Reasoned Opinion

A computer method for biomechanical analysis of the balance of acrobatic figures performed by two gymnasts

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Abstract:
In this paper, we present a biomechanical analysis of the balance of an acrobatic figure constructed by two girls. For the analysis, the Kinovea computer software was used. We demonstrate that the balance in the sagittal plane depends on the size of the base gymnast's feet and the angle between her feet: increasing the size of the feet of the base gymnast improves the balance, while increasing the angle between her feet weakens the balance. Balance also depends on the heights and masses of gymnasts: increasing the gymnasts' heights and/or the top gymnast's mass weakens the balance, while increasing the base gymnast's mass improves it. Such analysis is especially important when acrobats are relatively young (10-15 years old), as their bodies are undergoing growth and body parameters (such as sizes and weights of body parts) change non-proportionally.

Keywords: acrobatic gymnastics, sports biomechanics, balance, equilibrium.

Introduction. In many sports, the quality of performance depends on the athletes' ability to maintain balance. In some sports such as acrobatics, gymnastics, weight lifting and surfing, this ability plays a decisive role. To assess the balance of acrobatic figures, researchers use force plates and calculate deviations of the center of pressure from the average value [1, 2].

Scientists also use video-computer analysis, where the coordinates of athletes' centers of gravity may be calculated from video recordings [3-8].

At the same time, we know that the result in many sports also depends on the physical parameters of athletes such as their heights, masses, etc [9, 10]. In this paper, we study how the balance of the hand-to-hand stand in Fig. 1 depends on the heights, masses and other physical parameters of the athletes.

Research methods. From the photo, using line calibration and the human model tool available in the Kinovea computer program, we can find the coordinates of the centers of mass for each gymnast and then calculate the coordinates of the total center of mass of the whole acrobatic figure $CM(X_{CM}, Y_{CM})$. CM_1(78.86 cm, 92.89 cm) and CM_2(83.65 cm, 258.02 cm) – are the centers of mass of the base and top gymnasts, respectively, while CM(80.60 cm, 152.94 cm) is the total center of mass of the whole acrobatic figure, which may be obtained using standard formulas:

$X_{CM}=(m_1/(m_1+m_2))\cdot X_{CM}'+(m_2/(m_1+m_2))\cdot X_{CM}''$

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and $Y_{CM}=(m_1/(m_1+m_2))\cdot Y_{CM}'+(m_2/(m_1+m_2))\cdot Y_{CM}''$, where $m_1=42$ kg is the mass of the base gymnast, $m_2=24$ kg is the mass of the top gymnast, $h_1=160$ cm and $h_2=130$ cm are their heights, and (X_{CM}', Y_{CM}') and (X_{CM}'', Y_{CM}'') are the coordinates of their centers of mass.

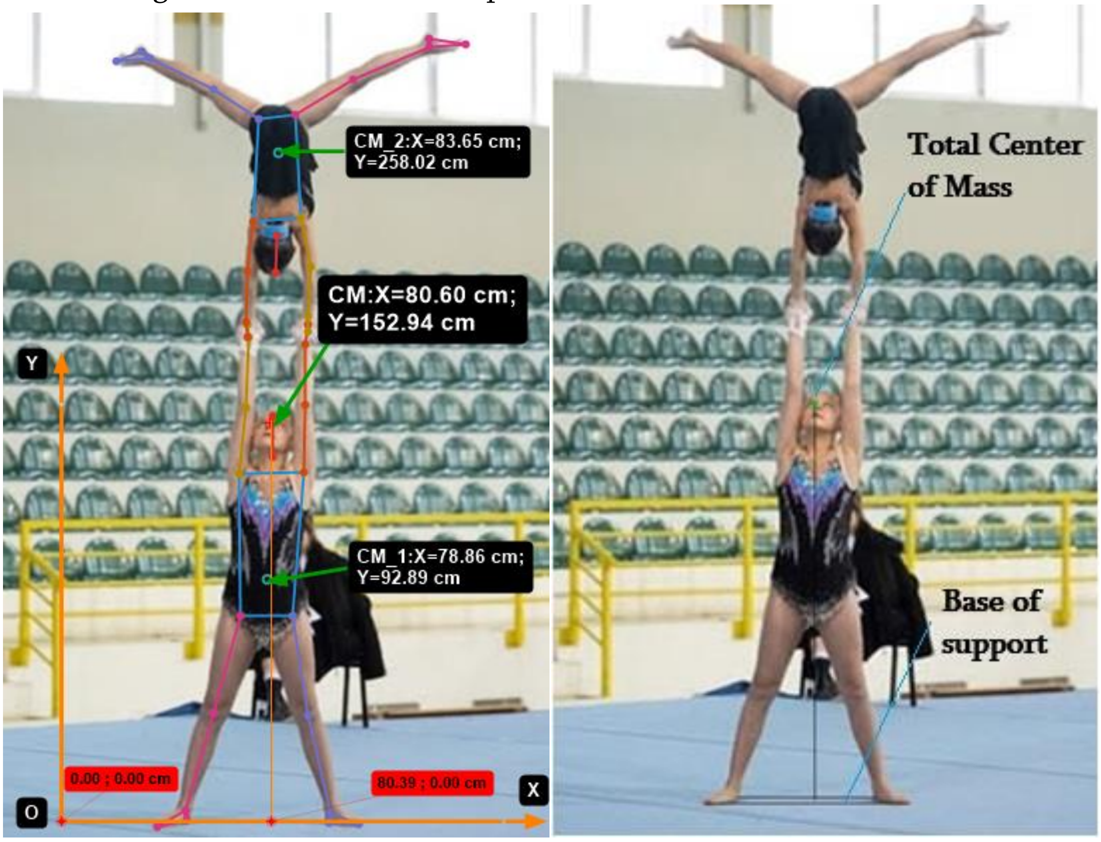

Fig. 1. The figure shows the centers of mass of the gymnasts obtained using Kinovea software and the calculated total center of mass of the whole acrobatic figure.

The balance of the hand-to-hand stand in the frontal plane is achieved by keeping a fairly large distance between the feet of the base gymnast. While balance in the sagittal plane during backward and forward leanings is much more difficult to achieve. As it was shown in our recent publication the balance of the stand in the sagittal plane may be characterized by four angles α_{cr}', α_{cr}'', $\alpha_{opt}=\alpha_{cr}'$ and $\alpha_{cr}=\alpha_{cr}'+\alpha_{cr}''$ [10].

The first angle α_{cr}' characterizes the maximum leaning of the body in the backward direction while maintaining balance, the second angle α_{cr}'' characterizes the maximum leaning in the forward direction without losing equilibrium, the third angle α_{opt} desribes the optimal position of the total center of gravity of the acrobatic stand when it is exactly over the geometric center of the base of support and the fourth angle $\alpha_{cr}=\alpha_{cr}'+\alpha_{cr}''$ characterizes the overall stability of the acrobatic figure in the sagittal plane during leanings backwards and forwards.

These angles depend on $Y_{CM}\approx 153$ cm - the vertical coordinate of CM and $l=|KM|=|LN|=22$ cm - the base gymnast's foot length, and $\alpha_{feet}\approx 70°$ - the angle between her feet (Fig. 2).

$\alpha_{cr}'=\arcsin((1/4)\cdot d/Y_{CM})$

and $\alpha_{cr}''=\arcsin((3/4)\cdot d/Y_{CM})$,(1)

where $d=|AB|=l\cdot\cos(\alpha_{feet}/2)$.

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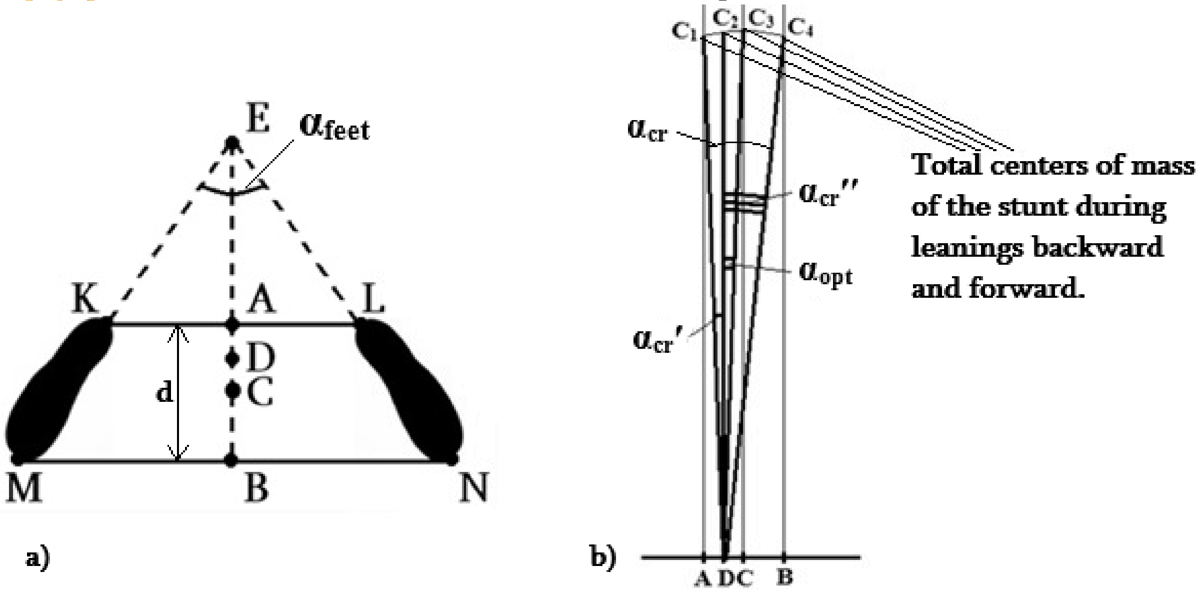

Fig. 2. a.) the feet of the base gymnast; b.) the angles α_{cr}', α_{cr}'', $\alpha_{opt}=\alpha_{cr}'$ and α_{cr} describing the balance of the acrobatic figure in the sagittal plane.

Using formulas (1), we can calculate values of the critical angles $\alpha_{cr}'=1.69°$, $\alpha_{cr}''=5.07°$, $\alpha_{opt}=1.69°$ and $\alpha_{cr}=6.76°$.

Discussion of the results of the study. Table 1 demonstrates how variations of the basic physical parameters of the gymnasts m_1, m_2, h_1, h_2, l, and the angle between the feet of the base gymnast α_{feet} affect the calculated values of the critical angles α_{cr}', α_{cr}'', $\alpha_{opt}=\alpha_{cr}'$ and α_{cr}.

Table 1. The table shows how the changes of the physical parameters of the gymnasts affect the balance of the whole acrobatic figure.

Table 1. The table shows how the changes of the physical parameters of the gymnasts affect the balance of the whole acrobatic figure

#	Variations of m_1, m_2, h_1, h_2, l and α_{feet}						Calculated parameters		
	Δm_1	Δm_2	Δh_1	Δh_2	Δl	$\Delta\alpha_{feet}$	$\Delta\alpha_{cr}'$	$\Delta\alpha_{cr}''$	$\Delta\alpha_{cr}$
1	5 kg	0	0	0	0	0	0.05°	0.14°	0.19°
2	0	5 kg	0	0	0	0	-0.08°	-0.23°	-0.31°
3	0	0	10 cm	0	0	0	-0.08°	-0.25°	-0.33°
4	0	0	0	10 cm	0	0	-0.02°	-0.06°	-0.08°
5	0	0	0	0	2 cm	0	0.15°	0.46°	0.62°
6	0	0	0	0	0	10°	-0.11°	-0.33°	-0.44°

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From Table 1, we can see that the balance of the whole acrobatic figure is most sensitive to the base gymnast's foot length l and the angle between her feet α_{feet}: the increase of the foot length l by 2 cm improves α_{cr} by 0.62°, while the increase of the angle α_{feet} by 10° decreases α_{cr} by 0.44°.

α_{cr} is also sensitive to the height of the base gymnast and the mass of the top gymnast: the increase of h_1 by 10 cm decreases α_{cr} by 0.33°, while the increase of m_2 by 5 kg leads to the decrease of α_{cr} by 0.31°. From Table 1 we see, that α_{cr} is less sensitive to variations of m_1 and h_2.

Conclusions. In this study, we show that the balance of the hand-to-hand stand depends not only on the professionalism of gymnasts, but also on their physical parameters and is most sensitive to the changes of two parameters: the foot size l and angle α_{feet} between the feet of the base gymnast. This fact is very important when working with young gymnasts, who are in the stage of intensive growth and development accompanied by changes in physical parameters. Trainers can use force plates to evaluate the quality of performance, but they should also take into account changes in the physical parameters of athletes.

ორი ტანმოვარჯიშის მიერ შესრულებული აკრობატული ფიგურების წონასწორობის ბიომექანიკური ანალიზის კომპიუტერული მეთოდი

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აბსტრაქტი:

ნაშრომში წარმოდგენილია ორი გოგონასაგან აგებული აკრობატული ფიგურის ბალანსის ბიომექანიკური ანალიზი. ანალიზი ჩატარდა კომპიუტერული პროგრამული უზრუნველყოფა Kinovea-ს გამოყენებით. შედეგად, ნაჩვენებია, რომ საგიტალურ სიბრტყეში ბალანსი დამოკიდებულია ქვედა ტანმოვარჯიშის ტერფის ზომაზე და კუთხეზე ტერფებს შორის: ტერფის ზომის გაზრდა ზრდის ბალანსის მდგრადობას, ხოლო ტერფებს შორის კუთხის გაზრდა პირიქით ამცირებს წონასწორობას. ბალანსი ასევე დამოკიდებულია ტანმოვარჯიშეების სიმაღლეებზე და მასებზე: ტანმოვარჯიშეების სიმაღლეების და ზედა ტანმოვარჯიშის წონის ზრდა ამცირებს ბალანსს, ხოლო ქვედა ტანმოვარჯიშის მასის ზრდა აუმჯობესებს მას. ასეთი ანალიზი განსაკუთრებით მნიშვნელოვანია, როდესაც აკრობატები შედარებით პატარა ასაკის არიან (10-15 წელი), როცა მათი ორგანიზმები განიცდიან ზრდას და სხეულების პარამეტრები (სხეულის ნაწილების ზომები და წონები) არაპროპორციულად იცვლება.

საკვანძო სიტყვები: აკრობატული ტანვარჯიში, სპორტის ბიომექანიკა, წონასწორობა, ბალანსი.

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