velocity of CG on leaving the horse
VYHDL - Change in vertical velocity on the horse.

FIGURE 3. Definitions of Variables




TIMES (Seconds)

TBRD - Time of board contact
TPRE - Time between leaving the board and contacting the horse
THRS - Time of horse contact
TPST - Time between leaving the horse and contacting the mat

ANGLES (Degrees)

ABC - Angle between horizontal and line through ankle - CG on board contact
ABL - Angle between horizontal and line through ankle - CG on leaving the board
AHC - Angle between horizontal and line through wrist - CG on horse contact
AHL - Angle between horizontal and line through wrist - CT on leaving the horse

ANGULAR VELOCITIES (Degrees/Second )

WBL - Angular velocity of shoulder about CG on leaving the board
WHC - Angular velocity of shoulder about CG on horse contact
WHL - Angular velocity of shoulder about CG on leavint the horse
WMX - Maximum angular velocity of shoulder about CG in postflight

FIGURE 3. Definitions of Variables (Continued)

The handspring front 1½ somersault in its basic form is one planar motion, which can be adequately studied with one camera, in two dimensions. This implies that it is sufficient to fit markers over the selected body points on one side of the subject. The body points selected were: a) the toe, b) the ankle, c) the knee, d) the hip, e) the shoulder, f) the elbow, g) the wrist, h) the hand and i) the head.

A total of three vaults for each gymnast was allowed. Each vault was filmed at 99 frames per second. The camera used was a Locam, model 51, 16 millimeter, high speed, motion picture camera. The camera was situated as far away as possible from the vaulting horse, in this case, 24.27 meters. The optical axis of the camera was perpendicular to the plane of action. The height of the camera lens was equivalent to the height of the vaulting horse (1.35 meters) and the lens axis was centered in the middle of the horse in order to minimize parallax error. A zoom lens was used to enlarge the image size as much as possible. The field of vision included about one meter before the beat board and one meter after the landing. A reference point was marked on the top front of the vaulting horse using white athletic tape.

The films of each vault were digitized and the coordinates of each body point fed into a Tektronix 4052 mini-computer frame by frame. The total body center of gravity was calculated using Dempster's (1955) segmental centers of gravity from the displacement data. The displacement data were smoothed using a Butterworth low-pass digitial filter with a cutoff frequency of 6Hz for the center of gravity curve and 12Hz for all other body points (Winter, 1979, pp. 32-37). The relevant kinematic variables were calculated from the smoothed displacement data using the equations as described by Winter (1979, p. 43). They were: a) displacements, b) angles, c) linear velocities and d) angular velocites. Times were calculated by counting the number of film frames between each event. The computer program also drew stick figure diagrams (figure 2), suitable for coaching applications.

The Statistical Analysis System package on the ASU computer system was used to calculate mean, standard deviation, sum, minimum and maximum on each of the kinematic variables. The SAS package was also used to correlate the early phase variables, which were the independent variables, with the postflight variables, which were the dependent variables. The correlation method used was the Pearson product-moment method. A significance level of 0.05 was chosen but was adjusted since numerous correlations were performed. This procedure minimizes the possibility of chance correlations appearing to be significant.

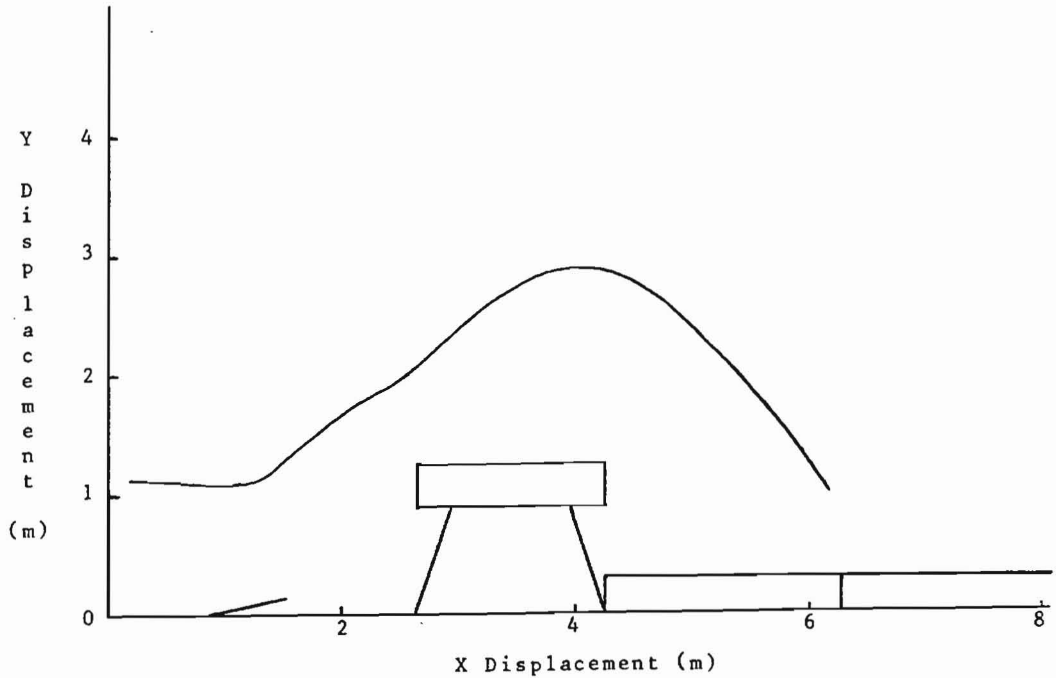



Figure 4. Center of Gravity Trajectory during the Handspring Front 1½ Somersault

## RESULTS AND DISCUSSION

One of the trials of one of the subjects was not used. His vault accidentally twisted and so invalidated the assumption that the motion of the handspring front 1½ somersault could be considered to be in one plane. Figure 3 defines all the variables measured in this study. Table 1 lists all the variables measured, the sample size (N=23), mean, standard deviation minimums and maximums. Table 2 presents the correlations of the main early phase variables to the three main post flight variables: height, distance and angular velocity. This table will be referred to while discussing the specific correlations.

### Judged Postflight Height (HJGD) and Angular Velocity on Leaving the Horse (WHL)

There are no significant correlations between the early phase variables and either HJGD or WHL. This is surprising since previous studies, notably Brüggemann and Nissinen (1981), did find some significant correlations. They found for example, approach velocity (VXBC, one of the early phase variables) was significantly correlated to HJGD and that angular velocity on leaving the board (WBL, again an early phase variable) was significantly related to WHL.

It should be mentioned however, that their study was on the basic handspring vault and that the subjects of their study varied widely in ability. They studied and compared three groups of male gymnasts, juniors, national class and world-class. Two possible reasons for the disagreement between the two studies are presented:

1. The handspring front 1½ somersault is a very complex vault. The energy from the take-off from both the board and the horse must be partitioned into height, distance and angular velocity in the postflight. In the handspring the angular velocity in postflight is not so important since only ½ a rotation rather than 1½ rotations, must be completed before landing.

2. The subjects of this study were all at a similar ability level, all were capable of scoring higher than 9.0 on this vault. In Brüggemann's and Nissinen's study, they were all of differing ability level.

### Judged Postflight Distance (DJGD)

Preflight distance (DPRE) and preflight time (TPRE) were found to be directly related to DJGD. This implies that the longer the preflight the further the landing from the end of the horse. This contradicts the results of the Brüggemann and Nissinen study of 1981 on the handspring. It also contradicts a generally accepted

TABLE 1

Statistics of All Kinematics Variables Calculated

| Variable | N | Mean | Std. Dev. | Minimum | Maximum |
|---|---|---|---|---|---|
| HCG | 23 | 1.46 | 0.10 | 1.28 | 1.63 |
| HJGD | 23 | 1.20 | 0.10 | 0.99 | 1.36 |
| DPRE | 23 | 1.65 | 0.23 | 1.25 | 2.09 |
| DPST | 23 | 3.51 | 0.24 | 2.98 | 4.02 |
| DTOT | 23 | 5.16 | 0.36 | 4.41 | 5.73 |
| DJGD | 23 | 2.39 | 0.30 | 1.83 | 2.84 |
| TBRD | 23 | 0.11 | 0.01 | 0.11 | 0.12 |
| TPRE | 23 | 0.15 | 0.03 | 0.09 | 0.20 |
| THRS | 23 | 0.13 | 0.02 | 0.09 | 0.16 |
| TPST | 23 | 1.04 | 0.62 | 0.86 | 3.87 |
| ABC | 23 | 109.74 | 2.49 | 106 | 114 |
| ABL | 23 | 73.61 | 3.93 | 67 | 83 |
| AHC | 23 | 33.00 | 6.67 | 17 | 42 |
| AHL | 23 | 76.57 | 6.41 | 62 | 88 |
| WBL | 23 | 445.30 | 78.01 | 316 | 586 |
| WHC | 23 | 376.04 | 56.13 | 285 | 477 |
| WHL | 23 | 425.22 | 48.55 | 356 | 546 |
| WMX | 23 | 1003.65 | 82.44 | 889 | 1184 |
| VXBC | 23 | 7.32 | 0.28 | 6.72 | 7.91 |
| VXBL | 23 | 4.53 | 0.32 | 3.95 | 5.02 |
| VXBDL | 23 | 2.79 | 0.40 | 2.09 | 3.53 |
| VXHL | 23 | 3.56 | 0.29 | 3.03 | 4.32 |
| VXHDL | 23 | 0.93 | 0.30 | 0.40 | 1.53 |
| VYBC | 23 | -0.95 | 0.14 | -1.20 | -0.67 |
| VYBL | 23 | 4.02 | 0.14 | 3.69 | 4.29 |
| VYBDL | 23 | 4.97 | 0.22 | 4.59 | 5.49 |
| VYHC | 23 | 2.50 | 0.36 | 1.76 | 3.28 |
| VYHL | 23 | 2.86 | 0.23 | 2.40 | 3.39 |
| VYHDL | 23 | 0.35 | 0.26 | 0.00 | 0.91 |

Heights (H) and Distances (D) in meters

Times (T) in seconds

Angles (A) in degrees

Angular Velocities (W) in degrees/second

Linear Velocities (V) in meters/second

TABLE 2

Correlations of Early Phase to Postflight Variables

| Early Phase Variables | Postflight Variables DJGD | HJGD | WHL |
|---|---|---|---|
| DPRE | 0.80* | 0.02 | -0.16 |
| TBRD | 0.25 | -0.29 | 0.12 |
| TPRE | 0.68* | 0.05 | -0.34 |
| THRS | 0.10 | 0.12 | -0.01 |
| ABC | -0.63 | 0.30 | -0.27 |
| ABL | -0.74* | 0.42 | -0.10 |
| AHC | 0.58 | -0.09 | -0.24 |
| AHL | 0.51 | -0.29 | -0.07 |
| WBL | -0.28 | 0.63 | -0.25 |
| WHC | 0.25 | 0.35 | -0.09 |
| VXBC | 0.14 | 0.51 | -0.05 |
| VXBL | 0.78* | 0.11 | 0.06 |
| VXBDL | -0.71* | 0.45 | -0.09 |
| VXHDL | 0.16 | 0.42 | -0.30 |
| VYBC | 0.19 | 0.18 | -0.07 |
| VYBL | 0.21 | -0.18 | 0.04 |
| VYBDL | 0.01 | -0.23 | 0.07 |
| VYHC | -0.73* | 0.34 | 0.10 |
| VYHDL | 0.51 | -0.09 | -0.10 |

*Indicates significance at the 0.05 level.

coaching edict that one should "get onto the horse as soon as possible". Perhaps this study points out that within this specific subject population, this coaching edict is not as important as is thought. Perhaps, once the subject is proficient at the vaul he can lengthen his preflight, contact further down the horse and hence lengthen his landing distance from the end of the horse. This was definitely the case with the subjects of this study.

The only angle in the early phase that was found to correlate to DJGD was the angle of the center of gravity to the horizontal on leaving the board, that is the take-off angle (ABL). It was found to be negatively related to DJGD. This implies the gymnasts with a greater forward lean had the longest postflight judged distance. Table 1 shows the minimum value of this angle was 63° and the maximum was 83°. Fukushima (1975) concluded this lean to be an important factor in the vault. Brüggemann and Nissinen (1981) concluded that the better gymnasts had smaller take-off angles, agreeing with the findings of this study.

No early phase angular velocity was found to correlate to DJGD. Correlation may have been found if angular momentum were measured rather than angular velocity. Once in free flight, angular momentum is fixed, and is equal to the moment of inertial times the angular velocity, however, angular velocity can vary greatly if the gymnast changes his moment of inertia by tucking or opening. Perhaps angular momentum should be the variable investigated in the future.

No significant correlation was found between approach velocity (VXBC) and judged postflight distance (DJGD). This was a very surprising result since Brüggemann and Nissinen (1981) suggested VXBC and DJGD should correlate significantly to one another.

Their subjects were very varied in skill level, from juniors to world-class, but the subjects of this study were all of a similar level as already mentioned. Hence, a possible explanation for the non-correlation could be that the gymnasts of this group already possessed more than enough horizontal approach velocity to complete the vault, that is, they were possible already running fast enough that slight variations in speed within this range did not affect the postflight judged distance (DJGD).

Obviously, VXBC must have some effect on DGJD in the extreme case, since if the gymnast has zero approach velocity, he must also have zero postflight distance, but with this group of gymnasts no significant correlation was found.

It is interesting to note, however, that Table 2 shows a significant correlation between horizontal take-off velocity (VXBL) and judged postflight distance (DJGD). Dainis (1981) also found this relationship in his mathematical model of the handspring vault.

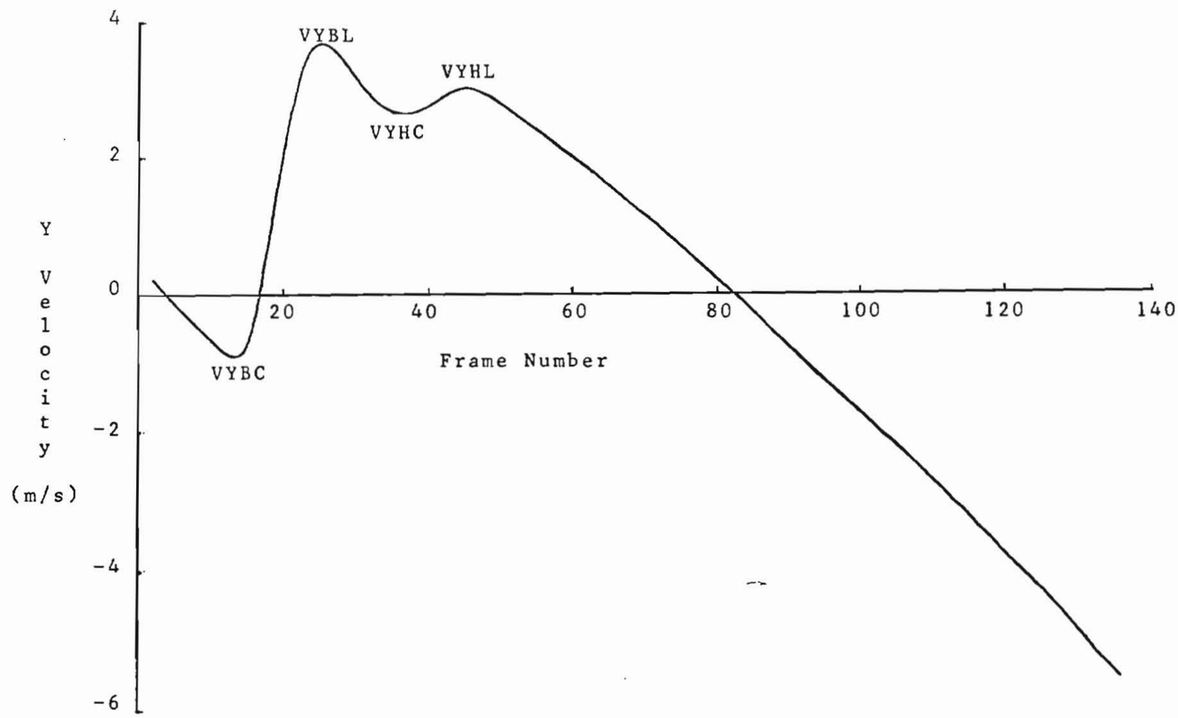



Figure 5. Vertical Velocity Curve of the Center of Gravity for the Handspring Front 1½ Somersault

Table 2 also shows that the change in horizontal velocity while on the board (VXBDL) is significantly inversely correlated to DJGD. The inverse relationship implies that the larger the change of velocity on the board, the smaller the postflight judged distance. So, if one of these subjects intends to increase his distance, he must endeavor not to block his horizontal velocity on the board too much.

In conclusion, it is evident that in this case, how fast one leaves the board, and how much one blocks the horizontal velocity while on the board, have more of an effect on postflight judged distance than the approach velocity.

A significant negative correlation was found between the vertical velocity on horse contact and DJGD. This is in agreement with the positive correlations of TPRE and DPRE with DJGD already discussed. The longer the gymnast is in the air in his preflight, the further he travels and the longer gravity has to decrease his vertical velocity. Hence the longer the preflight the lower the vertical contact velocity.

### Vertical Velocity and Change in Vertical Velocity During Horse Contact - VYHC & VYHDL

Two other questions regarding the handspring front 1½ somersault were answered by this study. The first was, "Does the gymnast's center of gravity have an upward or downward velocity on initial contact with the horse?" The direction of VYHC will answer this question. Table 2 shows the minimum value of VYHC to be +1.76m/sec. and Figure 4 shows a typical center of gravity trajectory during the vault. It can be seen that there is a point of inflection in this curve when the gymnast contacts the horse, but at no time in the early phase of the vault does this curve descend. Hence, the gymnast, contrary to earlier beliefs (Borrmann, 1978), never dives down onto the horse in this particular vault. If he did, it would make it very difficult to complete the 1½ somersault in the postflight. Brüggemann and Nissinen (1981) agree with this study. They found positive mean contact velocities for each of the three groups they analyzed.

The second question was "Is the gymnast in contact with the horse long enough to exert an impulse against it and aid his postflight?" Table 1, under the heading VYHDL, shows the change in vertical veloctiy while in the support phase. In only one case out of 23 is it zero; the rest are all positive changes. Figure 5 expresses graphically what is presented in Table 1, in all but one case. The graph shows VYHL to be higher than VYHC, indicating an increase in vertical velocity while on the horse. This evidence supports the idea that one can exert an impulse against the horse during the support phase.

The reason for this question is that it was suggested since the gymnast is only in contact with the horse for between 90 and 160 milliseconds (Table 2), he actually does not have time to react to the kinesthetic stimulus of the horse under his fingers and so cannot push on the horse to aid his postflight.

Schmidt (1982) states: "RT is rarely found to be less than about 120 msec. for kinesthetic stimuli" (P. 156). So, on some of the vaults studied, theoretically, the gymnast does not have time to react, but on some others he does, although at the very end stages of the support phase. It would seem then that the gymnast cannot, at least in some vaults, exert an impulse against the horse, but this study showed he does.

The key to the situation is anticipation. The gymnast learns to anticipate when he will contact the horse and is ready to push against it immediately. Schmidt (1982) states:

> If the fore periods are constant and very short (e.g., less than a few seconds), evidence shows that the subject can respond essentially simultaneously with the stimulus after some practice (provided that the subject knows which response to produce). (p. 160)

So, as the gymnast improves his timing, he begins to learn to respond immediately as he contacts the horse. This improves the effectiveness of the impulse.

Brüggemann and Nissinen (1981) consider this impulse to be one of the most important causes of a high and long post flight. Dainis (1981) agrees that an impulse can be exerted, but does not agree that it is an important factor in the postflight characteristics of the vault. This study shows no signifiacnt correlation between change in vertical velocity during the support phase (VYHDL) and the judged postflight distance (DJGD) or height (HJGD). Hence, it is concluded within this group of subjects and subjects of similar ability that while the gymnast can and does exert an impulse on the horse during the support phase, it has no significant effect on judged postflight height or distance.

## SUMMARY

The purpose of this study was to resolve which factors in the early phase of the handspring front 1½ somersault vault were significantly related to the postflight variables. The postflight variables were: (a) the judged postflight distance; (b) the judged postflight height and (c) the angular velocity immediately after leaving the horse.

A group of eight male gymnasts, seven from the ASU gymnastics team and one former Australian Olympian, were filmed at 99 frames per second, performing the handspring front 1½ somersault vault. Each gymnast had three vaults and each of the relevant body points were marked with white athletic tape prior to vaulting. The points marked were: a) the toe, b) the ankle, c) the knee, d) the hip, e) the shoulder, f) the elbow, g) the wrist, h) the hand, and i) the head. Each of these points was then digitized and fed into a Tektronix 4052 mini-computer. The appropriate software calculated the center of gravity using Dempster's (1955) segmental centers of gravity from the displacement data. The displacement data were smooted using a digital filter (Winter 1979, p. 35). Six hertz was the cut-off frequency used for the center of gravity curve, and 12 Hz for all other body points. Velocities and angles were calculated from these data. Times were calculated by counting the number of frames between events. The final kinematic variables were statistically analyzed using the SAS statistical package on the ASU computer.

The results showed that the judged postflight distance was:

1. directly related to the distance and time of preflight
2. inversely related to the angle of take-off
3. inversely related to the change in horizontal velocity on the board.
4. directly related to the horizontal take-off velocity.
5. inversely related to the vertical velocity on horse contact

No significant correlations were found between the main early phase variables and:

1. the postflight judged distance
2. the angular velocity of the body on leaving the horse

All vaulters were found to have a positive vertical velocity of the center of gravity on horse contact, and all but one vault exhibited an impulse by the gymnast on the horse.

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