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Francisca Teixeira da Costa Maia

Musculoskeletal Injury Profile of Acrobatic Gymnasts: an International Study

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Francisca Teixeira da Costa Maia

Musculoskeletal Injury Profile of Acrobatic Gymnasts: an International Study

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NOME

Francisca Teixeira da Costa Maia

NÚMERO DE ESTUDANTE	E-MAIL
201607360	francisca_maia2009@hotmail.com

DESIGNAÇÃO DA ÁREA DO PROJECTO

Ciências Médicas e da Saúde - Medicina Clínica

TÍTULO DISSERTAÇÃO

Musculoskeletal Injury Profile of Acrobatic Gymnasts: an International Study

ORIENTADOR

Manuel António Pereira Gutierres

COORIENTADOR (se aplicável)

Ana Úrsula da Costa Martins

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DEDICATÓRIA

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Musculoskeletal Injury Profile of Acrobatic Gymnasts: an International Study

Francisca Teixeira da Costa Maia[1]; Pedro Daniel Freixo Ribeiro[2]; Ana Úrsula da Costa Martins[3]; Manuel António Pereira Gutierres[4]

[1]Francisca Maia, Faculdade de Medicina da Universidade do Porto, Porto, Portugal
[2]Pedro Ribeiro, Department of Physical Medicine and Rehabilitation, Unidade de saúde local de Matosinhos, Porto, Portugal
[3]Úrsula Martins, Department of Physical Medicine and Rehabilitation, Unidade de saúde local de Matosinhos, Porto, Portugal
[4]Manuel Gutierres, Department of Surgery and Physiology, Centro hospitalar universitário de São João, Porto Portugal

Corresponding Author: Francisca Maia[1]
Postal Adress: 9 D. João IV St., Maia, 4470-309, Portugal
Email Adress: francisca_maia2009@hotmail.com

Word Count: 2955

ABSTRACT

Acrobatic gymnastics (ACRO) is increasing in popularity worldwide. Since its Olympic debut at the Summer Youth Olympic Games (2018), fans are eagerly waiting for its entrance at the Olympics. Despite its high physical demands, there is a knowledge gap on ACRO related injuries. We designed a cross-sectional survey to evaluate the incidence, anatomic distribution and type of acute and overuse injuries, and discuss preventive measures. With this aim, gymnasts were recruited worldwide through direct contact or contact with clubs and federations, by email, social media, and word of mouth communication. The questionnaire was completed by 480 gymnasts from various competitive levels, including national team gymnasts and European and World champions. It was found that the majority of acrobats (76.3%) had sustained an injury in the past 24 months, with an overall incidence rate of 1.5 injuries per 1000 hours of exposure, and bases being more injured than tops. For acute injuries, the ankle was the most affected body area, with fractures and ligament sprains being the most common injury types. From these, 53.2% were time-loss injuries, with a mean suspension time of 6.8 weeks. For overuse injuries, lumbosacral spine and tendinopathy were the most frequent body area and injury type, respectively. From these, 28.3% were time loss injuries, with a mean suspension time of 9.1 weeks. This is the first international and the largest study on ACRO related injuries, providing the basis for developing targeted and potentially more effective preventive measures.

Keywords: Acrobatic gymnastics; musculoskeletal injury; prevention; rehabilitation.

Summary Box:

- **What is already known:** there are few studies on ACRO related injuries, so this investigation is necessary and relevant.
- **What this study adds:**
  - This is the largest (480 gymnasts) and the first international (23 countries) injury study to date for ACRO.
  - Overall incidence rate was 1.5/1000h (95%CI: 1.40-1.65).
  - Ankle sprain was the most common acute injury for bases (17.6%) and tops (18.2%)
  - Wrist inflammation was the most common overuse injury in tops (10.4%), while bases sustained a high percentage of shoulder tendinopathy (11.4%).
  - We found correlation between higher training volumes and higher injury development.
- **How this study might affect research, practice or policy:**
  - Acro injury prevention should focus on ankle injuries.
  - Target training programs focused on strengthening and stretching of wrist and shoulder should be implemented for tops and bases, respectively.
  - Personalized management of training load is needed.

INTRODUCTION

Acrobatic gymnastics (ACRO) is a combination of art and skill. It started as a performative art that increasingly became a global sport. Over the last years, partly due to its exposure in media and its integration in various shows, the sport has experienced a surge in popularity. ACRO had its Olympic debut at the 2018 Summer Youth Olympic Games and fans are eagerly waiting for its entrance at the Olympics. Although *Federation Internationale de Gymnastique* reports 1332 licensed - international gymnasts (394 males and 938 females), there are innumerable gymnasts worldwide[1].

ACRO is carried out on a floor (12x12m) and gymnasts work in sets of two, three or four. Each set has gymnasts with different physical and psychological features, namely bases and top. The top is often younger, smaller, thinner and performs aerial skills. Bases are typically older,

taller, stronger, and have the role of supporting. Gymnasts perform group and individual elements (e.g. tumbling maneuvers), with music and choreography. Group elements include balance skills, requiring flexibility and isometric strength, and dynamic skills, requiring plyometric work (Figure 1). It is both a recreational and competitive activity, with various levels (high school, club and national team) and categories (youth, age group, junior and senior), based on age and ability. The best results depend on the difficulty and perfection of the elements, along with the artistic component[2]. Over time, coaches and gymnasts became more ambitious and creative, developing difficult routines with high-risk elements, requiring higher training loads. This may be associated with an increased injury risk.

Although safety measures are widely used, few studies[3-5] have investigated the ACRO injury profile. This knowledge is essential to minimize its occurrence and severity. Hence, the purpose of our study is to find out the distribution and determinants of injury rates in ACRO, taking into account training loads and gymnasts' characteristics. This is the first international and the largest study on ACRO related injuries, providing the basis for developing targeted and potentially more effective preventive measures, and for further research.

METHODS

Research Design

A cross-sectional retrospective study was designed and implemented by using an anonymous online questionnaire. During its development, a pilot has been distributed to 29 gymnasts from a local acrobatics club and adapted according to the obtained answers.

Acrobatic gymnasts were recruited worldwide in 2021 through direct contact or contact with clubs and federations, by email, social media, and word of mouth communication. All gymnasts who practiced ACRO in the last 24 months were included. For the data to be representative of the population, it was determined that a sample size of 299 participants was needed, considering a 95% confidence interval.

Demographics and Training

Participants were asked about their sex, age, height, weight and country. Sport related variables were evaluated: competitive category, competitive level, starting age, training volume (hours/week) and gymnast's session rating of perceived exertion (RPE), using Borg Scale (6-20)[6].

Injuries

Data regarding acute (sudden-onset) and overuse (gradual-onset) injuries was collected, and gymnasts were clarified about the meaning of each term (in accordance with IOC consensus statement[7]). Gymnasts were asked about the absolute number and body region and area of the injuries sustained in the previous twenty-four months. Injuries incidence rates were calculated: (number of injuries/number of exposure hours) x 1000. Focusing on the most impacting injury for each category, gymnasts reported data on specific injury type, time-loss (defined in accordance with IOC consensus statement[7]), use of medications, need for surgery or rehabilitation programs and perception of recovery, by using a scale from 0 (no recovery) to 5

(full recovery). Moreover, we evaluated the prevalence and intensity of current pain during the practice, by using the Numeric Rating Scale (0-10).

Data Analysis

The analyses were performed using the software Statistical Package for the Social Sciences (SPSS) v. 26.0 (SPSS Inc., Chicago, IL) to calculate frequencies and descriptive statistics. Comparison analyses between bases and tops, females and males, and national team gymnasts and gymnasts from other competitive levels were performed, using the Mann-Whitney-U test for continuous variables and the Chi-Square test for categorical variables. Risk factors associated with injury were investigated by identifying key areas of concern. Significant relationships between these variables were then explored using Pearson' s correlation. Differences were considered statistically significant when $p < 0.05$[8].

RESULTS

Demography

The questionnaire was filled by 480 gymnasts from 23 countries, with 91.0% being female and 9.0% being male, which is in line with the gender distribution in ACRO. The 480 gymnasts met the inclusion criteria and were included in the study. The mean age was 17.0 years (SD 5.1) (table1). We observed a mean body mass index of 21.9 (SD 2.7) for bases and 17.8 (SD 3.2) for tops ($p<0.01$). Gymnasts reported a mean experience of 9.7 (SD 5.6) years in ACRO, which corresponds to a mean starting age of 7.2 (SD 3.0) (table1).

Table 1 Demographic and Training Data

	Bases (N=369)	Tops (N=111)
	% (No.)	
Gender		
Female	91.1 (336)	91.0 (101)
Male	8.9 (33)	9.0 (10)
Age, years		
Up to 11	1.6 (6)	18.0 (20)
12 to 14	14.4 (53)	46.9 (52)
15 to 17	43.4 (160)	22.5 (25)
18 or more	40.7 (150)	12.6 (14)
Category		
Youth	9.8 (36)	9.9 (11)
Age group	31.2 (115)	34.2 (38)
Junior	29.3 (108)	36.9 (41)
Senior	29.8 (110)	18.9 (21)
Level		
Recreational	1.9 (7)	1.8 (2)
High School	2.7 (10)	1.8 (2)
Club	58.0 (214)	57.7 (64)
National Team	37.4 (138)	38.7 (43)
Training Volume, hours per week		
2-11	22.0 (81)	18.9 (21)
12-15	28.5 (105)	16.2 (18)
16-20	24.7 (91)	31.5 (35)
21-25	11.7 (43)	14.4 (16)
26 or more	13.3 (49)	18.9 (21)
	Means (SD)	
Age (years)	17.6 (4.5)	14.8 (6.5)
Height (cm)	164.7 (11.1)	149.6 (10.6)
Weight (kg)	59.7 (9.9)	40.2 (10.4)
BMI (kg/m2)	21.9 (2.7)	17.8 (3.2)
Starting age (years)	7.5 (3.1)	6.5 (2.3)
Years of practice (years)	10.2 (5.0)	8.3 (6.8)

The mean training volume was 17.4h/wk (SD 7.2). National team members reported higher training volumes (20.8h/wk; SD 7.0) than other competitive levels ($p<0.01$). The mean RPE was 14.7 (SD 2.03). National team members reported higher RPE than other competitive levels ($p<0.01$), with a mean of 15.2 (SD 1.9). A similar value was observed between tops (14.6; SD 2.3) and bases (14.7; SD 1.9) ($p>0.05$).

Furthermore, a greater percentage of bases (81.3%) currently train with pain when compared with tops (58.6%) ($p<0.01$). Nonetheless, identical mean pain intensities were reported (bases:4.8 SD 1.7; tops:5.1 SD1.6) ($p>0.05$).

Injury Incidence

One or more injuries were sustained in 76.3% of the gymnasts. The mean incidence rate of all injuries was 1.5/1000h (95%CI: 1.40-1.65), with bases (1.6/1000h; 95%CI: 1.43-1.78) reporting a higher overall injury incidence rate when compared with tops (1.2/1000h; 95%CI 0.92-1.39) ($p<0.01$). Overall incidence rate varied between female (1.6/1000h; 95%CI: 1.40-1.71) and male (1.0/1000h; 95%CI: 0.61-1.28) ($p<0.01$). However, it did not show significant differences between national team members and other competitive levels ($p>0.05$). In multivariate regression models, we found a correlation, although weak, between higher BMI ($p=0.003$; $r=0.137$), higher weekly training volume ($p=0.012$; $r=0.115$), lower starting age ($p=0.013$; $r=0.114$) and higher number of injuries experienced.

Regarding acute injuries, 43.1% of the total population reported an acute injury during the studied period, corresponding to a mean acute injury rate of 0.5/1000h (95%CI: 0.44-0.60). A similar acute incidence rate for both bases and tops was observed ($p>0.05$). Acute incidence rate varied significantly between females (0.6/1000h; 95CI: 0.46 to 0.63) and males (0.3/1000h; 95%CI: 0.18-0.42) ($p<0.05$). Additionally, no significant differences in acute incidence rate between national team members and other competitive levels were found. ($p>0.05$). In multivariate regression models, we found no statistically significant correlation among age,

category, level, age at onset, BMI, weekly training load, RPE and the development of acute injuries.

The percentage of gymnasts reporting an overuse injury during the evaluated time was 60.2%, with a mean overuse injury rate of 1.0/1000h (95%CI: 0.88-1.1). Among those, 30.1% reported 1 injury, 30.8% reported 2 and 39.1 % reported 3 or more overuse injuries. We found that bases (1.1/1000h; 95%CI: 0.95-1.21) had a higher injury rate compared to tops (0.7/1000h; 95%CI: 0.48-0.85) ($p<0.01$), and that female (1.0/1000h; 95% CI 0.90 to 1.13) had higher injury rate than males (0.7/1000h; 95%CI: 0.45 to 0.92) ($p<0.05$). No significant differences in overuse incidence rate between national team members and other competitive levels were found ($p>0.05$). However, there were statistically significant differences in overuse injury rates between age groups, with higher age groups showing gradually higher mean overuse injury rates ($p<0.05$). Gymnasts aged 18 and over showed a mean overuse incidence rate of 1.2/1000h (95%CI: 0.96 to 1.34). In multivariate regression models, we found a weak correlation between higher BMI and increased number of overuse injuries experienced ($p=0.007$; $r=0.123$). As well as, between a higher weekly training load and increased number of overuse injuries experienced ($p=0.003$; $r=0.137$).

Lifetime stress fractures were reported by 28.1% of the studied population, corresponding to 30.6% and 19.8% of bases and tops subgroups, respectively.

Injury Location

By body area for acute injuries, a similar distribution was observed for bases and tops ($p>0.05$). Foot/toes (17.4%) and ankle (15.2%) were the most commonly injured body parts for tops, while ankle (22.3%) and hand/fingers (13.4%) took the majority for bases (table 2). There was a similar distribution for the most impacting injuries (table 3).

Table 2 Total injuries by Location

Injuries by body region and area	Acute injuries		Overuse injuries	
	Bases %(No.)	Tops %(No.)	Bases %(No.)	Tops %(No.)
Head or neck (total for body region)	**7.9 (23)**	**10.9 (10)**	**3.8 (24)**	**3.9 (5)**
Skull	2.4 (7)	1.1 (1)	0.0 (0)	0.8 (1)
Face	2.7 (8)	5.4 (5)	0.0 (0)	0.0 (0)
Teeth	0.7 (2)	3.3 (3)	0.0 (0)	0.0 (0)
Neck	2.1 (6)	1.1 (1)	3.8 (24)	3.1 (4)
Trunk (total for body region)	**6.2 (18)**	**4.3 (4)**	**28.1 (179)**	**20.3 (26)**
Thoracic spine	1.0 (3)	1.1 (1)	6.4 (41)	5.5 (7)
Lumbosacral	4.5 (13)	2.2 (2)	21.0 (134)	14.8 (19)
Chest	0.3 (1)	1.1 (1)	0.3 (2)	0.0 (0)
Abdomen	0.3 (1)	0.0 (0)	0.3 (2)	0.0 (0)
Upper limb (total for body region)	**35.4 (103)**	**33.7 (31)**	**33.1 (211)**	**26.6 (34)**
Shoulder	5.8 (17)	1.1 (1)	9.9 (63)	5.5 (7)
Upper arm	1.0 (3)	7.6 (7)	1.6 (10)	0.8 (1)
Elbow	6.5 (19)	9.8 (9)	4.2 (27)	2.3 (3)
Forearm	1.4 (4)	2.2 (2)	1.6 (10)	0.0 (0)
Wrist	7.2 (21)	4.3 (4)	12.2 (78)	11.7 (15)
Hand/Fingers	13.4 (39)	8.7 (8)	3.6 (23)	6.3 (8)
Lower limb (total for body region)	**50.5 (147)**	**51.1 (47)**	**35.0 (223)**	**49.2 (63)**
Groin/Hip	3.4 (10)	1.1 (1)	3.9 (25)	4.7 (6)
Thigh	1.7 (5)	2.2 (2)	0.5 (3)	1.6 (2)
Knee	9.3 (27)	8.7 (8)	11.0 (70)	13.3 (17)
Lower leg	2.1 (6)	3.3 (3)	3.9 (25)	0.8 (1)
Ankle	22.3 (65)	15.2 (14)	7.2 (46)	12.5 (16)
Heel	1.0 (3)	3.3 (3)	3.8 (24)	7.0 (9)
Foot/Toes	10.7 (31)	17.4 (16)	4.7 (30)	9.4 (12)

Table 3 Most impacting Injuries by Location

Injuries by body region and area	Acute injuries		Overuse injuries	
	Bases %(No.)	Tops %(No.)	Bases %(No.)	Tops %(No.)
Head or neck (total for body region)	**5.9 (9)**	**10.9 (6)**	**1.7 (4)**	**0.0 (0)**
Skull	2.0 (3)	1.8 (1)	0.0 (0)	0.0 (0)
Face	3.9 (6)	7.3 (4)	0.0 (0)	0.0 (0)
Neck	0.0 (0)	1.8 (1)	1.7 (4)	0.0 (0)
Trunk (total for body region)	**4.6 (7)**	**1.8 (1)**	**34.6 (82)**	**17.3 (9)**
Thoracic spine	0.7 (1)	0.0 (0)	3.0 (7)	3.8 (2)
Lumbosacral	3.9 (6)	1.8 (1)	31.6 (75)	13.5 (7)
Upper limb (total for body region)	**34.9 (53)**	**32.7 (18)**	**34.2 (81)**	**28.8 (15)**
Shoulder	4.6 (7)	0.0 (0)	16.9 (40)	7.7 (4)
Upper arm	1.3 (2)	7.3 (4)	0.4 (1)	0.0 (0)
Elbow	8.6 (13)	12.7 (7)	4.2 (10)	1.9 (1)
Forearm	1.3 (2)	3.6 (2)	1.3 (3)	0.0 (0)
Wrist	5.3 (8)	3.6 (2)	10.1 (24)	11.5 (6)
Hand/Fingers	13.8 (21)	5.5 (3)	1.3 (3)	7.7 (4)
Lower limb (total for body region)	**54.6 (83)**	**54.5 (30)**	**29.5 (70)**	**53.8 (28)**
Groin/Hip	2.6 (4)	0.0 (0)	3.4 (8)	5.8 (3)
Thigh	3.3 (5)	3.6 (2)	0.8 (2)	0.0 (0)
Knee	9.2 (14)	9.1 (5)	12.2 (29)	19.2 (10)
Lower leg	1.3 (2)	0.0 (0)	2.5 (6)	1.9 (1)
Ankle	28.3 (43)	21.8 (12)	4.2 (10)	13.5 (7)
Heel	0.7 (1)	0.0 (0)	3.8 (9)	7.7 (4)
Foot/Toes	9.2 (14)	20.0 (11)	2.5 (6)	5.8 (3)

Regarding overuse injuries, a significant difference by body area was seen between tops and bases ($p<0.05$). Lumbosacral spine was the most affected body area for tops (14.8%), followed by knee (13.3%) and ankle (12.5%). In bases, lumbosacral spine (21.0%) was the most affected body part, followed by wrist (12.2%) and knee (11.0%) (table2). Tops reported the knee (19.2%) as the most impacting body area, while bases reported lumbosacral spine (31.6%) (table3). The most common body part for stress fractures was lumbosacral spine, for both bases and tops.

Injury Type

Regarding acute injuries, we found a similar distribution by injury type for both bases and tops (p>0.05), with fractures (bases:31.1%; tops:54.5%) being the most common, followed by ligament sprain (bases:22.3%; tops:18.2%) (table4). The most common body part for fractures in bases was hand/fingers (32.6%) and in tops was foot/toes (33.3%), while for ligament sprain was the ankle for both tops (100.0%) and bases (78.8%).

Table 4 Most impacting Injury by Type

Injury type, specific	Acute injuries		Overuse injuries	
	Bases %(No.)	Tops %(No.)	Bases %(No.)	Tops %(No.)
Muscle rupture/tear	5.4 (8)	1.8 (1)	5.0 (11)	2.1 (1)
Ligament sprain	22.3 (33)	18.2 (10)	4.5 (10)	12.5 (6)
Contusion/haematoma	2.7 (4)	3.6 (2)	0.5 (1)	0.0 (0)
Concussion	2.0 (3)	1.8 (1)	0.0 (0)	0.0 (0)
Fracture	31.1 (46)	54.5 (30)	0.0 (0)	0.0 (0)
Stress fracture	0.0 (0)	0.0 (0)	11.8 (26)	18.8 (9)
Hiperextension injury	0.7 (1)	5.5 (3)	2.7 (6)	2.1 (1)
Impingement	0.0 (0)	0.0 (0)	1.8 (4)	0.0 (0)
Tendinopathy	0.0 (0)	0.0 (0)	20.5 (45)	29.2 (14)
Ligament rupture	12.8 (19)	3.6 (2)	2.3 (5)	0.0 (0)
Laceration/abrasion/skin lesion	0.7 (1)	0.0 (0)	0.0 (0)	0.0 (0)
Dislocation/subluxation	8.8 (13)	9.1 (5)	1.8 (4)	2.1 (1)
Muscular strain / spasm	3.4 (5)	0.0 (0)	20.0 (44)	6.3 (3)
Tendon rupture	3.4 (5)	0.0 (0)	1.8 (4)	0.0 (0)
Arthritis/synovitis/bursitis	2.0 (3)	0.0 (0)	14.5 (32)	18.8 (9)
Lesion of meniscus cartilage or labrum	3.4 (5)	1.8 (1)	1.4 (3)	0.0 (0)
Nerve injury/spinal cord injury/herniated disks	0.7 (1)	0.0 (0)	6.4 (14)	4.2 (2)
Other bone injury (including osteochondritis dissecans, periostitis)	0.7 (1)	0.0 (0)	5.0 (11)	4.2 (2)

For overuse injuries, differences between tops and bases were not statistically significant (p>0.05). Tendinopathy was the most frequent for both tops (29.2%) and bases (20.5%) (table4), mostly in the shoulder (bases:55.6%; tops:28.6%).

By cross-referencing body areas and injury types we were able to determine the prevalence of specific diagnosis. The most common acute injuries for tops were ankle sprain

(18.2%) and foot/toe fracture (18.2%), while wrist inflammation (10.4%) was the most frequent overuse injury, followed by lumbosacral stress fracture (8.3%) and shoulder tendinopathy (8.3%). Growth enthesopathies were more frequently found in tops, most commonly affecting patellar (8.3%) and Achilles (8.3%) tendons. These injuries were found in gymnasts with a mean age of 11.4 years (SD 6.6). Ankle sprain (17.6%) and hand/fingers fracture (10.1%) were the most frequent acute injuries in bases, while lumbosacral muscle strain/spasm (15.1%) was the most frequent overuse injury, followed by shoulder tendinopathy (11.4%) and lumbosacral stress fracture (9.1%).

Severity

Regarding acute injuries, 53.2% were time-loss injuries with a mean suspension time of 6.8 weeks (SD 9.4). No significant differences in these severity parameters were observed between bases and tops ($p>0.05$), nor between competitive levels ($p>0.05$). The injury responsible for mean higher suspension time was thoracic vertebra fracture (32.0wk). The most common injuries in tops, namely ankle sprain and foot/toes fracture, led to a mean suspension time of 4.2wk and 4.0wk, respectively. While the most common injuries in bases, namely ankle sprain and hand/fingers fracture, led to a mean suspension time of 4.8wk and 3.3wk, respectively.

Regarding overuse injuries, 28.3% were time-loss injuries, with a mean suspension time of 9.1 weeks (SD 13.8). The percentages were similar for both bases (28.9%) and tops (25.5%) ($p>0.05$). However, bases reported a significantly higher suspension time (10.2wk; SD 14.5) than tops (2.0wk; SD 2.3) ($p<0.01$). No significant differences in these severity parameters were found

between competitive levels (p>0.05). The most common injury for tops (wrist inflammation) led to a mean suspension time of 1.5wk. While the most common injury for bases (lumbosacral spine muscle strain/spasm) led to a mean suspension time of 5.4wk.

Treatment

Regarding acute injuries, 60.2% required pharmacological approaches, 11.9% surgery and 68.7% rehabilitation programs. The mean recovery perception was 3.6 (SD 1.1). Concerning overuse injuries, 63.8% required pharmacological approaches, 3.6% surgery and 69.8% rehabilitation programs. The mean recovery perception was 3.3 (SD 1.1).

DISCUSSION

This is the largest and the first international study on ACRO related injuries. Any observer may notice its unique demands in flexibility, conditioning and full body recruitment. Unlike other sports, there are various possible injury mechanisms in ACRO. High-risk elements, dynamic take-offs and landings, body positions requiring various levels of back hyperextension and hyperflexion, use the upper limb for weightbearing, as well as the repetitive nature of this sport contribute to its injury pattern.

An overall injury rate of 1.5/1000h was found. The few previous studies[3 4] report higher incidence rates, ranging from 2.94-9.85/1000h. However, over the last few years, there has been an improvement in training facilities and security measures, which may have contributed to the

lower incidence rate observed. Therefore, despite being a seemingly risky sport, we found a low overall incidence rate.

In accordance with results by Vernetta et al., bases showed a higher overall injury rate. However, contrasting with this study[4], females reported more injuries than males, which may be due to lower physical conditioning for the same kind of elements.

Also, lower starting ages and higher overall incidence rates were correlated. Thus, higher starting ages may be protective against injury development. Despite limited, sports literature reports that early specialization may predispose athletes to injuries' development[9].

Although no significant correlation with RPE was found, higher weekly training volume was correlated with injury occurrence. Managing both variables is known as an important tool in the personalized establishment of the training load, and therefore potentially in the prevention of injuries. A recent study in rhythmic gymnastic[10] showed that gymnastics coaches' perception is the most frequently used tool to assess load, recovery/fatigue and performance. To our knowledge, this is also a reality in ACRO. Thus, further directions may include the accurate management of training-load based on approaches already validated in the scientific literature, such as wearable devices, athlete self-reported measures or session RPE[11]. This would be particularly beneficial for gymnasts being 11 to 15 years old, defined by Purnell et. al as the critical age for ACRO related injuries development[3].

Acute Injuries

As reported in previous artistic gymnastic[12-17] and ACRO studies[3-5], lower limb injuries were the most frequent (for bases and tops), reflecting its high weightbearing. In fact, it was demonstrated that during the take-off of a backward somersault by an artistic gymnast (a common element between these modalities), the vertical forces acting on the foot equal 3.4 to 5.6 times its body weight[18].

Ankle sprain was the most frequent acute injury for bases and tops. Although most studies do not focus on specific diagnoses, this is consistent with previous results on ACRO[3-5] and artistic gymnastics[12-15]. In fact, the main mechanisms described for ankle sprain in artistic gymnastics (take-offs and landings[13]) are common to ACRO. To prevent its occurrence neuromuscular training, correct use of mats and prophylactic taping and bracing are possible strategies[13 19].

Due to the specificity of their position, with high impact landings and falls from high heights, tops reported a high incidence of foot/toes fractures. These can be prevented by using the spotting belt while learning new elements, matts or foam pits, as well as spotting by experienced and well-formed coaches. The high incidence of hand/fingers fractures in bases is possibly related to catching tops during dynamic elements. For its prevention, early learning of the correct and safe catching technique is crucial. Also, sponge-based protective accessories can be used.

Overuse Injuries

In agreement with results from Purnell et. al[3], bases showed a higher overuse incidence rate than tops, probably due to higher external loads exposure when carrying their partners. Overuse injuries proved to have a cumulative nature as their development was associated with higher age and correlated with higher weekly training volume.

Tops reported a high incidence of wrist inflammation. In fact, during balance elements and blocks training there is a substantial overload of this joint. Moreover, bases reported a high incidence of shoulder tendinopathy. In fact, bases are exposed to repetitive shoulder moves (e.g. dynamic throws), as well as overhead upper limb work (e.g. hand-to-hand grips). Thus, we suggest the integration of strengthening and stretching plans in train targeting wrist and shoulder for tops and bases, respectively.[20]

As reported by various gymnastics' literature[4 15 16 21 22], our study found a high incidence of lumbosacral attainment. Programs focused on early detection of imbalance between flexibility and strength could be implemented to identify vulnerable gymnasts. The high incidence of stress fractures affecting lumbosacral spine probably reflects the high incidence of spondylolysis. Spine rotation and hyperextension, seen in contortionist positions (mainly in tops) and other elements (such as walkovers or handsprings), are its main underlying mechanisms.[13 16 23] In 2018, ACRO's "code of points" changed, adding value to the elements that require strength and technique, rather than flexibility. Thus, future changes in this injury pattern are expected, particularly in tops.

A correlation between higher BMI and higher overuse injuries incidence rate was found. These results may be biased from the fact that bases, which have a higher BMI, also have a

higher overuse incidence rate. Although we did not find a relationship with the development of injuries, tops showed a mean BMI in the underweight range, highlighting the need for an approach to prevent Relative Energy Deficiency in Sport (RED-S)[24], including education measures for coaches, gymnasts and their families.

The high percentage of gymnasts reporting the use of pharmacological approaches, as well as the partial mean perceived recoveries show that a great path in sports medicine and a close follow-up of gymnasts is still to be traced.

Study Limitations

There are limitations that can be attributed to our study. The retrospective report of injuries may be responsible for recall bias[25]. To minimize this limitation, we collected exhausting injury data no more than 24 months, and regarding the injuries that had the most impact for gymnasts. Also, the period of time assessed included competitive seasons conditioned by the SARS-CoV2 pandemic, in which gymnasts were restricted from training and competing. Other studies are needed to understand its impact. Moreover, the incidence rate is based on the assumption that gymnasts have trained every week during the previous 24 months, which may have contributed to its underestimation. Additionally, the variables used to evaluate severity may have underestimated the reality, as the diversity of the elements in gymnastics allows gymnasts to continue training while injured[16].

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Contributors All authors participated in the study design and development, analyses and interpretation of data and writing of the manuscript.
Funding Not declared.
Competing interests Not declared.
Data availability statement Data are available on reasonable request. Deidentified injury data that underlie the results reported in this article are available on reasonable request to primary author' s email address with researchers who provide a methodologically sound proposal and can be used to achieve the aims in the approved proposal. Data will be available immediately after publication with no end date.
Patient consent for publication Not required.
Ethics approval This study was approved by the ethics committee of the Centro Hospitalar Universitário de São João.

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FIGURES AND ILLUSTRATIONS

Uploaded as Separate Files

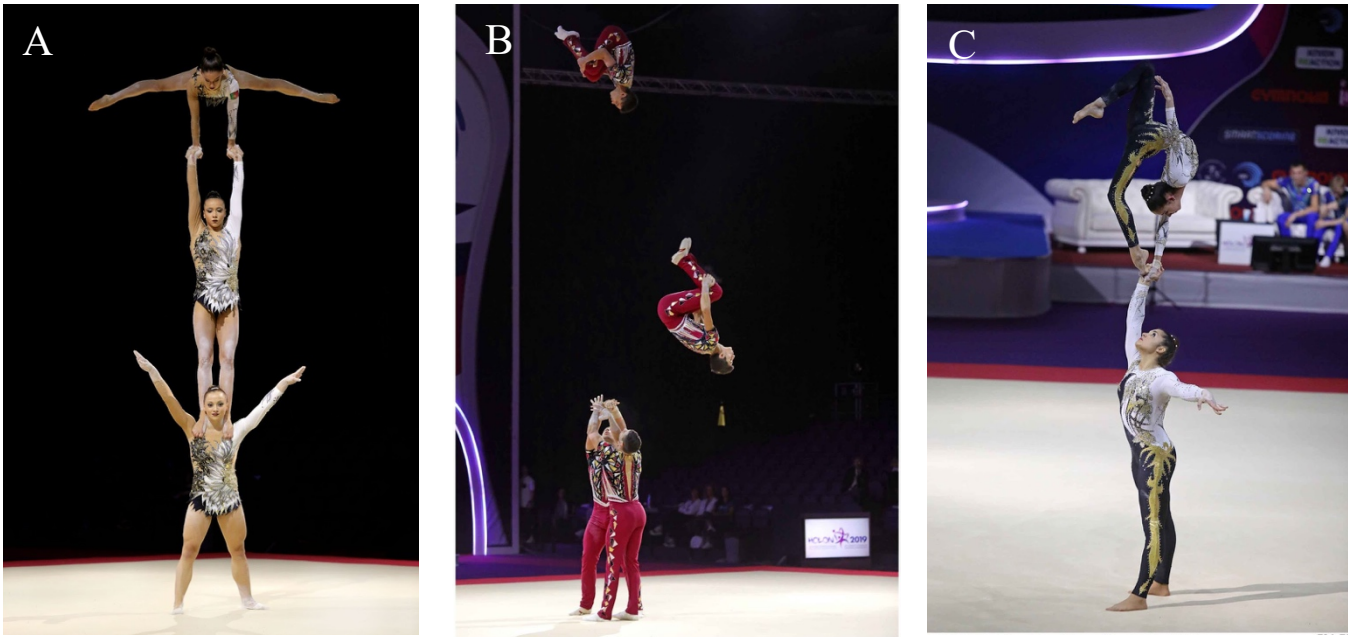

Fig.1 A) A women' s group performing a balance element. **B)** A men' s group performing a dynamic element. **C)** A women' s pair performing a balance element. **Photo credit:** Francisco Piqueiro/ 2019, November

Reporting Guidelines

Strobe Statement - Checklist of items that should be included in reports of cross-sectional studies

1) **Title and Abstract**

a) **Indicate the study' s design with a commonly used term in the title or the abstract:** Page 2 (paragraph 1): "We designed a cross-sectional survey" .

b) **Provide in the abstract an informative and balanced summary of what was done and what was found:** Page 2 (paragraph 1): "We designed a cross-sectional survey to evaluate the incidence, anatomic distribution and type of acute and overuse injuries, and discuss preventive measures" ; "It was found that the majority of acrobats (76.3%) had sustained an injury in the past 24 months, with an overall incidence rate of 1.5 injuries per 1000 hours of exposure, and bases being more injured than tops. For acute injuries, the ankle was the most affected body area, with fractures and ligament sprains being the most common injury types. From these, 53.2% were time-loss injuries, with a mean suspension time of 6.8 weeks. For overuse injuries, lumbosacral spine and tendinopathy were the most frequent body area and injury type, respectively. From these, 28.3% were time loss injuries, with a mean suspension time of 9.1 weeks."

2) **Introduction – Background/Rationale**

Explain the scientific background and rationale for the investigation being reported: Page 4 (paragraph 2): "Although safety measures are widely used, few studies[3-5] have investigated the ACRO injury profile. This knowledge is essential to minimize its occurrence and severity."

3) **Introduction – Objectives**

State specific objectives, including any prespecified hypotheses: Page 4 (paragraph 2): "Hence, the purpose of our study is to find out the distribution and determinants of injury rates in ACRO, taking into account training loads and gymnasts' characteristics."

4) **Methods – Study Design**

Present key elements of study design early in the paper: Page 4 (paragraph 3): "A cross-sectional retrospective study was designed and implemented by using an anonymous online questionnaire. During its development, a pilot has been distributed to 29 gymnasts from a local acrobatics club and adapted according to the obtained answers."

5) **Methods – Setting**

Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection: Page 5 (paragraph 1): "Acrobatic gymnasts were recruited worldwide in 2021 through direct contact or contact with clubs and federations, by email, social media, and word of mouth communication."

6) **Methods – Participants**

Give the eligibility criteria, and the sources and methods of selection of participants: Page 5 (paragraph 1): "All gymnasts who practiced ACRO in the last 24 months were included."

7) **Methods – Variables**

Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable: Page 5 (paragraph 2): "Participants were

asked about their sex, age, height, weight and country. Sport related variables were evaluated: competitive category, competitive level, starting age, training volume (hours/week) and gymnast's session rating of perceived exertion (RPE), using Borg Scale (6-20)[6]. Page 5 (Paragraph 3): "Gymnasts were asked about the absolute number and body region and area of the injuries sustained in the previous twenty-four months. Injuries incidence rates were calculated (number of injuries/number of exposure hours). Focusing on the most impacting injury for each category, gymnasts reported data on specific injury type, time-loss (defined in accordance with IOC consensus statement[7]), use of medications, need for surgery or rehabilitation programs and perception of recovery, by using a scale from 0 (no recovery) to 5 (full recovery). Moreover, we evaluated the prevalence and intensity of current pain during the practice, by using the Numeric Rating Scale (0-10)."

8) **Methods – Data sources/ measurement**

For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group: Page 4 (paragraph 3): All variables were assessed by the "anonymous online questionnaire" ; Page 5 (paragraph 2): "gymnast's session rating of perceived exertion (RPE), using Borg Scale (6-20)" ; Page 5 (Paragraph 3): "Injuries incidence rates were calculated: (number of injuries/number of exposure hours) x 1000." ; "time-loss (defined in accordance with IOC consensus statement)" ; "perception of recovery, by using a scale from 0 (no recovery) to 5 (full recovery)" ; "intensity of current pain during the practice, by using the Numeric Rating Scale (0-10)."

9) **Methods – Bias**

Describe any efforts to address potential sources of bias: Page 5 (paragraph 3): "Gymnasts were asked about the absolute number and body region and area of the injuries sustained in the previous twenty-four months." ; "focusing on the most impacting injury" . Both strategies were used to minimize recall bias.

10) **Methods – Study Size**

Explain how the study size was arrived at: Page 5 (paragraph 1): " It was determined that a sample size of 299 participants was needed, considering a 95% confidence interval."

11) **Methods – Quantitative Variables**

Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why: Due to word limit management, explanation on quantitative variables categorization (table 1) was omitted. Age grouping was based on ACRO' s categories. Training volume categories were based on a previous study regarding artistic gymnastics (O'Kane JW, Levy MR, Pietila KE, et al. Survey of injuries in Seattle area levels 4 to 10 female club gymnasts. Clin J Sport Med 2011;21(6):486-92. doi: 10.1097/JSM.0b013e31822e89a8 [published Online First: 2011/10/01])

12) **Methods – Statistical Methods**

a) **Describe all statistical methods, including those used to control for confounding:** Page 6 (Paragraph 2): "The analyses were performed using the software Statistical Package for the Social Sciences (SPSS) v. 26.0 (SPSS Inc., Chicago, IL) to calculate frequencies and descriptive statistics. Comparison analyses between bases and tops, females and males, and

national team gymnasts and gymnasts from other competitive levels were performed, using the Mann-Whitney-U test for continuous variables and the Chi-Square test for categorical variables. Risk factors associated with injury were investigated by identifying key areas of concern. Significant relationships between these variables were then explored using Pearson' s correlation. Differences were considered statistically significant when $p < 0.05$."

b) **Describe any methods used to examine subgroups and interactions:** Page 6 (paragraph 2): "Comparison analyses between bases and tops, females and males, and national team gymnasts and gymnasts from other competitive levels were performed, using the Mann-Whitney-U test for continuous variables and the Chi-Square test for categorical variables. Risk factors associated with injury were investigated by identifying key areas of concern. Significant relationships between these variables were then explored using Pearson' s correlation."

c) **Explain how missing data were addressed:** Due to word limit management, explanation on missing data management was omitted. We restricted analysis to records with complete data for the analysis model.

d) **If applicable, describe analytical methods taking account of sampling strategy:** Not applied.

e) **Describe any sensitivity analyses:** Not applied.

13) Results – Participants

a) **Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-**

up, and analysed: Page 6 (Paragraph 3): "The questionnaire was filled by 480 gymnasts"; "The 480 gymnasts met the inclusion criteria and were included in the study".

b) **Give reasons for non-participation at each stage:** Not applied.

c) **Consider use of a flow diagram:** Not applied.

14) Results – Descriptive Data

a) **Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders:** Page 6 (Paragraph 3): "The questionnaire was filled by 480 gymnasts from 23 countries, with 91.0% being female and 9.0% being male"; "The mean age was 17.0 years (SD 5.1) (table1). We observed a mean body mass index of 21.9 (SD 2.7) for bases and 17.8 (SD 3.2) for tops ($p<0.01$). Gymnasts reported a mean experience of 9.7 (SD 5.6) years in ACRO, which corresponds to a mean starting age of 7.2 (SD 3.0) (table1)."; Page 7 (Paragraph 1): "The mean training volume was 17.4h/wk (SD 7.2). National team members reported higher training volumes (20.8h/wk; SD 7.0) than other competitive levels ($p<0.01$). The mean RPE was 14.7 (SD 2.03). National team members reported higher RPE than other competitive levels ($p<0.01$), with a mean of 15.2 (SD 1.9). A similar value was observed between tops (14.6; SD 2.3) and bases (14.7; SD 1.9) ($p>0.05$)."

b) **Indicate number of participants with missing data for each variable of interest:** Not applied.

15) Results – Outcome Data

Report numbers of outcome events or summary measures: Numbers and summary measures are reported throughout the results section (Pages 6-14). These is particularly evident in tables 1-4.

16) Results – Main Results

a) **Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included:** Page 8 (Paragraph 2): "One or more injuries were sustained in 76.3% of the gymnasts. The mean incidence rate of all injuries was 1.5/1000h (95%CI: 1.40-1.65), with bases (1.6/1000h; 95%CI: 1.43-1.78) reporting a higher overall injury incidence rate when compared with tops (1.2/1000h; 95%CI 0.92-1.39) ($p<0.01$). Overall incidence rate varied between female (1.6/1000h; 95%CI: 1.40-1.71) and male (1.0/1000h; 95%CI: 0.61-1.28) ($p<0.01$)." ; Page 8 (Paragraph 3): "Regarding acute injuries, 43.1% of the total population reported an acute injury during the studied period, corresponding to a mean acute injury rate of 0.5/1000h (95%CI: 0.44-0.60). A similar acute incidence rate for both bases and tops was observed ($p>0.05$). Acute incidence rate varied significantly between females (0.6/1000h; 95CI: 0.46 to 0.63) and males (0.3/1000h; 95%CI: 0.18-0.42)" ; Page 9 (Paragraph 2): "The percentage of gymnasts reporting an overuse injury during the evaluated time was 60.2%, with a mean overuse injury rate of 1.0/1000h (95%CI: 0.88-1.1). Among those, 30.1% reported 1 injury, 30.8% reported 2 and 39.1 % reported 3 or more overuse injuries. We found that bases (1.1/1000h; 95%CI: 0.95-1.21) had a higher injury rate

compared to tops (0.7/1000h; 95%CI: 0.48-0.85) ($p<0.01$), and that female (1.0/1000h;95% CI 0.90 to 1.13) had higher injury rate than males (0.7/1000h; 95%CI: 0.45 to 0.92) ($p<0.05$)."

No confounder-adjusted estimates were calculated.

b) **Report category boundaries when continuous variables were categorized:** Page 7: Table 1; Page 9 (Paragraph 2): "Gymnasts aged 18 and over showed a mean overuse incidence rate of 1.2/1000h (95%CI: 0.96 to 1.34)."

c) **If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period:** Not applied.

17) **Results – Other Analyses**

Report other analyses done - eg analyses of subgroups and interactions, and sensitivity analyses: Page 9 (Paragraph 1): "In multivariate regression models, we found no statistically significant correlation among age, category, level, age at onset, BMI, weekly training load, PE and the development of acute injuries".

18) **Discussion – Key Results**

Summarise key results with reference to study objectives: Page 14 (Paragraph 4): "An overall injury rate of 1.5/1000h was found"; Page 15 (Paragraph 2): "bases showed a higher overall injury rate"; Page 15 (Paragraph 3): "lower starting ages and higher overall incidence rates were correlated"; Page 15 (Paragraph 4): "higher weekly training volume was correlated with injury occurrence"; Page 16 (Paragraph 2): "Ankle sprain was the most frequent acute injury for bases and tops."; Page 17 (Paragraph 2): "Tops reported a high

incidence of wrist inflammation" ; "bases reported a high incidence of shoulder tendinopathy" .

19) Discussion – Limitations

Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias: Page 18 (Paragraph 2): "There are limitations that can be attributed to our study. The retrospective report of injuries may be responsible for recall bias. To minimize this limitation, we collected exhausting injury data no more than 24 months, and regarding the injuries that had the most impact for gymnasts. Also, the period of time assessed included competitive seasons conditioned by the SARS-CoV2 pandemic, in which gymnasts were restricted from training and competing. Other studies are needed to understand its impact. Moreover, the incidence rate is based on the assumption that gymnasts have trained every week during the previous 24 months, which may have contributed to its underestimation. Additionally, the variables used to evaluate severity may have underestimated the reality, as the diversity of the elements in gymnastics allows gymnasts to continue training while injured" .

20) Discussion – Interpretation

Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence: Page 14 (Paragraph 4): "The few previous studies report higher incidence rates, ranging from 2.94-9.85/1000h" ; Page 15 (Paragraph 2): "In accordance with results by Vernetta et al., bases showed a higher overall injury rate. However, contrasting with this study, females

reported more injuries than males;" ; Page 15 (Paragraph 3): Thus, higher starting ages may be protective against injury development. Despite limited, existent literature report that early specialization may predispose athletes to injuries development" ; Page 16 (Paragraph 2): "This is consistent with previous studies on ACRO[4] and artistic gymnastics" ; Page 17 (Paragraph 3): "As reported by various gymnastics literature, our study found a high incidence of lumbosacral attainment" ; Page 18 (Paragraph 1): "A correlation between higher BMI and higher overuse injuries incidence rate was found. Although BMI is related to higher risk in previous studies, these results may be biased from the fact that bases, which have a higher BMI, also have a higher overuse incidence rate" .

21) Discussion – Generalisability

Discuss the generalisability (external validity) of the study results: Page 18 (Paragraph 3): **"**Also, the period of time assessed included competitive seasons conditioned by the SARS-CoV2 pandemic, in which gymnasts were restricted from training and competing. Other studies are needed to understand its impact."

22)Other information – Funding

Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based: Page 18: "Funding not declared" .

Submission Guidelines – Original Research
British Journal of Sports Medicine

Word count: up to 3000 words

Abstract: up to 250 words and structured including the headings Objectives, Methods, Results and Conclusion

References: up to 50

Tables/illustrations: up to 6 tables and/or figures. Please include a summary box summarising in 3-4 bullet points "what are the new findings" and "how might it impact on clinical practice in the future".

Statements: have you included the necessary statements relating to contributorship, competing interests and funding, data sharing, ethical approval and patient involvement?

Statistics: Please review that your statistical analysis and presentation are consistent with the CHAMP statement found at https://bjsm.bmj.com/content/55/18/1009.long and reference in the methods: *Mansournia MA, Collins GS, Nielsen RO, et al. A CHecklist for statistical Assessment of Medical Papers (the CHAMP statement): explanation and elaboration. Br J Sports Med. 2021;55(18):1009-1017*

Summary Box: Please include the key messages of your article after your abstract using the following headings. This section should be no more than 3-5 sentences and should be distinct from the abstract: be succinct, specific and accurate.

- **What is already known on this topic** – summarise the state of scientific knowledge on this subject before you did your study and why this study needed to be done

- **What this study adds** – summarise what we now know as a result of this study that we did not know before
- **How this study might affect research, practice or policy** – summarise the implications of this study

This will be published as a summary box after the abstract in the final published article.