RELATIONSHIP BETWEEN SHOULDER FLEXIBILITY AND HANDSTAND ALIGNMENT IN DIFFERENT FEMALE ARTISTIC GYMNASTICS APPARATUS

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Abstract

A study was performed with the objective of analyzing the relationship between shoulder flexibility and handstand performance across three female artistic gymnastics apparatuses: floor exercise (FX), balance beam (BB), and uneven bars (UB). Twenty-one gymnasts participated and were divided into two groups: "G1", consisting of twelve child gymnasts, and "G2", consisting of nine adolescent gymnasts, aged 9 and 14 respectively. The study aimed to consider the sensitive phases for the development of flexibility. Using the Kinovea program, the shoulder angle (°H) in the handstand and the alignment of the joint segments (AJS) involved were analyzed. Participants underwent two different active shoulder flexibility tests (GFMT and FIG), and results were compared between the groups. Significant differences were found between groups in the GFMT test (p = 0.018), the FIG test (p = 0.026), and AJS in the BB handstand (p = 0.043). Significant relationships were also observed between the GFMT test and °H in UB (p = 0.021); and between the FIG test and °H in BB (p = 0.006), both withing the cild gymnast group. Overall, the adolescent group presented better scores, supporting the notion of greater body awareness and technical mastery of the handstand across the different female artistic gymnastics apparatuses.

Keywords: *ROM, shoulder angle, handstand, sport performance.*

INTRODUCTION

In the long-term development of gymnasts, overall loading ability, particularly the loading ability of the motor and support systems, holds a central position (Fink, Hofmann, & Ortiz López, 2021). Poor posture can compromise the athlete's entire system and, due to the systematic strength training undertaken by gymnasts, may exacerbate existing muscle shortenings and create new ones (Bessi, 2016). According to the FIG (2021), achieving safe, systematic development and avoiding inefficient joint positions requires a high level of prerequisites such as flexibility, strength, and basic structural development. Optimal mobility ranges enhance technical efficiency and provide greater possibilities for performance (Weineck, 2005). This increase in mechanical efficiency results from executing sports movements at the limits of motion (Dantas, 2012). A gymnast lacking flexibility will have to exert more effort and will fatigue more quickly (Bessi, 2016). Flexibility limitations can lead to learning errors and faulty movement patterns, resulting in defective movement engrams

(Di Santo, 1997). Therefore, it is essential to thoroughly study the minimum angular amplitudes required for specific movements or gestures for each joint (Di Santo, 1997). The joint must possess both mobility and stability simultaneously—two seemingly opposite qualities (Dantas, 2012).

Gómez-Landero Rodríguez (2013) analyzed the correlations between variables related to active and passive flexibility and sports performance in trampolinists. McLaren et al. (2015) identified the mean angle of the wrist joint during a backward flic-flac in gymnasts and concluded that there is a relationship between the angle of wrist impact and the angle of shoulder flexion. León-Prados et al. (2011) verified the relationship between certain flexibility tests and competitive performance in male gymnasts across different apparatuses.

Many movements in gymnastics require a high degree of joint amplitude (Di Santo, 1997). The handstand often serves as the starting, finishing, or transition position between various elements, making its mastery central to the training and development of gymnasts (Bessi, 2016). The joints, from the wrist to the ankle, must be aligned along the same axis perpendicular to the ground, with scapulo-humeral flexibility being crucial. This flexibility must reach at least 180°; otherwise, the center of gravity of the trunk and lower limbs will be misaligned (Di Santo, 1997). The force of gravity on the respective barycenters of the different body segments is nearly aligned along a straight line (Bessi, 2016). A limitation in shoulder flexibility restricts the "open shoulder angle" position (Uzunov, 2008).

Several studies have highlighted the importance of strategies for maintaining handstand balance and the varied muscular activity involved (Kochanowicz et al., 2018; Rohleder & Vogt, 2019). Rohleder and Vogt (2018a; 2018b) explored the use of various feedback stimuli to improve and maintain posture. Gautier et al. (2007) evaluated the role of central and peripheral vision in the postural regulation of the handstand. Kochanowicz et al. (2017) described differences in muscle activation during handstands on different apparatuses in male gymnasts, considering variations in grips and hand positions. These coordinated responses involve feedback from the proprioceptive, visual, and vestibular systems (Uzunov, 2008).

Irurtia et al. (2010) evaluated flexibility in gymnasts and its evolution in relation to specific training. Other researchers have proposed measurement programs with various tests, including specific tests for assessing active shoulder joint flexibility (Gómez-Landero Rodríguez et al., 2011; Sleeper et al., 2012; Sleeper et al., 2016; Vernetta et al., 2017; Mkaouer et al., 2018). The FIG Age Group Program (Fink et al., 2021), within the "Physical Ability Development and Testing Program," offers a different alternative. Considering the sensitive phases for the development of flexibility, as proposed by Issurin (2012), between the ages of 7 and 10, and specifically by authors specializing in artistic gymnastics who suggest that the training/adaptation relationship between ages 6 and 12 is highly favorable for developing this ability (Bessi, 2016), it would be expected to find differences between child and adolescent gymnasts in joint ranges and postural control in both tests and more complex situations such as gymnastic elements.

The objectives of this study were:

1. To investigate the relationship between the ranges of shoulder joint flexibility in flexion with °H in the handstand and AJS in the handstand across different apparatuses in child and adolescent gymnasts.
2. To compare both groups in terms of shoulder flexibility, °H, and AJS in the handstand on FX, BB, and UB.

METHODS

An observational study was conducted involving 21 female artistic gymnasts from the Molins de Rei Gimnàs Club in

Barcelona. Following the criteria established by Bessi (2016), the gymnasts were divided into two groups: G1, consisting of 12 gymnasts aged 7 to 12 years, and G2, consisting of 9 gymnasts aged 13 to 17 years (Table 1).

The inclusion criteria were:

a) Having more than one year of artistic gymnastics training.

b) Being able to perform a handstand on FX, BB, and UB, with an alignment within 10° of the handstand position, as required by the gymnastics scoring code to be considered valid (FIG, 2020).

c) Training at least three times a week for a minimum of three hours per session.

d) Not having any excluding injuries.

All participants were informed about the study, and written informed consent was obtained from their parents or legal guardians. This study was conducted in accordance with the Declaration of Helsinki and the International Principles governing research, and it received a favorable opinion from the Bioethics Commission of the University of Barcelona.

Table 1

Descriptive profile of Group 1 and Group 2 (Mean ± SD).

	Age	Weight	Height	IMC	Years of training
G1	9.500 ± 1.834	32.867 ± 8.823	1.368 ± 0.124	17.264 ± 1.787	4.500 ± 1.679
G2	14.778 ± 1.856	54.733 ± 10.983	1.588 ± 0.088	21.493 ± 2.416	9.222 ± 2.819

The evaluations were conducted by the principal investigator, with assistance from artistic gymnastics coaches from the Molins de Rei Gimnàs Club who were familiar with the tests. The tests were performed during training sessions, following an initial warm-up that included general mobility exercises, active and passive flexibility, specific postures, and lumbo-pelvic activation/stabilization.

Five tests were conducted over two different days, during the middle of the competitive period. On the first day, two flexibility tests were recorded. On the second day, the execution of the handstand was recorded on video; in FX, on BB (20 centimeters high and 10 centimeters wide), and on UB (15 centimeters high). Before each evaluation, the gymnasts were given specific instructions and allowed time for familiarization with the procedures.

1) Shoulder flexibility test from the Age Group Program (Fink et al., 2021):

The gymnast stands with legs extended against a handstand bar, holding a club firmly with hands shoulder-width apart behind the bar. The distance between the bar (the edge closest to the gymnast) and the club is measured in centimeters. A score between 1 and 10 is given based on the centimeters achieved, as detailed in the test table (Fink et al., 2021) (Figure 1).

2) Shoulder flexibility test from GFMT (The Gymnastics Functional Measurement Tool), Sleeper et al., (2012; 2016).

The evaluation was conducted carefully following the “Instructions for the Administration of the GFMT.” The gymnast lay face down on the floor with a cane in her hands and raised her arms, extended to their maximum height. The final result was determined by measuring the height reached and relating it to the length of the gymnast's arm (Figure 2). A score between 0 and 10 was then assigned based on the obtained result.

3) The handstands were recorded using a Samsung Galaxy S20 Ultra LTE mobile phone with software version 12.0.01.6. The recordings were made from the sagittal plane with a white wall background, positioned 4.85 meters from the center of the support and at a height of one meter (Rohleder & Vogt, 2019). A line was drawn in front of the

gymnast for hand support as a reference. Each gymnast started the handstand from the side that allowed them to analyze their dominant side in relation to the leg used to take the first step. The instructions were to reach the handstand position, bring the feet together as aligned as possible, and descend under control to the starting position. Each gymnast made at least three attempts, with the best attempt being maintained for analysis.

Markers were placed at the following anatomical landmarks to identify angles of the different segments in the sagittal plane for subsequent analysis (Gautier, 2007): 1) wrist (styloid-ulna process), 2) shoulder (posterior deltoid), 3) hip (greater trochanter of the femur), 4) knee (lateral epicondyle of the femur), 5) ankle (apex of the fibula or lateral malleolus) (Rohleder & Vogt, 2019) (Figure 3A). The optimal handstand position for assessment was determined at the moment when the movement began to reverse to return to the starting position (Masser, 1993; Rohleder & Vogt, 2018b). The Kinovea analysis software, version 0.9.5, was used to observe and analyze performance in the handstand.

A) °H (Figure 3B). The shoulder joint angle was recorded in degrees and segments 1-2-3 considered.

B) AJS (Figure 3C). A screenshot of the handstand at its optimal point was captured, and a handstand line was drawn from the support (wrist joint). Using the five anatomical landmarks marked on the gymnasts and the handstand descriptions proposed by Di Santo (1997) and Bessi (2016), the analysis was conducted by evaluating the alignment of the segments (A).

Figure 1. Age Group Flexibility Test, FIG; Age Group High Competition Development Program for Women's Artistic Gymnastics.

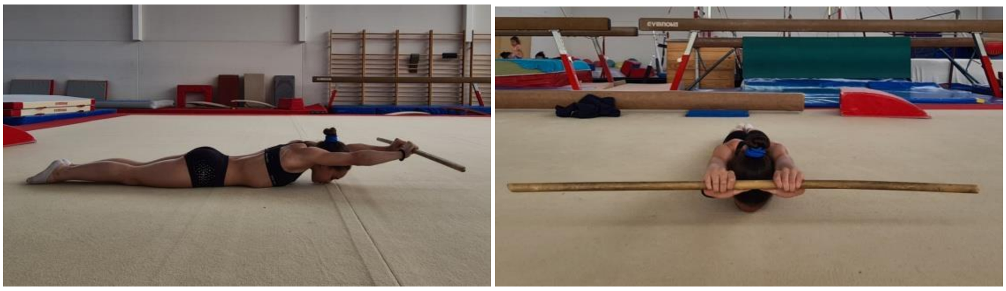

Figure 2. Shoulder Flexibility Test GFMT.

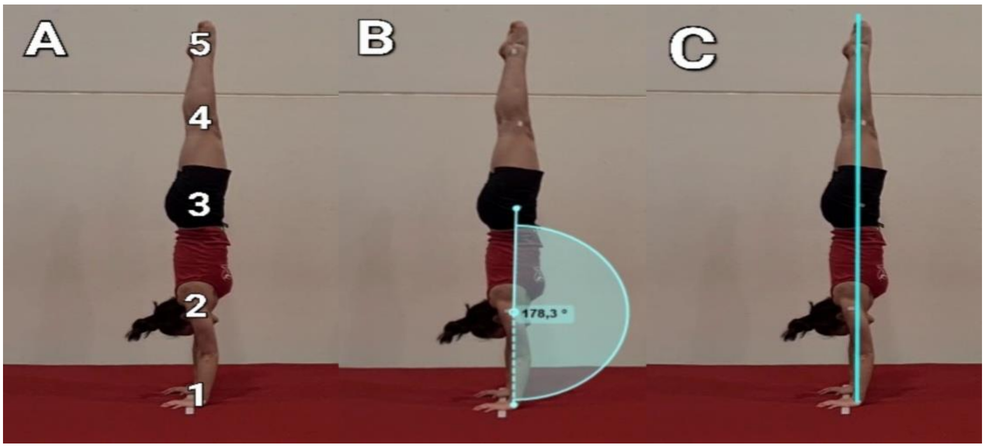

Figure 3. Evaluation of the handstand in the different apparatuses; F, BB and UB.
Note:
A) Joint segments marked for evaluation, numbered 1 to 5.
B) Shoulder joint angle.
C) Number of segments aligned.

A descriptive analysis (mean, standard deviation, and minimum/maximum range) was conducted for each group and their corresponding evaluations. The normality of the variables was assessed using the Shapiro-Wilk test, and homoscedasticity was checked with the Levene test where appropriate. Based on these results, differences between groups were analyzed using either the Student's t-test, Student's t-test with Welch correction, or the Mann-Whitney U test. Effect sizes were determined using Cohen's d or the rank biserial correlation coefficient, respectively.

To examine the relationships between tests, the normality of the distribution was verified using the Shapiro-Wilk test for the results of each flexibility test (independent variables) and the performance in the handstand (dependent variables). The Pearson or Spearman correlation coefficient, depending on the distribution, was used to observe the associations between the variables. Statistical significance was set at $p<0.05$. Statistical analyses were performed using JASP software, version 0.16.0.0 (Department of Psychological Methods, University of Amsterdam, Netherlands).

RESULTS

When comparing the results between G1 and G2, significant differences were found in three of the eight evaluations conducted (Table 2) (Figure 4).

For the GFMT test, one of the samples did not fit a normal distribution (W G1 = 0.859; p = 0.048; W G2 = 0.930; p = 0.481). Statistically significant differences were observed in favor of G2, which achieved higher scores (U = 21,000; p = 0.018) with a large effect size (rb = 0.611).

For the FIG test, one of the samples did not fit a normal distribution (W G1 = 0.931; p = 0.395; W G2 = 0.505; p < 0.001). Statistically significant differences were found in favor of G2, which scored higher (U = 23.500; p = 0.026) with a large effect size (rb = 0.565).

For AJS in the handstand on BB, both samples fit a normal distribution (W G1 = 0.900; p = 0.156; W G2 = 0.892; p = 0.208) and met the assumption of homoscedasticity (F = 0.086; p = 0.773). Statistically significant differences were found in favor of G2, which achieved higher scores (t = -2.175; p = 0.043), with a 95% confidence interval between -2.076 and -0.035 points, and a very large effect size (d = -0.955).

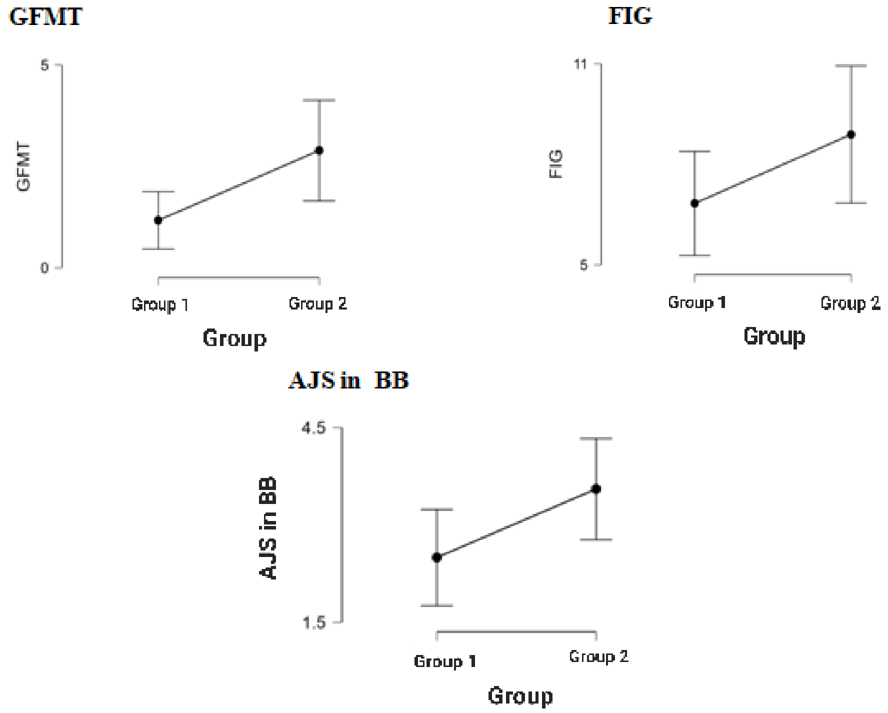

Figure 4. Statistically significant differences between G1 and G2 in the “GFMT / FIG” tests and the performance evaluations in the “AJS in BB” handstand.

Table 2.
Values achieved in the evaluations and differences between both groups.

	G1		G2					
Test	Mean ± SD	Range	Mean ± SD	Range	Estatistical	p	i.c 95%	d / rb
GFMT	1.167 ± 1.115	0 – 3	2.889 ± 1.616	0 – 5	21.000 [c]	0.018*		0.611
FIG	6.833 ± 2.443	3 – 10	8.889 ± 2.667	2 – 10	23.500 [c]	0.026*		0.565
°H - F	176.000 ± 5.099	167 – 184	178.778 ± 3.993	172 – 183	-1.350 [a]	0.193		0.595
AJS F	2.917 ± 1.240	1 – 5	3.889 ± 0.782	3 – 5	27.000 [C]	0.052		0.500
°H BB	176.667 ± 4.677	168 – 184	180.444 ± 7.892	171 – 195	-1.278 [b]	0.225		0.582
AJS BB	2.500 ± 1.168	1 – 5	3.556 ± 1.014	2 – 5	-2.165 [a]	0.043*	-2.076/-0.035	0.955
°H UB	178.000 ± 8.202	166 ± 194	180.111 ± 6.827	172 – 195	-0.626 [a]	0.539		0.276
AJS UB	2.167 ± 1.030	1 – 4	2.778 ± 0.833	2 – 4	36.000 [C]	0.194		0.333

*p < 0,05 statistically significant relationships.
[a] t de Student; [b] t de Student with the correction of Welch; [c] U de Mann-Whitney.

Finally, the associations and statistically significant relationships between the results of the GFMT/FIG tests and handstand performance (°H and AJS) on FX, BB, and UB are summarized (Table 3). Two statistically significant relationships were found in G1, while no statistically significant relationships were observed in G2 (Figure 5).

In G1, there was a statistically significant and directly proportional association between GFMT and °H in UB (r = 0.655; p = 0.021; 95% CI: 0.893 to 0.129). Additionally, there was a statistically significant and directly proportional association between FIG and °H in BB (r = 0.742; p = 0.006; 95% CI: 0.923 to 0.294).

Two associations approached significance: between FIG and °H in the handstand on UB (r = 0.553; p = 0.062), and between FIG and °H in the handstand on BB (r = 0.642; p = 0.062). Both associations showed a trend towards significance but were not statistically significant.

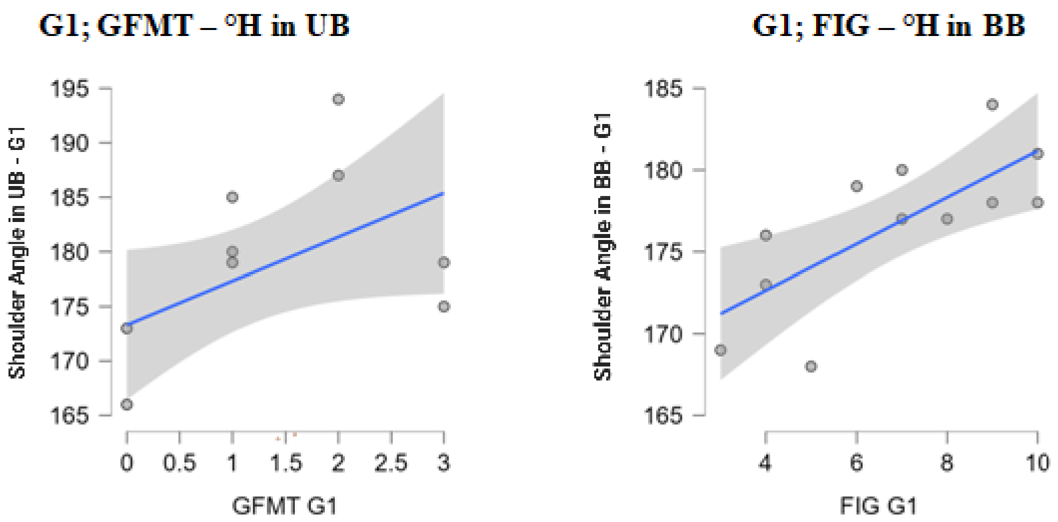

Figure 5. Statistically significant relationships between flexibility tests and performance evaluations in handstand.
A) GFMT / Shoulder angle in UB, G1.
B) FIG / Shoulder angle in BB, G1.

Table 3.
Significant relationships and directly or inversely proportional associations between flexibility tests and performance evaluations in the handstand.

	GFMT G1 r / p	FIG G1 r / p	GFMT G2 r / p	FIG G2 r / p
°H F	(+) 0.224 [a] / 0.484	(+) 0.224 [a] / 0.484	(+) 0.015 [a] / 0.969	(+) 0.069 [b] / 0.860
AJS SU	(-) 0.055 [a] / 0.866	(-) 0.275 [a] / 0.387	(+) 0.286 [a] / 0.456	(+) 0.232 [b] / 0.548
°H BB	(+) 0.343 [a] / 0.275	(+) 0.742 [a] / 0.006**	(+) 0.426 [a] / 0.253	(+) 0.642 [b] / 0.062
AJS BB	(-) 0.349 [a] / 0.266	(-) 0.223 [a] / 0.486	(+) 0.042 [a] / 0.914	(-) 0.036 [b] / 0.927
°H UB	(+) 0.655 [b] / 0,021*	(+) 0.553 [a] / 0.062	(-) 0.078 [a] / 0.842	(+) 0.232 [b] / 0.548
AJS UB	(-) 0.185 [a] / 0.565	(+) 0.337 [a] / 0.248	(+) 0.258 [a] / 0.503	(-) 0.464 [b] / 0.209

*p < 0,05; **p < 0,01 Statistically significant relationships.
(+) Directly proportional association; (-) Inversely proportional association.
[a] Pearson's r; [b] Spearman's r_S.

DISCUSSION

This study aimed to investigate the relationship between shoulder joint flexibility in flexion, handstand °H, and AJS in different apparatuses for child and adolescent gymnasts, and to compare performance between the two age groups. The results revealed significant differences favoring G2, which achieved better results in the evaluations. Significant differences were observed in the GFMT and FIG tests between the groups.

These findings contrast with those of Gómez-Landero Rodríguez et al. (2013), who evaluated flexibility in two groups of female trampolinists: under-15 (11.44 ± 1.23 years) and absolute (16.1 ± 2.02 years). They found no significant differences in the active shoulder flexion range, with results of 184.91° ± 13.97 and 184.56° ± 21.02, respectively, for each group. Their shoulder flexibility test, which is similar to the GFMT in terms of the athlete's position, measures degrees rather than centimeters of distance from the floor and arm length. Their study concluded that flexibility may not be an exclusively determining factor in performance for trampolinists, unlike other gymnastic disciplines.

Regarding the comparison of handstand performance, Kochanowicz et al. (2018) found that young male gymnasts (13.9 ± 0.7 years) exhibited significantly higher displacements of the center of pressure in both the medial-lateral and anteroposterior axes compared to elite adult gymnasts (23 ± 3 years). This aligns with our findings, which show statistically significant differences in AJS in the BB handstand in favor of G2. The more experienced G2 gymnasts appear to achieve greater control and body awareness, starting from the support and demonstrating better shoulder location and stability. When the base of support is small, an effective shoulder strategy becomes crucial (Hedbávný et al., 2013). As fitness levels improve, the quality and stability of the handstand are less influenced by external factors (Omorczyk et al., 2018).

Furthermore, Kochanowicz et al. (2019) highlighted that in floor handstands, parallel bars, and rings, the muscles with the highest EMG activity—exceeding 30% of the maximum voluntary contraction—are those of the upper limbs. The greatest EMG activity was observed on rings, the most unstable apparatus, where shoulder muscles exhibited increased activity. Significant differences were found in only five of the 13 muscles studied when comparing young gymnasts (13.9 ± 0.7 years) with adults (25.6 ± 3.94 years), who showed lower muscle activation. In our study, G2 demonstrated superior mastery and control, reflected in higher scores for °H (closeness to 180°) and AJS across all handstands. Although a statistically significant difference was found only in AJS of the BB handstand ($p = 0.043$), AJS in the FX handstand also tended towards significance ($p = 0.052$).

In the AJS of UB, the results showed the greatest parity between the two groups. This can be attributed to the inherent complexity of the UB handstand, where achieving and maintaining virtuosity is challenging due to the nature of the support and base. In routines and training, the handstand on UB is often used as a transitional position rather than one requiring sustained maintenance, unlike the handstands on FX and BB, where maintaining the position is more common, especially during developmental and training stages.

Although Kochanowicz's studies differ from ours in terms of gender, age, and developmental stages of the gymnasts, it is reasonable to assume that more years of training contribute to better control and technical mastery of the handstand. For more experienced athletes, maintaining an inverted position may become more "natural" compared to less experienced gymnasts (Omorczyk et al., 2018).

In general, flexibility is positively related to performance in gymnastics. León-Prados et al. (2011) found statistically significant relationships between active and passive flexibility tests and performance on three men's gymnastics apparatuses. They observed significant correlations between flexibility in hip flexion and performance on the parallel bars ($r = -0.842^{**}$) and the fixed bar ($r = -0.696^{*}$), as well as between flexibility in hip abduction and performance on the pommel horse ($r = 0.652$), parallel bars ($r = 0.629$), and horizontal bar ($r = 0.815$). Furthermore, flexibility emerged as a key quality in the fitness profile results, identified as one of the determinants of gymnastics performance (Mkaouer et al., 2018).

Referring to the relationships between GFMT/FIG results and performance evaluations in the handstand, only two statistically significant relationships out of the 24 proposed were found. These were between GFMT and °H in UB for G1 ($p = 0.021$) and between FIG and °H in BB for G1 ($p = 0.006$). These findings show some similarity to those of Sleeper et al. (2012), who did not find significant correlations between the competitive level of female gymnasts and the results of the GFMT shoulder flexibility test, although the results were close to significance (p = 0.05). However, they did find a significant correlation between test results and age (p = 0.00). Conversely, Sleeper (2016) identified statistically significant relationships between GFMT results and competitive level (p = 0.01) and age (p = 0.002) in male gymnasts.

In the current study, GFMT and FIG generally showed a directly proportional association with handstand performance measured in °H. This means that as flexibility scores increase, the °H in the handstand approaches 180°. This trend was observed for G1 across both tests and all handstands (F, BB, and UB), totaling six associations. For G2, only one association was inversely proportional (between GFMT and °H in PA), while the remaining five associations were directly proportional.

McLaren (2015) identified statistically significant relationships between shoulder angle and wrist angle during the impact phase of a backward flic-flac (p = 0.04), noting that greater shoulder amplitude reduces wrist hyperextension. This suggests that increased shoulder flexion amplitude can be beneficial for achieving optimal positioning during inverted supports, such as handstands or temporary positions like flic-flacs.

Regarding the association between GFMT/FIG and AJS, the results varied between groups. In G1, there were more inversely proportional associations, indicating that as flexibility test scores increased, AJS decreased. Specifically, G1 had five inversely proportional associations out of a total of six, with the relationship between FIG and AJS in UB being the only directly proportional association.

In contrast, G2 showed fewer inversely proportional associations, with only two out of six evaluated relationships being inversely proportional. These were the associations between FIG and AJS in BB and UB.

To maintain balance, gymnasts initially use a wrist strategy, followed by a shoulder strategy, and will resort to a hip strategy in cases of major disturbances or imbalances (Kochanowicz, 2018). Experience, maturity, and technical mastery over the years likely enhance postural control and alignment of body segments from the support to the ankles. Increased flexibility in younger gymnasts can lead to greater swings and disturbances that are harder to control. Consequently, achieving a shoulder angle of 180° in the handstand does not always ensure proper alignment of the other joint segments. As Gamble (2021) suggests, it is crucial to prioritize both mobility and neuromuscular training to help athletes control their range of motion while maintaining postural and joint integrity.

Regarding flexibility, it is noteworthy that in both groups, some gymnasts achieved the ideal score of "10" on the FIG test, while the maximum score on the GFMT test was only "5" out of a possible "10" points. This suggests that the GFMT may be a more demanding measure of flexibility. This distinction could be an important consideration for future studies or for coaches when evaluating their gymnasts.

Future studies could benefit from investigating which joint segments are most likely to align or misalign during handstands, as well as exploring the underlying reasons for these patterns. The data provided by this study offer a foundation for further exploration into the complex and multifaceted aspects of handstand performance.

LIMITATIONS OF THE STUDY

It is important to note that the sample size was small, and there may have been greater variations in technical level within Group 1 (ages 7 to 12) compared to Group 2 (ages 13 to 17). These differences in technical proficiency could have influenced performance, particularly on asymmetric parallel bars, which may have presented the greatest challenge.

CONCLUSIONS

Significant differences were observed between the two groups in the shoulder flexibility tests, with adolescent gymnasts generally achieving better scores than child gymnasts. However, significant differences were noted in only one of the performance evaluations—the AJS in the balance beam handstand.

Regarding the relationships between flexibility tests and performance evaluations, only two significant associations were found for Group 1: between GFMT and °H in the uneven bars handstand, and between FIG and °H in the balance beam handstand. For younger gymnasts, it is crucial to focus not only on shoulder flexibility but also on control and postural awareness to ensure optimal alignment and positioning of the shoulder in various elements for effective performance.

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