

Kinesiotherapy with Elements of Dynamic Neuromuscular Stabilization Aimed at Running in Artistic Gymnasts

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ABSTRACT

The aim was to determine the effect of kinesiotherapy with elements of the Dynamic Neuromuscular Stabilization concept on the kinematic parameters of the lower extremities during running in artistic gymnasts. The study included 10 competitive gymnasts (10.8 ± 1.3 years; 145.7 ± 12.2 cm; 35.2 ± 8.2 kg). Only girls who had not reached menarche and had no traumatic lower extremity injuries were selected. Another criterion was the assessment of hypermobility using the Sachs test. The intervention was carried out for two months through group exercise based on developmental kinesiology concept of Dynamic Neuromuscular Stabilization. Video analysis was used with two NINOXTM125 cameras and MR3 software was used to evaluate the effect of exercises on pelvic, knee, and ankle joints in the sagittal and frontal planes during the midstance phase of the running cycle. Foot rotation during the stance phase was assessed using a dynamic treadmill Rehawalk® with the zebris system. Measurements were taken before and after the two-month therapy period. The paired Wilcoxon test was used, and statistically significant differences were considered at a significance level of $\alpha = 0.05$. The effect size of the differences was evaluated using the r coefficient: < 0.1 trivial; $0.1-0.3$ small; $0.3-0.5$ moderate; > 0.5 large. There was a significant reduction in pelvic anteversion and lateral pelvic drop, increased ankle dorsiflexion, and a reduction in heel valgus during the midstance phase of the running cycle after therapy. The application of therapy that included elements of developmental kinesiology positively influenced dynamic stabilization of the pelvis and lower extremity weight bearing joints during running, which may have future beneficial effects on the health and performance of gymnasts.

Keywords: Running; Dynamic Neuromuscular Stabilization; hypermobility; zebris

INTRODUCTION

Artistic gymnastics is characterized by high demands on strength and coordination, combined with the need for aesthetic execution. A key aspect of performing gymnastic exercises properly is maintaining a high range of joint motion, which can also increase the risk of injury. The influence of hypermobility on injury risk in gymnasts is a frequently debated topic, although some coaches dismiss the potential risks. Ignoring these issues can lead to overloading certain body segments, functional changes, or even serious injuries (Bukva et al., 2019). In addition, the pathologies that arise from these issues can affect other movement patterns that are not directly related to the specific demands of gymnastics.

Running is an integral part of artistic gymnastics performance, utilized in conditioning, during acrobatic sequences on the floor, and especially during the vault approach. Proper running mechanics and achieving high speed are necessary prerequisites for executing difficult jumps that score higher (Bradshaw, 2004; Schärer et al., 2019). Observations of gymnast vault approaches suggest that some coaches do not prioritize the technique of running (Sands, 1999). There is often a lack of knowledge about running mechanics and potential adjustments (Marshall, 2017). Hypermobility in gymnasts not only increases the risk of injury, but also leads to deviations from proper running mechanics, which can negatively impact performance (Alsiri et al., 2020). Abnormal joint positioning due to hypermobility can reduce running speed and shorten stride length (Sahin, 2008). Therefore, a comprehensive analysis of the joints in the lower extremities of hypermobile individuals is crucial (Alsiri et al., 2020).

The primary approach to addressing joint hypermobility is through kinesiotherapy. Specific exercises can enhance the muscle activation of dynamic stabilizers during extreme movements and positively influence proprioception (Simmonds, 2022; Zech et al., 2009). Due to the inability to directly affect the quality of connective tissue, it is challenging from a therapeutic standpoint to specifically target hypermobile joints compared to hypomobile ones (Stackeová & Blažková, 2009). Kolář (2020) and Janda (2001) emphasize that for hypermobility patients, the primary goal of therapy is to strengthen muscles, often using resistance exercises with tools such as Thera-Bands or others, which provide constant resistance throughout the movement. This therapy focuses on training muscles to compensate for deficits in other structures responsible for instability (Simmonds, 2022). Řezaninová (2015) highlights the importance of focusing on activation of the deep stabilization system in both static positions and dynamic exercises. Simmonds (2022) also notes that for hypermobile individuals, it is crucial to include physiotherapeutic interventions aimed at improving proprioception, coordination, kinesthesia, activation of stabilizing muscles, and increasing muscle strength of specific segments.

Dynamic Neuromuscular Stabilization (DNS) is a rehabilitation approach that optimizes the movement system based on the scientific principles of developmental kinesiology and the neurophysiological aspects of locomotor system maturation. The goal of this therapy is joint centration, centre support, muscle coordination, activation of core stabilization, spinal alignment, and correct respiratory pattern through specific functional exercises based on the developmental kinesiology positions of a healthy child (Dehghani & Ghasemi, 2021; Kolář, 2020). The emphasis is placed primarily on the quality of execution (Mahdieh et al., 2020).

Currently, we have not found any studies focused on the impact of kinesiotherapy with elements of DNS on running in hypermobile individuals. This is significant, as running is a key locomotor

activity in many sports disciplines. Therefore, this study aims to observe changes in running kinematic parameters following kinesiotherapy inspired by DNS principles in artistic gymnasts.

METHOD

The study was approved by the Ethics Committee of the Faculty of Medicine of the University of Ostrava reference number 29/2020.

Research sample

The research sample consisted of 10 artistic gymnasts (age 10.8 ± 1.3 years; height 145.7 ± 12.2 cm; weight 35.2 ± 8.2 kg) from TJ Sokol Moravská Ostrava 1 the gymnastics club. Participants trained in the same group with the same coaches, with a training load exceeding 20 hours per week. Only premenarche girls who had not experienced any traumatic lower extremity injury in the past year were included. Another inclusion criterion was the assessment of hypermobility based on the Sachs test, with both the lower extremities and the spine classified as level B or C.

Before the study began, all selected gymnasts and their legal guardians were informed about the measurement procedures. Legal guardians signed an informed consent form, which included details about the measurement conditions and procedures anonymous processing of the data, and the right to withdraw from the study at any time.

Measurement procedures

To evaluate the kinematic parameters of the pelvis, knee, and ankle joints during running, two NINOX™125 cameras with MR3 software (Noraxon, USA, Arizona) were used. The Ninox 125 camera features a nonadjustable wide-angle lens with a fixed focal length. The lens does not require focusing, so all images should be sharp from 1 meter to infinity. The cameras were set to a frame rate of 30 FPS, with a resolution of 1280 x 960 and a shutter speed of 1/50 s. The recordings were made in the myoVideo module to allow subsequent video analysis. To evaluate foot rotation during the stance phase of running, a dynamic treadmill h/p/cosmos®Rehawalk® was used for measurement with the zebris system (zebris Medical GmbH, Germany).

Measurement process

The measurements were taken at the Centre for Biomechanics Research at the Department of Rehabilitation and Sports Medicine at the Faculty of Medicine, University of Ostrava. Before the measurement, each gymnast was familiarized with the procedure. This was followed by a 10-minute independent warm-up. The reference markers were then placed on the body of the gymnast at the following locations:

- middle of the shoulder joint,
- spina iliaca anterior superior (SIAS),
- spina iliaca posterior superior (SIPS),
- trochanter major,
- lateral knee joint fissure,
- dorsal centre of the knee joint,
- malleolus lateralis,

- centre of the Achilles tendon at the level of the malleoli,
- centre of the calcaneus at the level of the lower edge of the heel.

Before actual measurement, the cameras were placed around the dynamic treadmill, one camera recording movement from the side (in the middle of the treadmill) and the other from behind (in the centre of the treadmill) (Figure 1).

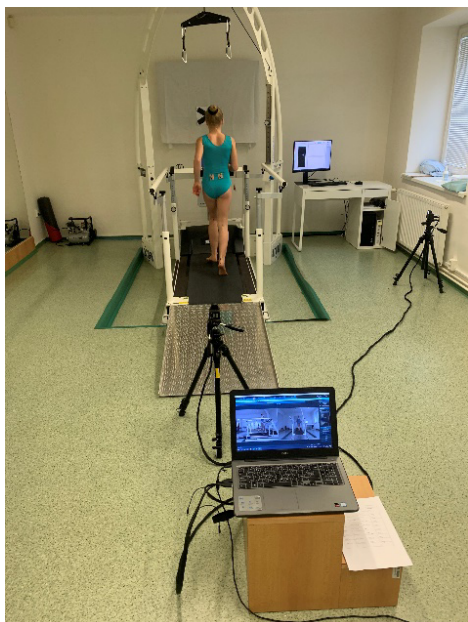


Figure 1. Measurement recording

Upon starting the dynamic treadmill, the speed was set to 3 km/h to allow the gymnast to familiarize its dimensions, surface, and movement. The speed was then gradually increased to 7 km/h. Measurement began once the gymnast adapted her running to the speed of the treadmill and was running in the centre of the treadmill. Camera records were taken for the right and left sides of the body for a duration of 1.5 minutes. After the measurement was completed, the speed gradually decreased to a stop. Measurement was carried out barefoot and was performed twice before therapy and after the two-month therapy.

Progress of therapy

Therapy was carried out over two months in the form of group exercises twice a week for 20 minutes, complemented by self-therapy once a week with exercises learned during group sessions. Exercise units comprised exercises inspired by the DNS concept, tailored to the age of the participants, and were performed in the gymnastics hall on the floor after training sessions. The objectives of the therapy included activation of the spinal stabilization system, increasing stability of the main joints, modification of the movement stereotype, and its gradual integration into everyday training. The initial therapy sessions focused on understanding the principles of the Dynamic Neuromuscular Stabilization concept. Gymnasts were instructed on the proper position of particular body segments, diaphragmatic breathing, and activation of trunk stabilization. First, the three-month supine position, followed by transition into a low oblique sitting position with various modifications were used. Large gymnastic balls were also used for variety. As therapy progressed, difficulty increased with the introduction of higher exercise positions. Gradually, exercises in high oblique sitting, tripod

position, high kneeling, bear, and squats were added. During the final therapy sessions, when the gymnasts had mastered the positions, they also learned various transition possibilities between the positions. In self-therapy, simpler positions were practiced, focusing on the precision of the exercises and the correct alignment of the segments. After each home exercise session, a verbal review was conducted during the subsequent meeting, where the participants briefly evaluated which exercises they found successful and if they observed any shortcomings. Selected DNS exercises are shown in Figures 2 and 3. Gymnasts were explained the connection between the newly learned exercises and their application in training. Additionally, they were educated to embed a five-minute exercise routine ideally every day before training.



Figure 2. Three-month supine position – crawling with the use of a large gymnastic ball



Figure 3. Twelve-month position – squat

Data processing and evaluation

The parameters measured in the video analysis included the position of the pelvis, the angles in the knee and ankle joints in the sagittal and frontal planes during the midstance of the running cycle. During this phase the upper body is above the stance leg and the knee of the swing leg passes

the knee of the stance leg. To assess the angles during the stance phase of the running cycle, seven consecutive recordings from the running cycle were selected for both the sagittal and frontal planes. The dominant (d) and nondominant (nd) lower extremities were defined based on the take-off leg. The MR3 program used the 2-Marker Angle tool to measure the following angles:

Sagittal Plane (Figure 4):

- pelvis (P_S) – line connecting SIAS and SIPS with the horizontal plane, where positive values indicate pelvic anteversion and negative values indicate pelvic retroversion,
- knee joint (K_S) – line connecting trochanter major, joint gap of the knee, and malleolus lateralis, assessing the range of flexion,
- ankle joint (A_S) – line connecting the joint gap of the knee, malleolus lateralis, and the head of the fifth metatarsal, assessing the range of dorsal flexion.

Frontal Plane (Figure 5):

- pelvis (P_F) – line connecting the SIPS l. dx. and l. sin. with the horizontal plane, where the vertex of the angle is located on the side of the stance lower extremity, positive values indicate a drop and negative values indicate an elevation of the pelvis,
- knee joint (K_F) – line connecting the SIPS, the centre of the knee joint, and the centre of the Achilles tendon, positive values indicate varosity and negative values indicate valgosity at the knee joint,
- heel (A_F) – line connecting the centre of the knee joint, the centre of the Achilles tendon, and the centre of the calcaneus, positive values represent valgosity and negative values represent varosity of the heel.

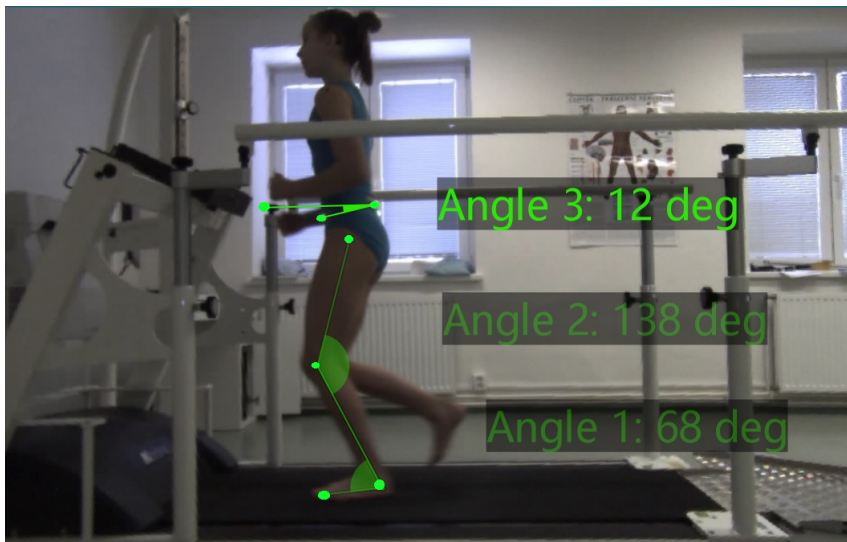


Figure 4. Angles evaluated at the vertical moment of the stance phase of running in the sagittal plane

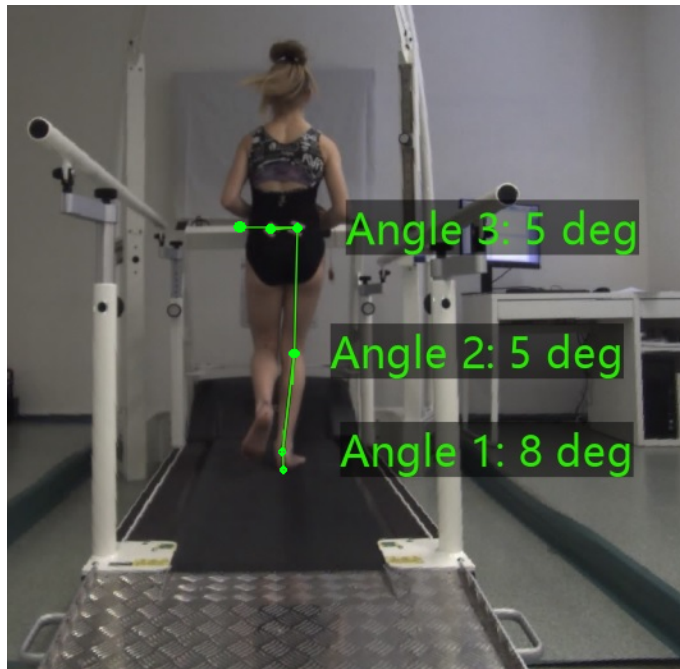


Figure 5. Angles evaluated at the vertical moment of the stance phase of running in the frontal plane

Statistical Data Processing

Statistical analysis of the data was performed using the PAST2.17c software. For each observed variable, the mean, standard deviation, median, and 95% confidence interval were calculated. Due to the small number of subjects, nonparametric tests were used. The paired Wilcoxon test was used to assess differences in observed parameters between individual measurements within the group. Differences were considered statistically significant at a significance level of $\alpha = 0.05$. The effect size of the differences was evaluated using the coefficient r , calculated using the formula $r = Z/(\sqrt{N})$, where Z is the value of the criteria tested, and N is the number of pairs measured. Cohen (1992) interprets the effect size ranges as follows: $r < 0.1$ trivial; $0.1 - 0.3$ small; $0.3 - 0.5$ moderate; $r > 0.5$ large.

RESULTS

Table 1 presents the basic statistical characteristics of the measured parameters and the results of comparisons between measurements at different time periods.

Table 1. Values of the median, lower, and upper quartiles, and results of statistical comparisons of measurements.

PARAMETER	BEFORE THERAPY	AFTER THERAPY	p	r
ndP_S	10 (5; 12)	5 (3; 6)	0,012	0,78
dK_S	140 (136; 144)	142 (139; 144)	0,047	0,63
ndA_S	71 (68; 77)	74 (71; 80)	0,005	0,89
dP_S	10 (5; 12)	4 (3; 5)	0,007	0,85
dK_S	138 (135; 141)	142 (138; 145)	0,092	0,53
dA_S	72 (71; 75)	73 (72; 76)	0,919	0,03
ndP_F	6 (2; 8)	4 (2; 5)	0,022	0,73
ndK_F	5 (4; 7)	6 (4; 7)	0,514	0,21

PARAMETER	BEFORE THERAPY	AFTER THERAPY	<i>p</i>	<i>r</i>
ndA_F	7 (5; 8)	4 (3; 6)	0,007	0,85
dP_F	6 (5; 8)	4 (3; 6)	0,037	0,66
dK_F	8 (4; 9)	5 (4; 7)	0,025	0,71
dA_F	6 (5; 8)	4 (3; 6)	0,005	0,89
ndLE	2 (-7; 7)	3 (-1; 4)	0,838	0,05
dLE	1 (-2; 7)	1 (-2; 7)	0,594	0,12

Explanations: ndP_S – pelvis side on the nondominant leg movement in the sagittal plane, d_S – pelvis side on the dominant leg movement in the sagittal plane, ndP_F – pelvis side on the nondominant leg movement in the frontal plane, dP_F – pelvis side on the dominant leg movement in the frontal plane, ndK_S – knee joint on the nondominant leg movement in the sagittal plane, dK_S – knee joint on the dominant leg movement in the sagittal plane, ndK_F – knee joint on the nondominant leg movement in the frontal plane, dK_F – knee joint on the dominant leg movement in the frontal plane, ndA_S – ankle joint on the nondominant leg movement in the sagittal plane, dA_S – ankle joint on the dominant leg movement in the sagittal plane, ndA_F – ankle joint on the nondominant leg movement in the frontal plane, dA_F – ankle joint on the dominant leg movement in the frontal plane, ndLE – foot rotation on the nondominant leg, dLE – foot rotation on the dominant leg, *p* – probability value, *r* – effect size coefficient.

After therapy, there was a significant reduction in pelvic anteversion ($p = 0.01$, for both the nondominant and dominant sides), as well as a decrease in pelvic tilt ($p = 0.02$, for the nondominant side and $p = 0.04$ for the dominant side) during the vertical phase of the running cycle compared to the pre-therapy values. Furthermore, there was a significant increase ($p = 0.01$) in dorsiflexion of the ankle joint in the nondominant lower extremity and reduction of the calcaneus valgus ($p = 0.01$) for both lower extremities during the midstance of the running cycle compared to pre-therapy values.

DISCUSSION

The results of the previous research highlighted the importance of fast and efficient running before take-off to achieve the best performance (Boersma, 2021; Bradshaw, 2004). Running in gymnasts is to some extent affected by joint hypermobility, which is an important component of athletic performance in artistic gymnastics. Study by Alsiri et al. (2020) confirm the impact of hypermobility on the biomechanics of the lower extremity joints, including the spatiotemporal parameters of gait. One of the possibilities for affecting joint hypermobility is kinesiotherapy, which aims to normalize muscle tone, improve proprioception and coordination, with the goal of joint centration and stabilization (Bukva et al., 2019; Řezaninová, 2015). This study used elements of the DNS concept, which serves as a tool to examine and activate spinal stabilizers in athletes, aimed at optimizing the movement system. Trunk stabilization is important here for efficient muscular activity that allows coordination of movement and generation of optimal forces (Davídek et al., 2018). Inadequate stabilization of the trunk, and therefore the limbs, can lead to impaired control and poor coordination or altered technique, and therefore increased risk of injury due to altered movement biomechanics (Mahdih et al., 2020). We believe that compensatory mechanisms occur in association with exceeding the capacity of the deep stabilization system during physical load (Kolář, 2020). We could refer to this as a stress functional threshold, where after crossing this

threshold, the athlete is no longer able to maintain the ideal movement stereotype and is forced to use compensatory movement strategies. Prolonged performance in this zone increases the athlete's susceptibility to injury due to overloading of passive structures caused by the use of movement strategies with decentered joints. Therefore, the goal of artistic gymnasts whose musculoskeletal system faces significant loading is to increase this functional threshold and reduce risk situations or compensate for overload in certain segments. The paper presented examined changes in the kinematic parameters of the lower extremities at the moment of the midstance phase of running influenced by kinesiotherapy with elements from the DNS concept. After the intervention, there was a significant reduction in pelvic anteversion and lateral pelvic drop at that time. The movement of the pelvis in the sagittal plane is influenced by reduced hip extension or running speed. Lateral movement of the pelvis during the running cycle is crucial for smooth rise and fall of the body's centre of gravity. Any greater drop in the pelvis in the mid-stance phase may indicate insufficient engagement of stabilizing muscles (Ferber & Macdonald, 2014).

Among other statistically significant changes were the parameters of ankle joint movement in the sagittal plane and heel positioning during the vertical phase of the running cycle. The results showed effect of the therapy on increased dorsiflexion of the ankle joint on the non-dominant lower extremity and a significant reduction in calcaneus valgosity in both lower extremities. The reason for the increase in dorsiflexion in only the nondominant side might be an averagely greater load on the dominant lower extremity during take-offs or landings as a result of lateralization among gymnasts. Research by Galli et al. (2011) discussed the reduction of dorsiflexion in the gait cycle compared to nonhypermobility individuals, describing a "stiffening" in hypermobile individuals to prevent reaching extreme ranges of motion and fears of pain. Monaghan et al. (2005) described excessive mobility of the talocrural joint as one of the causes of mechanical instability. Nathan et al. (2018) reported a higher percentage of joint injuries in hypermobile individuals. Chinn (2013) noted an increased risk of ankle injury in cases of increased heel mobility in the frontal plane. Therefore, it is crucial to find an optimal joint mobility and stability to minimize the risk of injury (Murphy et al., 2003). Improving the stability of ankle joints and their proper loading could reduce the risk of injury during training or competition. The increase in the dorsiflexion range of the ankle joint and the reduction in the valgosity of the heels in both lower extremities of the gymnasts we observed can also be largely attributed to changes in pelvic positioning or optimization of muscle activity in the hip joints. The biomechanics of the knee joint in the sagittal plane and foot rotation were also examined, where no significant changes were found. Further investigation over a longer period of therapy and larger studies would be appropriate to clarify the influence of therapy, considering the possible effects on the joints of both the peripheral and central segments.

In the context of physiotherapeutic intervention for artistic gymnasts, it is debatable to what extent hypermobility can be influenced given the demands of this sport and whether reducing the range of motion of certain joint connections would be counterproductive. Exercises with elements from the DNS concept should primarily have a compensatory character, aimed at reducing the risk of injury without negatively affecting performance. Therefore, the primary goal was not to reduce the joint mobility of hypermobile joints to physiological norms, but rather to limit the range of motion during movement phases when excessive joint mobility is undesirable, leading to joint

decentring. These changes could be a positive factor not only for reducing injuries in gymnasts, but also for improving the technical execution of gymnastics elements. The long-term goal after acquiring and consolidating the skill of ideal stabilization is to increase the functional capacity of gymnasts thanks to centring throughout the entire range of motion, improving muscle timing, range, and direction of movement, which is a prerequisite not only for optimizing the technique of gymnasts' running but also for achieving better performance.

Limitations

A limitation of the study is the small sample size of gymnasts, which could not be further expanded due to the desire for maximum homogeneity within the group. Gymnasts in the research sample train in one group under the guidance of the same coaches. Due to the age range, all gymnasts are classified at the same performance level in artistic gymnastics, thus adhering to the same training plan. It is necessary to take into account that the changes may also have been influenced by the gymnastics training itself. Another, limitation is the focus of the study solely on the midstance phase of the running cycle. Furthermore, the incorporation of group exercises does not allow an individualized approach and constant monitoring throughout the exercise. A longer duration of exercises would also be more appropriate, however, given the structure of the season, it is not feasible to maintain this regimen for an extended period. However, the exercises can be revisited during the preparatory phase of the training period. Given the limited number of studies available on the kinematic analysis of the midstance phase during running, another limitation is the inclusion of studies focusing on jogging and walking to ensure a broader overview of the available findings.

CONCLUSION

The results demonstrated the impact of therapy including elements inspired by the DNS concept on pelvic, ankle joints, and heel positioning during the vertical phase of the running cycle. Reduced pelvic anteversion, lateral pelvic drop, and heel valgosity may have a positive effect on running in artistic gymnasts. Additionally, mastering the fundamental principles of the DNS concept can be beneficial for more effective execution not only of gymnastics skills but also for reducing the risk of injury. From a practical point of view, the findings emphasize the value of integrating regular exercises with DNS elements into the gymnast training plan.

ACKNOWLEDGEMENTS

The article is an output of the thesis "The effect of Dynamic Neuromuscular Stabilization on running kinematic parameters of artistic gymnasts" (Pavlasová, 2023).

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