On-horse mechanical differences between the handspring category vaults performed by elite gymnasts

Y. Takei
Northern Illinois University, DeKalb, IL e-mail: ytakei@niu.edu

Introduction
The handspring (HS) vault forms the basis for mastering the more advanced handspring and salto forward tucked (HSS) vault, which in turn provides the basis for learning the handspring and double salto forward tucked (Roche) vault with increased effectiveness and safety. The Roche is one of the most advanced and high-risk vaults seen in major competitions today. In fact, of the 48 Roche vaults attempted at the 2000 Olympic Games, only four gymnasts performed error-free, stick landings and more than a dozen committed major landing errors, which included kneeling, sitting, and rolling over due to lack of height and body control in post-flight. According to Hay and Reid (1988), faults or errors in performance revealed during the latter phase of a skill is likely to be caused by the performance of the earlier phases. This means that the outcome of post-flight performance is largely influenced by what took place during the preceding on-horse phase. Therefore, the pre-flight and on-horse mechanical variables have important causal influence on the subsequent post-flight phase and overall performance of a vault. The purpose of this study was to identify the on-horse mechanical variables that are crucial in achieving successful transition from the basic HS vault to a more advanced HSS vault.

Methods
The subjects were 40 male gymnasts performing the HS vault at the 1987 Pan American Games and 51 male gymnasts performing the HSS vault at the 1988 Olympic Games. The vaults were filmed using a 16-mm camera operating at 100 Hz. Approximately 50 frames were digitized for each vault. The horizontal and vertical 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. A theoretical model was developed to identify the mechanical variables that determine the linear and angular motions of the vaults. The data analysis consisted of the computation of the means and standard deviations of the variables identified in the model. In conducting t tests for comparison of the variables between the two groups, a value of P < .005 was chosen to indicate significance and to control the potential increase in Type I error rate as a result of conducting multiple tests.

Results & Discussion
The results of t tests indicated that the HSS vault, compared to the HS vault, had significantly: (1) greater horizontal and vertical velocities, greater normalized somersaulting angular momentum, and lower body center of mass (CM) at touchdown on the horse; (2) shorter time of hand contact, smaller horizontal displacement of body CM, and greater vertical displacement of CM on the horse; (3) greater average horizontal and vertical forces exerted and greater horizontal and vertical impulses exerted while on the horse; (4) greater change in the horizontal and vertical velocities on the horse and smaller change in the normalized somersaulting angular momentum on the horse; and (5) greater vertical velocity and normalized somersaulting angular momentum at take-off from the horse. Based on the results of the study, successful transition from the basic handspring vault to the handspring and salto forward tucked vault is most likely when the focus is on achieving: (1) large horizontal and vertical velocities, large somersaulting angular momentum, and low body CM at touchdown on the horse by a) sprinting the approach and contacting the board with the arms held above the shoulders, b) elevating and protracting the shoulder girdle, stretching the arms fully over the head toward the horse, c) exerting the force in downward and backward direction through the point of contact on the board, and d) reaching quickly and directly toward the mid-section of the horse with the hands (flexion of the humerus) upon take-off from the board; (2) large change in the horizontal and vertical velocities and small change in the somersaulting angular momentum on the horse by blocking and
pushing off the horse forcefully and quickly in downward and forward direction (while the body CM moves a large vertical distance and small horizontal distance during a brief duration of on-horse phase), using the muscles of the shoulder girdle (protraction and elevation), shoulder joint (flexion), elbow (stabilization), and wrist (flexion) during the take-off; and, consequently, (3) large vertical velocity and large somersaulting angular momentum at take-off from the horse. These actions ensure great height, long duration of time, and maximum control for somersaulting rotation in post-flight that the judges seek in awarding bonus points.

**Descriptive Statistics and t Values of Horse Touchdown, On-Horse, and Horse Take-off Variables in Two Handspring Category Vaults Performed by Elite Gymnasts**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Handspring and salto forward tucked vaults (n = 51)</th>
<th>Handspring vaults (n = 40)</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>CM height at TD, m</td>
<td>$1.81 \pm 0.06$</td>
<td>$1.90 \pm 0.10$</td>
<td>4.93**</td>
</tr>
<tr>
<td>$V_H$ of CM at TD, m/s</td>
<td>$5.31 \pm 0.31$</td>
<td>$5.04 \pm 0.40$</td>
<td>3.46**</td>
</tr>
<tr>
<td>$V_V$ of CM at TD, m/s</td>
<td>$2.36 \pm 0.41$</td>
<td>$2.08 \pm 0.51$</td>
<td>2.88*</td>
</tr>
<tr>
<td>H at TD, 1/s</td>
<td>$0.53 \pm 0.03$</td>
<td>$0.438 \pm 0.04$</td>
<td>12.00**</td>
</tr>
<tr>
<td>Time on Horse, m</td>
<td>$0.19 \pm 0.02$</td>
<td>$0.22 \pm 0.03$</td>
<td>6.14**</td>
</tr>
<tr>
<td>$d_H$ of CM on horse, m</td>
<td>$0.76 \pm 0.09$</td>
<td>$0.88 \pm 0.12$</td>
<td>5.35**</td>
</tr>
<tr>
<td>$d_V$ of CM on horse, m</td>
<td>$0.58 \pm 0.06$</td>
<td>$0.51 \pm 0.09$</td>
<td>4.37**</td>
</tr>
<tr>
<td>Normalized $F_H$ on horse</td>
<td>$-1.02 \pm 0.21$</td>
<td>$-0.68 \pm 0.20$</td>
<td>8.04**</td>
</tr>
<tr>
<td>Normalized $F_V$ on horse</td>
<td>$1.37 \pm 0.27$</td>
<td>$1.08 \pm 0.14$</td>
<td>6.65**</td>
</tr>
<tr>
<td>Horizontal Impulse on Horse, Ns</td>
<td>$-110.57 \pm 23.55$</td>
<td>$-86.50 \pm 27.30$</td>
<td>4.43**</td>
</tr>
<tr>
<td>Vertical Impulse on Horse, Ns</td>
<td>$39.14 \pm 26.74$</td>
<td>$9.69 \pm 19.70$</td>
<td>6.05**</td>
</tr>
<tr>
<td>Change of $V_H$ of CM on horse, m/s</td>
<td>$-1.75 \pm 0.30$</td>
<td>$-1.39 \pm 0.40$</td>
<td>4.73**</td>
</tr>
<tr>
<td>Change of $V_V$ of CM on horse, m/s</td>
<td>$0.62 \pm 0.42$</td>
<td>$0.16 \pm 0.30$</td>
<td>6.05**</td>
</tr>
<tr>
<td>Change of H on horse, 1/s</td>
<td>$-0.170 \pm 0.034$</td>
<td>$-0.207 \pm 0.048$</td>
<td>4.13**</td>
</tr>
<tr>
<td>$V_V$ of CM at TO, m/s</td>
<td>$2.98 \pm 0.35$</td>
<td>$2.23 \pm 0.61$</td>
<td>6.84**</td>
</tr>
<tr>
<td>H at TO, 1/s</td>
<td>$-0.361 \pm 0.025$</td>
<td>$-0.231 \pm 0.025$</td>
<td>24.66**</td>
</tr>
</tbody>
</table>

CM = Center of mass; TD = Touchdown on horse; $V_H$ = Horizontal velocity; $V_V$ = Vertical velocity; H = Normalized angular momentum; $d_H$ = Horizontal displacement; $d_V$ = Vertical displacement; $F_H$ = Horizontal Force; $F_V$ = Vertical Force; TO = Take-off from horse; *$P < .005$; **$P < .001$

**References**
Figure - The shown are the highest-scoring handspring and salto forward tucked vault (upper, 9.90 points) and the handspring vault (lower, 9.90 points) from the 1988 Olympic Games and the 1987 Pan American Games, respectively.