

The Influence of Body Position on the Straddled Tkatchev's Flight Phase in Men's Horizontal Bar

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ABSTRACT

To examine the effect of level of expertise on the flight phase of the straddled Tkatchev we analysed six male gymnasts (mass = 64.0 +/- 3.0kg, height = 1.67 +/- 0.06m) split into three proficiency levels Elite, Intermediate and Beginners. The preparation phase, flight phase and re-grip phase were sub-divided into ten steps that focussed on three different angularities (bar, shoulder and torso). Angular dimensions between the shoulder and torso and leg were measured using digitised points at the shoulder, trochanter major and lateral malleolus using Sportscore Elite (V10, Sportstec, Australia). A one-way ANOVA was conducted to determine differences between the groups. The results found different angles and body positions influence the flight phase of the Tkatchev. A late flexion in the downward phase with a straight position at the vertical line below the high bar influences the following movement of the Tkatchev positively. An early-piked position with a late straight/hyperextension upward phase increases the energy of the gymnast to reach a greater height above the bar. Both come with a shorten time of preparing and increased time during flight phase. By starting the preparing phase of Tkatchev before reaching the handstand position the gymnast also shorten the time of the giant swing. But then the athlete has to be faster in each execution for each segment, especially in hip flexion during the countermovement. The best time of re-grasping the bar is with a bonded body position and at an angle degree of 412°. **Key words:** GYMNASTICS, BIOMECHANICS, EXPERTISE, ANGULAR-MOVEMENT, TORQUE

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INTRODUCTION

This analysis is about a flight element called Tkatchev in the field of apparatus gymnastics. It can be executed in two common ways: straddled and straightened. The third execution is a piked Tkatchev and usually exercised by women.

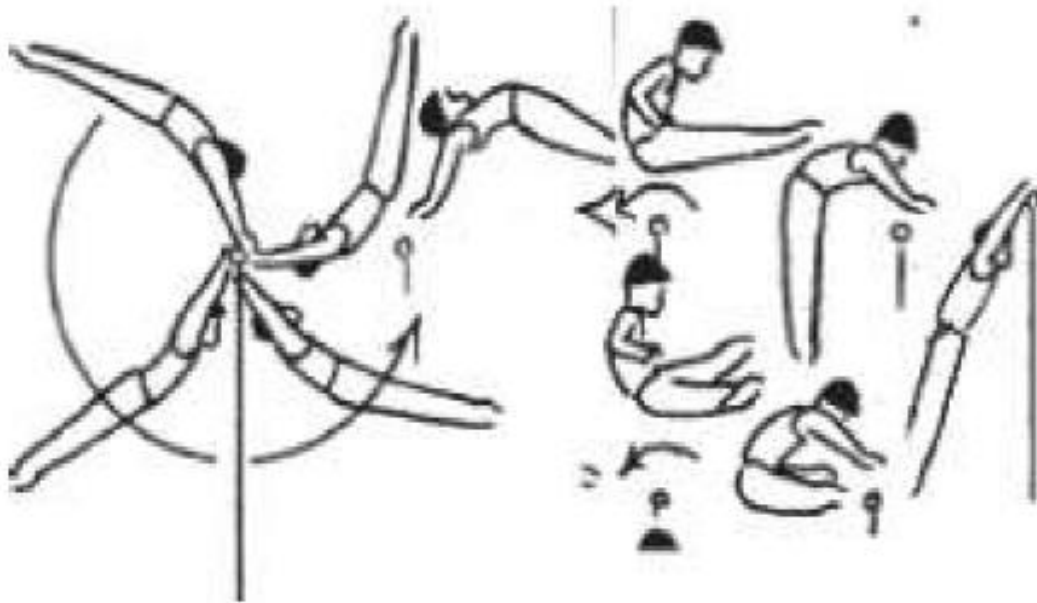
Apparatus gymnastics has been represented by men and women in Olympia since the first Olympic Games 1896 in Athens. Since then the Fédération Internationale de Gymnastique (FIG) has aided this international sport. During this time some apparatuses have changed. Nowadays ten apparatuses exist in total; four apparatuses for women and six apparatuses for men (FIG, 2013). In the Olympic order women do gymnastics on vault, uneven bar, balance beam and floor. Floor, pommel horse, rings, vault, parallel bars and horizontal bar are challenged by men. Each routine on an apparatus is made up of five element groups with a total skill of ten. Those element groups with its skills are listed in the Code de Pointage (FIG, 2013).

To focus on the research question; the contemplated Tkatchev is a skill of the “flight element” group of the men’s horizontal bar. The other four element groups besides the flight elements are “Long-hang swings and turns”, “In-bar elements”, “El-grip and dorsal hang elements” and “Dismounts”. This apparatus is a 2.4m horizontal bar and 2.6m high which is made of high quality steel and fibre glass. Four steel cables attached to the bar and the ground fix this apparatus. Those four cables and the high quality steel bar make it elastic whereby gymnasts can perform their modern routine.

This analysis refers to the straddled Tkatchev. It is a popular international element which has been performed for approximately 40 years. Many elite athletes and world championship winners such as Fabian Hambüchen, Sam Mikulak and David Bishop have this release element in their routine. Despite its popularity only little research exists.

The Tkatchev can be divided into four phases (Cuk, et. al. 2009);

1. Preparation phase (from handstand to long hang in vertical position)
2. Release phase (from long hang up to the release)
3. Flight phase (from release to re-grasp)
4. Re-grasp (the moment of re-grasping the high bar)



Picture 1. Straddled Tkatchev: The straddled Tkatchev is described by hang with over-grip swing front-ways, counter straddle reverse, hecht backwards into hang with over-grip swing backways. That means the gymnast travels backward over the bar with a forward body rotation (around the sagittal axis) (FIG. 2013).

Each phase has a biomechanical characteristic (A Arampatzis & Brüggemann, 1999). During the preparation phase the gymnast accumulates as much energy as possible. On one hand that energy is stored in the horizontal bar. On the other hand it comes from the gymnast by lengthening the pendulum. This signifies a larger distance between the bar and the centre of mass. Therefore the torque of inertia ($I=m*r^2$) and the moment of force ($F*r$) is increased. The result is a higher kinetic energy ($kin E=1/2*I*r^2$) (Kopp & Reid, 1980). The second phase is characterised by a shorter pendulum because of the negative effect of force of gravity on the gymnast. Thus, as much energy as possible has to be saved by the athlete to use it for the translator and rotation of the next phase (A Arampatzis & Brüggemann, 1999). During the flight phase angular momentum is constant. An optimal trajectory of the centre of mass is described as a parabola (Cuk, et. al. 2009).

Summary

The aim of the flight phase is to achieve the highest trajectory possible in y-axis to extend the time of flight without shortening or lengthening the distance in x-axis and to let the Tkatchev look aesthetically pleasing. The re-grasping of the high bar is characterised by an optimal body position, not too close, nor too far away of the bar, to continue the routine without making a mistake (Cuk, et. al. 2009).

The aim of this research is to find out how the different body positions during those four phases influence the Tkatchev's flight phase. This will involve investigating the point of time of release, the flight duration and the re-grasping.

METHODS

The performances were gathered from two different events; at the Gymnastics World Championship 2014 in Nanning and during training at the Gymnastics Performance Centre Tri Star in Auckland in 2015. In both cases a “Longines” branded horizontal bar was utilised. Performances were recorded using a Panasonic HC-V500 full HD video camera with 50Hz. The camera recorded the movement of the gymnasts. In total six videos were analysed twice by Sportstec Elite Version software which was used to measure the angles between the bar and the centre of mass. Additionally, the angular dimensions between the shoulder and torso and leg were measured using digitised points at the shoulder, trochanter major and lateral malleolus.

Six male gymnasts (mass = 64.0 +/- 3.0kg, height = 1.67 +/- 0.06m) split into three groups, with a various proficiency level (Elite, Intermediate and Beginners) were analysed. The subdivision of these groups was based upon international level-grouping system. To be in the elite group participants needed to have taken part in the Gymnastics World Championship 2014 in Nanning. The intermediate group competed at the national Championship 2014 in their own country. Beginners were those who started learning the Tkatchev.

To analyse the data between each group a One-Way ANOVA was used to test for significance $p < 0.05$. The reliability of the data collected was determined using the percentage error calculation (Hughes, et. al., 2004)

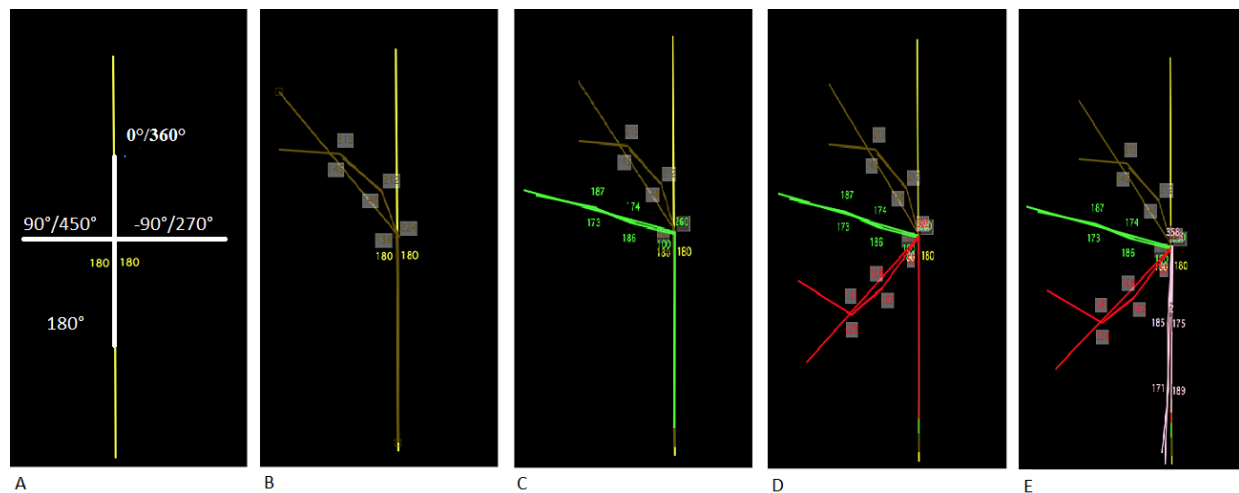
$$\%_{\text{error}} = \sum [\text{mod}(V_1 - V_2) / V_{\text{tot}}] * 100\%.$$

For this research the preparation phase, release phase, flight phase and re-grasp phase were subdivided into 10 steps (Picture 2 and Picture 3). This focused on three different angularities:

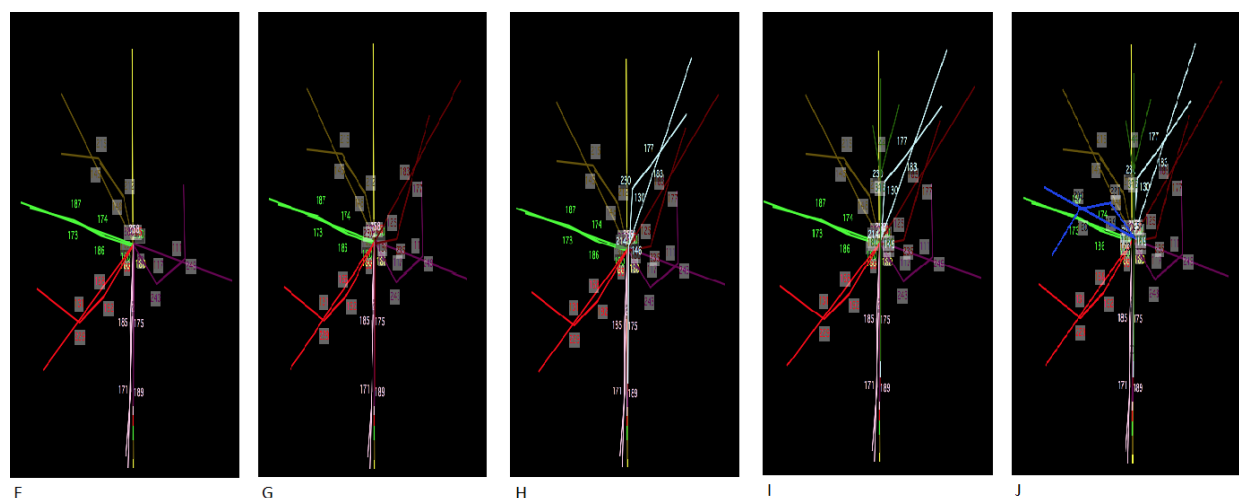
- Bar – centre of mass
- Shoulder – torso
- Torso – Hip

Each step represents a different colour:

1. Handstand – Yellow
2. Flexion downwards (dw) – Karkee
3. Straight downwards (dw) – light green
4. Hyperextension downwards (dw) – red
5. Straight downwards (lh) – light purple
6. Flexion/pike upwards (up) – purple
7. Straight upwards (up) – dark red
8. Release – light blue
9. Flight – dark green
10. Re-grasping – blue



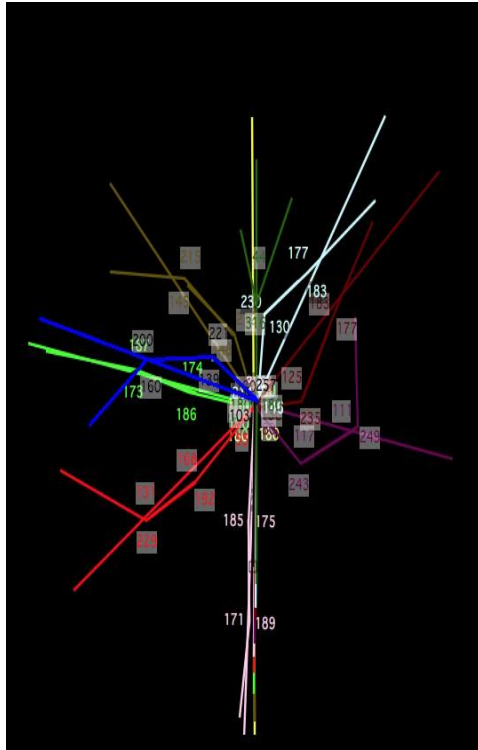
Picture 2. Steps A- E: A shows the handstand position at the beginning in y-axis. Moving forward in a circle B describes the first flexion phase, C the straight position, D the hyperextension and E the straight position in a long hang at the end of the preparation phase.



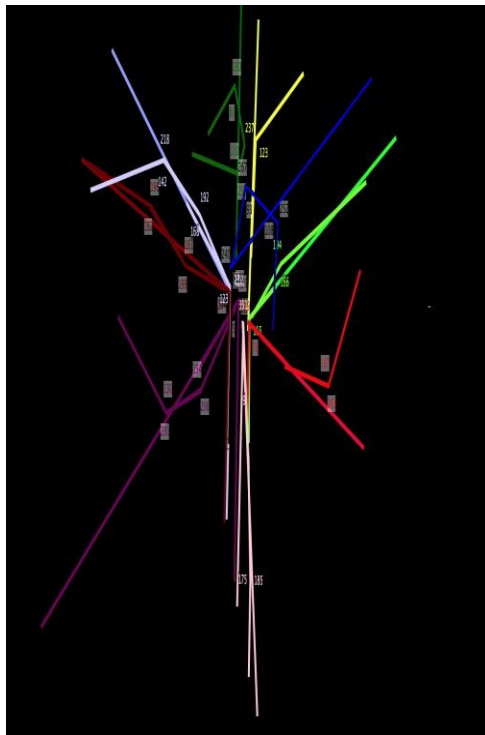
Picture 3. Steps F-G: F – H represent the release phase with an upwards flexion/pike position in F. G describes the straight position before the actually release in H with a hyperextension phase. In I the gymnast's position above the bare during the flight phase is represented. J shows the re-grasping phase.

RESULTS

Each gymnast's Tkatchev was analysed by Sportstec Elite Version 10 software (Pictures 4-9). The data for the different body angles during the exercise of the athletes are listed below in Table 1 and Pictures 4-9 (Image 9 is an example of an unformatted image from the software).



Picture 7: Analysis of the body angles of Intermediate 2



Picture 8. Analysis of the body angles of Beginner 1



Picture 9. Analysis of the body angles of Beginner 2

A fully extended body position is assigned an angle value of 0° . The analysis started when the gymnast was in the handstand position (Picture 2a) and had a perpendicular angle of 0° to the y-axis (Table 1). The measurement of the analysis for Elite 2 and Inter 1 started before they passed the longitudinal axis of angle 0° (Table 1 – Handstand position; Picture 5 and 6: orange line). Table 1; Picture 5 and 6 and Figure 1 and 2 show that these two gymnasts reached the piked position of the flexion dw phase before the Handstand position and the flexion dw phase. The giant swing before the release on the high bar characteristically contains two extension phases and two flexion phases at the shoulder and hip joints; the elevation of the arms is defined as a shoulder joint extension (Figure 1 and 2). The hip joint has a third flexion phase due to the straddled position during the flight phase.

Table 1 describes each segment of all six gymnasts with the attendant body angles. The Beginners show a handstand position with greater flexion at the hip joint (Beg1: 57° ; Beg2: 13°) when compared to a subset of the Elites and Intermediates. Because Elite 2 and Inter 1 started their Tkatchev preparation before the longitudinal axis they do not have an explicit handstand position (Picture 5 and 6). The angle of centre of mass to the high bar at this point is -32° for the Elite 2 and -44° for Inter 1. This explains why they have their hip and shoulder flexion at the flexion (dw) at the vertical line to the bar (Picture 5 and 6 – yellow line; Table 1). All other athletes except Elite 1 reach the flexion (dw) segment shortly after the vertical line of 0° with an average of 15° (Table 1). Elite 1 has his flexion (dw) phase of 44° . The Elite group has a significance of $p=0.049$ at this phase in comparison to the Beginner group. Another significance ($p=0.04$) between Elites and Beginners is seen in the shoulder extension during the hyperextension (dw) phase (Table 1 and Figure 1). The Elites have an average of -17.5° in their shoulder joint compared to the average of Inter (-6°) and Beg groups (2°). The Intermediates have no significant difference in their shoulder extension to each of the groups.

Table 1. Body position data: On the y-axis the different segments of the Tkatchev (angle of bar – centre of mass), described in Picture 2 and 3, are listed. Below that the angular body position of the shoulder – torso angle is described. The third point of each row represents the torso – hip angle. On the x-axis the different gymnasts (n=6) are listed. Elite = Elite; Inter = Intermediate; Beg = Beginner (Pictures 4-9).

Position	Elite 1	Elite 2	Inter 1	Inter 2	Beg 1	Beg 2
Handstand	0	-32	-44	0	0	0
Shoulder	0	72	62	5	0	0
Hip	0	88	77	0	57	13
Flexion (dw)	44 *	0 *	0	21	10 *	15 *
Shoulder	32	70	76	9	10	11
Hip	35	37	37	45	55	50
Straight (dw)	88	72	89	79	65	72
Shoulder	-6	17	13	4	14	4
Hip	7	0	6	-8	0	0
Extension (dw)	125	150	125	138	109	128
Shoulder	-12 *	-23 *	-6	-6	0 *	4 *
Hip	-49	-56	-77	-52	-63	-40
Straight (lh)	178	180	200	180	171	191
Shoulder	5	0	7	0	0	12
Hip	-9	0	8	5	5	5
Flexion (uw)	260	235	266	228	235	257
Shoulder	63	47	43	30	26	46
Hip	69	62	61	74	50	60
Straight (uw)	310	315	313	284	284	289
Shoulder	55	27	0	53	19	49
Hip	3	-25	0	0	-18	18
Release	326 *	327 *	322	315	303 *	310 *
Shoulder	-32	-17	-15	-15	-14	-7
Hip	-3	-26	-17	-67	-38	-49
Flight	360	360	360	360	360	360
Shoulder	0	0	0	0	80	0
Hip	136 **	126 **	99 *	100 *	70 *	54 *
Re-grasp	401	423	438	422	420	441
Shoulder	41	27	32	25	87	36
Hip	20	63	60	48	72	-5

* $p < 0.05$

All the gymnasts had an almost straight position at the vertical line under the high bar (straight lh; Table 1). Only Inter 1 is far behind the vertical line with an angular degree of 266° (Table 1). The upwards flexion phase (uw) was at angles with different degree values (Table 1). The average piked positions of hips and shoulders of the gymnasts (Beg shoulder: $36^{\circ} \pm 10^{\circ}$; Inter shoulder: $36.5^{\circ} \pm 6.5^{\circ}$; Elite shoulder: $55^{\circ} \pm 8^{\circ}$; Beg hip: $55^{\circ} \pm 5^{\circ}$; Inter hip: $67.5^{\circ} \pm 6.5^{\circ}$; Elite hip: $65.5^{\circ} \pm 3.5^{\circ}$) show a large difference, but this does not reach significance (Beg – Elite: $p=0.09$; Beg – Inter: $p=0.12$; Inter – Elite: $p=0.10$). The straight (uw) taken position constantly decreases in angle to the bar from Elites to Beginners (Table 1). The same can be seen at the release. This difference is significant between the Elite and Beginner groups ($p=0.03$). In addition the hyperextension of the shoulder increases from the Beginners to the Elites at the point of release (Table 1, Figure 1).

For the vertical line that runs on the y-axis to the bar (360°) the Elites have the highest hip flexion during the flight phase which is documented with a significance of $p=0.05$ between Intermediate and Elite group and with a significance of $p=0.006$ between Beginner and Elite group; in all cases a larger angle corresponds to a higher hip and shoulder flexion (Table 1, Figure 1 and 2). The re-grasping phase demonstrates that the Beginners either have an increased piked or hyperextended position in their hips in comparison to the Elites and Intermediates. The same is shown for the shoulder joint of Beginner 1.

Table 2. Duration: In the table the different times of preparing phase and flight phase of each athlete are given in seconds

Duration	Elite 1	Elite 2	Inter 1	Inter 2	Beg 1	Beg2
Handstand – Release in sec	1.52s *	1.24s *	1.41s	1.61s	1.75s *	1.84s *
Release – Re-grasping in sec	0.73s *	0.79s *	0.71s	0.68s	0.6s *	0.62s *

* $p<0.05$

Furthermore, the duration between the handstand position and release and the release and re – grasping was measured (Table 2). Except Inter 1, who had the second fastest time, a distinct increase in duration was determined between the handstand – release phases from the Beginners to the Elites. This is reflected by a significance between Elite and Beginner group of $p=0.03$. The flight time between release and re-grasping was determined to increase from Beginners to Elites (Average Elite: 0.76s, Inter: 0.695s, Beg: 0.61s; Table 2) which was also reflected by a significance of $p=0.03$ between the Elite and Beginner groups.

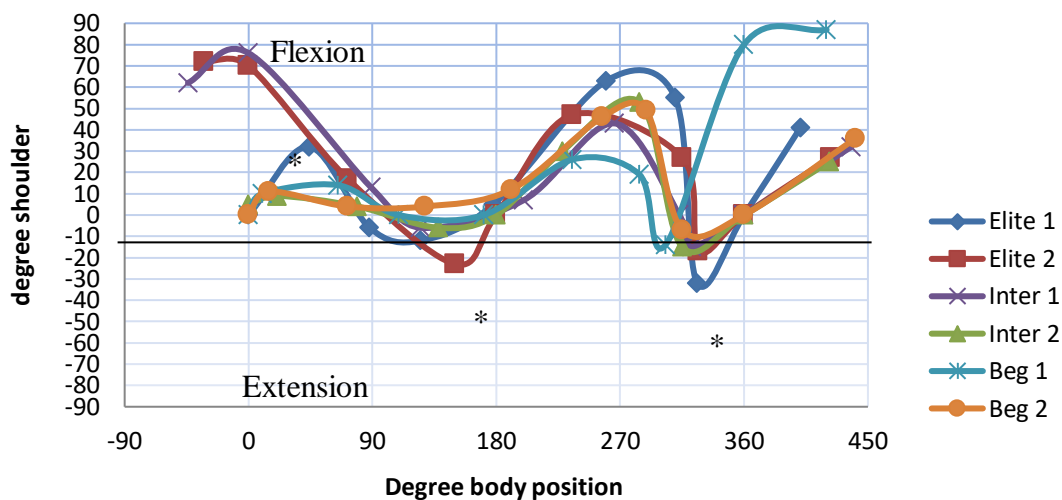
* $p < 0.05$

Figure 1. Shoulder degree

The x-axis shows $1\frac{3}{4}$ circles around the bar. Some athletes start with their preparation for the Tkatchev before they reach the handstand position at 0° ; that is shown by the negative degree. At 360° the gymnast is above the bar during the flight phase. Bigger than 360° shows the re-grasp. The y-axis shows the hyperextension (negative degree) and flexion (positive degree) of the shoulder during the movement shown by the x-axis.

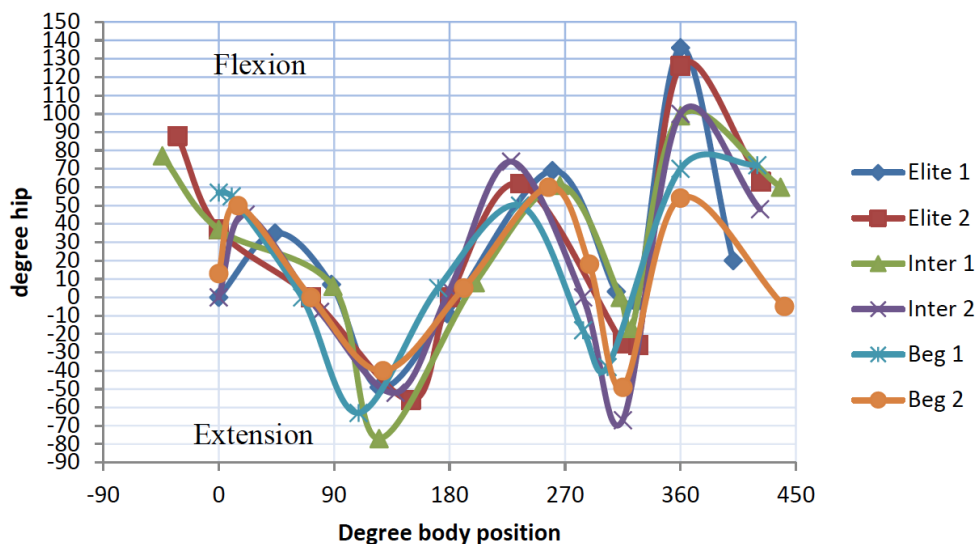
* $p < 0.05$; ** $p < 0.01$

Figure 2. Hip degree

The x-axis shows 1 $\frac{3}{4}$ circles around the bar. Some athletes start with their preparation for the Tkatchev before they reach the handstand position at 0°; that is shown by the negative degree. At 360° the gymnast is above the bar during the flight phase. Bigger than 360° shows the re-grasp. The y-axis shows the hyperextension (negative degree) and flexion (positive degree) of the hip during the movement shown by the x-axis.

The Reliability of all measured data was calculated using the percentage error calculation:

$$\%_{\text{error}} = \sum [\text{mod}(V_1 - V_2) / V_{\text{tot}}] * 100\%; V_{\text{tot}} = (V_1 + V_2) / 2 \text{ (Hughes, et. al. 2004).}$$

The athletes' angles from Table 1 were used for V_1 and Table 3 was purpose-made for V_2 of the formula. Table 3 shows the control angles which were measured after one week.

For the two duration times of the "Handstand – Release" and "Release – Re-grasping" phases, data from Table 2 were used for V_1 and data of Table 4 was used for V_2 . In this case Table 4 shows the control durations of each athlete which were also measured after one week.

On the y-axis the different segments of the Tkatchev (angle of bar – centre of mass), described in Picture 2 and 3, are listed. Below that the angular body position of the shoulder – torso angle is described. The third point of each row represents the torso – hip angle. On the x-axis the different gymnasts ($n=6$) are listed. Elite = Elite; Inter = Intermediate; Beg = Beginner

Table 3. Control group Body position data.

Position	Elite 1 control	Elite 2 control	Inter 1 control	Inter 2 control	Beg 1 control	Beg 2 control
Handstand	0	-30	-42	0	0	0
Shoulder	0	73	63	5	0	0
Hip	0	88	80	0	55	11
Flexion (dw)	45	0	0	23	10	15
Shoulder	34	70	75	11	10	10
Hip	35	35	35	45	55	50
Straight (dw)	87	74	87	81	65	75
Shoulder	-5	20	15	5	12	2
Hip	10	1	7	-10	0	0
Extension (dw)	125	150	125	140	113	130
Shoulder	-12	-24	-6	-6	0	4
Hip	-50	-54	-77	-53	-62	-40
Straight (lh)	179	181	200	180	174	189
Shoulder	5	0	7	0	0	12
Hip	-9	0	10	5	5	5
Flexion (uw)	260	236	269	225	235	258
Shoulder	61	45	43	30	28	45
Hip	71	64	61	72	48	61
Straight (uw)	310	315	311	285	285	290
Shoulder	55	28	0	52	19	49
Hip	3	-25	0	0	-18	18
Release	328	330	320	315	300	315
Shoulder	-32	-19	-15	-15	-16	-8
Hip	-3	-27	-16	-66	-39	-52
Flight	360	360	360	360	360	360
Shoulder	0	0	0	0	80	0
Hip	45	54	84	80	110	126
Re-grasp	399	420	440	425	422	439
Shoulder	44	27	32	24	87	38
Hip	20	62	60	48	72	-6

The “Intra-operator” type of reliability was used to verify each angle and duration. As shown in Table 5–10 the reliability of each measurement with $\leq 5\%$ error is given.

Sum of angles	Elite 1	Elite 1 control	Elite 2	Elite 2 control	Sum of angles	Inter 1	Inter 1 control	Inter 2	Inter 2 control
Σ Centre of mass	2092	2093	2030	2036	Σ Centre of mass	2069	2070	2027	2034
Reliability	0.04%		0.29%		Reliability	0.05%		0.34%	
Σ Shoulder	146	150	220	220	Σ Shoulder	212	211	105	108
Reliability	2.70%		0%		Reliability	0.47%		2.82%	
Σ Hip	117	122	197	198	Σ Hip	236	242	125	119
Reliability	4.18%		0.5%		Reliability	2.51%		4.91%	
Table 4: Reliability of the Elite gymnasts: % _{error} ≤ 5					Table 5: Reliability of the Intermediate gymnasts: % _{error} ≤ 5				

Sum of angles	Beg 1	Beg 1 control	Beg 2	Beg 2 control
Σ Centre of mass	1957	1964	2068	2071
Reliability	0.36%		0.14%	
Σ Shoulder	222	220	155	152
Reliability	0.90%		1.95%	
Σ Hip	230	228	178	173
Reliability	0.87%		2.85%	

Table 6: Reliability of the Beginner gymnasts; %_{error} ≤ 5

DISCUSSION

Six gymnasts with various proficiency levels performed the straddled Tkatchev. In this research the angles of different body positions, the duration between the handstand and the release and during the flight phase of the Tkatchev were measured. The Elite 2 and Inter 1 gymnasts try to accelerate the giant swing during the preparation phase by starting the Tkatchev before the Handstand position (Table 1, Figure 1 and 2) to increase the angular velocity and the moment of force in order to raise the height of the flight phase. Arampatzis, A. & Brüggemann, G. (2001) and Naundorf, F., Brehmer, S., Lehmann, T., & Seidel, I. (2012) also determined that an increasing angular velocity of the preparation phase during the giant swing raises the height of the flight phase. Elite 2 and Intermediate 1 have this kind of movement (Picture 5 and 6, Table 1). Both gymnasts diminish the distance between centre of mass and the bar during upwards movement to increase the angular velocity. This acceleration is verified by the duration of the preparation phase (Handstand – Release). Both gymnasts had the least time of preparation but this did not reach significantly (Table 2). Only the Elite 2 athlete could transfer this acceleration to a longer flight time (Table 2). This represents a higher height. Therefore Inter 1 has a shorter flight phase than Elite 2 and as well as Elite 1 (Table 2).

All the gymnasts had a similar preparation phase from handstand to long-hang. Yet there is a difference at the first flexion phase dw and the hyperextension dw. The beginners and the Intermediate 2 had an early piked position (flexion dw) whereas the Elite 1 gymnast reach this position later in order to increase the torque of inertia more than the others and therefore the duration of the giant swing gets shorter (Table 1, Table 2). This is associated with a significance of $p=0.03$ (average duration handstand – release: Elite group: 1.38s; Beginner group: 1.79s). Because the Elites have a significantly ($p=0.04$) larger arch in their shoulder during the hyperextension dw phase than the other groups (Table 1, Figure 1). It was determined that the Elite gymnasts had a higher initial tension on their body which allowed them to get into a better the piked position at the flexion uw phase. At the long-hang straight phase the body should be in a vertical line to 180° fully straighten (Arampatzis, A. & Brüggemann, G. 2001). The Elite gymnasts almost have this position (Table 1). The Beginners are either too far behind or in front of the y-axis with Inter 1 the furthestmost. That is because this athlete cannot transfer the velocity of his giant swing into the right movement to reach the straight position. Thus, his piked position at the flexion uw phase is very late (Table 1).

Furthermore, the more angular the hip and shoulder position is at the upward flexion phase the higher the angular velocity and therefore a longer duration of the flight phase. Additionally, the piked position should be taken as early as possible to decrease the torque of inertia. The Elites have these small angular parameters of the hip and shoulder joints and angle of centre of mass to the bar in order to reduce the torque of inertia (Table 1, Figure 1 and 2). The beginners have a lower average angular parameter of the hip and shoulder joints and angle of centre of mass. Therefore there is more negative force which slows down the gymnast's duration of preparing. The Intermediate athletes are in between these parameters. Table 2 displays the relationship between the piked position and flight time. The Elite group has the most piked position and the longest duration of flight phase. The degree of flexion facilitates the initial tension to get into the countermovement for the Tkatchev during and after the release. There is no significant difference between the groups at the flexion uw phase but between Elite and Beginner at flight time ($p=0.02$). But the piked position is not only important; the degree of release is also a main factor to improve the countermovement and flight time (Arampatzis, A. & Brüggemann, G. 2001).

During the release phase, defined by Cuk, et. al. (2009), the Elite athletes examined in this research take up the straight position later than the other athletes (Table 1, Figure 1 and 2). Thereby they increase the angular moment and vertical release duration (Table 2) which was likewise ascertained by Naundorf, f., et. al. (2012). Arampatzis, A. & Brüggemann, G. (2001) describe this phenomenon of vertical release duration as a returned energy of the bar produced by the hyperextension of the upward phase. This influences the duration of flight phase (Table 2). In comparison to Elite 1 and 2, Intermediates and Beginners have a lower angle degree size at the release (Table 1). As such, the Beginners start the parabola of trajectory earlier and have the lowest height above the bar compared to the Intermediates followed by the Elites. The angle degree size of release of Beginners is significantly earlier than the Elite group ($p=0.03$). Additionally, the hip joint at the flight phase, which shows significance between each group (Elite – Beginner: $p=0.006$; Elite – Inter: $p=0.05$; Inter – Beg: $p=0.03$) is less than the Elites. This infers that Intermediates and Beginners might not be fast enough in their hip flexion (Table 1) or not as flexible as Elites during this countermovement. Another problem might be in the initial tension of the piked position for preparing the countermovement. As such they cannot transfer the time into a perfect parabolic flight phase. This can lead to the athlete being too close or failing to catch the bar. If the flight phase has a parabolic shape which ends too close to the bar the gymnast cannot straighten his shoulder joint and he will drop down; that is what happened to Beginner 1 (Figure 1). If the athlete moves into a hyperextension of the hip while grasping the bar the moment of the giant swing will be disturbed and a fluent further giant swing will not be possible; as seen with Beginner 2 (Figure 2). The Elite gymnasts catch

the bar at an average angle of 412° with a bonded body position (Table 1). This allows them to swing on with a fluent motion.

CONCLUSION

This research was successful in showing how the different angles and body positions influence the flight phase of the Tkatchev. A late flexion in the downward phase with a straight position at the vertical line below the high bar influences the following movement of the Tkatchev positively. An early piked position with a late straight/hyperextension upward phase increases the energy of the gymnast to reach a greater height above the bar and let the Tkatchev looks aesthetically pleasing. Both comes with a shorten time of preparing and an increasing time during the flight phase. By starting the preparing phase of Tkatchev before reaching the handstand position the gymnast also shorten the time of the giant swing. But then the athlete has to be faster in each execution for each segment, especially in hip flexion during the countermovement. The best time of re-grasping the bar is with a bonded body position and at an angle degree of 412° .

An interesting future direction for this research would be a comparison between all the angles of each body position and the energy produced by the gymnast and the high bar. Additionally it would be exciting to find out how these angular body segments change while learning a straighten Tkatchev.

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