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A biomechanical examination of the inclusion of active flexibility in artistic gymnastic movements requiring mobility

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Abstract

Background and Study Aim The purpose of the study is a biomechanical examination of the inclusion of active flexibility in artistic gymnastic movements requiring mobility (muscles' ability to stretch), flexibility and other motor abilities such as force, power, etc.

Material and Methods The study included 17 girl gymnasts aged 7-9 years old, with a body height of 140.7±10.2, weight of 34.1±6.4, and a body mass index of 17.6±3.0. Data collection in the study was made by using performance tests developed by FIG such as a Forward-Backward Split, Side Spit, Arm-Trunk Angle Backward, Trunk Bent Forward, Leg Raise forward, Leg Raise Sideward, Bridge, Standing long Jump, Lift Trunk Forward-60secs, Angle Degree of the Leg Split Position in Cartwheel, and Arm-Upper Body Angle Backward in Bridge Technique. The Kinovea 0.8.15 program was used in the data analysis of the variables in the study. The SPSS 24 software program was used for the data analysis. Percentages of the angle degree calculated by the formula "%= (angle^0 of the mobility in functional movement / angle^0 of the active flexibility) *100" were found.

Results Results indicate that active flexibility was 90% functional in the leg raise sideward, 90% in the leg split during execution of the cartwheel, 17.5% in the bridge technique, and completely functional for the flexibility ratio expressed in the leg raise forward technique. In the analysis of the various elements of the similar biomechanics, the anatomic structure and similar body planes, it was concluded that active flexibility expressed in the movements required a mobility of around 65-75%.

Conclusions: It was determined that the functionality rate of the techniques requiring active flexibility and requiring mobility of the same biomechanical and anatomical structure was around 65-75%. Therefore, to execute 100% of the flexibility in action (during active elements) as it is in a passively or actively, it may significantly increase force, motor control, dynamic balance, coordination etc., in the large range of motion.

Keywords: functional flexibility, range of motion (ROM), biomechanics, techniques.

Introduction

Artistic gymnastics is a branch characterized by the difficulty degree of elements, which is determined according to biomechanical features. One of the many reasons for these difficulties is involvement of more than one motor ability in the same movement and execution of the movements in different body planes [1, 2]. This makes it more difficult to determine the dominance of the motor abilities in each movement on artistic gymnastics. However, despite the mix and unclear definitions found in the literature, it is not very difficult to determine the inclusion of general motor abilities such as power, speed, endurance and flexibility in each movement. However, there is no clearly defined mobility; a skill that can be defined as the ability to move actively through a range of motions [3, 4]. This means that mobility is a way of functional flexibility . Accordingly, it is an inevitable fact that mobility combines flexibility with motor skills such as force, power, etc. In artistic gymnastics, the essential element of active flexibility is that it leads to maximal performance if it works in coordination with other motor skills [5, 6].

When more than 800 gymnastics techniques are analyzed, results have shown that dominance or importance of mobility is found as a fourth and flexibility as a fifth motor ability, led by coordination, strength, and speed [7]. However, execution of the routines, which includes coordination, means inclusion of both mobility, flexibility and other motor abilities [8]. Furthermore, execution of the elements such as a side split, forward-backward split, or arm trunk angle, require flexibility [2, 3]. On the other hand execution of the elements such as a straddle jump, wolf jump, stag leap, split leap, turn variations, etc., require high active flexibility at the same time when force is the dominant skill in a certain movements. Thus, execution of the elements requiring high force and active flexibility at the same time, may be called mobility or functional flexibility (muscles' ability to stretch) [1, 2, 8]. Flexibility can be defined as the range of motion of a body joint [9]. As it can be seen, it is not including the range of motion which is expressed during movements that require force. It means that a combination of flexibility and motor skills similar to force that reveals mobility.

Alternatively, coordination, the most crucial ability in artistic gymnastics, includes a combination of the different movements at the same time It also includes the combination of different motor abilities at the same time in different movements. This fact is based on different research that can be found in the literature. The focus on

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mobility, or actively moving through a range of motions, requires a combination of motor control, stability and flexibility, and more closely relates to the movement requirements an athlete will face [3, 4]. Thus, explaining the involvement of flexibility, especially active flexibility, to the movements that require mobility such as a trunk bent forward, leg raises forward, leg raises sideward, etc., which may increase the gymnast's performance. For this reason, the movements mentioned above and used by us in this study were determined as a test to measure the gymnasts' performance [1, 2].

However, what in reality is the problem that caused the need for this study? One of the authors of the NSCA argues that improving the range of motion (ROM) will not be fully reflected in functional movements. Moreover, he mentioned that, "this seems to be one of the first studies suggesting that increasing the ROM of a joint may not translate into function or change of a default movement pattern" [8].

Therefore, as it is challenging for the gymnast to improve their general motor abilities such as coordination, force and speed, it is also difficult to improve active and passive flexibility. Nevertheless, the biggest challenge for gymnasts is to combine these abilities. The question arises as to whether these improvements in flexibility or strength will transfer to function. Specifically, if a gymnast presents with limited hip mobility, is there any evidence that improvements in hip range of motion (ROM) or core endurance will alter functional movement patterns? [8].

Even gymnasts improve their flexibility enough according to the norm values given by the World Gymnastic Federation (FIG), which can be tested by side split, forward-backward split, and arm- angle in a passive way, in the execution of the elements with the similar biomechanical and anatomical requirements but, where force is involved such as a leg raise sideward, leg raises forward, arm-trunk angle in bridge techniques is a usual image to see that not 100% of the flexibility is functional. For instance, even the gymnasts can open legs in forward-backward split more than 180^0 during the execution of the element with similar biomechanical and anatomical requirements, such as a split leap or tour jete, it can be seen that not more than 60-70% of the flexibility showed in the forward-backward split are expressed. Aims of all gymnastics coaches and gymnasts are to make the flexibility during dynamic movements 100% functional, which requires both force and flexibility. Unfortunately, the literature does not clarify the ratio of the functional flexibility during movements required, in both flexibility and other motor abilities, such as force, power, etc.

Based on these facts, this study's aim is to conduct a biomechanical examination of the inclusion of active flexibility in artistic gymnastic movements requiring mobility (actively moving through a range of motion), flexibility and other motor abilities such as force, power, etc. Besides this, the study aims to determine the ratio of the functional flexibility in the movements required for mobility in certain movements in artistic gymnastics.

Material and Methods

Participants

To determine the correlations and effects of the active flexibility to mobility in functional movement patterns a causal relational research model was used. The study included 17 girl gymnasts aged 7-9 years old, with a body height of 140.7±10.2, weighing 34.1±6.4, and body mass index of 17.6±3.0. As some gymnasts did not participate in all performance tests, the study sample may vary for each test. For that reason, we have given the sample size in each group in the tables of the results.

The gymnasts and their parents were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study. The study was approved by the Ethics Board of the Istanbul Gelisim University.

Research design

In line with the purpose of the present study, the Correlational Survey Method, which aims to determine the presence and/or level of a covariance among variables identified in the relevant part of the method, and the causal-comparative method, which aims to determine the reasons of an existing / naturally occurring situation or event, its effects on these causes, and the contributing variables or the results of an effect, were used.

Testing Procedures

Forward-Backward Split (FBS^0): The test's main aim is to measure the active flexibility of the lower limbs and hips *(iliopsoas: psoas major, iliacus, quadriceps femoris group: rectus femoris, vastus lateralis, vastus medialis, sartorius, hamstrings: biceps femoris, semitendinosus, semimembranosus etc.)* [10]. The angle reference point was the hips (greater trochanter) and the angle line was put across the legs to the ankle (lateral malleolus). In exceptional situations (if the athlete's knee was not straight), the angle tool's reference point was the thigh plane to the knee. The test was applied on two sides; right leg forward position, and left leg forward position. The results were recorded us a different variable for the left and right leg and the results were given in degrees [1, 2].

Side Spit (SS^0): The test's main aim is to measure the active flexibility of the lower limbs adductors *(pectineus, gracilis, adductor brevis, adductor longus, adductor magnus, etc.)* [10]. The angle reference point was the coccyx bone and the angle line was put across the legs to the ankle (lateral malleolus). The results were given in degrees [1, 2].

Arm-Trunk Angle Backward (AT_^{0}B): The test's main aim is to measure the active flexibility and mobility of the shoulders and upper limbs (*triceps brachii, posterior deltoid, teres minor, teres major, latissimus dorsi pectorals abdominal and sternocostal part, etc.)* [10]. The angle reference point was the upper limit of middle axillary line (biacromial elevation level) and the angle line was put across the hand joint (styloid process of ulna) and hips (greater trochanter). The results were recorded us an angle given between the trunk and raised arms [1, 2].

Trunk Bent Forward (TBF): The test's main aim is to measure the active flexibility and mobility of the low back *(hips muscles: gluteus maximus, multifidus, quadratus lumborum, intertransversarii, longissimus, erector spinae group, iliocostalis muscle)* and hamstrings *muscles (biceps femoris, semitendinosus, semimembranosus, etc.)* [10]. During the measurement, the gymnast stands on the bank, leaning ahead-down reaching the longest point as is possible with their fingers. The results were registered based on the toes and in centimeters. During the test, the knees should be straight and the maximal position reached must be held for at least 2 seconds.

Leg Raise forward (LRF^0): The test's main aim is to measure the lower limbs flexor muscles *(iliopsoas, pectineus, rectus femoris, sartorius, adductor longus, tensor fasciae latae, etc.)* mobility *(the ability of the athlete to apply movements from a wide-angle and in different directions as far as the joints allow)* [10]. The reference of the measurement, where the angle was based on, was the hips (greater trochanter). The angle line was put across the raised leg to the ankles (lateral malleolus) and the angle's other line was put across the upper body exactly on the vertical line on the coronal plane (frontal plane). The results of the test were determined by the angle degree between raised leg and upper body [1, 2].

Leg Raise Sideward (LRS^0): The test's main aim is to measure the lower limbs abductor muscles *(gluteus medius, gluteus minimus, tensor fascia lata, gluteus maximus, etc.)* mobility *(the ability of the athlete to apply movements from a wide-angle and in different directions as far as the joints allow)* [10]. The reference of the measurement was the angle based on was the coccyx (tailbone). The angle line was put across the raised leg to the ankles (lateral malleolus) and the angle's other line was put across the upper body exactly on the vertical line on the sagittal plane. The results of the test were determined by the angle degrees between raised leg and upper body [1, 2].

Bridge (B^0): The bridge technique was made according to the FIG rules and used to measure the mobility *(the ability of the athlete to apply movements from a wide-angle and in different directions as far as the joints allow)* of the gymnasts. The criteria of the evaluation for the bridge technique based on the angle degrees between two imaginary lines that were across the leg *(the line was across the malleolus and greater trochanter)* and arm *(the line was across the styloid process of the ulna and acromial elevation level)* [10]. The application of the test was; no break on the knee, and elbow ankle [1, 2].

Standing long Jump (SBJ): The test's aim is to measure the power (*low extremities explosive force*) of the gymnasts [11] by jumping forward from the starting position (on both feet) in order to cover a distance. The explosive force of the lower extremities is measured [12]. The result is registered in centimeters. However, according to FIG this test's evaluation base is the body length of lying on the face, and hands reach forward [1, 2].

Lift Trunk Forward-60secs (Crunches) (LTF_60s): The test's aim is to measure the strength continuity of the abdominal muscle *(rectus abdominis, external oblique, internal oblique, transversus abdominis, etc.)* of the gymnasts [10]. The gymnast lies on his back, joins his hands at the nape, pulls his knees gently towards his abdomen (*knees at 90 degrees*), and the soles completely touch the mat. When getting up, the elbows should come forward and touch the knees at the end of the movement. Hands must be tied together at the nape throughout the entire movement. The ankles of the subject are held by an assistant. While starting the second movement, enough time should be given in order to let the shoulders touch the mat. The subject tries to repeat this movement as many times as possible within 60 seconds. The assistant keeps the subject's feet on the mat during the entire test. The right and image 13 measurement of 60-Lift Trunk Forward Test completed crunches are counted and recorded as a result within 60 seconds. A "QQ Japanese HS45 10 Lap Memory" stopwatch was used to measure the time [1, 2, 13, 14,].

Angle Degree of the Leg Split Position in Cartwheel (A^{0}LSPCT): The test's aim is to measure the ratio of active flexibility during performance (*inaction*) that requires mobility. Recorded videos of the cartwheel technique were used in the test. The video was stopped in the frame the gymnast is in at a handstand position and the legs are split in the sagittal plane. The criteria of the evaluation for the angle degree of the leg split position in the cartwheel technique based on the angle degree based on the coccyx of two imaginary lines, which were across the leg (heel). The application of the test was; no break on the knee [1, 2].

Arm-Upper Body Angle Backward in Bridge Technique (AUB°BB): The bridge technique was made according to the FIG rules and used to measure the mobility *(the ability of the gymnast to apply movements from a wide-angle and in different directions as far as the joints allow)* of the gymnasts [10]. The criteria of the evaluation for the bridge technique were based on the angle degree between two imaginary lines which were across the leg *(the line was across malleolus and greater trochanter)* and arm *(the line was across the styloid process of the ulna and acromial elevation level)*. The application of the test was; no break on the knee, and elbow ankle [1, 2].

Statistical Analysis

For the data analysis of the variables the Kinovea 0.8.15 program, which is a video player for sports analysis and provides a set of tools to capture, slow down, study, compare, annotate and measure technical performances [15], was used. To mark location, measure distance and determine the angle degree of the videos, tools of the program such as a line, circle, cross marker, angle, etc. were used. The videos are made by a Galaxy S10 which has three cameras on the back: a main 12-megapixel with an aperture that shifts between f/1.5 and f/2.4 depending on light, an ultra-wide 16-megapixel unit, and a telephoto 12-megapixel for zooming.

In the SPSS 24 program was used for data analysis. General descriptive analysis was made by using descriptive analysis; correlations between variables were made by the Pearson correlation; and relationships between variables and success scores were revealed by the Pearson correlation analysis. The percentage of the functional active flexibility were calculated by using the formula "%= (angle⁰ of the mobility in functional movement / angle⁰ of the active flexibility) *100".

Results

Table 1 shows active flexibility (SS°) and mobility (LRS°) in degrees. The results have shown that active flexibility expressed in the SS° technique was used 90.7% in movements including mobility (LRS°). Furthermore, the p-values (LL_RS°: .358 and RL_RS°: .839) were not statistically significant, and 100% of the active flexibility requiring mobility was found to be not functional in gymnastics movements.

Table 2 shows active flexibility (SS°) and mobility (A°LSPCT) in degrees. According to the results, only 78.5% of the active flexibility exhibited in the SS° technique was functional in mobility-requiring techniques such as A°LSPCT. In addition, p-values (.190) not found to be statistically significant and 100% of the active flexibility requiring mobility was not functional in gymnastics movements requiring mobility.

The results shown in the previous table 3 have made clear that active flexibility (AT_°B) is not completely used in techniques that require active flexibility, force and mobility. Active flexibility expressed in the AT_°B technique was used just 17.5% in the movements with a similar biomechanical and anatomical structure including mobility (AUB°BB). Moreover, the p-values (.785) were not statistically significant, indicating that 100% of active flexibility was not functional in mobility-requiring gymnastics movements such as a bridge, cartwheel, forward Salto and backward Salto techniques.

The previous table shows the results of active flexibility (FBS°) and mobility (LRF°) in degrees. According to Table 4, the active flexibility expressed in the FBS° technique was used 99.7% in the movements including mobility (LRF°). When the correlation between LLA_FBS° and LL_RF° was not significant (p-value: .548), the correlation between RLA_FBS° and RL_RF° was significant (p-value: .011). It seems that unlike other variables given in the above tables, gymnasts used 99.4% of their active flexibility during the execution of the techniques requiring force and flexibility, i.e. mobility. The cause of this can be seen in the analysis of the results in the discussion part.

Table 5 gives the results that show the differences by bridge techniques scores between active flexibility expression, mobility expression, and force expression variables. The results show that compared to the active flexibility expression variables (AT_°B and TBF) and

Table 1. Functional active flexibility "Side Split (SS°)" during the execution of the techniques requires mobility "Leg Raise Sideward (LRS°)"

Variables	N	X̄±SD		%		r	p
		SS°	LRS°				
LL_RS°	15	168.3±14.53	106.8±11.46	90.5	90.7	.266	.358
RL_RS°			105.5±11.07	90.9		.060	.839

X̄±SD: mean and std. Deviation, LL_RS°: Left Leg Raise Sideward (°),RL_RS°: Right Leg Raise Sideward (°), N: sample, SS° : Side Split (°), LRS°: Leg Raise Sideward (°), %: Percentage of functional SS° in the LRS°, r: correlation, p: p: sig. (p< 0.05)*

Table 2. Functional active flexibility "Side Split (SS°)" during the execution of the techniques requiring mobility "Leg Split in Handstand Position in Cartwheel Technique (A°LSPCT)"

Variables	N	X̄±SD	%	r	p
SS°	9	173.6±13.17	78.5	.481	.190
A°LSPCT		136.0±12.23			

SS° : Side Split (°), A°LSPCT: Angle Degree of the Leg Split Position in Cartwheel Technique (°), N: sample, X̄±SD: mean and std. Deviation, %: Percentage of functional SS° in the A°LSPCT, r: correlation, p: sig. (p< 0.05*)

Table 3. Functional active flexibility "Arm-Trunk Angle Backward (AT_°B)" during the execution of techniques requiring mobility "Arm-Upper Body Angle Backward in Bridge Technique (AUB°BB)"

Variables	N	X̄±SD	%	r	p
AT_°B	7	139.9±11.83	17.5	.088	.785
AUB°BB		174.6±13.21			

AT_°B: Arm-Trunk Angle Backward (°), AUB°BB: Arm-Upper Body Angle Backward in Bridge Technique (°), N: sample, X̄±SD: mean and std. Deviation, %: Percentage of functional AT_°AB in the AUB°BT, r: correlation, p: sig. (p< 0.05)*

Table 4. Functional active flexibility “Forward-Backward Split Technique (FBS°)” during execution of techniques requiring mobility “Leg Raise Forward (LRF°)”

N	FBS° Variables	X̄±SD	LRF° Variables	X̄±SD	%		r	p
15	LLA_FBS°	146.7±12.11	LL_RF°	99.5±9.97	101.4	99.4	-.176	.548
	RLA_FBS°	153.3±12.38	RL_RF°	99.4±9.97	97.5		-.657	.011*

N: sample, FBS°: Forward-Backward Split (°), LLA_FBS°: Left Leg Ahead Forward-Backward Split Degree (°), RLA_FBS°: Right Leg Ahead Forward Backward Split Degree (°), LRF°: Leg Raise Forward (°), LL_RF°: Left Leg Raise Forward Degree (°), RL_RF°: Right Leg Raise Forward Degree (°), X̄±SD: mean and std. Deviation, %: Percentage of functional FBS° in the LRF°, r: correlation, p: sig. (p< 0.05)*

Table 5. Differences between flexibility, mobility and force tests to the bridge technique in artistic gymnastics

Ability	Variables	Bridge score	X̄ ±Ss	F	P	Tukey
Active flexibility	AT_°B	1 (poor)[1]	152,0±15.6	.68	.584	-
		2 Statisfactory[2]	128.5±38.5			
		3 (good)[3]	146.5±13.6			
		4 (excelent)[4]	151.0±4.2			
	TBF	1 (poor)[1]	4.4±9.1	1.62	.296	-
		2 Statisfactory[2]	9.0±1.4			
		3 (good)[3]	13.1±3.6			
		4 (excelent)[4]	15.5±6.2			
Mobility	AUBA°BB	1 (poor)[1]	183±4.0	5.39	.025*	1>4 2>4
		2 Statisfactory[2]	185.2±5.1			
		3 (good)[3]	176.3±3.0			
		4 (excellent)[4]	167.5±10.6			
	B°	1 (poor)[1]	97.3±13.6	7.09	.012*	1<4 2<4
		2 Statisfactory[2]	87.5±10.5			
		3 (good)[3]	71.0±11.2			
		4 (excellent)[4]	55.5±.7			
Force	SBJ	1 (poor)[1]	124.1±11.1	2.47	.176	-
		2 Statisfactory[2]	124.5±2.1			
		3 (good)[3]	127.0±13.2			
		4 (excellent)[4]	146.8±1.6			
	LTF_60s	1 (poor)[1]	25.6±18.1	.589	.637	-
		2 Statisfactory[2]	31.0±18.7			
		3 (good)[3]	24.2±20.3			
		4 (excellent)[4]	44.0±4.2			

AT_°B: Arm-Trunk Angle Backward (°), TBF: Trunk Bent Forward (cm), AUBA°BB: Arm-Upper Body Angle Backward in Bridge Technique (°), B°: Bridge (°), SBJ: Standing Broad Jump (cm), LTF_60s: Lift Trunk Forward in 60 secs (crunches), p: sig. (p< 0.05)*

force expression variables (SBJ and LTF_60s and B°), mobility expression variables (AUBA°BB and B°) had a significant difference of gymnast’s whose bridge techniques scores were high and low. Respectively, the gymnasts who have more positive results in the mobility variables (AUBA°BB: 1>4, 2>4, B°:1<4, 2<4) also had more positive scores in the bridge technique.

Discussion

Results of the study have shown that active flexibility performed in the movements such as side split, forward-backward split, and arm-trunk angle has not been highly functional in mobility-requiring movements (actively moving through a range of motion). Convenient levels of flexibility are a precondition for proper performance of many basic body elements such as a jumps, balance and rotation [16]. Subsequently, one of the crucial reasons for failure in artistic gymnastics is the fact that active flexibility and force are not combined and functional during active movements.

To be more specific in this topic we have made an analyze of the results of the study where it can be seen that active flexibility expressed in the side split technique was functional around 90.7% in movements requires mobility, such as the leg raise forward. This result is reinforced by the correlation analysis between flexibility and mobility based on the techniques mentioned above. Thus, it is statistically verified that one of the biggest challenges of gymnasts is making functional all ranges of motions during active movements that require force, power, etc. Baptista's research concluded that many gymnasts with high spine flexibility failed to achieve the higher level in the maximum trunk lift due to the gymnasts showing high flexibility in spine joints, but not yet presenting sufficient strength to maintain the determined position [17].

Similarly, active flexibility showed in the side-split technique (173.6°) resulted to be functional at just around 78.5% in the movements requiring mobility, such as the angle degree of the leg split in the cartwheel technique (136.0°) in the floor routine. The result was reinforced by the correlation analysis of these two variables, which also did not result in any statistical significance. In this way, even the side-split technique and the side split position in the cartwheel technique which have similar biomechanical and anatomical structures, gymnasts failed to use 100% of active flexibility as a source of mobility. The literature also showed that despite the large increases in passive hip ROM, there was no evidence of increased hip ROM used during functional movement testing [8]. Similarly, the only significant change in lumbar motion was a reduction in lumbar rotation during the active hip extension maneuver (p, 0.05). These results indicate that changes in passive ROM, or core endurance, do not automatically transfer to changes in functional movement patterns. This implies that training and rehabilitation programs may benefit from an additional focus on "grooving" new motor patterns if a newfound movement range is to be functional.

Another example of functional flexibility during movements that require mobility is given. When it the angle degree between arm-upper and trunk in the bridge position (174.6°), which requires both force and flexibility was measured, i.e. mobility, and in the same test according to the biomechanical and anatomical perspective, the arm-trunk angle backward in the stand position (139.9°) again resulted to be different. Only 17.5% of the active flexibility had been functional in the movement where both force and flexibility are required, i.e. mobility. The arm-trunk angle is key to gymnasts' performance, such as it is in the bridge technique, for that reason this test is used worldwide to determine gymnasts' performance [18, 19, 20]. The literature indicates that hip extension measurements obtained passively do not reflect those used during dynamic activity [21, 22].

Unlike other variables mentioned above, it seems that 99.7% active flexibility, which is expressed in the forward backward split technique (LLA_FBS°: 146.7°, RLA_FBS°:153.3°) was also functional in the leg raise forward technique (LL_RF°99.5°, RL_RF°:99.4°). However, the main reason for the high rate of functionality of active flexibility in these variables, is the fact that the test which measures flexibility and the test measuring mobility were not identical in a biomechanical and anatomic perspective. In the measurement of the right or left leg flexibility, the other leg was extended back also, the extension of the quadriceps muscle group of the leg which is back, reduced the extension of the leg which is ahead. Whereas, during the leg raise ahead test, the other leg was straight in the standing position, which does not stretch the quadriceps muscle. If we eliminate the effect of this anatomical difference, it can be seen that the ratio of flexibility-mobility will be similar to the above variables. Furthermore, there is little objective evidence that combined improvements in hip mobility and core endurance will be reflected in volitional functional activity [8].

To clarify the effect of the development of mobility (actively moving through a range of motions) per contra force and flexibility as an independent motor skills, the study has applied correlation analysis between mobility, flexibility and force to bridge technique execution success, which was evaluated in stages (1: poor, 2: satisfactory, 3: good, 4: excellent) (1, 2).

Statistically significant results have shown that gymnasts who have better scores in the bridge execution technique, also had better arm-upper body angle degrees in the bridge technique, an ability which requires mobility.

The results have shown that flexibility did not directly reflect movement where force is required. This may be because flexibility still was not functional in the active movements. According to the literature, many gymnasts with high spine flexibility failed to achieve the higher level in the maximum trunk lift. This result is probably due to the gymnasts showing high flexibility in spine joints, but not yet presenting sufficient strength to maintain the determined position [17]. Besides, the bridge angle degree which were measured between two imaginary lines across the leg (the line across malleolus and greater trochanter) and the arm (the line across the styloid process of the ulna and acromial elevation level), and which requires both flexibility and force (mobility) to execute, it had a positive impact to the bridge technique score. Flexibility ability plays a major role in the power-intensive and high-difficulty techniques of the Artistic Gymnastics [18, 19, 23].

In conclusion, the results of the study have shown gymnasts and coaches must concentrate on mobility (actively moving through a range of motions) as much (or more) as they concentrate on force and flexibility improvement, rather than concentrating on flexibility and force as an independent motor skills. Based on the results on the study of Moreside, and Mcgill (2013), despite large increases in passive hip mobility in groups 1 and 2, there were no significant increases in hip extension or rotation used during dynamic activities

In summary, the functionality ratios of active flexibility in techniques requiring mobility are limited to the techniques in this study, which gives an idea for other techniques. Much of the literature discussing changes to movement patterns subsequent to an exercise routine is sport specific [24, 25, 26].

A limitation for interpretation of the data is that the subject numbers are low. Therefore, we suggest increasing the study sample and including also males, as there can be significant differences in the technique angle degrees between males and females. In artistic gymnastics, it is more important to analyze the movements, motor skills, and training reliability from the biomechanical perspective instead of classic methods such as a heart rate, repetition number, sets, or volume per session, etc.

To achieve better results we should conduct more similar studies and include more elements that measure the flexibility, mobility, and success scores of gymnasts. By including a larger number of elements in the study, the rate of functionality of the given active flexibility will be more valid and reliable.

Conclusions

As a result, it was determined that the functionality rate of the techniques requiring active flexibility and requiring mobility of the same biomechanical and anatomical structure was around 65-75%. Therefore, to execute 100% of the flexibility in action (during active elements) as it is in a passively or actively, it may significantly increase force in the large range of motion. In the light of this information, we put forward some practical suggestions below that may be useful for coaches and gymnasts.

Training applied in different body planes and positions may result in more functional flexibility during the execution of high difficulty degree elements in artistic gymnastics.

Based on the fact that gymnasts and coaches aim to use or expose 100% of the flexibility during the execution of the active or dynamic elements, we can conclude that artistic gymnastics training should be prepared according to these aims. Thus, increasing mobility means also increasing coordination and other motor abilities. Furthermore, increasing a mobility also means force is combined with other motor abilities and used better; and especially flexibility is more functional in different elements of artistic gymnastics such as a cartwheel, bridge, walkover forward, walkover backward, handspring forward, Salto variations, etc.

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Conflict of interests

No potential conflict of interest was reported by the authors.

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