SPORTS INJURIES IN YOUNG GYMNASTS FOLLOWING THE COVID-19 ONSET: PREVALENCE AND ASSOCIATED FACTORS

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Abstract

COVID-19 lockdowns had a negative impact on training practices and other fitness- and coaching-related aspects across many sports disciplines. This study analyzed the relationship between different training routines and performance, as well as the prevalence of musculoskeletal injuries (MI) in young gymnasts following the onset of the COVID-19 pandemic. The sample consisted of 67 artistic gymnasts (AG) from Campo Grande, MS, Brazil, aged 8 to 17 years. Participants were divided into two groups: G1, which included gymnasts in remote training, and G2, comprising gymnasts in face-to-face training. Subjects were assessed for anthropometric variables, flexibility, muscle power, and sensorimotor stability, and completed a questionnaire to record MI cases. A total of 34 MI cases were reported by 23 participants (34.3%), with the majority affecting the lower limbs. Eight individuals reported at least two retrospective MI cases. Additionally, G2 demonstrated higher muscle power, greater flexibility, and improved sensorimotor stability. Face-to-face training conditions were associated with at least a tenfold increase in the likelihood of MI. Weekly training time (exposure) was linked to a ~9% increase in lower limb MI, while factors such as age, dynamic balance, and training were directly associated with MI occurring during floor exercises.In conclusion, although regular face-to-face training was linked to enhanced motor performance, it was also associated with a higher prevalence of MI, particularly in the lower limbs. Floor exercises were the primary circumstances under which injuries occurred.

Keywords: *gymnastics; training setting; COVID-19; performance; sports injuries.*

INTRODUCTION

Artistic gymnastics (AG) requires a combination of artistic expression with physical and biomechanical effort (Gasparetto et al., 2022; Moeskops et al., 2019). Gymnastics, in general, has the youngest average age of single-sport specialization at 8.9 years and is one of the few sports where early specialization has been associated with higher rates of elite-level competition (Myer et al., 2016). Women's artistic gymnastics includes floor exercise, uneven bars, balance beam, and vault, while men's includes floor exercise, parallel bars, rings, pommel horse, horizontal bar, and vault. These exercises are brief but high-intensity, consisting of gymnastics elements—complex movements that involve extreme ranges of motion and generate high forces (Desai et al., 2019; Gasparetto et al., 2022; Hernández-Beltrán et al., 2023).

Challenging AG elements require substantial strength, power, flexibility, and agility, all performed on various apparatuses (Campbell et al., 2019; Gasparetto et al., 2022; Moeskops et al., 2019). Enhancing AG performance is typically linked to significant overloads, often sustained through repetitive training and competition exposure. Athletes may train between 16 and 40 hours per week, enduring a combination of these physical demands (Buckner et al., 2017; Moeskops et al., 2019; Sastre-Munar et al., 2022). Importantly, a combination of high training volumes and inadequate recovery intervals can compromise performance and is a potential contributor to the onset of sports-related musculoskeletal injuries (MI) (Boullosa et al., 2020; Campbell et al., 2019).

Musculoskeletal injuries (MI) have multiple adverse effects on athletic performance, including training interruptions, detraining, and significant medical costs (Hart et al., 2018; Ling et al., 2020). A review of injuries in gymnastics found that athletes are at higher risk of injury at more competitive levels, with increased training hours, and particularly if they participate in artistic gymnastics (Atiković et al., 2017; Sastre-Munar et al., 2022; Thomas & Thomas, 2019). MI incidence and prevalence are notably high among gymnasts, with 0.3 to 3.6 injury cases per athlete (Campbell et al., 2019). Younger age and participation in competitive settings have been linked to a higher injury risk (Tisano et al., 2022).

From an etiological perspective, MI results from complex interactions between external conditions and both modifiable and non-modifiable intrinsic risk factors (Boullosa et al., 2020; Kalkhoven et al., 2020). Additionally, a primary injury may impact motor performance, increasing the likelihood of recurrence or exacerbation of MI (Campbell et al., 2019; Nunes et al., 2021).

In this context, COVID-19 lockdowns negatively impacted training practices, affecting training frequency, duration, intensity, technique, recovery, and other fitness and coaching-related aspects across multiple sports modalities (Washif et al., 2022). Many athletes experienced significant reductions in training frequency and time spent on various training-related activities during remote training sessions, leading to notable disruptions in training and performance (Jagim et al., 2020; Patel et al., 2022). Moreover, remote and unsupervised training activities may be associated with a higher risk of sports injuries due to inadequate supervision and compromised training environments (Bobo-Arce et al., 2021; Pillay et al., 2020). However, these issues have been insufficiently investigated in epidemiological studies involving gymnasts.

The current investigation aimed to analyze the association between different training routines and performance parameters, as well as the prevalence of MI in young gymnasts following the onset of the COVID-19 pandemic. Additional objectives included characterizing sports injuries and exploring potential associations between MI occurrence and performance measures. Understanding the prevalence of injuries in artistic gymnastics is crucial for developing effective prevention strategies. By identifying intrinsic and extrinsic factors associated with MI, this study seeks to inform coaches, athletes, and healthcare professionals about targeted interventions to reduce injury rates and enhance athlete safety.

METHODS

The current investigation is a descriptive study based on a cross-sectional design. A convenience sample was drawn from gymnasts aged 8 to 18 years, representing two artistic gymnastics (AG) teams from Campo Grande, MS, Brazil. To be included, participants were required to have engaged in uninterrupted sports training for at least 30 days. Exclusion criteria included reporting a musculoskeletal injury at the time of the initial assessment, using medication for inflammatory processes or infections, and having known metabolic or cardiorespiratory diseases that disrupted AG training.

In total, 67 gymnasts from two AG training sites in Campo Grande participated in the study. Participants were divided into two groups (G) based on their training conditions: G1, consisting of gymnasts in remote training, and G2, comprising gymnasts in face-to-face training.

In terms of ethical considerations, the study adhered to the principles of the Declaration of Helsinki and the Nuremberg Code, as well as the research standards involving human subjects established by the National Health Council (CNS/Brazil). Participants, along with their parents and/or legal guardians, were provided with verbal and written information about the study before giving their consent by signing the informed consent forms. The research protocol was approved by the local ethics committee (Protocol 5.013.655/2021; CAAE 33562220.6.0000.0021).

After the initial approach, each participant completed a questionnaire providing descriptive information on individual characteristics, competitive level and category, retrospective training history, daily and weekly exposure to AG training, and participation in regular competitions.

For anthropometric characterization, body weight was measured using a mechanical scale (Welmy R-110, SP-BR). Height, both standing and sitting, was measured using a portable stadiometer (Personal Caprice Sanny Stadiometer, SP-BR) with participants in an anatomical reference position and the head aligned in the Frankfurt plane (Bacciotti et al., 2018). Body weight and height were used to calculate body mass index (BMI; mass(kg) ÷ height(m)^2) (Malina et al., 2013). Additionally, triceps and subscapular skinfolds were measured to estimate body composition. Body fat percentage (%F) was determined using an equation developed for children and adolescents (Slaughter et al., 1988).

Somatic maturation was assessed using a maturational offset, which estimates the time (in years) remaining to reach peak height velocity (PHV) (Mirwald et al., 2002).

Regarding physical-motor aspects, flexibility was assessed using the sit-and-reach test (Wells & Dillon, 1952). The Sargent Jump Test was employed to evaluate lower limb performance (Sargent, 1921), while upper limb performance was assessed by throwing a medicine ball (Cronin & Owen, 2004). Additionally, the Star Excursion Balance Test (SEBT) was used to evaluate dynamic balance (Robinson & Gribble, 2008). Postural balance was assessed with a force plate equipped with a 500 mm platform, four load cells, and a 100 Hz calibration system (BIOMEC 400_V4, EMG System®) (Scarmagnan et al., 2021). Participants performed the tests on both bipedal and unipedal supports and were instructed to maintain their position on the plate for 30 seconds, following previous protocols (Paterno et al., 2004; Scarmagnan et al., 2021).

Musculoskeletal injury (MI) cases were reported using a self-reported morbidity survey (Hoshi et al., 2008; Silveira et al., 2013). In this study, an MI case was defined as any physical complaint resulting from training and/or competition that prevented participation for at least one day, regardless of the need for medical care, as defined in previous studies (Kolt & Kirkby, 1999; Vanderlei et al., 2013). The morbidity survey gathered information on individual characteristics such as gender, duration of training, and details about past MI cases. Information on sports injuries included the affected anatomical site, injury mechanism, circumstances of onset, severity, time to return to normal training, and recurrence. Anatomical sites were categorized as head/neck, trunk, and upper or lower limbs. The injury mechanism was described based on the participant's perception of the contact or action that triggered the acute episode and/or the activity in which the symptoms were aggravated. The circumstance of injury onset was classified according to whether it occurred during training or competition (Vanderlei et al., 2013). MI recurrence was defined as present when a participant reported two or more retrospective MI cases.

Data normality assumptions were tested using the Kolmogorov-Smirnov test for quantitative variables. The Student's t-test was used to compare parametric results between groups, while the Mann-Whitney test was applied for non-parametric results. Gender and musculoskeletal injury prevalence by group were analyzed using the Chi-square test (χ^2). An aggregated z-score, derived from individual z-scores of five variables, was used to describe postural balance results. Since these variables followed a normal distribution, they were analyzed using two-way repeated measures analysis of variance (Two-Way RM ANOVA) with Bonferroni's correction. The Z-test was employed to compare proportions regarding musculoskeletal injury prevalence by anatomical site, onset circumstance, mechanism, and number of cases. Backward stepwise logistic regression models were used to evaluate the association between potential variables and four different sports injury outcomes. The predictive accuracy and performance of the logistic regression models were assessed using the area under the Receiver Operating Characteristic Curve (ROC curve). All statistical analyses were conducted with a significance level set at $p<0.05$.

RESULTS

Table 1 presents comparative results regarding general characteristics based on training schedule, with groups categorized as remote (G1) and face-to-face (G2). Both groups were similar in terms of age, anthropometric characteristics, and training experience. Weekly training exposure was higher in G2 compared to G1 ($p<0.001$). Although females were more prevalent in both groups, the remote training group had a higher proportion of males compared to the face-to-face training group ($p<0.05$). Regarding musculoskeletal injuries, a total of 34 MI cases were reported by 23 participants, resulting in a prevalence of 34.3%. G2 exhibited a higher prevalence of MI ($p=0.006$) and a greater number of injury cases than G1.

Next, figures 1A and 1B show the upper limb power and lower limb power values, respectively. While the upper limb power values were similar between groups, lower limb power was higher in G2 ($p=0.023$).

Figure 2 shows muscle flexibility and dynamic balance scores. For flexibility, G2 demonstrated higher scores compared to G1 (Figure 2A). However, there were no statistically significant differences in dynamic balance scores between or within the groups (Figure 2B).

Table 2 presents postural balance results by lower limb side. Within each group (side's effect), both lower limb sides showed similar performance scores across all measurements ($p>0.05$). In intergroup comparisons, G2 participants exhibited lower sways, speeds, and areas compared to G1 on both sides.

Table 3 provides information on the characterization and prevalence of musculoskeletal injury (MI) cases. Descriptively, lower limb regions were the most common anatomical sites for MI onset, with a single MI case being the most frequently reported ($p>0.05$). Conversely, exercises on the floor were the primary circumstance associated with MI onset ($p<0.01$).

Table 1
General characteristics in accordance with group (n=67)

Variable	Group G1	Group G2	p-value
Age (years) [a]	10.9 ± 2.1	10.3 ± 2.1	0.339
Height (cm) [a]	144.1 ± 13.4	140.2 ± 12.7	0.250
Body weight (kg) [b]	35.5 (29.0 – 41.0)	37.0 (29.0 – 42.5)	0.800
BMI (kg/m^2) [b]	17.3 (16.1 – 18.3)	18.2 (16.6 – 20.3)	0.054
Body adiposity (%) [b]	13.2 (10.1 – 18.6)	15.3 (10.4 – 20.5)	0.526
Maturation [a]	12.95 ± 0.66	12.69 ± 0.74	0.168
Training practice (years) [b]	2.0 (2.0 – 4.0)	3.0 (1.8 – 4.3)	0.428
Week training time (h) [b]	2.0 (2.0 – 2.0)	6.0 (5.0 – 9.0)	<0.001 *
Gender			
Female	12 (54.5%)	37 (82.2%)	0.035 *
Male	10 (45.5%)	8 (17.8%)	
MI prevalence			
No	20 (90.9%)	24 (53.3%)	0.006 *
Yes	2 (9.1%)	21 (46.7%)	
Participants (n)	22 (32.8%)	45 (67.2%)	-
MI cases	2 (5,9%)	32 (94,1%)	-
Injury/gymnast	0.09	0.71	
Injury/injured gymnast	1.0	1.52	-

BMI, body mass index; MI, musculoskeletal injuries; G1, participants in remote training; G2, participants in face-to-face training. **a** Quantitative variables presented in mean ± SD and analyzed using Student t-test; **b** quantitative variables presented in median and interquartile interval and analyzed using Mann-Whitney test. Gender and MI prevalence analyzed with Chi-square test. * p<0.05.

Table 2
Postural balance analysis according to group and lower limb side

Variable	Group	Lower Limb (Side) Dominant	Lower Limb (Side) Non-Dominant	p-value Group	p-value Side	p-value Interaction
AP Sway (cm)	G1	4.58 ± 1.42	5.31 ± 2.14 #	0.012*	0.106	0.050 †
	G2	3.55 ± 2.13 *	3.50 ± 2.00 *			
ML Sway (cm)	G1	3.35 ± 0.66	4.24 ± 3.90	0.011*	0.097	0.240
	G2	2.55 ± 1.38	2.60 ± 1.44			
Area (cm²)	G1	10.11 ± 5.86	10.28 ± 4.65	<0.001*	1.000	1.000
	G2	7.13 ± 5.49	7.31 ± 5.09			
API Speed (cm/s)	G1	4.19 ± 1.15	4.30 ± 1.40	0.013*	0.532	0.845
	G2	3.29 ± 2.00	3.29 ± 1.91			
MLI Speed (cm/s)	G1	4.21 ± 1.15	4.33 ± 1.28	0.020*	0.580	0.566
	G2	3.40 ± 1.91	3.41 ± 1.88			

AP, anteroposterior; ML, mediolateral; API Speed, anteroposterior imbalance speed; MLI Speed, mediolateral imbalance speed. Results expressed in mean ± standard deviation; * p<0.05, group's effect; #p<0.05, lower limb side effect; † p<0.05, interaction's effect. Two-Way RM ANOVA and Bonferroni's test.

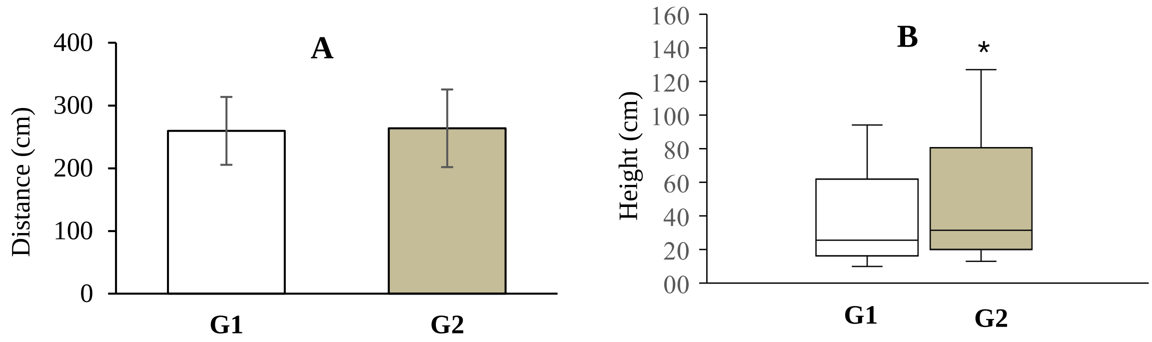

Figure 1. (A) Mean and standard deviation of upper limbs reaching performance, according to group; G1, participants in remote training; G2, participants in face-to-face training; Student-t test (p>0.05). (B) Descriptive measures of lower limbs performance; * p<0.05 vs. G1; Mann-Whitney test.

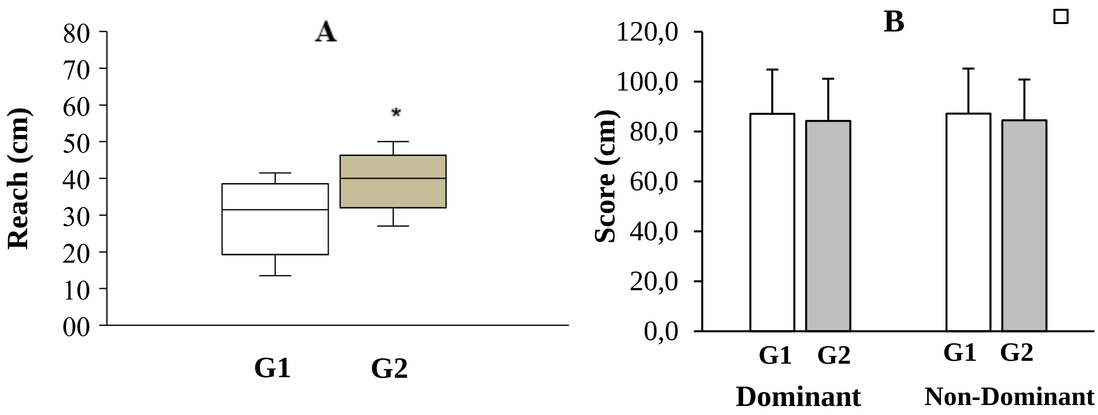

Figure 2. (A) Descriptive measures of muscle flexibility according to group; G1, participants in remote training; G2, participants in face-to-face training; * p<0.05 vs. G1; Mann-Whitney test. (B) Mean and standard deviation of dynamic balance according to group and lower limb side (p>0.05); Two-way RM ANOVA and Bonferroni's test.

Table 3
Musculoskeletal injuries prevalence according to anatomical site, onset circumstance, mechanism, and number of cases

Variables	Prevalence		p-value
	Absolute (n)	Relative (%)	
Anatomical site			
Lower limbs	20	58.8%	0.508
Other	14	41.2%	
Total (cases)	34		
Onset circumstance			
Floor exercises	28	82.4%	0.007 *
Other	6	17.6%	
Total (cases)	34		
Number of MI cases			
1 retrospective case	15	65.2%	0.340
2-3 retrospective cases	8	34.8%	
Total (participants)	23		

Z-test comparison of proportions; * p<0.05.

Based on associated characteristics and MI records, Table 4 presents numerical data related to probability models for four different outcomes: retrospective MI onset, MI in lower limbs, MI from floor exercises, and MI recurrence.

Firstly, the time of practice, dynamic balance (non-dominant lower limb), and training condition (face-to-face) were directly associated with the chances of MI onset. Conversely, SEBT (dominant lower limb) was negatively associated with MI risk, showing a 25% increased chance of MI onset. Face-to-face training conditions were associated with at least a 10-fold increase in MI onset risk. The ROC curve for this model showed an AUC value of 0.897, with an optimal cut-off value of 0.351, corresponding to a specificity of 0.795 and a sensitivity of 0.913 (Figure 3A).

For MI cases in lower limbs, time of practice (experience) and flexibility were directly associated with an increased risk of MI onset in lower limb sites. Increases in these variables were linked to a higher risk of MI among gymnasts. Dynamic balance (dominant lower limb) was associated with an 8.7% increased risk of lower limb MI onset. The ROC curve for this model had an AUC value of 0.836, with an optimal cut-off value of 0.231, resulting in a specificity of 0.740 and a sensitivity of 0.882 (Figure 3B).

Table 4
Model of probability to musculoskeletal sports injury (MI) onset prediction

Outcome	Variable	Coefficient	SE	p-value	OR	CI (95%)
Sports Injury	Constant	-0.71	2.07	0.73		
	Time of practice (years)	0.72	0.25	<0.01	2.05	1.32 – 3.53
	SEBT (dominant)	-0.23	0.08	<0.01	0.80	0.66 – 0.90
	SEBT (non-dominant)	0.18	0.07	0.01	1.20	1.08 – 1.42
	Training (face-to-face)	2.33	1.00	0.02	10.25	1.78 – 101.89
LL cases	Constant	-0.99	2.26	0.66		
	Time of practice (years)	0.36	0.18	0.05	1.43	1.02 – 2.14
	SEBT (dominant)	-0.08	0.03	<0.01	0.92	0.86 – 0.97
	Flexibility	0.15	0.06	0.01	1.16	1.04 – 1.33
Floor (cases)	Constant	-0.04	2.11	0.99		
	Age category	0.76	0.26	<0.01	2.15	1.37 – 3.82
	SEBT (dominant)	-0.22	0.07	<0.01	0.81	0.68 – 0.91
	SEBT (non-dominant)	0.16	0.06	0.01	1.17	1.06 – 1.35
	Training (face-to-face)	2.59	1.04	0.01	13.27	2.19 – 149.82
Rec	Constant	-8.66	3.31	0.01		
	Flexibility	0.17	0.08	0.03	1.19	1.01 – 1.39

SE, standard error; OR, odds ratio; CI, confidence interval; SEBT, star excursion balance test; Training condition: 0, remote; 1, face-to-face; LL cases, lower limbs MI cases; WTT, week training time; Rec., MI recurrence.

Age, dynamic balance (non-dominant lower limb), and training condition were directly associated with sports injuries resulting from floor exercises. Face-to-face training conditions were linked to approximately a 13-fold increase in the risk of MI onset from floor exercises. A reduction in dynamic balance of the dominant leg was associated with a 23.4% increased risk of MI onset during floor exercises. The ROC curve for this model had an AUC value of 0.895, with an optimal cut-off value of 0.285, resulting in a specificity of 0.759 and a sensitivity of 0.909 (Figure 3C).

The MI recurrence prediction model indicated that flexibility was directly associated with increased chances of MI recurrence (p=0.03). The ROC curve for this model showed an AUC of 0.770 and an optimal cut-off value of 0.111, with specificity and sensitivity values of 0.627 and 0.875, respectively (Figure 3D).

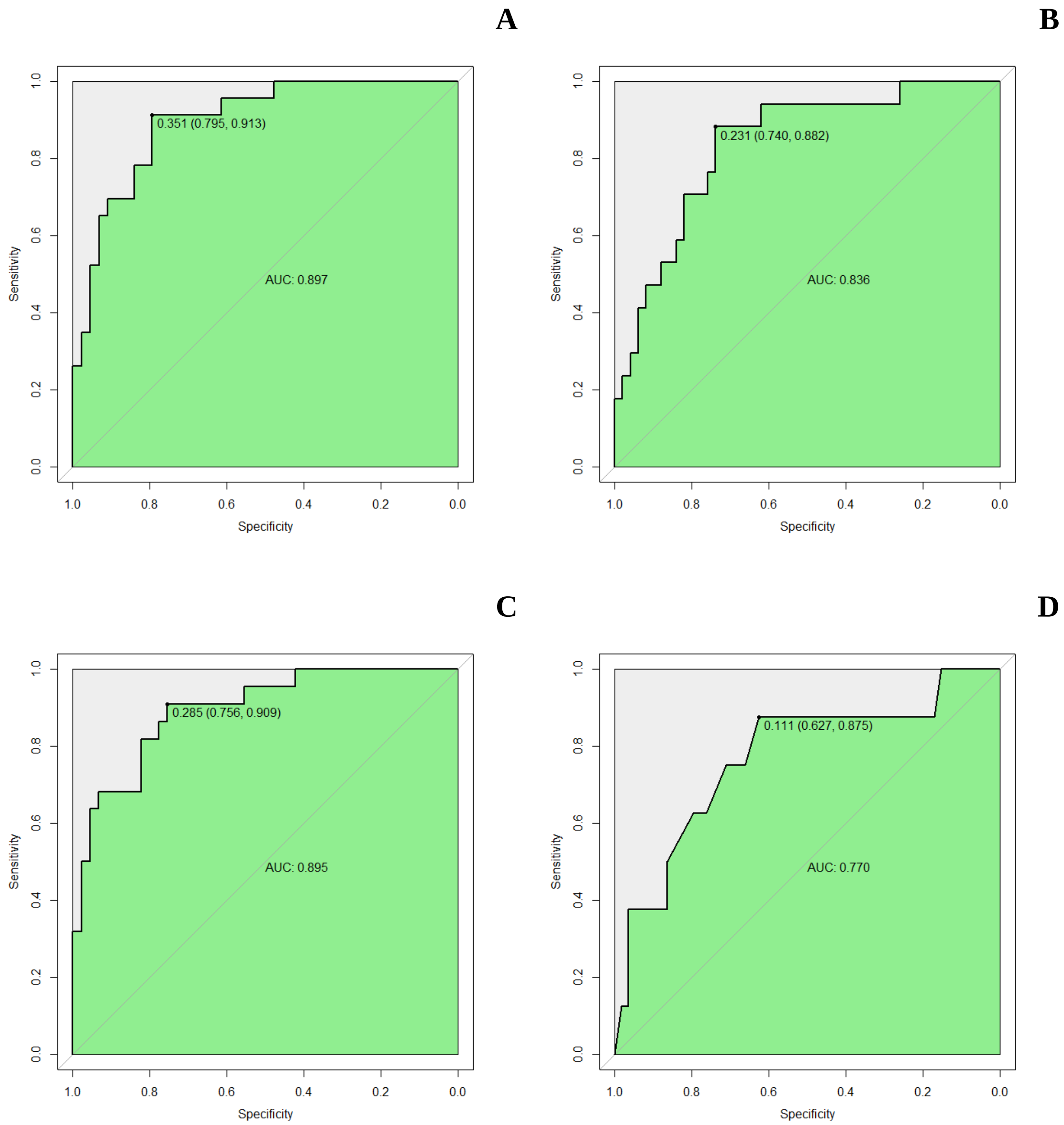

Figure 3. ROC curve for the (A) sports injury onset; (B) lower limb sports injury; (C) sports injury associated with floor exercises; and (D) sports injury recurrence. AUC, area under curve obtained from respective sensitivity and specificity values.

DISCUSSION

This study aimed to analyze the association between different training routines and performance parameters, as well as the prevalence of musculoskeletal injuries (MI) in young gymnasts following the onset of the COVID-19 pandemic. The initial hypothesis posited that remote training schedules were associated with lower performance levels and a higher prevalence of sports injuries in gymnasts.

The COVID-19 pandemic led to significant adaptive changes in training schedules and routines. Specifically, face-to-face training was associated with improvements in performance, including greater muscle power, flexibility, and postural stability, compared to remote training. These findings not only support the initial hypothesis but also confirm that COVID-19 lockdowns had a detrimental impact on training practices and coaching-related aspects. Remote training schedules were linked to reduced training exposure and overload, which contributed to a significant decline in performance, as supported by previous evidence (Jagim et al., 2020; Patel et al., 2022; Washif et al., 2022).

Regular AG training is associated with improvements in power, speed, balance, and muscle flexibility, as demonstrated by the results from the G2 subjects. Muscle flexibility development, in particular, is a common outcome of AG training, linked to a greater range of motion and enhanced muscle power (Moeskops et al., 2019; Root et al., 2019). Lima et al. (2019) compared the effects of two stretching interventions, non-periodized versus periodized, on gymnasts' motor skills and found that periodized training significantly increased muscle flexibility and performance scores.

Regarding postural balance, gymnastics experience may enhance proprioceptive balance in young athletes (Busquets et al., 2018). A systematic review with meta-analysis by Gebel et al. (2018) assessed the effects of balance training (static vs. dynamic interventions) on measures of static and dynamic balance in healthy children and adolescents. The review concluded that regular balance training improves balance performance with moderate to large effects on both static and dynamic balance, regardless of age, sex, training status, setting, and testing method. Our balance results (Table 2) align with this background, showing that higher training scores (G2) were associated with improved performance and static balance control.

Advanced motor skill levels are important for enhancing physical, social, and psychological characteristics in children and adolescents (Kirialanis et al., 2015). However, results from the star excursion balance test indicate that different AG training conditions did not lead to specific changes in dynamic balance biomechanical adaptations. The imprecise control of workload during the retrospective period may have contributed to the lack of substantial impact on dynamic balance.

Regarding the prevalence of musculoskeletal injuries, a total of 23 participants (34.3%) reported at least one case of retrospective sports injury during the training period following the COVID-19 pandemic onset (2020 to 2021). Face-to-face training routines were associated with increased exposure to training overloads, which may constitute an extrinsic factor related to the onset of sports injuries (Boullosa et al., 2020; Root et al., 2019). Other studies have reported similar training characteristics between uninjured and injured competitive participants (Hoshi et al., 2008).

Our investigation involved a high number of young participants classified as competitive and "non-elite," according to previous definitions (Ling et al., 2020). These gymnasts are generally exposed to greater demands in learning training elements and developing basic physical abilities. Consequently, a focus on lower limb exercises, as opposed to upper limb exercises, is common in these situations (Šarabon & Čeklić, 2021), which may be associated with various biomechanical effects.

Historically, previous MIs have been known to impact dynamic balance, with lower limb injuries in AG becoming increasingly prevalent (Dallas et al., 2017; Kirialanis et al., 2015). Lower limb sites were the most commonly reported locations for MI in this study, often accompanied by residual symptoms such as pain, impaired proprioception, and reduced neuromuscular control (Dallas & Dallas, 2016). Research has shown that differences in performance between lower limb sides can increase the probability of sports injuries (Plisky et al., 2006).

In this study, logistic regression models indicated that reduced dynamic balance in the non-dominant lower limb was associated with a higher likelihood of MI onset, both in general and specifically from floor exercises. The ROC curves for these models demonstrated satisfactory predictive performance. These findings suggest that non-dominant limbs play a crucial role in maintaining functional stability. However, the observed differences in dynamic balance measures were minimal and may not significantly impact the results of the Star Excursion Balance Test (SEBT).

Besides biomechanical factors, face-to-face training conditions and time of practice were the main characteristics associated with the onset of MIs)(Table 4). Understanding the potential causes of sports injuries requires a multifactorial approach that considers the interactions among various conditions and both modifiable and non-modifiable risk factors (Bahr & Krosshaug, 2005).

The COVID-19 pandemic led to varying levels of mobility restrictions, interrupting face-to-face training across multiple sports modalities and replacing it with remote activities. These remote activities were often marked by inadequate monitoring and load management, as well as lower adherence (Wang et al., 2021). The reduced and less specific stimuli from these remote training sessions could impair performance development and conditioning, increasing the risk of injury due to the accumulation of workload during subsequent sports activities (Boullosa et al., 2020). The progressive return to regular face-to-face training, coupled with a denser competitive calendar in 2021, likely contributed to a higher odds ratio for MI onset.

The training schedule was directly associated with the onset of lower limb injuries and cases derived from floor exercises (Table 4). These associations were supported by high sensitivity and specificity in the ROC curve analyses (Figure 3). Face-to-face training activities often involve repetitive practices and overloads, with significant demands on the lower limbs due to floor movements. Other studies have identified floor exercises as a primary context for MI onset in AG athletes, linked to increased exposure and overload during floor training (Campbell et al., 2019).

Floor exercises involve high-impact activities, particularly during the landing phase of jumps, which is when many gymnastics injuries occur (Kirialanis et al., 2015). Training at an advanced competitive level and performing in competitions exacerbate the risks associated with floor exercises (Campbell et al., 2019). Additionally, flexibility was directly associated with lower limb injuries and the recurrence of MIs. Flexibility improvements are commonly achieved through regular AG training, and extended practice time promotes this adaptation (Mkaouer et al., 2018). However, from a biomechanical perspective, increased training volume during face-to-face activities may enhance movement specificity but also result in greater flexibility. Over time, this can negatively affect muscle strength and power, potentially leading to injury onset and recurrence of MIs (Sweeney et al., 2019).

Understanding musculoskeletal injuries and their associated factors is crucial for developing effective preventive and rehabilitation strategies in sports. The findings of this study are valuable for athletes, coaches, physiotherapists, and parents concerned with the performance and health of young athletes. Previous research has highlighted differences in workload management between individual and team sports, suggesting that individualized periodization in team sports can improve fitness-fatigue balance, reduce injury risk, and enhance performance (Boullosa et al., 2020).

In this context, the results of the current study underscore the importance of workload management in artistic gymnastics—not only for injury prevention but also for performance monitoring. This has practical implications for training regimens. However, a limitation of this study is the potential for high recall bias regarding the occurrence and characteristics of injuries, as reported by adolescents (Vanderlei et al., 2017). Future studies with a prospective follow-up design are more likely to identify causal relationships and better understand the onset of musculoskeletal injuries.

CONCLUSION

In conclusion, while face-to-face training regular routine was associated with greater performance, it resulted in higher MI prevalence. Lower limbs were the main injured anatomical sites, and exercises on the floor constituted the main circumstances for injury onset.

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