LANDING ERRORS IN THE MEN'S FLOOR EXERCISE ARE CAUSED BY FLIGHT CHARACTERISTICS

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ABSTRACT: Landing errors on men's floor exercises are caused by the flight parameters. Depending of the flight phase is determined the magnitude of the landing mistake. On the sample of all gymnasts (n=97) who were competing in the qualifications of the senior Men's European Championships 2004 in Ljubljana, we analyzed saltos which were performed by them. Variables according to the theoretical model for the evaluation of salto landings in the floor exercise were used. From the mentioned model we chose only those variables that relate to the flight phase. Axis of rotation, number of turns around longitudinal axis and initial landing height have a significant impact on the magnitude of the landing mistake.

KEY WORDS: gymnastics, floor exercise, landings, flight phase

INTRODUCTION

In modern gymnastics landing is one of the most important factors which determine the final rank of gymnasts in competitions. On each piece of apparatus except of floor only one landing occurs. In the floor exercise where competition routine comprises several acrobatic elements many landings occur. Acrobatic elements are composed of the take off phase, the flight phase and the landing. Two types of landings are being used in modern gymnastics: landings connected to the next salto and (stick) landings to the standstill position.

Stick landing is the goal of the gymnasts. Stick landing means to absorb the body's energy (kinetic energy is zero) produced at the take off phase. In adherence to the conservation of mechanical energy the kinetic energy will be the same at the take off and at the landing if no external forces are applied to the body in the flight phase. For acrobatic elements such as, for example, saltos this rule is completely affective.

The gymnast has to assess the amount and direction of energy in the flight phase and anticipate the amount and direction of energy at the landing [6]. The direction of kinetic energy at the contact can be oriented towards or aside the energy from the flight phase. If the kinetic energy at landing is oriented towards the energy of the flight phase than the total sum of energies is equal to the difference between them and oriented in the direction of the greater one. If the direction of energies is the same than the total amount is equal to the sum of both energies. Therefore it is necessary for the stick landing to develop such initial conditions that the impulse of the ground reaction force would be oriented towards the energy of the flight phase and equal to its amount. These are the characteristics of landings that occur after an independent acrobatic element or at the end of acrobatic series. The ability of the gymnast to control a reaction force during the landing is limited by his muscular coordination, the ability of an individual to predict the magnitude of loading, and the ability to overcome the load created at the time of contact with the surface. If the body is not capable to efficiently control the loading at the time of landing, acute or overuse injuries can occur.

The second group of landings includes landings that are connected to the next acrobatic element. These landings are performed in motion after touching the floor which enables gymnasts to perform another acrobatic element. This means that the impulse of the ground reaction force has to be oriented in the same way as the energy of the flight phase, or the impulse of the ground reaction force has to be greater than the energy of the flight phase [6]. In such case the gymnast maintains a certain kinetic energy which allows him to continue the acrobatic series.

In these terms we can define landings whose goal is to land in a standstill position but are executed with motion as landings with a mistake. On the other hand, landings with mistakes are also those whose goal is to maintain certain kinetic energy for the execution of the next acrobatic element but are performed with lack of needed energy.

Additional problem represents the rule that feet should beF together at landings [2]. One of the important factors affecting the stability is the magnitude of the base support. The base of support is the area bound by the outermost regions of the body in contact with the supporting surface. In the feet-together stance, the base of support is small and this fact aggravates the gymnast's stability. Another factor that affects stability is the angle between the line of action of the body's weight and the boundaries of the base of support. When the line of action of the body's weight moves outside the base of support, stability is disrupted.

If the gymnast keeps his feet together at landing, he can increase his stability by horizontally positioning the center of gravity near the edge of the base of support on the oncoming external force and vertically positioning the center of gravity as low as possible.

Before the gymnast makes an (un)necessary step at landing, he can perform modification movements. Research shows that the distribution of momentum among segments at the flight phase and the contact influences the gymnast's stability during his interaction with the landing surface [8,12,13,16]. Modifications in shoulder torque during the flight phase enable the gymnast to reach kinematic characteristics which are consistent with successful landings. After the contact, the gymnast can circle the arms in the same or the opposite direction to the direction of movement, or lower his center of gravity. Modifications with hands help him to preserve and transfer angular quantity [11]. When he lowers his center of gravity, he enhances the time interval in which he can actively lower the impulse of the ground reaction force with his muscles.

Variability of movement is an important functional factor when researching stability of movement and provides important information in the process of motor learning [1,15]. Variability is an important criterion for defining the quality of execution of movement [12]. The theory of motor learning [14] stipulates that variable practice is more successful than constant practice. With variable motor learning we can apply the knowledge of landings acquired on one apparatus onto another one.

Minnetti et al. [10] discovered that dynamic characteristics of landings from different heights are dependent of muscle activation. Muscles are activated prior to the contact. The influence of pre-activation on the landing success and the foot stability has been investigated by several researchers [3]. The greatest activity of the lower extremities muscles occurs when hips start to drop [10]. Even a small delay in the muscle activity can lead to unsuccessful landings and injuries. Therefore neuromuscular control plays a very important role in the performance of landings.

Research results show a rather low rate of success of landings in competitions [5,9,11]. At the Olympic Games 1996 in Atlanta, McNitt – Gray et al. [7] investigated landings from high bar and parallel bars. Competitors performed twenty landings. Only one was performed without a mistake. Eight were over- and eleven under-rotated.

When performing acrobatic elements, mistakes can occur in every phase of the element. These phases are interdependent. Mistakes that occur in the later phases can be in correlation with the earlier phases. Therefore, it is reasonable to look for the cause of unsuccessful landings in the earlier phases. From what we know about biomechanics, we believe that both the push-off and the flight phase are related to the landing.

In our research we will focus on the flight parameters that are related to the execution of the landing. Subject of this research are salto landings in the floor exercise. The problem is the influence of chosen parameters of the flight phase on the magnitude of the landing mistake.

MATERIALS AND METHODS

In our research, we analyzed landings of saltos performed after an independent salto or at the end of an acrobatic series of saltos (n=241). The analyzed saltos were performed by all gymnasts (n=97) who were competing in the qualifications of the senior Men's European Championships 2004 in Ljubljana. The gymnasts were at the time of the competition 16 or more years old.

We defined the variables according to the theoretical model for the evaluation of salto landings in the floor exercise [4]. From the mentioned model we chose only those variables that relate to the flight phase:

1. Position of the body:
-tucked
-piked
-stretched
2. Initial landing height (at contact):
-high landing (body's center of gravity is above the hips)
-medium landing (body's center of gravity is in the height of the hips)
-low landing (body's center of gravity is below the hips)
3. Axis of rotation (in accordance with FIG's Code of Points 2006):
-around transverse axis (saltos forward and saltos backward)
-around sagital axis (saltos sideways)
-complex rotations
-forward around transverse and around longitudinal axis (saltos forward with turns)
-backward around transverse and around longitudinal axis (saltos backward with turns)

-around longitudinal and forward or backward around transversal (jumps with ½ turn to saltos forward or backward)
4. Number of turns around transverse axis (900 of salto = 1)
5. Number of turns around longitudinal axis (1800 of salto = 1)
6. Number of turns around sagital axis (900 of salto = 1)
7. Visibility of the landing surface
-visible landing surface
-not visible landing surface
8. Decisions during movement
-execution of the desired movement
-interruption of the desired movement

For all variables we computed the frequencies and their percentages in comparison with the magnitude of the landing mistake (cross tabs). With Chi square test we determined the differences between the chosen variables and the saltos with landing mistakes.

RESULTS

Out of all performed saltos at the EC 2004 (n=684), 62.9% (n=413) were performed without error and 37.1% (n=244) were performed with errors.

Among saltos performed with errors (n=244) 98.8% were performed with the intention to stick the landing at the end of an acrobatic series or performed on its own. The rest (1.2%) were connected saltos.

TABLE 1. DISTRIBUTION OF SALTOS WITH LANDING MISTAKES ACCORDING TO SALTO GROUPS

	Independent salto or at the end of acrobatic series	Saltos in connection	Sum
Saltos without error	103 (29.9%)	310 (99.1%)	413 (62.9 %)
Saltos with error	241 (71.9%)	3 (0.9%)	244 (37.1 %)
Sum	344 (50.3 %)	313 (49.7 %)	657 (100.0 %)

The stick landing is the most important and errors were almost exclusively shown while performing saltos with intention to stick landing; in further research we took a closer look at this salto and landing type (independent saltos). As the aim of the landing of independent saltos and saltos at the end of an acrobatic series is the same, hereof we'll refer to them as ‚independent saltos'. Distribution of the errors magnitude among independent saltos (n=344) is: small errors (62.7%), medium errors (31.5%), large errors (1.7%) and falls (4.1%) (Table 2).

The highest frequency of small errors was in the high and medium initial landing height, while most medium and large errors and all falls were performed with a low initial landing height and these differences between the magnitude of error and the initial landing height are significant (Table 3).

The most frequent landing errors to the axis of rotation are saltos forward with and without turns (51.0%; n=123), much less so saltos backward with or without turns (34.9%; n=84), and the lowest frequency have jumps with ½ turn and salto or saltos

TABLE 2. DISTRIBUTION OF SALTOS WITH LANDING MISTAKES ACCORDING TO THE MAGNITUDE AND THE TYPE OF THE LANDING MISTAKE

	Number of saltos	% according to magnitude of error	% according to type of error
Small error	151	62.7 %	
- short step	61		25.3 %
- short hop	90		37.3 %
Medium error	76	31.5 %	
- large step	56		23.2 %
- large hop	20		8.3 %
Large error	4	1.7 %	
- touch with hands	0		0.0 %
- support with hands	4		1.7 %
Fall	10	4.1 %	
Sum	241		

TABLE 3. DISTRIBUTION OF THE MAGNITUDE OF ERROR AND THE INITIAL LANDING HEIGHT

INITIAL LANDING HEIGHT	Magnitude of error							Sum
	Small		Medium		Large		Fall	
	Step	Hop	Step	Hop	Touch	Support		
High landing [n]	22	26	13	12		1		69
% within initial landing hight	31.9 %	37.7 %	18.8 %	17.4 %		1.4 %		100.0 %
% within magnitude of error	36.1 %	28.9 %	23.2 %	60.0 %		25.0 %		28.6%
Medium landing [n]	20	40	22	3		1		78
% within initial landing hight	25.6 %	51.3 %	28.2 %	3.8 %		1.3 %		100.0 %
% within magnitude of error	32.8 %	44.4 %	39.3 %	15.0 %		25.0 %		32.4 %
Low landing [n]	19	24	21	5		2	10	70
% within initial landing hight	27.1 %	34.3 %	30.0 %	7.1 %		2.9 %	14.3 %	100.0 %
% within magnitude of error	31.1 %	26.7 %	37.5 %	25.0 %		50.0 %	100.0 %	29.0 %
Sum [n]	61	90	56	20	0	4	10	241
% within initial landing hight	25.3 %	37.3 %	23.2 %	8.3 %	0.0 %	1.7 %	4.1 %	100.0 %

note: Chi square test between magnitude of error and initial landing height; $\chi^2(6)= 20,3$; p=0,002

TABLE 4. DISTRIBUTION OF LANDING MISTAKES ACCORDING TO THE AXIS OF ROTATION

AXIS OF ROTATION	Magnitude of error							Sum
	Small		Medium		Large		Fall	
	Step	Hop	Step	Hop	Touch	Support		
Salto fwd. [n]	14	15	14	13			7	53
% within axis of rotation	26.4 %	28.3 %	26.4 %	24.5 %			13.2 %	100.0 %
% within magnitude of error	23.0 %	16.7 %	25.0 %	65.0 %			70.0 %	22.0 %
Salto fwd.with turns [n]	13	27	21	6			3	70
% within axis of rotation	18.6 %	38.6 %	30.0 %	8.6 %			4.3 %	100.0 %
% within magnitude of error	21.3 %	30.0%	37.5%	30.0%			30.0%	29.0 %
Salto bwd. [n]	2	9	7	1				
% within axis of rotation	10.5 %	47.4 %	36.8 %	5.3 %				100.0 %
% within magnitude of error	3.3 %	10.0 %	12.5 %	5.0 %				7.9 %
Salto bwd. with turns [n]	18	25	10	8		4		
% within axis of rotation	27.7 %	38.5 %	15.4 %	12.3 %		6.2 %		100.0 %
% within magnitude of error	29.5 %	27.8 %	17.9 %	40.0 %		100.0 %		27.0 %
Saltos sideways [n]	3	2						
% within axis of rotation	60.0 %	40.0 %						100.0 %
% within magnitude of error	4.9 %	2.2 %						2.1 %
Jumps with ½ turn to saltos fwd. or bwd. [n]	11	12	4	2				29
% within axis of rotation	37.9 %	41.4 %	13.8 %	6.9 %				100.0 %
% within magnitude of error	18.0 %	13.3 %	7.1 %	10.0 %				12.0 %
Sum [n]	61	90	56	20		4	10	241
% within axis of rotation	25.3 %	37.3 %	23.2 %	8.3 %	0.0 %	1.7 %	4.1 %	100.0 %

note: Chi square test between landing mistakes and axis of rotation; $\chi^2(15)= 34{,}2$; p=0,003

sideways (14.1%; n=34). Forward saltos with turns (29.0%) were performed more frequently with errors than forward saltos without turns (22%). Backward saltos with turns (27.0%) were also performed more frequently with errors than backward saltos without turns (7.9%). Gymnasts did 12.0% jumps with ½ turn and salto with errors while only 2.1% saltos sideways were performed with errors (Table 4). The differences between the magnitude of error and the axis of rotation are significant.

The highest frequency of small errors occurred with saltos backward with turns (28.5%; n=43) and saltos forward with turns (26.5%. n=40), followed by saltos forward (19.2%; n=29), jumps with ½ turn to saltos fwd. or bwd. (15.2%; n=23) and saltos backward (7.3%; n=11); the lowest frequency of errors occurred in saltos sideways (3.3%; n=5). Small errors show that gymnasts did more often a small hop rather than a small step. With a small hop were more often ended saltos forward with turns, while with a small step were more often performed saltos backward with turns. Medium errors mostly occurred in saltos forward with turns (35.5%; n=27) and without turns (35.5%; n=27); slightly less frequently in saltos backward with turns (23.7%; n=18) and in saltos backward without turns (10.5%; n=8); only 7.9% of jumps with ½ turn to saltos fwd. or bwd. were performed with medium errors (n=6). In middle errors, there is higher prevalence of long steps than long hops. All large errors occurred in saltos backward and all falls happened in saltos forward (Table 4).

The highest frequency of errors was noticed in saltos with turns (68.5%). The difference between the number of turns and the magnitude of error is significant. Small errors and falls are most frequent in saltos without turns, while middle and large errors are mostly performed in saltos with turns. Small hops are characteristic of small errors and large steps are a more frequent medium error (Table 5).

Differences between body positions during the flight, the number of turns around the transverse axis, the number of turns around the sagital axis, visibility of the landing surface, and the deciding between movements were not significant (Table 6.).

DISCUSSION

Each element is expected to be performed to the perfect end position [2]. Any deviation from the perfect end position means error and is penalized by the judges. Errors on landings are caused by the previous phases of element, e.g., the take off and the flight. Flight characteristics, such as the axis of rotation, the number of turns or the initial landing height, do influence the success and quality of landing.

The salto's height is important for the initial landing height [6]. The lower is the initial landing height the higher is the probability of a larger error. With a lower initial landing height the time for landing preparation is shorter which means a higher probability for an error in the sensor system (late data recognition); the movement control

TABLE 5. DISTRIBUTION OF LANDING MISTAKES ACCORDING TO THE NUMBER OF TURNS AROUND THE LONGITUDINAL AXIS

NUM. OF TURNS – LONGIT. AXIS	Magnitude of error							Sum
	Small		Medium		Large		Fall	
	Step	Hop	Step	Hop	Touch	Support		
Without twist	18	26	21	4			7	76
% within number of turns	23.7 %	34.2 %	27.6 %	5.3 %			9.2 %	
% within magnitude of error	29.5 %	28.9 %	37.5 %	20.0 %			70.0 %	31.5 %
1/2 (180°)	11	14	5	3				33
% within number of turns	33.3 %	42.4 %	15.2 %	9.1 %				
% within magnitude of error	18.0 %	15.6 %	8.9 %	15.0 %				13.7 %
1/1 (360°)	12	16	15	2			1	46
% within number of turns	26.1 %	34.8 %	32.6 %	4.3 %			2.2 %	
% within magnitude of error	19.7 %	17.8 %	26.8 %	10.0 %			10.0 %	19.1 %
3/2 (540°)	7	16	6	4			2	35
% within number of turns	20.0 %	45.7 %	17.1 %	11.4 %			5.7 %	
% within magnitude of error	11.5 %	17.8 %	10.7 %	20.0 %			20.0 %	14.5 %
2/1 (720°)	12	18	6	7		3		46
% within number of turns	26.1 %	39.1 %	13.0 %	15.2 %		6.5 %		
% within magnitude of error	19.7 %	20.0 %	10.7 %	35.0 %		75.0 %		19.1 %
5/2 (900°)	1		3			1		5
% within number of turns	20.0 %		60.0 %			20.0 %		
% within magnitude of error	1.6 %		5.4 %			25.0 %		2.1 %
sum	61	90	56	20		4	10	241
% within number of turns	25.3 %	37.3 %	23.2 %	8.3 %	0.0 %	1.7 %	4.1 %	100.0 %

note: Chi square test between magnitude errors and number of turns around longitudinal axis; $\chi^2(15)= 34,0$; $p=0,003$

TABLE 6. CHI SQUARE TEST RESULTS BETWEEN MAGNITUDE OF ERROR AND OTHER VARIABLES

Variables	Value	Degrees of freedom	Significance
Body position	5.534	6	0.477
Number of turns around transverse axis	11.896	9	0.219
Number of turns around sagital axis	3.043	3	0.385
Visibility of landing surface	4.328	3	0.228
Deciding between movement	4.750	3	0.191

at the central nerve system (problems with processing information) or at the effectors level (too late muscle activation). With a higher initial landing height, the time for landing preparation is longer and therefore there is less room for errors. It is very important to perform saltos with high amplitude and prolonged flight time for landing preparation.

In artistic gymnastics, it is almost impossible to learn invariable (constant) performance of the element. Elements are always performed slightly differently, due to the environment (e.g. every apparatus has slightly different physical characteristics) or due to the gymnast's abilities (e.g. emotions, fear). It is very important to teach the gymnast to do the appropriate supplementary movements during the element performance in order to achieve the perfect landing. The variability of landing depends on the variability of the element's performance. The gymnast needs to solve different tasks during his training – landing from different heights (saltos from horse, springboard, mini trampoline etc.) [10] and landing saltos with different angular velocity (»fast« salto, »slow« salto) and to do landings on different surfaces (soft, hard, elastic, etc.). With variable training, the gymnast will acquire the knowledge to adjust his landing according to the circumstances and therefore become more successful.

From the motor control point of view, the gymnast needs a variety of landings from different heights. From the dynamic characteristics point of view, landings from different heights need to be taught separately.

Our analysis shows that saltos with turns are causing most problems in achieving a still equilibrium standing position. Coaches should be more focused on correct landings during saltos with turns as load on the left and on the right leg are different. Also, coaches should be more focused on the take off characteristics, aiming to prolong the time of flight during saltos with turns as height gives better chances of stick landings. For more turns during saltos, higher angular velocity around the longitudinal axis is needed, which puts higher demands on the stick landing. The gymnast receives during saltos with turns at least two types of backup information: the first type is about the technical execution of elements (e.g. how many turns have already been performed) and the second is about the landing execution (what corrections are needed for the perfect landing). During the element execution, both information types are coming into the central nervous system and they require different reactions. Problems occur when an element has not yet been mastered and the gymnast is focused on its technical execution information which disables the processing and the use of information for the landing execution. Usually such processing problems end with an uncontrolled landing and a large error or fall. Among other things, the gymnast receives also information from the environment (e.g. cheering, applauding, music, very bright light etc.) and a selection of this information is also needed. During his training, the gymnast needs to learn to select the useful information which will lead him to the stick landing (for competition it is useful to train in e.g. laud, quite, very bright or shadowy conditions).

Only 29.9% of saltos were performed into the stick landing. This means that a huge majority of coaches and gymnasts should restructure their training programs by type of activity and by loads in order to raise the level of their landings.

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