MECHANICAL ANALYSIS OF "ARTISTIC AMPLITUDE" OF POSTFLIGHT IN THE HANDSPRING AND SALTO FORWARD TUCKED VAULT PERFORMED AT THE 1988 OLYMPICS

Y. Takei
Northern Illinois University, Dekalb, IL USA

With the current emphasis placed on the difficulty and originality aspects of gymnastic vault performances, reinforced by downgrading the base score for the existing vaults and simultaneously providing bonus points for new vaults. the amplitude of postflight has become increasingly important. Physical amplitude of postflight is considered a critical factor in learning advanced vaults because it provides the height. horizontal distance, and rime necessary to execute complex maneuvers in midair. Artistic amplitude is also important in enhancing the aesthetic aspects of the vault. For these reasons, it is not surprising that the Federation of International Gymnastics (1985) assigned 7.0 points out of 10.0 for the postflight phase. Of the remainder, 2.8 points are assigned to preflight and blocking, with 0.2 point set aside for demonstrated virtuosity. Although a breakdown of points for blocking is not available, it is generally considered to be of greater importance than preflight in determining the linear motions and trajectory of CG in postflight Once the gymnast is in the air after takeoff from the horse. body control and precise timing are crucial for successful performance of the salto forward and kickout. Furthermore, to achieve successful results, the moment of inertia of the body must be properly altered at the critical instants and height in space to maximize the body style of artistic expression and simultaneously to prepare for a controlled landing on the mat.

An in-depth study of blocking and postflight should provide meaningful and useful results because well over 70% of the total score awarded by judges is allotted for these two phases of the vault. Although a number of studies have been conducted on the handspring and salto forward tucked vault (see Figure 1), an important "common denominator" skill that provides an array of carry-over elements for advanced vaults and safety, none have focused specifically on the blocking technique and body control for salto forward and kickout prior to landing. The purpose of this study was to identify factors that govern successful performance of (a) blocking or pushoff against the horse with the arms and shoulders and (b) body control for somersault and kickout or rapid

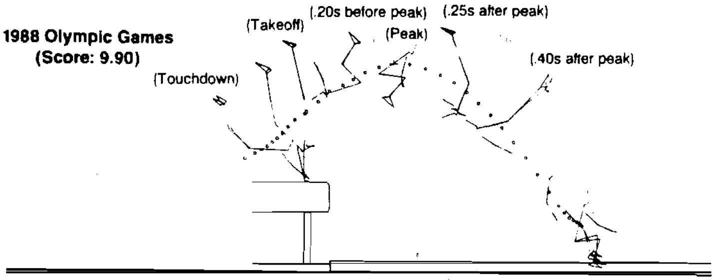

Figure 1. Selected positions and trajectory of the center of gravity of the highest scored handspring and salto forward tucked vault performed at the 1988 Olympic Games.

extension during postflight in the handspring and salto forward tucked vault which, according to Miwa (1984), in turn enhance the expression of artistic amplitude and earn virtuosity points. The hypothesis of this study was that some mechanical factors identified in the model were significantly correlated with successful performance of (a) the blocking and (b) the body control for salto forward and kickout in the handspring and salto forward tucked vault as rated by the judges.

METHODOLOGY

The method described by Hay and Reid (1988) was used to develop a deterministic model to identify mechanical factors governing successful performance of blocking and body control for somersault, kickout, and landing of the handspring and salto forward tucked vault. "Artistic amplitude" was not defined in the form of a deterministic model in this study because the precision required to define all of the factors in mechanical terms is nearly impossible. As an initial attempt to understand form or aesthetics, however, this study focused on the phases of the vault which were presented by Miwa (1984) to be most closely related to the expression of artistic amplitude.

The subjects were 51 male gymnasts from Bulgaria, Canada, China, East Germany, France, Hungary, Japan, Korea, Romania, Soviet Union, and West Germany participating in the 1988 Olympic Games. A 16-mm motion-picture camera filming at a nominal rate of 100 Hz was used to record each vaulter's performance, which included the preflight, horse contact, postflight, and landing. The filming was conducted during the actual competition in the men's compulsory session at the Games.

The x and y coordinates of 21 points defining a 14-segment model of the human body described by Clauser, McConville, and Young (1969) were recorded for each frame analyzed. These data were then used as input to a computer program designed to identify gross errors in the digitizing process. Any errors identified were corrected by interpolation or by re-digitizing. The data were then smoothed using a second-order polynomial square approximation to five data points as described by Wood (1982). Subsequently, the location of CG in each analyzed frame was computed using the segmental mass proportion and segmental CG location data of Clauser et al. (1969) and the basic segmental procedure described by Hay (1985) after which the angular momentum, impulses, average forces and other variables in the model were determined.

The data analysis consisted of (a) computation of the means and standard deviations of all the variables identified in the model and for which data could be collected, and (b) computation of the Pearson product-moment correlations between the judges' score and each of the above variables. In the present study, a correlation coefficient of .39 ($p < .005$) indicated a significant relationship. This meant that 15.2% of the variation in the judges' score could be accounted for by a variable that had a correlation coefficient of .39.

RESULTS AND DISCUSSION

It was found that, for the mechanical factors that are related to blocking, (a) the horizontal velocity at touchdown on the horse, (b) the vertical force and impulse exerted on the gymnast by the horse, and resulting change in vertical velocity while on the horse, (c) the time of contact with the horse, and (d) the horizontal and vertical velocities at takeoff from the horse are important determinants for successful performance (Table 1).

For the mechanical factors which are related to the body control for takeoff from the horse to full tuck, (a) the time taken and the horizontal distance traveled by CG after takeoff from the horse to reach peak of flight, (b) the upward vertical displacement or rise in CG from takeoff to the peak, and (c) the height of CG at the instant of the tightest tuck position during the salto forward were important factors in achieving successful results (see Table 1).

For the mechanical factors that are related to the body control from full tuck to landing on mat, (a) the horizontal distance travel by CG and the time taken from the tightest tuck position during the salto forward to landing and (b) the angular speed of body rotation from the full tuck to landing are important factors for successful performance of the vault (see Table 1).

Table 1. Descriptive Statistics and r Values with the Judges' Score for Variables in the Men's Compulsory Vault Performed at the 1988 Olympics

Variable	M	SD	Min	Max	r
V_H at horse TD, m/s	5.31	0.32	4.61	6.05	.49***
Vertical forces on horse, N	850.0	188.4	444.0	1236.0	.36*
Vertical forces/WT on horse	1.37	0.27	0.78	1.96	.45***
Vertical impulses on horse. Ns	39.1	26.7	-27.5	85.9	.40**
Change of V_V on horse. m/s	0.62	0.42	-0.47	1.41	.42**
Time on horse, s	0.19	0.03	0.14	0.23	-.41**
V_H at horse TO, m/s	3.56	0.25	2.94	4.11	.51***
V_V at horse TO, m/s	2.98	0.35	2.24	3.81	.55***
Time. TO to peak, s	030	0.04	0.23	039	.56***
Horizontal distance. TO to peak, m	1.08	0.17	0.79	159	.65***
Rise in CG, TO to peak, m	0.46	0.11	0.26	0.74	.54***
Height of CG at MinI, m	2.75	0.20	230	3.10	.49***
Horizontal distance. MinI to TD, m	1.62	0.41	0.90	2.65	.55***
Time. MinI to TD, s	0.45	0.10	0.27	0.69	.45***
Angular velocity, MinI to TD, deg/s	499.0	45.6	421.0	631.0	-.40**

V_H = Horizontal velocity; V_V = Vertical velocity; TD = Touchdown on horse; TO = Takeoff from horse; WT = Body weight of subject; MinI = Minimal moment of inertia $*p \leq .05$; $**p \leq .005$; $***p \leq .001$.

CONCLUSIONS

The above findings indicated that a large horizontal velocity at touchdown on the horse achieved by vigorously sprinting the approach run is an important prerequisite for successful performance. A blocking of forceful nature, applied over a brief period of time, is effective in developing a large vertical impulse, which in turn produces a large change of vertical velocity while on the horse. This enables the gymnast to depart from the horse with a large vertical velocity which in nun ensures a large upward vertical displacement resulting in a large trajectory of CG in postflight. Once in the air, during the salto forward, focus should be to alter the moment of inertia of the body in such a way that the full tuck position is achieved just before or as close as possible to the peak of flight. This maximizes the time and height available for the remainder of postflight including the kickout in midair, maintenance of the extended body position in flight, and preparation for landing. Effort should also be made to stretch the body fully, while well above the horse. and rotate it slowly as it travels a large horizontal distance to enhance the expression of artistic amplitude of postflight for virtuosity points. The small angular velocity thus achieved by early kickout well above the horse and the long-held extended body position as it travels a large horizontal distance during the descent phase of postflight not only contribute to the artistic amplitude but also provide a greater control for landing absorption of a large quantity of kinetic energy and impact force of landing over a longer distance.

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