TKACHEV SALTO ON HIGH BAR

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Abstract

With the new FIG Code of Points for men (2006) based on the philosophy of open ended difficulty score, point advantages have been given, again, to those who are in search for and willing to perform new elements. Each element in the Code of Points can be developed by changing its start and its final position, the start and the final grip with the apparatus, the body position during the element, by adding a flight phase or a rotation around the frontal, the longitudinal or the sagital axis. The Tkachev is quite an old release element (approximately 40 years old) on high bar. In line with the knowledge available to us today, we have been looking into the possibility of performing the Tkachev salto. Following series of biomechanical analysis with consideration of the gymnast's safety, we calculated that the Tkachev salto could be performed by those gymnasts who can perform the straight Tkachev with a high amplitude. Gymnast who will be able to perform the Tkachev salto at a major competition will enter the gymnastics history and have huge chances of wining the most prestigious competitions.

Key words: *artistic gymnastics, biomechanics, new elements, Tkachev salto*

INTRODUCTION

During the seventies and eighties of the 20th century, the International Gymnastics Federation (FIG) Code of Points (1980) awarded gymnasts who performed new elements by giving them an advantage of 0.2 points for originality and 0.2 points for courage. From that time Tkachev, Gienger, Jaeger, Delchev, Kovacs, Gaylord and others competed on high bar (Goetze and Uhr, 1994). In the nineties those advantages were removed from the code and a number of the newly introduced elements were dropped. From 2006, the FIG Code of Points introduced a new philosophy of an open ended difficulty score which rewards gymnasts for performing very difficult elements. With the performance of super new element gymnasts also makes his name popular among judges what gives him non material (in points) advantage. The Tkachev element is described by hang with overgrip swing frontways, hecht backward with split legs into hang with overgrip swing backways. When introduced it was a huge attraction as during the flight the gymnast attraction as during the flight the gymnast travels backward over the bar with a forward body rotation (around the sagital axis). The originally element was designed in the USSR originally element was designed in the USSR laboratories by Gaverdovskij (1987) and was first performed in the late sixties by the soviet gymnast, Pitomcev, at national competitions. However, it was first performed on the international by another Soviet gymnast, Vladimir Tkachev, in Vilnus during the European championships in 1977. Soon afterwards a piked version was performed by Tkachev himself and in 1988 Valerij Ljukin (USSR) performed a straight Tkachev and a straight Tkachev with 1/1 (360 degrees) turn (fig.1., fig.2., fig.3.). Since then, the Tkachev family of elements has remained unchanged.

The Tkachev can be divided into four phases: preparational phase (from handstand to hang in vertical position), release phase (from hang up to the release), flight phase (airborne phase), and re-grasp (the moment of re-grasping high bar).

Each phase has the following main biomechanical characteristics. In the first phase (traveling downwards), the gymnast accumulates as much energy as possible, part of this energy is also stored in high bar.

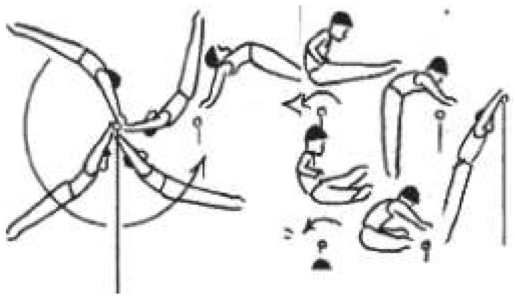

Figure 1. *Tkachev, piked Tkachev (FIG, 2006)*

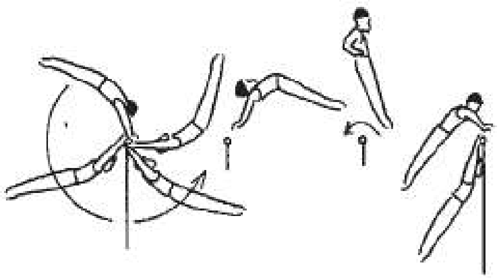

Figure. 2. *Stretched Tkachev (FIG,2006)*

Figure 3. *Stretched Tkachev with 1/1 turn (FIG, 2006)*

In the second phase (traveling upwards), the gymnast tries to save as much energy as possible and to split this energy into the needed proportion between translator and rotational energy for the next phase (Arampratzis and Brueggemann, 1999). In the flight phase angular momentum is constant during flight to perform the element safely, the parabolic trajectory of the body's center of gravity has to be optimal (in x axis), not too far from the high bar (followed by a fall), nor too close (resulting in a fall on the bar or a seriously slowed movement hindering the continuation of the exercise), to re-grasp the bar with the body position and energy to continue the exercise without mistakes. The aim of a higher trajectory of the body's center of gravity in y axis during flight is to extend the time of flight and the aesthetic view for the judges with a bigger amplitude.

Researchers from all over the world have done extensive investigations on Tkachevs. Their results will be of importance in determining whether a Tkachev salto is possible or not according to the release, flight and re-grasp characteristics. Qian, Cai, Tang and Zhou (1987) published their case study about a straight Tkachev performed by gymnast Zhao Zhinqiang. They reported an optimal moment of release with a 41.8 degree angle between the x-axis and the body center of gravity, with a body center of gravity vertical velocity of 4.18 ms^{-1}; after the release they reported an angular velocity of 2.58 rad/s (147.8^{o} s^{-1}). Krug (1992) reported the following results after analysing ten regular Tkachevs: average angular momentum of 24 kgm^2 s^{-1}, minimum 18 kgm^2 s^{-1} and maximum 29 kgm^2 s^{-1}, and an average load to apparatus of 5.3 G-force with a maximum load of 6.1 G-force. Yilmaz, Brueggemann and Cheetham (1993) reported the following data for the original Tkachev: body center of gravity vertical velocity at the moment of release 2.44 ms^{-1} (standard deviation = 0.23), body center of gravity horizontal velocity of -2.40 ms^{-1} (standard deviation = 0.32). Takeda, Tuchiya and Shiraishi (1993) reported the following data for the Stretched Tkachev: at the moment of release the hip angle is 212 degrees and the shoulder angle is 190 degrees, while hip velocityis 4 ms^{-1}. Čuk, Piletič (1995) reported the following data for a case study of Ivankov's straight Tkachev: horizontal velocity at release 2.54 ms^{-1}, vertical velocity at release 2.52 ms^{-1}, total velocity of body center of gravity 3.59 ms^{-1}, total velocity of body center of gravity 3.59 ms^{-1}, and angular velocity of 229.3°/s^{-1}. Arampatzis and Brueggemen (2001) reported the following data for the original Tkachev (numerus = 20): body center of gravity horizontal velocity 1.97 ms^{-1} (standard deviation = 0.38), body center of gravity vertical velocity 3.08 ms^{-1} (standard deviation = 0.44), angular momentum at release 33.39 kgm^2 s^{-1} (standard deviation=4.55). Atiković (2006) reported the following flight times for Tkachev's performed at the European Chamiponships 2005 in Debrecen: traditional Tkachev mean-0.68s, max-0.80s, min-0.56s ; piked Tkachev mean-0.67s, max-0.72s, min-0.64s; stretched Tkachev mean-0.70s, max-0.76s, min-0.64s. Research showing the minimum flight time for a 540 degree salto tucked (Gaylord salto) on uneven bars was reported by Mclaughlin, Geiblinger, Morrison (1995). Kerwin, Irwin and Samuelson (2007) obtained from the 2000 Olympic Games angular momentum for ten straight Tkachev 34.1 (standard deviation = 7.6) kgm^2 s^{-1}. Čuk and Colja (1996) defined a general model for developing new elements in gymnastics. According to data collected, we thought of an idea for a new element: a Tkachev salto (fig. 4). The aim of our investigation is to discover under which conditions a Tkachev salto can be performed safely.

METHODS

Methods of analyzing data are mostly logical and theoretical with acknowledgement of previous research results with similar elements of body position and movement. For calculating physical values we used Newton's physics, subsequently we modeled and adjusted those physical values in order to find a combination of them that can be performed in practice. For calculating position of body center of gravity we used Dempster's body model (by Winter 1979) and Ivan Ivankov's (Belarus) basic anthropometric data (body height 1.60 m, and body mass 57 kg). For calculating the moment of inertia of the body we used Petrov and Gagin's (1974) cylindrical model. As a basis for calculations of other physical values we used data of the straight Tkachev from Ivan Ivankov (Čuk and Piletič 1995); data from Ivan Ivankov was obtained in 1994 during the European championship.

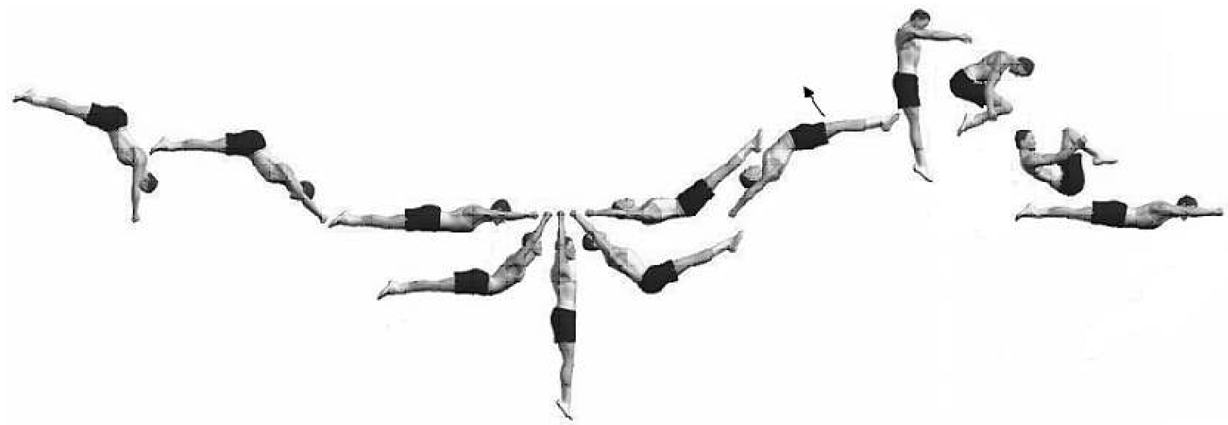

Figure 4. *Idea of Tkachev salto*

The year of 1994 was the best year ever for Ivankov as he won the all around World and European title; he was 18 years old and was in the best condition of his sporting life From 1996 he experienced injuries and was never in such excellent sporting form again.

RESULTS AND DISCUSSION

Results show that a Tkachev salto can be safely performed under the conditions which follow. When performing a forward salto the gymnast's head (or any other part of the body) must be far away from the bar for the safety reasons. For the reason of safety and the reason of an appropriate moment of inertia, we chose the following body position with the following angles between body parts: angle between trunk and head 65°, hip angle 60°, and knee angle 70° (fig. 5.). Tkachev salto tucked was chosen because of the ease of motor control and motor learning. Most of the handspring saltos on vault and floor have combination arched body/tucked body, split legs require an additional operation and muscle group to activate and control. This tucked position is still within FIG rules without any deductions (FIG rules define a tucked position as angles are smaller or equal to 90 degrees in the hip and knee joint) and also has a lower moment of inertia.

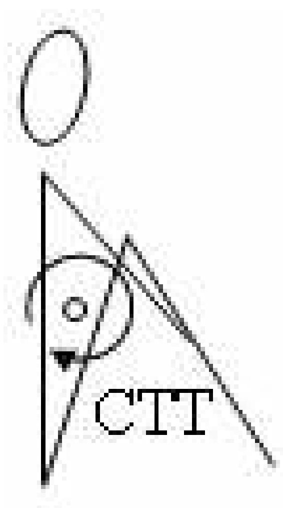

Figure 5. *Ideal tucked position for Tkachev salto*

The calculated length and mass of body parts by Dempster (by Winter, 1979) for Ivan Ivankov (h = 1.6m; m = 57kg) are: head with neck (length (m) = 0.291, mass (kg) = 4.62); trunk (0.541m, 28.33kg); upper arm (0.244m, 3.19kg), lower arm with hand (0.23m, 2.51 kg); thigh (0.392m, 11.40 kg); calf with feet (0.456m, 6.95kg). In the defined tucked position the body center of gravity is 0.07m in x axis and 0.29m in y axis (0.0 is in hip joint); distance between head and body center of gravity = 0.52m, while the distance between feet and body center of gravity is = 0.51 m. For the chosen position we calculated the moment of inertia for rotation around the frontal axis by the suggested formula $J = ml^2/12$ of Petrov and Gagin (1974) for a tucked position, position at release and position at re-grasp: for height l = 0.804m of Ivankov in tucked position $J_{tucked} = 3.076\ kgm^2$ *(tucked position);* for height (length) l = 1.647 m of Ivankov at release $J_{release} = 12.885\ kgm^2$ *(arched position with arms upward)*, for height (length) l = 1.247 m of Ivankov at regrasp $J_{regrasp} = 7.386\ kgm^2$ *(tucked position with arms upward).* Time of flight is determined by 540 degrees rotation forward. Full rotation can be divided into three phases: arched body releases high bar and then rotates until it reaches tucked position, rotating tucked body, opening and re-grasp. Čuk and Karacsony (2004) note the fastest bend from stretched or arched body into full tucked position is 0.24 seconds. We will accept this time as the time required for bending to calculate the angle of rotation, we are presuming linear change of body length when calculating the moment of inertia. Čuk and Piletič (1995) reported for Ivankov during a stretched Tkachev that the angular velocity when releasing the high bar was $229.3°/s^{-1}$. During the flight, angular momentum (the product between moment of inertia and angular velocity) is constant and we can calculate when the required 540° angle of rotation will be fulfilled. We calculated the angular momentum for Ivankov's stretched Tkachev by the formula: $\Gamma_{\text{during flight}} = J_{\text{moment of release}}\ \omega_{\text{moment of release}}$ = constant = 51.56 Nms (table 1.). The calculated angular momentum for the straight Tkachev seems quite high. Krug's (1992) measurement for a regular Tkachev's maximum angular momentum was 29 Nms. Even though our estimation of an angular momentum of 51.6 kgm2s-1 is too high, we can say that Kerwin *et al* (2007) also obtain similar high end values (34, 1 + 7, 6 * 2, 33 standard deviation) = 51.808

kgm2s-1. That means that 1% of those who are performing a straight Tkachev can also perform a Tkachev salto which gives this element an extremely high difficulty value and still proves that it is possible. The angle of rotation in the first 0.24 seconds is calculated in steps by each 0.01 second. In the first 0.24 second, a gymnast will finish 116.46 degrees of rotation (table 1.).To fulfill 540 degrees the gymnast has to rotate another 424.54 degrees. After 0.24 second the gymnast in tucked position has a constant angular velocity of 962.23°/s. This angular velocity is in accordance with Krug (1993), where triple saltos performed on different apparatus can reach an even higher angular velocity than 1000°/s. Preparation to assume the proper position for re-grasp (tucked with arms upward) can be performed by the gymnast in half the time of tucking, as the gymnast has only to move arms upward, again we presumed linear change of gymnasts length. Angle of rotation in the last 0.12 seconds is calculated in steps of 0.01 second. In the last 0.12 second, the gymnast will finish 71.69 degrees of rotation (table 2.). The whole angle of rotation of tucking and opening is: 116.46° + 71.69° = 188,15°. To fulfill a 540° salto the gymnast has to rotate another 351.85 degrees. We calculated the time needed to fulfill the following angle by the formula: angle = ω*t ; t = angle/ω = 351.85° / 962.23°s^{-1} = 0.36 s, therefore the whole time to complete a Tkachev salto is: time of tucking + time rotating

Table 1. *Change of angle of rotation in the first 0.24 second*

Step	t (time) (s)	Change of height (m)	$J=ml^2/12$ (kgm^2)	$\omega=\Gamma/J$ ($^o s^{-1}$)	$\Gamma=J\omega$ (Nms)	Angle= ω*0,01s (degrees)	**Total angle (degrees)**
1	0	1.65	12.88	229.3	51.56	0	0
2	0.01	1.61	12.34	239.4		2.39	2.39
3	0.02	1.58	11.81	250.19		2.5	4.9
4	0.03	1.54	11.29	261.72		2.62	7.51
5	0.04	1.51	10.78	274.06		2.74	10.25
6	0.05	1.47	10.28	287.31		2.87	13.13
7	0.06	1.44	9.8	301.53		3.02	16.14
8	0.07	1.4	9.32	316.84		3.17	19.31
9	0.08	1.37	8.86	333.34		3.33	22.64
10	0.09	1.33	8.41	351.17		3.51	26.16
11	0.1	1.3	7.98	370.47		3.7	29.86
12	0.11	1.261	7.55	391.40		3.91	33.77
13	0.12	1.226	7.13	414.16		4.14	37.92
14	0.13	1.190	6.73	438.96		4.39	42.31
15	0.14	1.155	6.34	466.06		4.66	46.97
16	0.15	1.120	5.96	495.74		4.96	51.92
17	0.16	1.085	5.59	528.36		5.28	57.21
18	0.17	1.050	5.24	564.31		5.64	62.85
19	0.18	1.015	4.89	604.05		6.04	68.89
20	0.19	0.980	4.56	648.14		6.48	75.37
21	0.2	0.945	4.24	697.25		6.97	82.34
22	0.21	0.909	3.93	752.15		7.52	89.87
23	0.22	0.874	3.63	813.80		8.14	98.00
24	0.23	0.839	3.34	883.36		8.83	106.84
25	0.24	0.804	3.07	962.23		9.62	116.46

completely *tucked + time of opening = 0.24s + 0.36s + 0.12s = 0.68s***.** From Atikovć (2006) studies better gymnasts performing a straight Tkachev at the European championship of 2005 would also have enough time to perform a Tkachev salto. For calculating the trajectory of body center of gravity in x and y axis we were modeling the position of the body in the release phase and in the moment of re-grasp. To calculate body center of gravity at the moment of release we used a three segment body model (arms, trunk with head, and whole leg), for the moment of regrasp we used a four segment body model (arms, trunk with head, thigh, and calf with feet). Reasons why we chose different models are practical and common for gymnastic performance of the Tkachev; during release the arms and legs are stretched, while during re-grasp we presumed that the gymnast should stay in tucked position until re-grasp in order to have enough rotation. By modeling different release and re-grasp positions we found the best fit with the following positions as shown in figure 6. Release position has the following data (center of high bar is 0.0) angle x axis – arms 40°, x-axis – trunk 0° and x axis – legs 340°, and re-grasp angle x axis – arms 180°, x-axis – trunk 180°, x axis – thigh 330°, x axis – calf with feet 240°. While the release position can be quite different, with adjusted vertical and horizontal velocity, the re-grasp position is much more determined and this is what makes the new element very difficult. The body center of gravity has to be close to the high bar height, far enough from the high bar to re-grasp with shoulders at 180 degrees. Late re-grasps which are usual for the original Tkachev or for some other release elements are dangerous as the gymnast is too close to the bar during salto (fig. 6.).The body center of gravity horizontal velocity during the flight is constant and is therefore calculated by the formula: $(s_{xrelease} - s_{xregrasp})$ / time of flight = (0.808m-(-0.784m)) / 0.68 s^{-1} = 2.34 ms^{-1}. For the calculation of body center of gravity vertical velocity we were modeling vertical velocity from 2.00 ms^{-1} and calculate time of uprising ($t_{uprise}=v_{yrelease}/g$; $g=9.81ms^{-2}$), reached height ($h_{max}=h_{release}+gt_{uprise}^2$), whole height of falling ($h_{fall}=h_{max}-h_{regrasp}$)(difference between re-grasp position and maximum height), time of falling (t_{fall}=sqrt(h_{fall}/g) and whole time of flight ($t_{total}= t_{uprise}+ t_{fall}$). For the whole flight time of 0.68

Table 2. *Change of angle of rotation in last 0.12 second*

Step	t (time) (s)	Change of height (m)	$J=ml^2/12$ (kgm^2)	ω= Γ/J (° s^{-1})	Γ=Jω (Nms)	Angle= ω*0,01s (degrees)	**Total angle (degrees)**
1	0	0.8	3.07	962.23	51.56	0	0
2	0.01	0.84	3.36	879.6		8.8	8.8
3	0.02	0.88	3.66	807.17		8.07	16.87
4	0.03	0.92	3.98	743.34		7.43	24.3
5	0.04	0.95	4.3	686.79		6.87	31.17
6	0.05	0.99	4.64	636.45		6.36	37.53
7	0.06	1.03	5	591.45		5.91	43.45
8	0.07	1.062	5.361	551.06		5.51	48.96
9	0.08	1.099	5.741	514.67		5.15	54.11
10	0.09	1.136	6.133	481.77		4.82	58.92
11	0.1	1.173	6.538	451.93		4.52	63.44
12	0.11	1.210	6.955	424.78		4.25	67.69
13	0.12	1.247	7.386	400.00		4.00	71.69

second (according to release and re-grasp position) body center of gravity vertical velocity is 2.77ms^{-1}, total body center of gravity velocity in xy at release is 3.62 ms^{-1} (vertical, horizontal and xy velocity are lower than published in previous research). The minimum distance between BCG and high bar is 0.59m which means that the gymnast's body parts are a minimum of 0.07m away from high bar at any time (fig. 7.).

CONCLUSION

The high demands of performing a Tkachev salto can be achieved by excellent gymnasts who can perform a straight Tkachev with a very high amplitude. However, the new element is extremely difficult to perform as its basic conditions are: position of release requires very good flexibility of the arms and trunk (angle x axis – arms 43, arms-trunk 223, trunk - legs 200); a very good physical preparation as a tucking time of 0.24s can be only be performed by the best prepared gymnast; the time of flight has to be at least 0.68s which should not be a problem for the gymnasts who can perform a straight Tkachev; vertical velocity should be as high as possible, but minimum safe velocity is 2.77 ms^{-1}, as this gives the gymnast more airborne time and a higher distance from the high bar (in this case the gymnast's position can also be more open); one problem which has yet to be analysed is how to preserve angular momentum during release. All the calculated data for a safe Tkachev salto; time of flight; vertical, horizontal and total velocity at release; body angles at release and re-grasp; angular momentum during flight; and the distance of the gymnast from the high bar, are equal to or lower than other comparative researches. As maximum known load to apparatus (at rings, at the gymnasts vertical position in hang performing triple salto backward tucked) is 13G (Čuk, Karacsony, 2002), we can conclude that the production and preservation of angular momentum during the preparation phase until the release phase should be solved. As gymnasts can produce even higher biomechanical values than those needed for a Tkachev salto, we can conclude that a Tkachev salto can be accomplished, and will probably, in the near future, be performed at competitions.

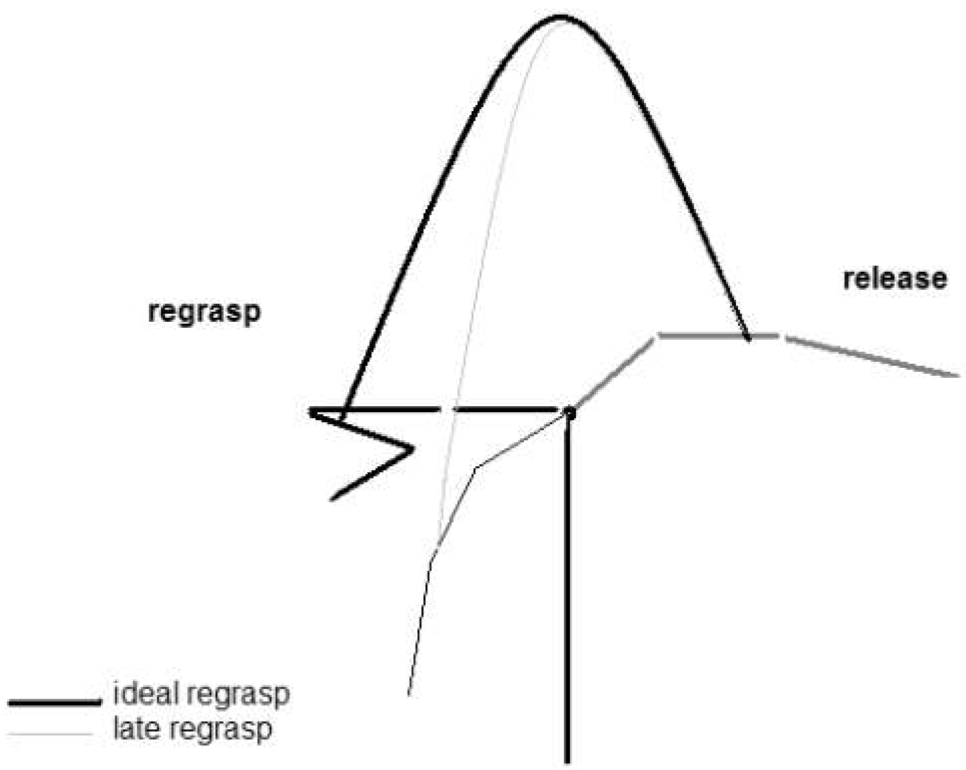

Figure 6. *Body position at release and regrasp*

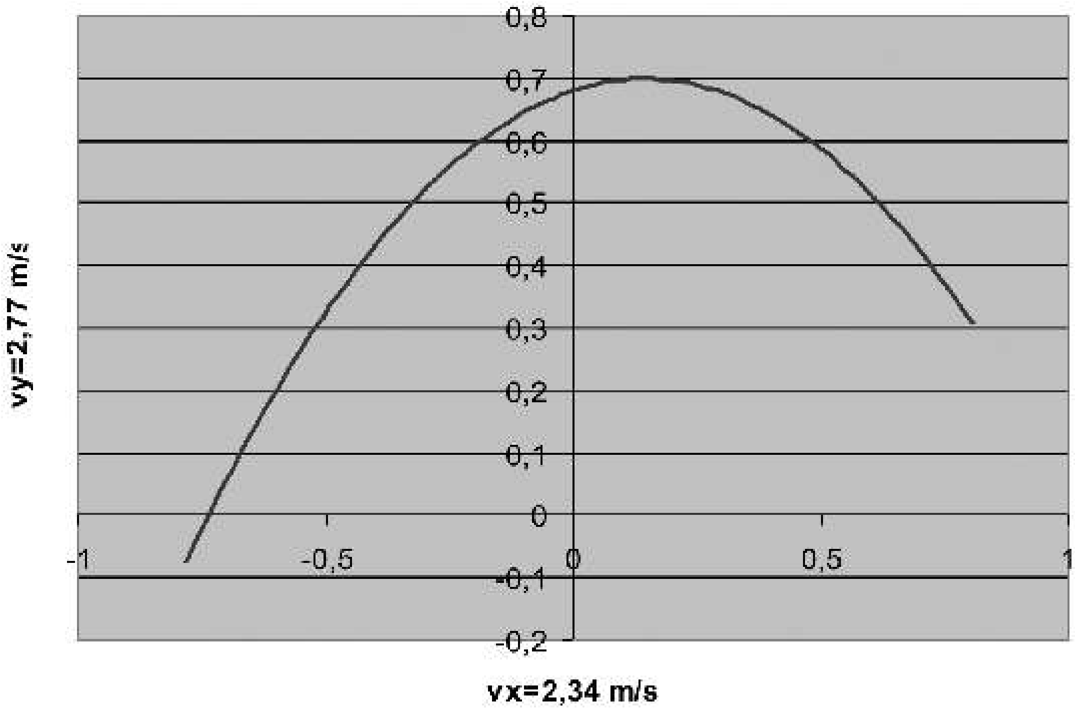

Figure 7. *Pathway of body center of gravity in x,y axis (m)(0,0 = high bar)*

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