ORIGINAL ARTICLE ENGLISH VERSION

Study of the physical components implied with the angle of landing in the rolling movement executed at the floor apparatus in artistic gymnastic

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ABSTRACT

Introduction: Biomechanics is a sub-area of physics responsible for the study of the human movement. The artistic gymnastics is a sport modality that intrigues the researchers, in this context; this work comes to analyze one of the movements most important of this modality, the rolling. **Scope:** To analyze the implied physical components with the execution of the movement of the rolling, looking for to establish some relation between these and the angle of landing measured to the end of this acrobatic element. **Methods:** The sample was composed for seven gymnasts, with age varying between 14 and 20 years, with a time of training of at the very least five years. This research was used of tools based on principles of the classic mechanics, techniques of photogrammetry and statistical treatments. **Results:** From the implied physics related with the execution of the rolling, the external torque presented greater relevance. The results were obtained from analysis of groups with distinct levels of experience. The variability of the experimental data was statically treated providing a set of conclusions relevant to this study. **Conclusions:** The results showed the relation between the values of angle and external torque. The increase of the torque was related with low values of the angle. It was verified the influence of the torque by the initial acceleration, according with preliminary works.

Keywords: Biomechanics. Gymnasts. External torque. Acceleration.

INTRODUCTION

Since ancient Greece, Biodynamics is a research field that interests researchers, among them, Aristotle, who may be considered the first researcher in Biodynamics in history(1). Such knowledge field, strongly multidisciplinary, can be characterized as a sub area of Physics and Physiology. It is straightly related to sport and the study of human movement, and even as the time passes by, it has been receiving massive researchers‘ dedication(2-3).

A specific case where Biodynamics plays an important role is in Artistic Gymnastics, which is characterized by its complexity of movements that calls researchers‘ attention. They have been producing countless scientific works with the aim to improve the techniques and many movements related to such sport(4-5). Among this sport’s apparels, the Land is one of the most complex, being by definition, consisted of dynamic elements developed by gymnasts on an elastic surface(6).

Within the great complexity of movements, one may highlight the *rolling scope*. Observing the physical variables involved in this movement, one may say that a typical sequence begins with an approximation run, which can be quantified through the linear momentum greatness. When the *rolling scope* begins, there is an energy transformation, that is, the initial energy that was only kinetic, is decomposed in two other forms of energy: rotation kinetic and potential. These changes occur concomitantly with two new physical greatnesses: the *angular momentum* and the External Torque. The rotation movements, which relate to the mass core of a given body, has a great influence in the calculation of the acting energy over it(7), hence, the external forces acting over a gymnast during her movements on land, may reach from 5 to 17.5 times her own body’s weight(8). Such evidence explains the difficulty faced by gymnasts during the landing of acrobatic elements(9). Moreover, it is important to remind that the higher the level of difficulty of a given acrobatic movement, the higher the risk of an injury(10), since the size of the external forces that act over the athlete, substantially increases her weight. Thus, it is clear the importance to know the size of the physical components implied in each acrobatic element. The *rolling scope* is extremely important, once it is the precursor and propagator of all acrobatic sequences done backwards. Therefore, the study of the physical components implied in its performance, allows its technique improvement, which consequently, will help in the acrobatic movements following it, decreasing the penalizations from the referees board(11-12).

The performance of more complex acrobatic elements such as double mortals and mortals with spinning, quantitatively depends on the physical components: *linear momentum, angular momentum* and External Torque, generated during the approximation and exit of the *rolling scope*(13). Among them, only the *angular momentum* and *External Torque* directly relate with this movement, once only these components are implied in the rotation action promoted by it. However, the External Torque is the most relevant component in this study, since this physical greatness represents the variation of the *angular momentum* in relation to time. Therefore, the aim of this study has become to establish a relation between this physical component and landing angle. Tests with groups with different technical performance levels were conducted with this purpose.

METHODS

The majority of the recent studies use computerized technology to virtually simulate exercises, as well as sophisticated mathematical models of the studied movements(14-15). The present study on the other hand, has as its objective to conduct a simplified experimental study strongly rooted in theoretical ideas within the Physical context of movement, though. For that reason, it has used mathematical equations involved with the physical components

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related to the *Rolling Scope* movement, as well as statistical tools for the treatment of the obtained results.

Besides that, the necessary tools for the data inference related to the *External Torque* calculation and with the landing angle measurement, were quite simple, adapting to this study's objective The values referring to the External Torque were calculated through the equation (1)[16].

$$\tau = m \,.\, |\, a \,|\, .\, r \,.\, sen(\theta) \qquad (1)$$

Where τ represents the value for the External Torque, m the mass value, $|\, a \,|$ the module of the acceleration concerning the execution of each movement, r is the size of the leg segment of each gymnast and θ is the landing angle.

The landing angles were obtained through photometry, where the filmed image of the movement was frozen on screen, making it possible to measure the landing angle, called figure 1 graphically demonstrates how this measurement happened.

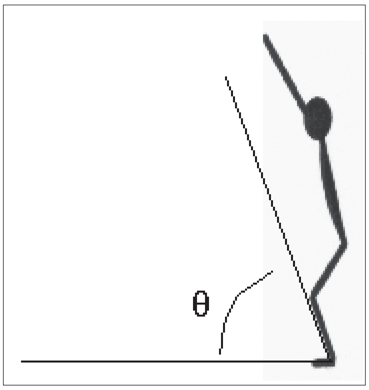


Figure 1 *– Landing moment on the ground where the image was frozen, making it possible to measure the θ angle, made with the horizontal and the segment of the leg of each gymnast*

The tools used in this research consisted of a measuring tape, used to measure the dislocations and the length of the leg's segment of each gymnast; a scale of domestic use to weight the gymnasts; two digital stopwatches of ordinary use, to measure the times related to the dislocations; a camcorder and a reproduction system, where the photometric technique was applied to measure the landing angle of each *Rolling scope.* The study group consisted of 7 gymnasts, with ages between 14 and 20 years, with a training time of at least five years. Five gymnasts did four tests each, and two, eight tests each, being in that case, the four pilot tests done by each one included, which resulted in a total of 36 completed tests. Figure 2 graphically demonstrates the performance of this movement, as well as the referential instants and phases of segmentation of the movement, where the data related to the dislocations and implied times like these were extracted from.

In step A, consisted of an impulse run, the time and the dislocation of the 0 instant were measured, where the gymnast is in her fundamental position to 1, where she touches the ground with her hands, characterizing the *Rolling Scope* movement's beginning. In step C the values referring to times and dislocation necessary to perform the complete movement were measured, that is, of the instant 0 to 2, where the gymnasts' feet arrival determines its end. The calculation of the difference between the obtained values for the A and C steps show the values for the dislocation and time referring exclusively to the *Rolling Scope,* characterized by the step B. The manipulation of these data may provide the value of the acceleration concerning each movement, which finally made the calculation of the External Torque involved with each *Rolling Scope* possible.

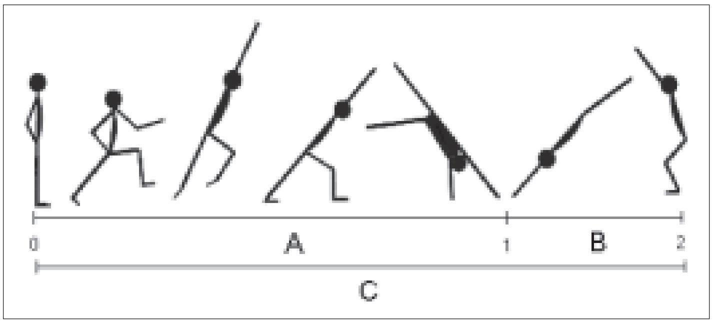


Figure 2 *– Graphic simulation of the Rolling scope on the ground, with the segmentation phases and referential instants adopted in this study*

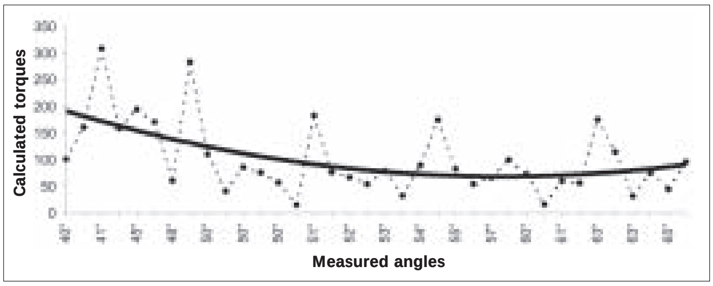
RESULTS

The values calculated for the External Torque (τ) and measured for the landing angles (θ) were then concentrated in table 1.

TABLE 1
Values calculated for the External Torque, represented by the Greek letter τ, in Newton.meter (Nm) and of the landing angles measured, represented by the Greek letter θ. The gymnasts are represented by the A, B, C, D, E, F, G letters. They are the gymnasts who participated in the experience

Gymnasts	θ	τ (Nm)	Gymnasts	θ	τ (Nm)
A	50°	110	D	53°	79
	54°	33		50°	41
	60°	73		65°	45
	63°	176		56°	54
	54°	90	E	60°	16
	51°	183		65°	96
	50°	57		63°	115
	55°	83		63°	32
B	48°	61	F	50°	86
	52°	67		40°	101
	50°	15		45°	195
	54°	175		43°	159
	52°	54	G	57°	66
	48°	284		41°	309
	50°	76		40°	161
	51°	77		46°	171
C	58°	100			
	61°	56			
	64°	75			
	61°	60			

Observing table 1 a great dispersion of values presented for the landing angle θ can be seen and consequently, in the values calculated for the External Torque τ. Such data behavior is even more evident when graph 1 is observed. Such dispersion is expected due to the applied technique in the experiment: present results with this variability due to the measures lack of precision in some tests.



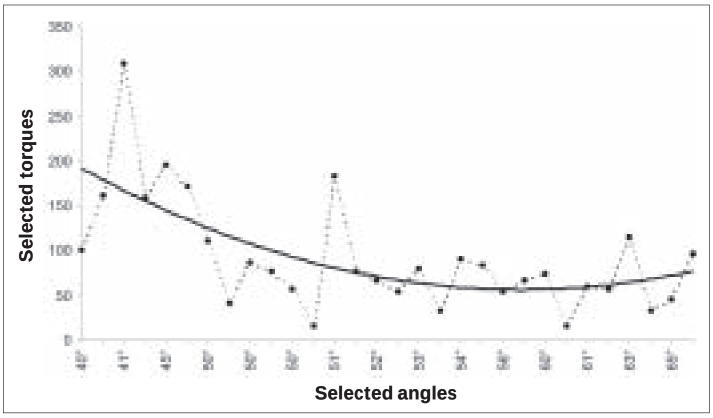
Graph 1 *– Variation of the External Torque calculated according to the landing angle measured (curve with dots). Curve of the experimental data trend (continuous line). In the horizontal axis we found the values of the experimentally measured angles and in the vertical axis the values of the External Torque calculated for each angle.*

A remarkable descending inclination may be observed through the analysis of the data behavior in graph 1, despite the dispersion to the represented curve tendency. Some data were distant from this curve; therefore, to establish a more clear relation between the angle and External Torque variables, a selection using known statistical techniques was used in order to clarify the behavior of these variables for the different groups of athletes studied. The data were selected in intervals and the averages of External Torque per interval as well as the dispersion of these values in the same intervals were calculated. This grouping per interval technique generates more clear behavior patterns. A better elaborated statistical test is not necessary for this case, since the measures suffer little influence of external variables.

In table 2, the value of the External Torque for different angles is shown. Graph 2 shows the data representation presented in table 2. The values in grey were ignored for analysis.

TABLE 2
Data selection through the standard deviation applied to the average. The values that did not follow the interval of each sample group are in grey. Where $\bar{\theta}$ represents the average landing angle and σ (θ) the standard deviation of this average. The angles and External Torque are respectively represented by the letters θ and τ

Gymnasts	$\bar{\theta}$	σ (θ)	θ	τ
A 50°|—| 60°	55°	± 5°	50°	110
			54°	33
			60°	73
			63°	176
			54°	90
			51°	183
			50°	57
			55°	83
B 49°|—| 53°	51°	± 2°	48°	61
			52°	67
			50°	15
			54°	175
			52°	54
			48°	284
			50°	76
			51°	77
C 59°|—| 63°	61°	± 2°	58°	100
			61°	56
			64°	75
			61°	60
D 50°|—| 62°	56°	± 6°	53°	79
			50°	41
			65°	45
			56°	54
E 61°|—| 65°	63°	± 2°	60°	16
			65°	96
			63°	115
			63°	32
F 41°|—| 49°	45°	± 4°	50°	86
			40°	101
			45°	195
			43°	159
G 38°|—| 54°	46°	± 8°	57°	66
			41°	309
			40°	161
			46°	171



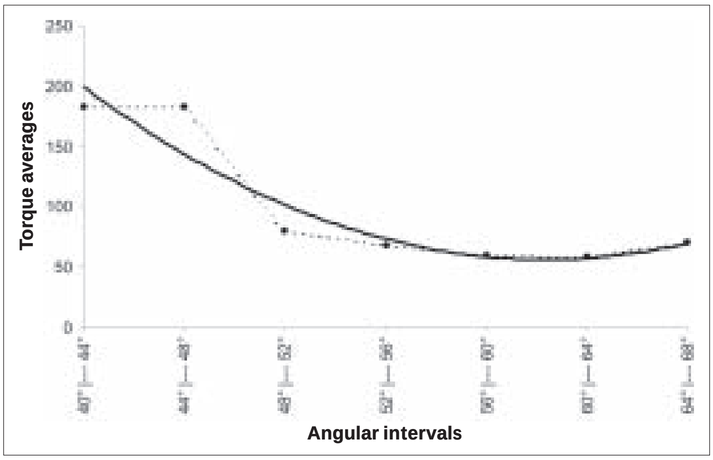
Graph 2 – *External Torque variation related to the selected angles. The dotted line represents the curve of the selected values, while the continuous line, the curve of their tendency. Again in the horizontal axis the angles measures are found, and in the vertical axis the values of the External Torque calculated for these angles.*

In graph 2, smaller dispersion of the values related to the tendency curve is observed. Even with this dispersion, the tendency curve presents a similar behavior. The second step of the treatment through interval is the calculation of the average External Torque per interval. These values are shown in table 3. In this case the values are not separated by athlete.

TABLE 3
Angular intervals and the representative average of the External Torque related to them represented by $\bar{\tau}$ datum in Newton. meter (*Nm*)

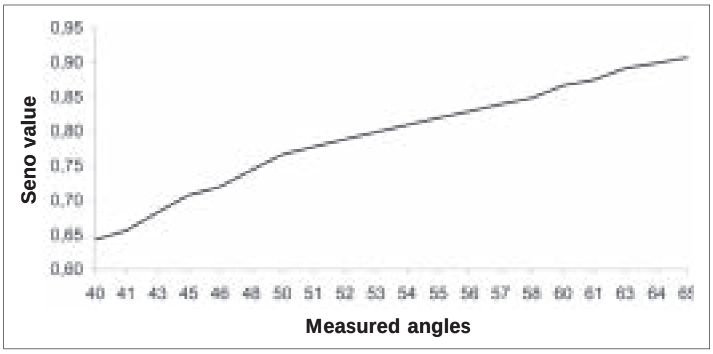
Angular interval	$\bar{\tau}$ *(Nm)*
40° |— 44°	183
44° |— 48°	183
48° |— 52°	81
52° |— 56°	68
56° |— 60°	60
60° |— 64°	59
64° |— 68°	71

Graph 3 shows the representation of data shown in table 3. The angular intervals are in the horizontal axis and the values of the External Torque averages, represented by τ, in the vertical axis.



Graph 3 – *Variation of the External Torque averages related to the angular intervals*

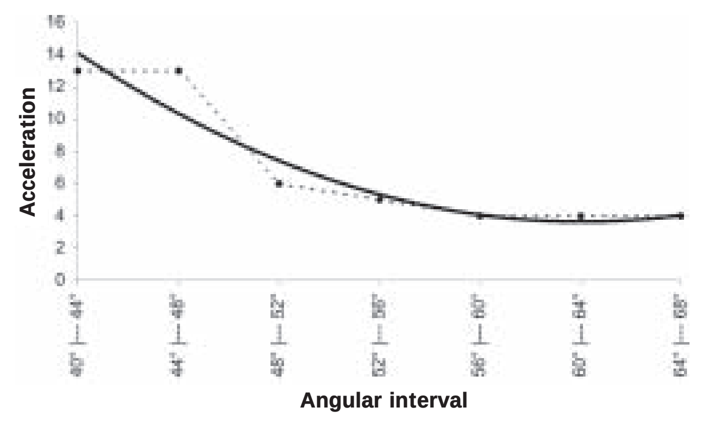
Graph 3 presents a more evident assintotico behavior, when compared to the previous figures. The result shows a counterbalance, the seno, sen(θ), of the measured angle tends to increase when its value increases in the interval in which the measurement is made. Such behavior may be observed in graph 4.



Graph 4 – *Variation of the senos values for the measured angles in the proposed experiment*

DISCUSSION

The values for the External Torque should behave alike, once as may be observed in the equation (1), the External Torque is directly proportional to the seno value of the angle. Such fact occurs due to the other variables direct influence in the External Torque value in the *Rolling Scope* movement case. As the mass and length of each gymnast's leg are constant, these two variables do not influence the External Torque value. The remaining variable is the acceleration. This variable is not constant, therefore, may present some direct relation with the External Torque values presented. In order to solve and confirm this fact, an analysis through the graphic representation of the average behavior of the accelerations related to the respective angular intervals was chosen, which may be observed in graph 5.



***Graph 5** – Variation of the acceleration in relation to the angular interval. In the horizontal axis the values of the measured angles separated by interval are found. In the vertical axis the average values of the accelerations in these intervals are found.*

Through graph 5 analysis it is possible to observe that the acceleration decreases when the angular interval increases. Thus, the values of the acceleration seem to be more relevant to the behavior of the final External Torque values, due to their similar behavior. In other words, when the acceleration variable decreases, the External Torque also does, even if the seno values increase in the angular interval in which the measure is taken.

Graph 5 establishes an indirect relation between the landing angle and the acceleration. Through this relation we may observe that a high acceleration causes a maximum value for the resulting External Torque, and a minimum value for the landing angle. Consequently, the movement as a whole, has a remarkable dependence on the approximation run and on the acceleration imposed by the gymnast to the movement itself to perform it(16).

Such result corroborates with the results in consulted bibliography, presenting important biodynamic implications to the movement. In an acrobatic sequence where the best Rolling Scope feedback is expected, it is relevant to implement acceleration values which are more suitable to the objectives following the movement. For instance: when one wants to end a sequence, the deceleration or a smaller acceleration should be the objective to its ending, as confirmed by this study. The angles position is also essential, since it serves as balance between the acceleration when inversely proportional Torque values to growth values of the landing angle value. The observed relations between the physical components through this cinematic analysis determine a group of relations among these variables which is little described in specific bibliography.

The results obtained in the gymnasts' jumps present a great dispersion, which may be due to the decrease or increase of the acceleration during the run phase, which may modify the entrance angle of the jump. As it is an acrobatic exercise, any change in this sense can greatly modify the landing angle and consequently in the correct movement. Since this study is limited to measure the landing angle and the external torque, the influence of the entrance angle of the jump in relation to its finalization was not observed.

CONCLUSIONS

The results of this study reached the conclusion that the smaller the landing angle of the *rolling scope*, the bigger the external torque will be. It was also verified that the initial acceleration, that is, the run moment, directly influences in this angle and consequently, in the external torque production.

The best landing angle obtained among the studied gymnasts was of 40 to 48°. Whenever the athlete's objective is to give sequence to the collection of movements that begin after the rolling scope, the balance between acceleration and angles position should be observed in order to obtain higher External Torque values.

All the authors declared there is not any potential conflict of interests regarding this article.

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