A KINEMATIC ANALYSIS OF THE HANDSPRING DOUBLE SALTO FORWARD TUCKED ON A NEW STYLE OF VAULTING TABLE

Matjaž Ferkolj

University of Ljubljana, Faculty of Sport, Slovenia

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Abstract

At the 2001 world championships in Ghent, the FIG (The International Federation of Gymnastics) replaced the traditional horse with a new vaulting table. The new style table is wider and has a more elastic surface. This has resulted in an increase in the number of male gymnasts performing the forward handspring double salto tucked.. This study aimed to determine important kinematic variables during specific phases of the vault (trajectories, time, velocity, angular velocity, angles) that influence the quality of the handspring double salto forward tucked (Roche). The sample consisted of gymnasts that performed the handspring double salto forward tucked at the 2002 World Championship in Debrecen (N=9). Statistical analyses were carried out using SPSS 15.0, 98 kinematic variables were identified, we reported the most important variables identified during the handspring double salto forward tucked movement.. The handspring forward double salto tucked is becoming a basic element on which new derivations of vaulting movements are based (i.e. piked position, or with turns); it is therefore essential to understand its parameters. The results from this study provide useful information for competitors, coaches, and judges.

Keywords: *artistic gymnastics, vault, table, biomechanics, handspring, double salto tucked.*

INTRODUCTION

In competitive gymnastics, gymnasts can choose from five families of vaults: direct vaults (without passing handstand); vaults with a turn in the first flight phase; forward handspring, where the gymnast puts his hands directly forward onto the table; Tsukahara vault, where the gymnast completes a half twist before pushing off the table; and the Yurchenko style vault, where the gymnast does a round off onto the springboard and a backward handspring onto the table.

At the 2001 World Championships in Ghent the FIG (FIG, 2001) replaced the traditional style horse with a new style of vaulting table (Figure 1). This is the biggest change in gymnastics apparatus since the introduction of pre-tensioned apparatus in the 1950's.

The vaulting table is 95 cm wide and 95 to 105 cm long and 135 cm high. Wider and shorter tables are safer (McNeal, 2003). The upper area of the table is slightly inclined (5 degrees). The elastic characteristics of the new table has more advantages than the old style horse, with the wider and slightly inclined support area providing better support for the arms during take-off (Figure 2) (McNeal, 2003; Čuk and Karacsony, 2004).

Following the introduction of the new vaulting table, the number of male gymnasts who decided to perform the handspring double salto tucked has increased.

Several studies involving the vault have been carried out (Prassas, 2002; Sands, Caine, Borms, 2003; Penitente, Merni, Fantozzi and Franceshetti,2006), however few of these studies have examined the kinematics of the handspring vault, and none of them analyzed the vault handspring double salto forward tucked on the new vaulting table. Aim of the research was to do kinematic analyse of handspring double salto forward tucked on new vaulting table. The vaulting sequence was divided into seven phases: run, jump on springboard, springboard support phase, first flight, support on the table, second flight, and landing. In modern gymnastics the handspring double salto forward tucked is becoming the primary jump. Handspring double salto forward tucked is the base for further development with different body position and added turns. Therefore it is important to know the biomechanical characteristics of this movement.

Figure 1. *Vaulting table (Jenssen&Fritsen, 2003)*

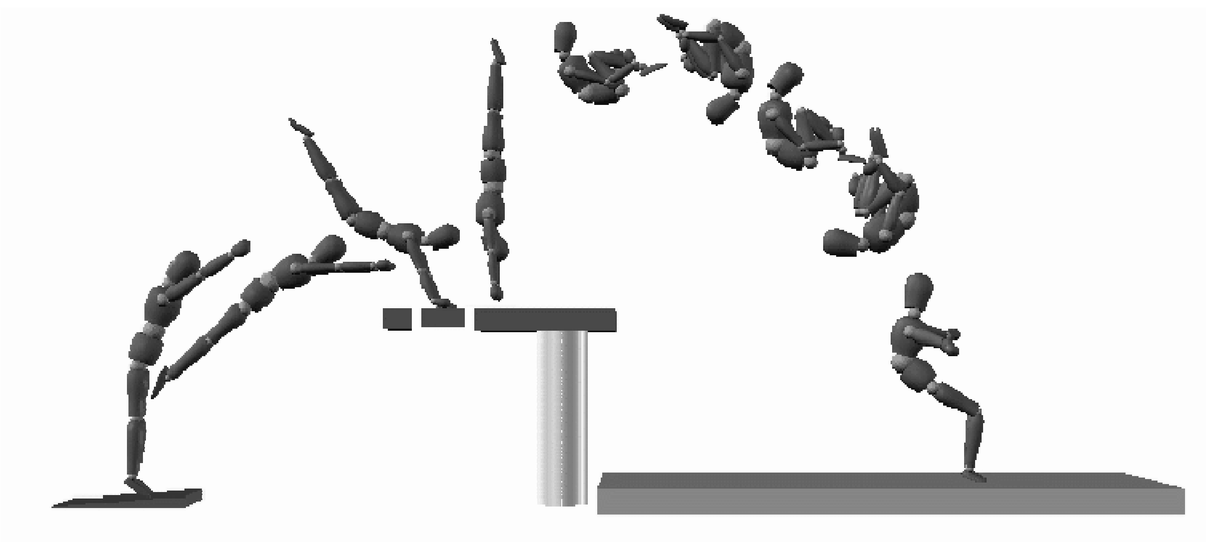

Figure 2. *Handspring and double salto forward tucked (Čuk and Karacsony, 2004)*

The first phase is a sprint towards the vault. This is an important phase because the following phases are dependent on it (Čuk, Bricelj, Bučar, Turšič and Atiković, 2007). The FIG`s Code of Points (FIG, 2006) states that the distance of the run for male gymnasts is 25 meters, measured from the edge of the table. After considering the springboard take-off and flight, this leaves gymnasts with 20 meters to make their approaching sprint. Most gymnasts cover this distance in 13 to 14 steps (Čuk and Karacsony, 2004). A fast approach sprint can be translated into horizontal velocity, combined with a successful take-off to result in a good vaulting movement. This research did not examine the first phase of the vaulting movement.

The jump on the springboard must be completed with minimum loss of sprint speed. Higher sprint speed can be maintained if the gymnast focuses their attention on the sprinting phase and not the vault ahead (Prassas, 2002). This has been shown through research carried out by Usenik (2006) with fourteen elite gymnasts. Čuk and Karacsony (2004) found that top gymnasts spent only 0.24 seconds to complete the take-off phase on the springboard following the sprint approach. In our research we didn`t investigate this phase in detail.

The others phases are represented in the results and discussion.

METHODS

The study sample consisted of elite gymnasts (n=9) that performed the handspring and double salto forward tucked at the 2002 World Championships in Debrecen.

Kinematic analysis was using the APAS-Ariel performance analyses system (Ariel Dynamics Inc., SanDiego, Ca). We used Sušanka, Otahal and Karas (1987) 15-segment body model defined with 17 points. All jumps were recorded during the competition using two orthogonal SVHS cameras at 50 frames per second. All data were smoothed with a digital filter of range 7. We calculated trajectories, velocities, time and angles of important positions in following phases of the vault: support on springboard, the first flight, support on the apparatus, the second flight, and landing. We identified 98 variables in total and have reported the most important ones. In results and discussion mean values are shown.

Statistic analysis was carried out using SPSS (Statistical package for the social sciences, 12.0, Chicago, IL, USA). For each variable we calculated descriptive statistics including mean, standard deviation, standard error, and minimum and maximum values.

RESULTS AND DISCUSSION

We divided the vault into seven phases. From these phases nine important positions have been identified positions for our analysis:

1. Touch down on springboard
2. Take off from the springboard
3. Touch down on table
4. Take off from the table
5. Maximum tuck position in salto
6. Maximum height of body center of gravity (BCG)
7. Finished first salto
8. Finished second salto
9. First contact at landing

Springboard support position

With our research we wanted to show kinematic variables at: springboard support phase, first flight, support on the table, second flight and landing.

Table 1. *Touch down on springboard*

	hBCGtds [m]	ltds [m]	ttos [s]	Vxtds [m/s]	Vytds [m/s]	Vxyztds [m/s]	stds [deg.]	etds [deg.]	htds [deg.]	ktds [deg.]	tttds [deg.]
X	**0.978**	**0.337**	**0.102**	**7.967**	**1.113**	**8.049**	**107.2**	**126.5**	**103.0**	**144.9**	**69.7**
MAX	1.059	0.496	0.120	8.350	1.350	8.459	124.2	147.5	111.9	158.9	73.2
MIN	0.912	0.100	0.100	7.575	0.725	7.624	95.3	83.7	92.6	135.6	65.9
SD	0.039	0.112	0.007	0.283	0.236	0.298	10.4	21.7	5.9	7.6	2.5
SE	0.070	0.118	0.029	0.188	0.172	0.193	1.1	1.6	0.9	1.0	0.6

hBCGtds – height of the BCG at touch down on springboard
ltds – distance from toes to the end of the springboard
ttos – time of take off from the springboard
Vxtds – BCG velocity in x axis at touch down on springboard
Vytds – BCG velocity in y axis at touch down on springboard
Vxyztds – BCG velocity in xyz axis at touch down on springboard
stds – shoulder angle at touch down on springboard
etds – elbow angle at touch down on springboard
htds – hip angle at touch down on springboard
ktds – knee angle at touch down on springboard
tttds – angle between trunk and x axis at touch down on springboard

The height of the gymnasts BCG at touch down on the springboard is 0.978 m (measured from the floor). Distance from toes to the end of springboard is 0.337 m. This is similar to previous findings from Čuk and Karacsony (2004) that showed male gymnasts took off 34 cm from the end of springboard.

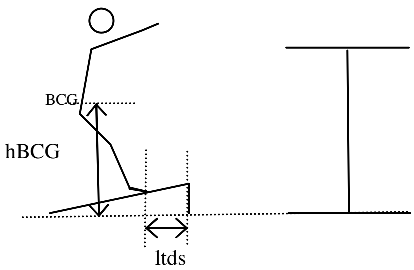

Figure 3. *Height of gymnasts BCG and distance from feet fingers to end of springboard at touch down on springboard*

Time of take off at springboard support phase is 0.102s. Velocity (in x axis) of gymnasts BCG at touch down on springboard is 7.967 m/s, velocity (in y axis) is 1.113 m/s, velocity (in xyz axises) is 8.049 m/s.

Shoulder angle at the moment of touch down on springboard is 107.2 degree, elbow angle is 126.5 degree, hip angle is 103.0 degree, knee angle is 144.9 degree, angle between trunk and x axis is 69.7 degree. Similar results for the angle between trunk and x axis were obtained by Prassas (2002) (handspring and Tsukahara vault), Pentiente et al (2006) (Yurchenko vault) and Takei (2007) (Handspring vault). After analyzing the angular kinematic data it is possible to deduct that the gymnasts used the hip joint and a body angle (angle between trunk and x axis) to generate a proper angular momentum. From the lower body angular data it is possible to conclude that the gymnasts don't use the hip joint for the take off actions (Penitente et al, 2006).

Lower angle of hip joint at the take off action could mean that the body is stiffer. Therefore the gymnasts can harness the elastic energy of the springboard.

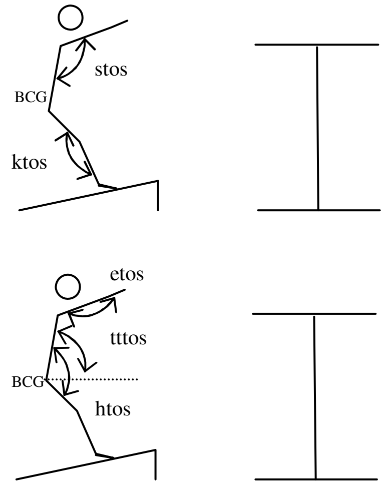

Figure 4. *Angles at the moment of touch down on springboard*

Table 2. *Take off from the springboard*

	hBCGtos [m]	Vxtos [m/s]	Vytos [m/s]	Vxyztos [m/s]	stos [deg.]	etos [deg.]	htos [deg.]	ktos [deg.]	tttos [deg.]
X	**1.165**	**5.042**	**4.654**	**6.868**	**142.2**	**165.6**	**139.4**	**172.7**	**45.6**
MAX	1.226	5.625	4.725	7.346	155.5	174.1	150.6	176.2	50.2
MIN	1.119	4.525	4.300	6.475	125.1	153.2	129.7	165.5	37.8
SD	0.032	0.328	0.138	0.244	10.3	6.2	7.1	3.3	3.9
SE	0.063	0.202	0.131	0.175	1.1	0.9	0.9	0.6	0.7

hBCGtos – height of the BCG at take off from the springboard
Vxtos – BCG velocity in x axis at take off from the springboard
Vytos – BCG velocity in y axis at take off from the springboard
Vxyztos – BCG velocity in xyz axis at take off from the springboard
stos – shoulder angle at take off from the springboard
etos – elbow angle at take off from the springboard
htos – hip angle at take off from the springboard
ktos – knee angle at take off from the springboard
tttos – angle between trunk and x axis at take off from the springboard

The mean height of the gymnasts BCG (body centre of gravity) at take off from the springboard was 1.165 m. Velocity (in x axis) of gymnasts BCG at touch down on the springboard was 5.042 m/s. velocity (in y axis) is 4.654 m/s, velocity (in xyz) is 6.868 m/s. From the analyses it is possible to affirm that during the springboard phase gymnasts exploit the decrease in the horizontal velocity to increase the vertical component of the velocity. This is essential for a successful contact with the table, and to set up the following phases of the vault properly (Penitente et al, 2006). The vertical component initially decreases the vertical velocity and subsequently generates the upward velocity. Such combination of the velocity is required, so that the gymnast has sufficient angular and radial velocity and sufficient body angle. With regard to rotation, the vertical force promotes angular momentum only when the BCG passes over the base of support (feet) (Prassas, 2002).

The mean shoulder angle at the moment of take off from the springboard was 142.2 degrees, the mean elbow angle was 165.6 degrees, the mean hip angle was 139.4 degrees, the knee angle was 172.7 degrees, and the mean angle between the trunk and the x axis was 45.6 degrees.

The first flight

Table 3. *The first flight*

	dft [m]	tff [s]
X	**1.555**	**0.136**
MAX	1.819	0.160
MIN	1.279	0.100
SD	0.191	0.024
SE	0.155	0.055

dft – distance from feet fingers to touch down on table
tff – time of first flight

Distance from the toes on springboard to touch down on the table is 1.555 m. The mean time of first flight was 0.136 s.

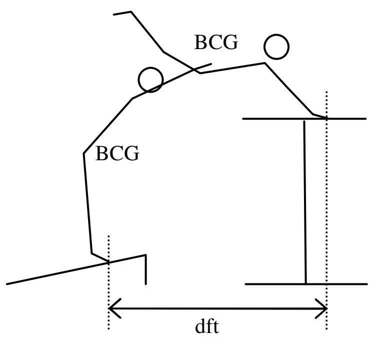

Figure 5. *Distance from the feet fingers on springboard to touch down on the table*

The time of the first flight depends on the relationship between horizontal and vertical velocity (Prasas, 2002). The time of the first flight also depends on the type of vault. The shortest first flight times are recorded on the Tsukahara vault, followed by the Yurchenko and handspring vault. The longest time of the first flight are recorded when turns are carried out in the first flight (Čuk, Karacsony, 2004).

Table 4. *Time of first flight (World Championship in Debrecen 2002) (Čuk and Karacsony, 2004)*

Vault	**Time [s]**	**N**
Tsukahara vault	0.06	37
Handspring vault	0.10	27
Yurchenko vault	0.13	11
Nemov vault	0.10	2
AVERAGE	***0.09***	***77***

S*upport on the table*

Table 5. *Touch down on the table*

	hBCGtdt [m]	**wstdt [m]**	**wwtdt [m]**	**tst [s]**	**Vxtdt [m/s]**	**Vytdt [m/s]**	**Vxyztdt [m/s]**	**stdt [deg.]**	**etdt [deg.]**	**htdt [deg.]**	**ktdt [deg.]**	**tttdt [deg.]**	**ahttdt [deg.]**	**atBCGtdt [deg.]**
X	**1.710**	**0.429**	**0.439**	**0.162**	**5.229**	**3.267**	**6.175**	**114.7**	**166.3**	**152.3**	**153.7**	**15.4**	**47.0**	**25.0**
MAX	1.799	0.451	0.490	0.180	5.575	3.650	6.320	133.5	176.0	167.2	177.1	24.5	55.7	33.1
MIN	1.558	0.404	0.325	0.140	4.500	2.475	5.642	101.6	152.1	132.7	121.6	4.4	38.2	15.5
SD	0.083	0.015	0.054	0.012	0.307	0.364	0.212	13.0	8.1	11.9	17.9	7.5	7.1	6.7
SE	0.102	0.043	0.082	0.039	0.196	0.213	0.163	1.3	1.0	1.2	1.5	1.0	0.9	0.9

hBCGtdt – height of the BCG at touch down on the table
wstdt – width of shoulders at touch down on the table
wwtdt – width of wrist at touch down on the table
tst – time of support on the table
Vxtdt – BCG velocity in x axis at touch down on the table
Vytdt – BCG velocity in y axis at touch down on the table
Vxyztdt – BCG velocity in xyz axis at touch down on the table
stdt – shoulder angle at touch down on the table
etdt – elbow angle at touch down on the table
htdt – hip angle at touch down on the table
ktdt – knee angle at touch down on the table
tttdt – angle between trunk and x axis at touch down on the table
ahttdt – angle between hand and table at touch down on the table
atBCGtdt – angle between table and BCG at touch down on the table

The mean height of the gymnasts' BCG at touch down on the table was 1.710 m, the width of the shoulders at touch down on the table was 0.429 m, width of the wrists was 0.439 m. As we expected, on the new vaulting table the gymnast's arms were almost parallel and orthogonal; this is the most efficient support position, generating higher take off power.

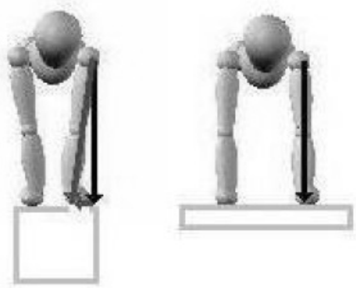

Figure 6. *Support position on old horse (left), support position on new vaulting table (right) (Čuk, Karacsony, 2004)*

The average time gymnasts spent in the support position was 0.162 seconds.

Table 6. *The time of support on the table (World Championship in Debrecen 2002) (Čuk andKaracsony, 2004)*

Vault	Time [s]	N
Handspring vault	0.19	27
Tsukahara vault	0.26	37
Yurchenko vault	0.21	11
Nemov vault	0.20	2
Average	***0.23***	***77***

Velocity (in x) of gymnast's BCG at the moment of support on the table was 5.229 m/s, velocity (in y) was 3.267 m/s, and the velocity (in xyz) was 6.175 m/s.

Shoulder angle at the moment of support on the table was 114.7 degree, the elbow angle was 166.3 degrees, the hip angle was 152.3 degrees, the knee angle was 153.7 degrees, the angle between the trunk and the x axis was 15.4 degree, the angle between the hand and table was 47.0 degree, the angle between the table and the BCG was 25.0 degree.

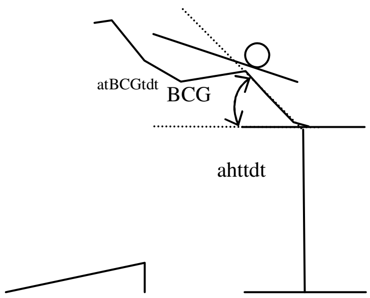

Figure 7: *Angle between hand and table and angle between table and BCG*

Table 7. *Take off from the table*

	hBCGtot [m]	Vxtot [m/s]	Vytot [m/s]	Vxyztot [m/s]	stot [deg.]	etot [deg.]	htot [deg.]	ktot [deg.]	tttot [deg.]	ahttot [deg.]	atBCGtot [deg.]
X	**2.317**	**3.929**	**4.146**	**5.724**	**145.3**	**167.6**	**160.8**	**139.5**	**108.9**	**99.5**	**86.0**
MAX	2.402	4.675	4.425	6.235	163.2	174.0	173.5	167.8	130.6	109.2	96.4
MIN	2.168	3.225	3.900	5.257	123.7	157.7	141.4	81.3	95.4	90.0	77.0
SD	0.075	0.438	0.183	0.286	13.2	6.2	10.3	27.0	11.1	8.3	6.6
SE	0.097	0.234	0.151	0.189	1.3	0.9	1.1	1.8	1.2	1.0	0.9

hBCGtot – height of the BCG at take off from the table
Vxtot – BCG velocity in x axis at take off from the table
Vytot – BCG velocity in y axis at take off from the table
Vxyztot – BCG velocity in xyz axis at take off from the table
stot – shoulder angle at take off from the table
etot – elbow angle at take off from the table
htot – hip angle at take off from the table
ktot – knee angle at take off from the table
tttot – angle between trunk and x axis at take off from the table
ahttot – angle between hand and table at take off from the table
atBCGtot – angle between table and BCG at take off from the table

The mean height of the gymnasts' BCG at take off from the table was 2.317 m. Velocity (in x) of gymnasts BCG at the moment of take off from the table was 3.929 m/s, velocity (in y) is 4.146 m/s, velocity (in xyz) is 5.724 m/s. From the table we can see that the velocity in x axis by the touch down on the table was higher, while at take off from the table the velocity in y axis was higher. This relationship between velocity components enables high take off, so that after the jump the gymnast can always land on his legs.

Shoulder angle at the moment of take off from the table is 145.3 degree, elbow angle is 167.6 degree, hip angle is 160.8 degree, knee angle is 139.5 degree, angle between trunk and x axis is 108.9 degree, angle between hand and table is 99.5 degree, angle between table and BCG is 86.0 degree.

Studies have shown Prassas (2002), Takei (2007), Čuk and Ferkolj (2007) that it is within a gymnast`s capability to increase the angular momentum during this phase. This requires a slightly different body position, specifically greater shoulder joint extension and a smaller hip joint angle at the vaulting table contact phase, as well as a higher angular velocity at vaulting table impact (Prassas, 2002).

The second flight

Table 8. *Maximum tuck position*

	hBCGmtp [m]	dsf [m]	tomtp [m]	tsf [s]	Vxmtp [m/s]	Vymtp [m/s]	Vxyzmtp [m/s]	smtp [deg.]	emtp [deg.]	hmtp [deg.]	kmtp [deg.]	ttmtp [deg.]
X	**2.957**	**4.241**	**0.230**	**1.056**	**3.629**	**1.633**	**4.006**	**46.6**	**138.7**	**36.5**	**46.0**	**141.8**
MAX	3.053	4.913	0.240	1.080	4.550	2.100	4.757	56.4	154.1	43.3	52.5	159.8
MIN	2.810	3.879	0.220	1.000	3.025	1.050	3.344	34.6	115.1	27.150	37.400	130.6
SD	0.067	0.428	0.011	0.024	0.467	0.291	0.424	6.8	14.1	4.744	5.794	9.8
SE	0.091	0.207	0.036	0.055	0.242	0.191	0.230	0.9	1.3	0.770	0.851	1.1

hBCGmtp – height of the BCG at maximum tuck position
dsf – distance of second flight
tomtp – time from take off from the table to maximum tuck position
tsf – time of second flight
Vxmtp – BCG velocity in x axis at maximum tuck position
Vymtp – BCG velocity in y axis at maximum tuck position
Vxyzmtp – BCG velocity in xyz axis at maximum tuck position
smtp – shoulder angle at maximum tuck position
emtp – elbow angle at maximum tuck position
hmtp – hip angle at maximum tuck position
kmtp – knee angle at maximum tuck position
ttmtp – angle between trunk and x axis at maximum tuck position

The mean height of the gymnasts' BCG at maximum tuck position was 2.957 m. The mean distance of the second flight (from support position to landing) was 4.241 m. The mean duration of the second flight was 1.056 s.

The duration of the second phase and the maximum height of the vault are dependant on the vertical velocity (y axe) at take off from the table. Greater vertical velocity results in a longer flight time and therefore a higher vaulting movement.

The time from take off from the table to maximum tuck position is 0.230 second.

Analyses from Čuk and Karacsony (2004) gave similar results.

Velocity (in x axis) of gymnasts BCG at the moment of maximum tuck position is 3.629 m/s, velocity (in y axis) is 1.633 m/s, velocity (in xyz) is 4.006 m/s.

Shoulder angle at the moment of maximum tuck position is 46.6 degree, elbow angle is 138.7 degree, hip angle is 36.5 degree, knee angle is 46.0 degree, angle between trunk and x axis is 141.8 degree. Similar results were obtained also by Takei (2007).

Table 9. *Maximum height of BCG*

	hBCGmh [m]	Vxmh [m/s]	Vymh [m/s]	Vxyzmh [m/s]	smh [deg.]	emh [deg.]	hmh [deg.]	kmh [deg.]	ttmh [deg.]
X	**3.125**	**3.725**	**0.100**	**3.735**	**36.0**	**118.2**	**50.7**	**55.8**	**101.8**
MAX	3.234	4.275	0.200	4.294	43.1	137.9	62.0	61.3	141.0
MIN	3.028	2.875	0.000	2.878	27.5	93.4	36.3	49.4	76.5
SD	0.070	0.436	0.073	0.441	5.3	11.7	8.2	3.4	21.3
SE	0.093	0.233	0.095	0.235	0.8	1.2	1.0	0.6	1.6

hBCGmh – height of the BCG at maximum high of BCG
Vxmh – BCG velocity in x axis at maximum high of BCG
Vymh – BCG velocity in y axis at maximum high of BCG
Vxyzmh – BCG velocity in xyz axis at maximum high of BCG
smh – shoulder angle at maximum high of BCG
emh – elbow angle at maximum high of BCG
hmh – hip angle at maximum high of BCG
kmh – knee angle at maximum high of BCG
ttmh – angle between trunk and x axis at maximum high of BCG

The mean maximum height recorded for a gymnast's BCG was 3.125 m.

The velocity (in x axis) of the gymnast's BCG at the highest point was 3.725 m/s, velocity (in y axis) was 0.100 m/s, and velocity (in xyz) was 3.735 m/s.

The shoulder angle at the highest point of the vaulting movement was 36.0 degrees the elbow angle was 118.7 degrees, the hip angle was 50.7 degree, the knee angle was 55.8 degree, and the angle between the trunk and x axis was 101.8 degrees.

Table 10. *Finished the first salto*

	hBCGfs [m]	ttofs [s]	Vxfs [m/s]	Vyfs [m/s]	Vxyzfs [m/s]	sfs [deg.]	efs [deg.]	hfs [deg.]	kfs [deg.]	ttfs [deg.]
X	**3.098**	**0.480**	**3.979**	**0.438**	**3.847**	**42.2**	**111.4**	**49.3**	**48.6**	**87.9**
MAX	3.209	0.500	4.750	1.075	4.753	46.7	125.9	91.7	54.0	94.2
MIN	2.995	0.460	3.075	0.125	3.141	34.9	91.0	34.3	39.1	80.5
SD	0.072	0.013	0.600	0.260	0.492	3.7	11.4	16.7	5.1	4.7
SE	0.095	0.041	0.274	0.180	0.248	0.7	1.2	1.4	0.8	0.8

hBCGfs – height of the BCG at finished first salto
ttofs – time from take off from the table to finished first salto
Vxfs – BCG velocity in x axis at finished first salto
Vyfs – BCG velocity in y axis at finished first salto
Vxyzfs – BCG velocity in xyz axis at finished first salto
sfs – shoulder angle at finished first salto
efs – elbow angle at finished first salto
hfs – hip angle at finished first salto
kfs – knee angle at finished first salto
ttfs – angle between trunk and x axis at finished first salto

Height of the gymnast BCG at finished first salto is 3.098 m.

The time from take off from the table to finished first salto is 0.480 second.

Velocity (in x axis) of gymnasts BCG at the moment of finished first salto is 3.979 m/s, velocity (in y axis) is 0.438 m/s, velocity (in xyz) is 3.847 m/s.

Shoulder angle at the moment of finished first salto is 42.2 degree, elbow angle is 111.4 degree, hip angle is 49.3 degree, knee angle is 48.6 degree, angle between trunk and x axis is 87.9 degree.

Table 11. *Finished the second salto*

	hBCGss [m]	ttoss [s]	Vxss [m/s]	Vyss [m/s]	Vxyzss [m/s]	sss [deg.]	ess [deg.]	hss [deg.]	kss [deg.]	ttss [deg.]
X	**2.294**	**0.807**	**3.717**	**3.675**	**5.244**	**43.4**	**101.9**	**40.1**	**51.6**	**90.8**
MAX	2.528	0.860	4.575	4.375	6.031	52.1	117.1	50.7	59.4	97.2
MIN	2.069	0.760	3.375	3.250	4.953	36.3	80.6	30.6	38.4	81.7
SD	0.162	0.032	0.410	0.342	0.385	4.7	10.9	5.7	6.9	5.3
SE	0.142	0.063	0.226	0.207	0.219	0.8	1.2	0.8	0.9	0.8

hBCGss – high of the BCG at finished second salto
ttoss – time from take off from the table to finished second salto
Vxss – BCG velocity in x axis at finished second salto
Vyss – BCG velocity in y axis at finished second salto
Vxyzss – BCG velocity in xyz axis at finished second salto
sss – shoulder angle at finished second salto
ess – elbow angle at finished second salto
hss – hip angle at finished second salto
kss – knee angle at finished second salto
ttss – angle between trunk and x axis at finished second salto

High of the gymnast BCG at finished second salto is 2.294 m.

The time from take off from the table to finished second salto is 0.807 second.

Velocity (in x axis) of gymnasts BCG at the moment of finished second salto is 3.717 m/s, velocity (in y axis) is 3.675 m/s, velocity (in xyz) is 5.244 m/s.

Shoulder angle at the moment of finished second salto is 43.4 degree, elbow angle is 101.9 degree, hip angle is 40.1 degree, knee angle is 51.6 degree, angle between trunk and x axis is 90.8 degree.

Table 12. *Average velocity of rotation*

	Vfs [degrees/s]	Vss [degrees/s]	Vl [degrees /s]
X	**800.5**	**1104.5**	**693.2**
MAX	822.9	1200.0	820.9
MIN	728.0	1000.0	605.0
SD	29.5	64.1	86.0
SE	1.9	2.8	3.3

Vfs – from take off from table to finished first salto
Vss – from finished first salto to finished second salto
Vl – from finished second salto to first contact at landing

From the take off from the table to finished first salto is angular velocity 800.5 degree/second, from the finished first salto to finished second salto is angular velocity 1104.5 degree/second, and from finished second salto to first contact at landing is angular velocity 693.2 degree/second.

During the final phase (in table 12, variable Vl) the gymnast stretch his legs in hip and knee joints and with this he increases the moment of inertia. This is the reason for lower angular velocity.

Table 13. *Comparison of angular velocity between different saltos*

VAULT	AVERAGE ANGULAR VELOCITY [degree/second]	Author
VAULT – Handspring double salto forward tucked	843	Takei, 2007
FLOOR – Double salto forward tucked	838	Štuhec, 2001
RINGS – Triple salto backward tucked	1000	Držaj, 2001
FLOOR – Double salto backward tucked	665	Ferkolj, 2000; Čuk and Ferkolj, 2000
FLOOR – Triple salto backward tucked	853	Ferkolj, 2000; Čuk and Ferkolj, 2000

Landing (the first contact on the mat)

Table 14. *Landing – the first contact on the mat*

	hBCGl [m	Vxl [m/s]	Vyl [m/s]	Vxyzl [m/s]	sl [deg.]	el [deg.]	hl [deg.]	kl [deg.]	ttl [deg.]	atBCGl [deg.]
X	**1.045**	**3.588**	**5.783**	**6.816**	**59.8**	**98.3**	**137.7**	**133.0**	**108.3**	**52.3**
MAX	1.210	4.200	6.609	7.230	82.8	120.9	165.0	152.4	130.8	74.6
MIN	0.921	2.675	5.300	6.257	38.5	71.3	98.5	94.1	72.9	35.3
SD	0.104	0.455	0.432	0.352	15.4	17.2	22.2	19.6	19.5	12.7
SE	0.114	0.239	0.232	0.210	1.4	1.5	1.7	1.6	1.6	1.3

hBCGl – height of the BCG at finished second salto
Vxl – BCG velocity in x axis at finished second salto
Vyl – BCG velocity in y axis at finished second salto
Vxyzl – BCG velocity in xyz axis at finished second salto
sl – shoulder angle at finished second salto
el – elbow angle at finished second salto
hl – hip angle at finished second salto
kl – knee angle at finished second salto
ttl – angle between trunk and x axis at finished second salto
atBCGl – angle between floor and BCG at first contact on the floor

The height of the gymnast's BCG at the moment of the first contact on the mat is 1.045 m.

Velocity (in x axis) of gymnasts BCG at the moment of the first contact on the floor is 3.588 m/s, velocity (in y axis) is 5.783 m/s, velocity (in xyz) is 6.816 m/s.

Shoulder angle at the moment of the first contact on the floor is 59.8 degree, elbow angle is 98.3 degree, hip angle is 137.7 degree, knee angle is 133.0 degree, angle between trunk and x axis is 108.3 degree, angle between feet fingers and BCG is 52.3 degree.

CONCLUSIONS

The handspring double salto tuck is one of the top elements of the vault and has become a basic element within vaulting routines, on which other movements are based. Vaults with piked body positions and turns have also been performed. Coaches should therefore be familiar with the biomechanical breakdown of these movements. Coaches that are coaching elite gymnasts should emphasise the following points:

- fast approach sprint,
- correct feet position on springboard (few gymnasts use the optimal position of feet on springboard),

- maximum active extension in handstand at the point of take off from the apparatus,
- very fast tucking after take off from apparatus,
- as the angular velocity of rotation is very high it is essential for gymnasts to gain appropriate motor control (a good sense of height and body position) to prepare for landing.

This new apparatus allows less skilled gymnasts to perform the vault (improved arm position on apparatus), however the landing phase of the vault may still prove to be difficult for these gymnasts and caution must be taken when less skilled gymnasts use the vaulting apparatus.

For the development of new vaulting routines or to perform more difficult vaulting routines, gymnasts should increase approach sprint speed, increase take off speed from the springboard, and implement a faster bend during their vaulting routines.

REFERENCES

Čuk, I. and Ferkolj, S.M. (2000). Kinematics analysis of some backward acrobatic *jumps*. *Proceedings of XVIII. international symposium on biomechanics in sports (36-38)*. Hong Kong: The Chinese university of Hong Kong..

Čuk, I. and Karacsony, I. (2004) Vault: methods, ideas, curiosities, history. Ljubljana: ŠTD Sangvinčki

Čuk, I., Bricelj, A., Bučar, M., Turšič, B. and Atiković, A. (2007). Relations between start value of vault and runway velocity in top level male artistic gymnastics. *Zbornik naučnih i stručnih radova / II. Međunarodni simpozium nove tehnologije u sportu.* Sarajevo: Fakulteta sporta i tjelesnog odgoja.

Držaj, S. (2001). *Tehnika in metodika trojnega skrčenega salta nazaj s krogov.* Diplomsko delo. Ljubljana: Fakulteta za šport.

Ferkolj S.M. (2007). *Kinematics characteristics of handspring double salto forward tucked performed on horse and vaulting table.* Ljubljana, Fakulteta za šport.

FIG (2001) *Code of Points – Artistic Gimnastics for Men*. Moutier.

FIG (2006) *Code of Points – Artistic Gimnastics for Men.* Moutier.

Jenssen&Fritsen (2003). *The vault of the next generation*. http://www.gymmedia.com/jenssen-fritsen/.

McNeal, J. R. (2003) *Some guidelines on the transition from the old horse to the new table.* USA: Esteren Washington University.

Penitente, G., Merni, F., Fantozzi, S. and Franceschetti, F. (2006) *Yurchenko vault`s springboard phase*. University of Bologna: Faculty of exercise and sport science.

Prassas, S. (2002). *Vaulting mechanics*. USA: Colorado State Unversity.

Rand, T. (2003) *New vaulting table*. http://www.usa-gymnastics.org

Sands W.A., Caine, D.J., Borms, J. (2003). *Scientific Aspect of women's gymnastics*. Basel: Karger.

Sušanka, P., Otahal, S. and Karas, V. (1987) *Zaklady biomechanicky telesnyh cvičeni.* Praha: Universita Karlova.

Štuhec, S. (2001) *Kinematična analiza nekaterih akrobatskih prvin z rotacijo naprej okrog čelne in vzdolžne osi.* Diplomska naloga. Ljubljana: Fakulteta za šport.

Takei, Y. (2007) The Roche vault performed by elite gymnasts: Somersaulting technique, deterministic model and judges scores. *Journal of applied biomechanics, 23, (1), 1-1.*

Usenik, D. (2006). *Vpliv trajanja posameznih faz preskoka na njegovo izhodiščno vrednost v moški športni gimnastiki*. Diplomska naloga. Ljubljana: Faculty of sport.

Winter, A. D. (1990) *Biomechanics and motor control of human movement.* Waterloo: University of Waterloo.

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