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KINETIC AND KINEMATIC CHARACTERISTICS AS THE BASIS FOR EVALUATING TAKE-OFF IN BACKWARD ACROBATIC JUMPS

HENRYK KRÓL[1], MAŁGORZATA KLYSZCZ-MORCINIEC[2]

[1]*Jerzy Kukuczka Academy of Physical Education in Katowice, Faculty of Physical Education, Department of Biomechanics*
[2]*Former student, Jerzy Kukuczka Academy of Physical Education in Katowice, Faculty of Physical Education*

Mailing address: Henryk Król, Jerzy Kukuczka Academy of Physical Education in Katowice, Department of Biomechanics, 72a Mikołowska Street, 40-065 Katowice, tel.: +48 32 2075173, fax: +48 32 2075200, e-mail: h.krol@awf.katowice.pl

Abstract
Introduction. Some of the most important roles of coaches are organising the technical training for evaluating movement technique and indicating errors as gymnasts perform the elements of this movement. This can only be applied in individual gymnasts [2, 3], and there are gaps in our knowledge about the details of the technique of individual gymnasts. Therefore, due to the structural complexity of acrobatic elements, the evaluation of a technique should precisely locate errors indicated in specific phases of the exercise. ***Material and methods.*** In this paper, the results of the atypical back tucked somersault and counter movement jump of one of the participants are reported on. This participant was a 16-year-old female gymnast with a body mass of 51 kg and a height of 156 cm. While coaches use a subjective qualitative analysis of the sporting movement to determine what advice must be given, a sports biomechanics researcher must make use of objective quantitative data. In our study, we have used the multimodular measuring system SMART when studying the structure of the acrobatic jumps, and we conducted a complex analysis of these exercises. ***Results.*** These exercise approaches may be used to achieve important training goals. It seems logical, therefore, that physical educators, coaches, and athletes should look to biomechanics for a scientific basis for the analysis of the individual techniques used in sports. As for practical implications, we recommend that coaches and physical education educators carefully monitor the gymnast's leg joints and avoid extension of the knee and ankle at the counter movement phase during standing acrobatic jumps.

Key words: acrobatic jumps, biomechanical analysis, case study, comprehensive methodology

Introduction

Biomechanical research on artistic gymnastics has grown substantially over the years. Artistic gymnastics has received considerable attention from investigators of biomechanics. The kinematic analysis of gymnastics provides information that can be used in two ways: scientists can learn about the nature of gymnastic movements, and a framework within which coaching analysis can be objectively interpreted is provided [1].

Some of the most important roles of coaches are organising the technical training for evaluating movement technique and indicating errors as gymnasts perform the elements of this movement. This can only be applied in individual gymnasts [2, 3]. However, most biomechanical research involves generalisation [4], which is done by averaging the temporal characteristics of the movement. Consequently, our understanding of the principles and bases of this sport, although improved, is still marginal. There are gaps in our knowledge concerning the details of the technique of individual gymnasts.

One way to get out of this situation is to use an experimental approach. Sometimes this approach takes the form of direct intervention in the activity. Such intervention may understandably meet with some resistance from the gymnast and the coach. More often, the gymnast is not aware of the ongoing experiment. The experiment is actually the way in which the biomechanist selects the data. By obtaining movement data on an individual gymnast, it may be possible to identify those elements of a technique which are associated with better performance. The movement data can indicate how personal performance may be improved. By obtaining data on the gymnast and identifying the characteristics of the better gymnasts, it may be possible to gain insight into how the training should be structured [5].

A special way to assess the efficiency of mastering a technique involved in acrobatic jumps is based on the results achieved in sport competitions (the scores given by the jury). Scoring, however, does not contain detailed information on the movement technique, nor does it indicate in which phase and to what extent the gymnast deviated from the ideal technique. Furthermore, the results of the assessment of acrobatic jumps obtained by observing gymnasts, which are often similar to scores given during competitions, are flawed, mainly due to the imperfection of visual perception [6]. Therefore, due to the structural complexity of acrobatic elements, the evaluation of a technique should precisely locate errors indicated in specific phases of the exercise. This is possible only by means of a complex analysis of the movement [7]. In our study, we have checked the usefulness of the multimodular measuring system SMART (BTS, Italy) in studying the structure of acrobatic jumps.

Material and methods

Materials

Twelve healthy female artistic gymnasts participated in this investigation. The participants were a convenient sample of highly competitive national-standard female gymnasts who demonstrated proficiency in performing the skills required for the investigation. The gymnasts were informed about the nature of the study. Prior to data collection, the participants were required to sign a consent form according to human subject regulations. Parental or guardian consent was required for those younger than 18 years. The research project was approved by the Ethics Committee for Scientific Research at the Jerzy Kukuczka Academy of Physical Education in Katowice, Poland.

All subjects were tested under the same conditions in a laboratory setting. Each gymnast performed three randomised trials of four acrobatic skills (jumps): standing backward tucked somersault, standing backward piked somersault, standing backward handspring with landing in the place of take-off, and counter movement jump (CMJ). The rest periods between these acrobatic jumps lasted about 3 minutes. In this paper, the results obtained for the atypical back tucked somersault and counter movement jump of one of the participants are reported on. This participant was a 16-year-old female gymnast with a body mass of 51 kg and a height of 156 cm.

Methods

Using the SMART-E measuring system (BTS, Italy), a multidimensional registration of the motion was performed. The system includes six infrared cameras with a frequency of 120 Hz, synchronised with a module for wireless measurement of the electrical activity of the muscle called Pocket EMG (BTS, Italy), and a force platform. Infrared camera recordings of the performances were collected to allow access to kinematic parameters of the take-off techniques of the acrobatic jumps. The parameters could help explain the characteristics of muscle activation. The set of passive markers permitting the calculation of some chosen parameters were applied. Modelling in 3D space as well as the calculations of parameters were performed with Smart Analyzer software (BTS, Italy). The technical accuracy of the system was 0.4 mm after the calibration process – it was the accuracy of measurement, i.e. the distance between two markers in 3D.

Multichannel electromyography (EMG) may be used in studies of muscular coordination, enabling, in turn, certain evaluations of motor skills. The electromyography signals were monitored using disposable surface electrodes (1 cm^2, silver-silver chloride). Two electrodes with an interelectrode distance of 1 cm were placed parallel to the muscle fibres on the belly of eight muscles (*anterior tibialis*, *medial gastrocnemius*, *rectus femoris*, *biceps femoris*, *rectus abdominis*, *gluteus maximus*, *erector spinae*, and *anterior deltoideus*), in accordance with the European Recommendations for Surface Electromyography – SENIAM [8]. All electrodes were placed on the right side of the subject's body and secured with athletic tape. The surface electrodes were used to obtain the muscle activation characteristics of the gymnasts during the counter movement, take-off, and flight phases of each acrobatic jump. All electrodes remained in place until the end of all the trials. Wires connecting the electrodes to the transmitter were secured to the gymnast's body with athletic tape to minimise distraction to the subject and interference with the EMG signal. The transmitter was placed in a belt pack worn snugly around the waist by the gymnast.

The electromyography signals were sampled at a 1-kHz rate. All active channels had the same measuring range and were fitted to the subject (typically +/– 5 mV). Analogue signals were converted to digital ones with 16-bit sampling resolution. After a single trial, the signals were immediately transmitted to a computer via a Wi-Fi Network. Following the data collection, the signals from each trial were stored on a hard drive and later analysed using the Smart Analyzer software. The raw EMG signal was filtered (pass band Butterworth filter, 10-300 Hz). Next, the full-wave was rectified and smoothed using the root-mean-square (RMS) method with a 100-ms mobile window. Then, the RMS EMG signals were normalised to maximal voluntary isometric contraction (MVC) amplitudes, in accordance with the European Recommendations for Surface Electromyography – SENIAM [8]. This was done before the series of acrobatic jumps.

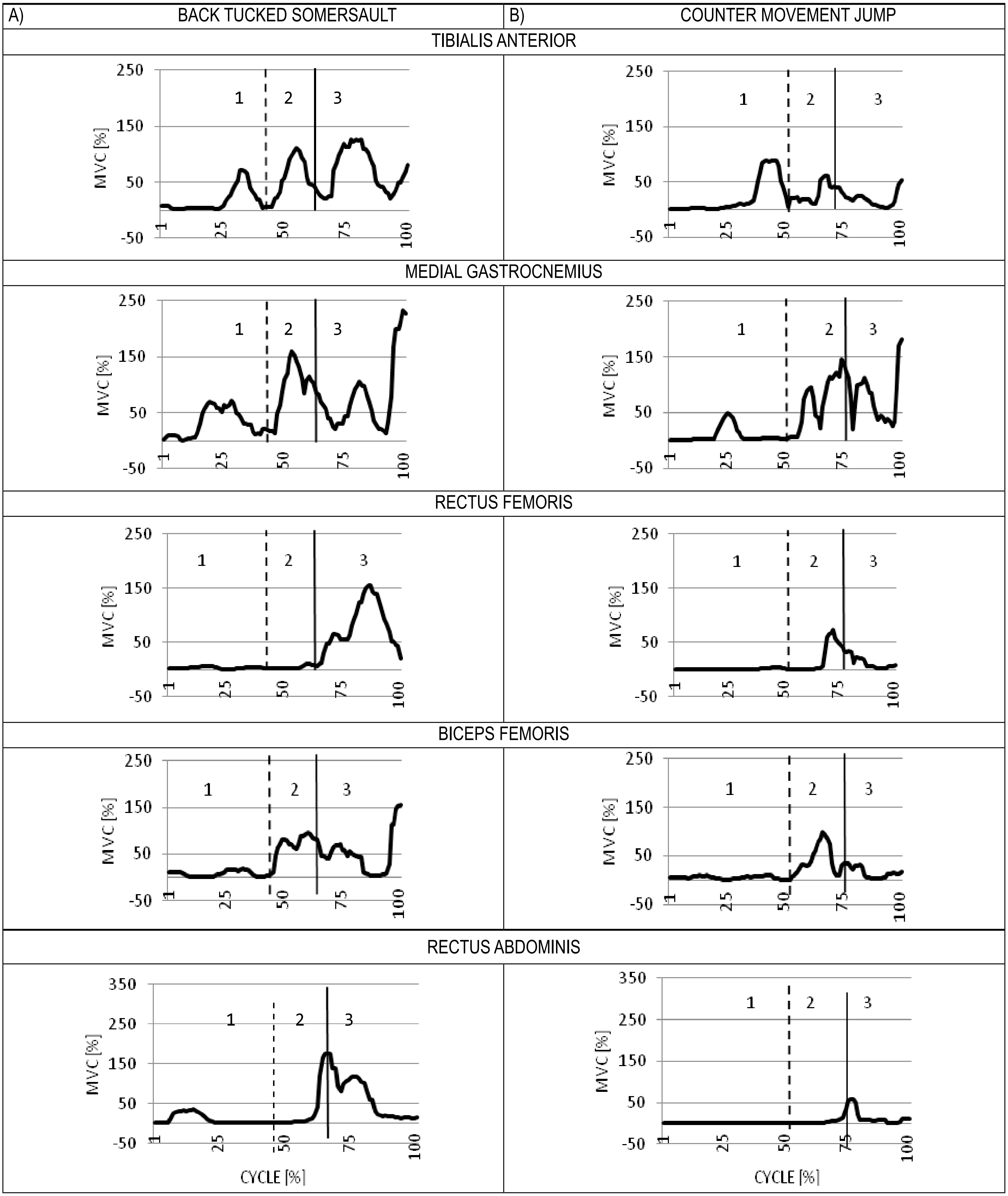
The gymnasts were instructed to perform the acrobatic jumps from a standing position with take-off from the Kistler force platform (type 9182C, Kistler Instuments Corp., Switzerland). The vertical and horizontal (anterior-posterior) components of the ground reaction force were recorded. Computer software (MATLAB) was used to calculate the following: the vertical and horizontal force impulse (J_y; J_x), the centre of mass (COM) velocity (v_y; v_x), and displacement (d_y; d_x).

Results

The comparison of EMG patterns in the set of muscles between the two acrobatic jumps (the back tucked somersault and counter movement jump) performed by the same female gymnast indicated large differences (Fig. 1). The differences in the muscle activation were especially evident for the *rectus femoris* muscle in the take-off phase and for the *rectus abdominis* muscle in the flight phase. Interesting information about of the back tucked somersault and counter movement jump was also delivered by the vertical and horizontal components of the ground reaction force (Fig. 2 and 3). The vertical force in the back tucked somersault proved to be especially interesting. For a period equal to about 2/3 of the time of the take-off phase of this acrobatic jump, the vertical component of the reaction force was almost equal to the body weight of the gymnast. The cause seemed to be the angle-time curves. Angular displacement of the ankle joint, knee joint, hip joint, and shoulder joint is shown in Figure 4.

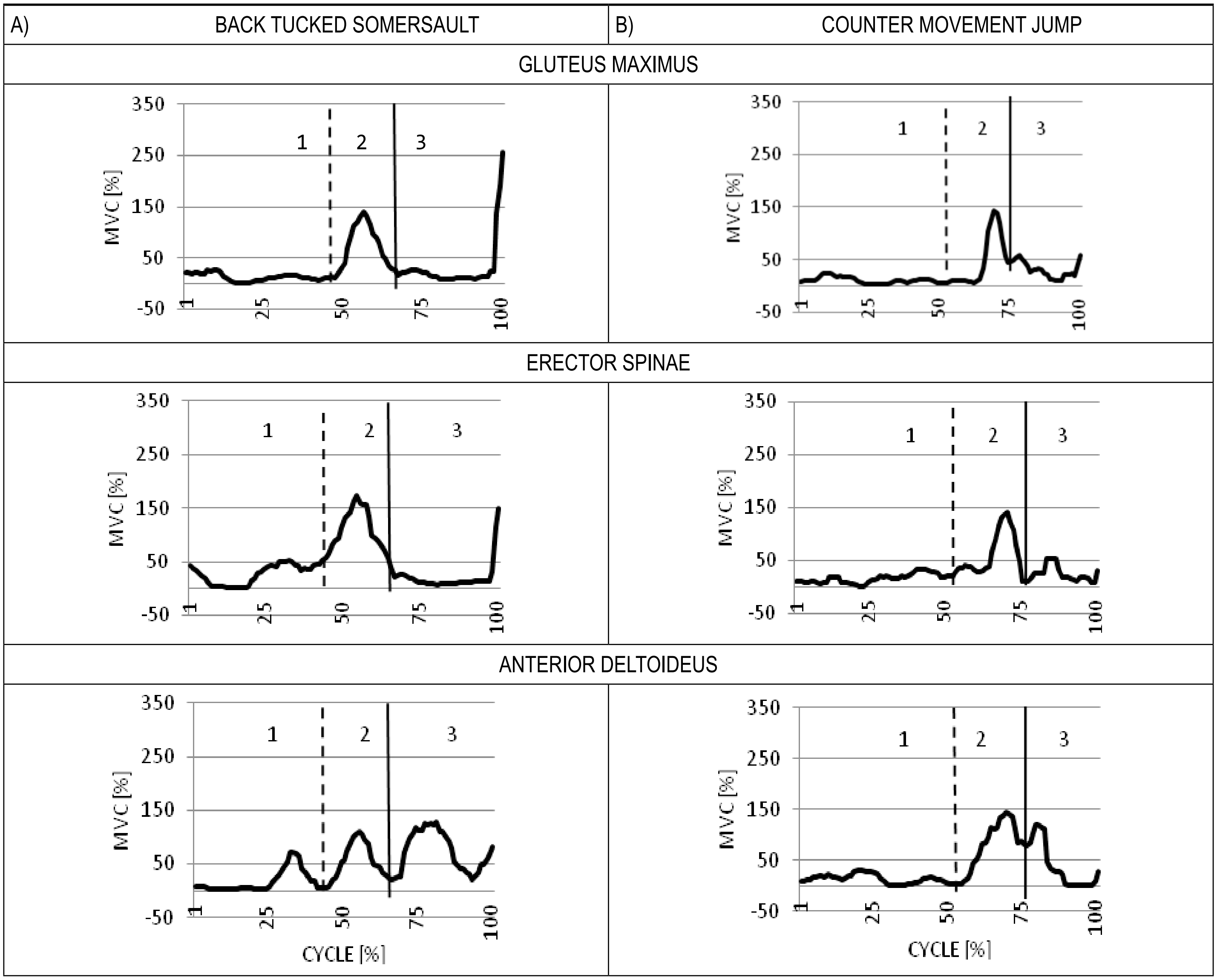
Discussion

Bounces (take-offs) are complex multi-degree free exercises requiring good muscle coordination. Thus, the control strategy implemented during take-off performed under certain conditions can be identified on the basis of muscle activity. Muscle activation on both sides of the lower extremity joints was evident in both acrobatic jumps (the back tucked somersault and counter movement jump). These findings suggests that biarticular muscles play a main role in adjacent joint power flow during bounces. Thus, these biarticular muscles serve as the stabilisers of the prime "mover muscles" (the stabilisers are the muscles that hold the body parts in place, and the prime movers are the muscles that move the body parts). The differences in muscle activation were especially evident for: the *anterior deltoideus*



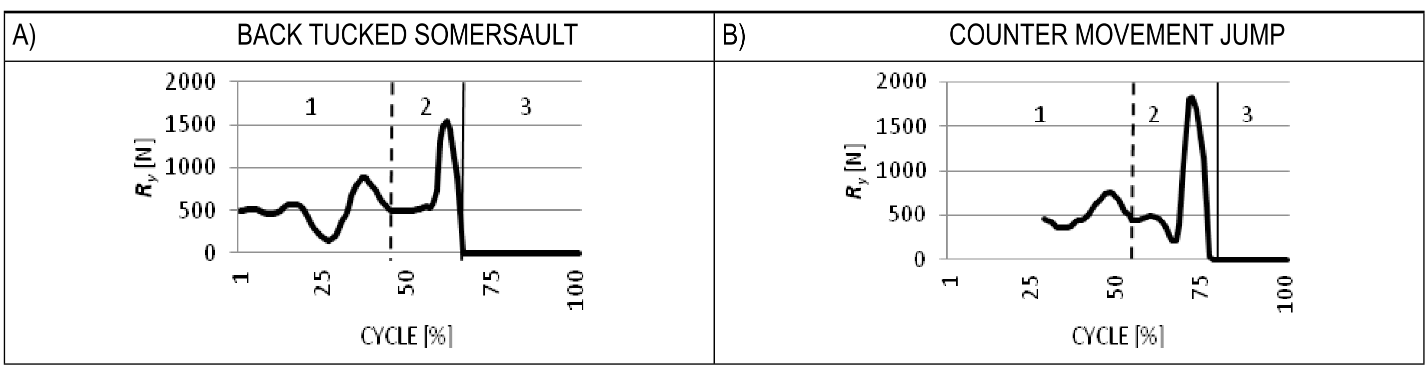
1 = counter movement phase; 2 = take-off phase; 3 = flight phase. The vertical dashed line shows the beginning of the take-off phase, and the solid vertical line shows the end of the take-off phase.

Figure 1. Root-mean-square (RMS) normalised (MVC) EMG for eight muscles during acrobatic jumps performed by the selected female gymnast



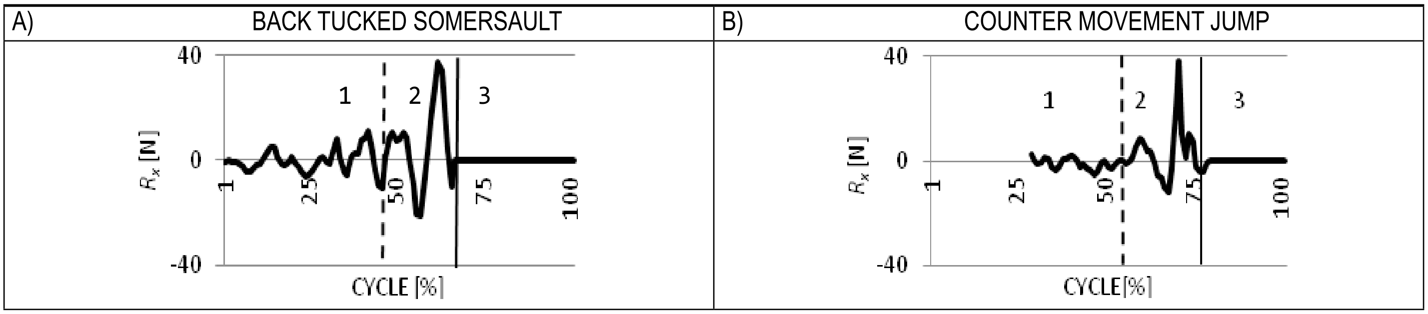
1 = counter movement phase; 2 = take-off phase; 3 = flight phase. The vertical dashed line shows the beginning of the take-off phase, and the solid vertical line shows the end of the take-off phase.

Figure 1. Root-mean-square (RMS) normalised (MVC) EMG for eight muscles during acrobatic jumps performed by the selected female gymnast (continued).



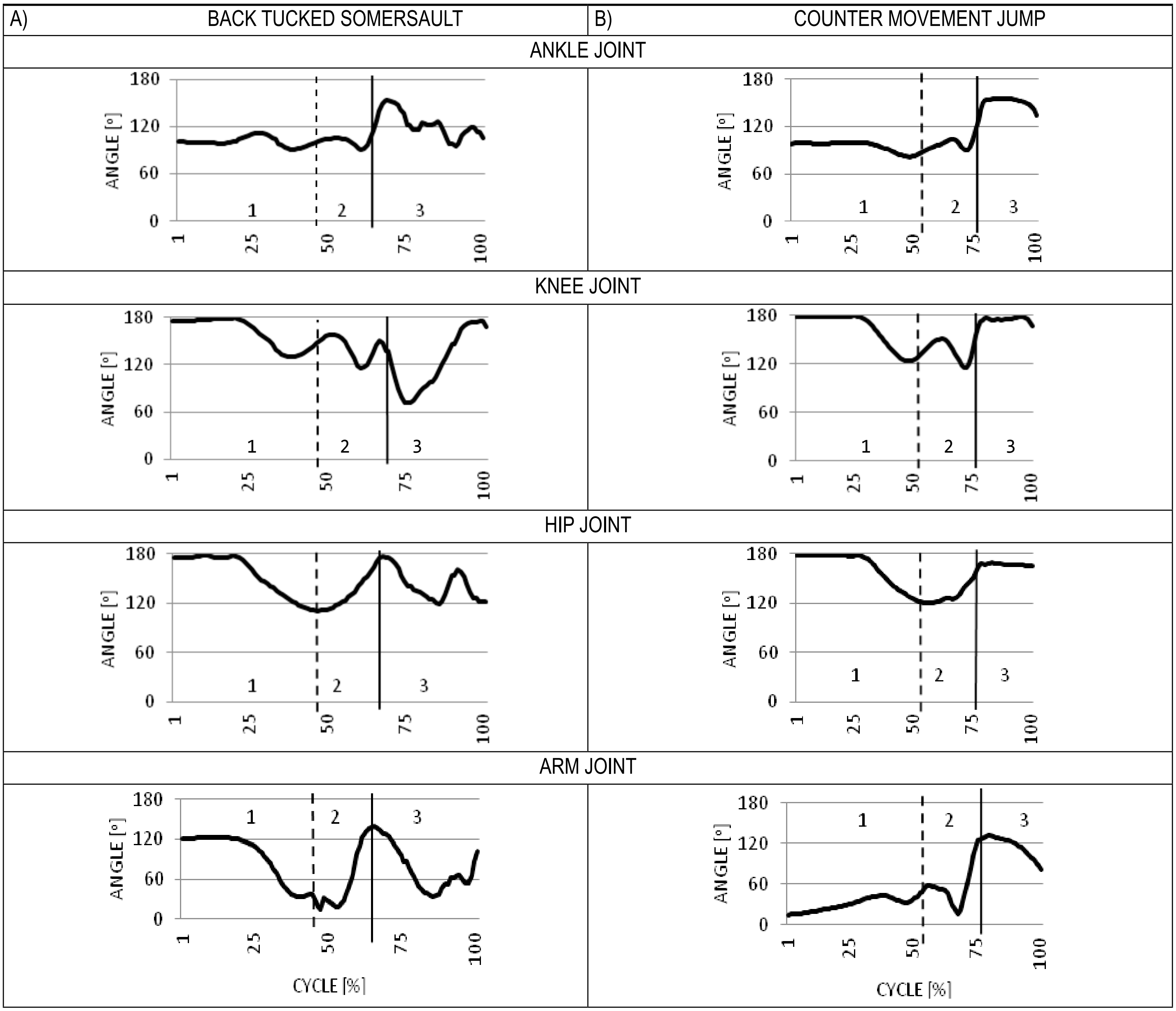
1 = counter movement phase, 2 = take-off phase, 3 = flight phase. The vertical dashed line shows the beginning of the take-off phase, and the solid vertical line shows the end of the take-off phase.

Figure 2. Vertical component of ground reaction force in A) back tucked somersault and B) counter movement jump, performed by the selected female gymnast



1 = counter movement phase, 2 = take-off phase, 3 = flight phase. The vertical dashed line shows the beginning of the take-off phase, and the solid vertical line shows the end of the take-off phase.

Figure 3. Horizontal component of ground reaction force in A) back tucked somersault and B) counter movement jump, performed by the selected female gymnast



1 = counter movement phase, 2 = take-off phase, 3 = flight phase. The dashed vertical dashed line shows the beginning of the take-off phase, and the solid vertical line shows the end of the take-off phase.

Figure 4. Joint angle patterns in A) back tucked somersault and B) counter movement jump, performed by the selected female gymnast

muscle in the counter movement phase, the *rectus femoris* muscle in the take-off phase, and the *rectus abdominis* muscle in the flight phase.

Kinetics indicate muscle involvement in acrobatic jumps, which is characterised by the graph of the ground reaction force (Fig. 2). Two-thirds into the back somersault take-off phase (Fig. 2A), the vertical force maintains a nearly constant value equal to the gymnast's body weight. A similar force-time pattern is commonly obtained in the vertical jump (CMJ without arm swing) when the body stops in the squat. One might therefore assume that in the back somersault, the gymnast also remained motionless for a very long time – she stopped in the lowest bottom position, which should be regarded as an error. The question is whether this was indeed an error.

It turns out that at the end of the counter movement phase, when the gymnast is still bending the legs at the knee and ankle joints have changed direction, extension and plantar-flexion are changed, respectively (Fig. 4). The change of direction in the motion also took place in the shoulder joint, which undoubtedly influenced the effectiveness of the somersault. According to various authors [9, 10, 11], the height of the jump and its mechanical efficiency are considerably affected by the following: the starting position at take-off, the direction of the arm swing, and the final position of the arms during the jump. Therefore, it is not without significance which specific movements are performed by the body parts of the jumper; by averaging the kinematics, reaction forces, and muscle activation patterns, we lose the individual nature of acrobatic jumps and the main features of these movements become blurred. While coaches use a subjective qualitative analysis of the sporting movement to determine what advice must be given, the sports biomechanics researcher must make use of objective quantitative data.

Conclusions

In our study, we have used the multimodular measuring system SMART to study the structure of acrobatic jumps, and we conducted a complex analysis of these exercises. These exercise approaches may be used to achieve important training goals. It seems logical, therefore, that physical educators, coaches, and athletes should look to biomechanics for a scientific basis for the analysis of the individual techniques used in sports.

As far practical implications are concerned, we recommend that coaches and physical educators carefully monitor the gymnast's leg joints and avoid extension of the knee and ankle at the counter movement phase during standing acrobatic jumps.

Literature

1. Panitente G., Merni F., Sands W.A. (2011). Kinematic analysis of the centre of mass in the back handspring: A case study. *Gym Coach* 4, 1-11.
2. Miller D.I., Henning E., Pizzimenti M.A., Jones I.C., Nelson R.C. (1989). Kinetic and kinematic characteristics of 10-m platform performances of elite divers: Back takeoffs. *International Journal of Sport Biomechanics* 5, 60-88.
3. Król H., Klyszcz-Morciniec M., Sobota G. (2014). Takeoff mechanics of the acrobatic tumbling exercises (case study). In C. Urbanik, A. Mastalerz, D. Iwańska (eds), *Selected problems of biomechanics of sport and rehabilitation*, vol. II (pp. 62-75). Warsaw: Józef Piłsudski University of Physical Education in Warsaw.
4. Prassas S., Know Y-H., Sands W.A. (2006). Biomechanical research in artistic gymnastics: A review. *Sports Biomechanics* 5, 261-291.
5. Yeadon M.R., Challis J.H. (1994). The future of performance-related sports biomechanics research. *Journal of Sports Science* 12, 3-32.
6. Omorczyk J., Nosiadek L., Nosiadek A., Chwała W. (2014). Use of biomechanical analysis for technical training in artistic gymnastics using the example of a back handspring. In C. Urbanik, A. Mastalerz, D. Iwanska (eds), *Selected problems of biomechanics of sport and rehabilitation*, vol. II (pp. 104-115). Warsaw: Józef Piłsudski University of Physical Education in Warsaw.
7. Czaplicki A., Silva M.T., Ambrósio J.C. (2004). Biomechanical modelling for whole body motion using natural coordinates. *Journal of Theoretical and Applied Mechanics* 42, 927-944.
8. Freriks B., Hermens H.J. (1999). *SENIAM 9: European Recommendations for Surface ElectroMyoGraphy, results of the SENIAM project*. Roessingh Research and Development B.V. (CD-rom).
9. Hara M., Shibayama A., Takeshita D., Hay D.C., Fukashiro S. (2008). A comparison of the mechanical effect of arm swing and countermovement on the lower extremities in the vertical jumping. *Human Movement Science* 27, 636-648.
10. Domire Z.J., Challis J.H. (2010). An induced energy analysis to determine the mechanism for performance enhancement as a result of arm swing during jumping. *Sports Biomechanics* 9, 38-46.
11. Marina M., Jemni M., Rodriguez F.A., Jimenez A. (2012). Plyometric jumping performances' comparison between elite male and female gymnasts and similar age groups. *Journal of Strength Conditioning Research* 26, 1879-1886.

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