

Epidemiology of injuries in elite Women's Artistic Gymnastics: a retrospective analysis of six seasons

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ABSTRACT

Background Women's Artistic Gymnastics (WAG) is a sport well known for requiring a heavy and difficult training load from a younger age to reach a high level of performance. This also is associated with an injury risk. Epidemiological studies are thus needed to improve injury prevention strategies.

Objective We aimed to determine the injury epidemiology in French high-level WAG.

Methods We conducted a retrospective analysis of injury data collected prospectively over six seasons from the 2014–2015 season to the 2019–2020 season among French high-level Women's Artistic Gymnasts from the France Gymnastics National Centre of Saint-Etienne. We performed descriptive analyses, including the calculation of the 1-year injury prevalence.

Results 43 gymnasts were included in this study, representing 111 gymnast-seasons. A total of 285 injuries were collected over the study period, that was, an average of 2.6 injuries per gymnast per season. On average, 91.4% of gymnasts had at least one injury per season. The estimated injury incidence rate was 1.8 injuries per 1000 hours of gymnastics practice. The knee was the most affected joint (16%), followed by the elbow (12%) and the ankle (12%). The most frequent injury type was physis pathologies (16%) and bone injuries (15%). Eighty-eight per cent of injuries required a modification of the gymnastics practice.

Conclusions The results of this study allowed a description of the epidemiology of injuries in this population of young and elite gymnasts. This very high injury prevalence supports the need to improve injury risk reduction strategies in WAG.

INTRODUCTION

Women's Artistic Gymnastics (WAG) is an Olympic sport discipline including four apparatus: the vault, the uneven bars, the balance beam and the floor.¹ Vault requires dynamism and acrobatics.¹ Uneven bars are very physical, especially at the level of the upper limbs, because of the suspensions and the supports and require agility.¹ Beam is very technical and requires a lot of elegance.¹ The floor is the apparatus where the artistic component is most expressed. Performance in gymnastics is

WHAT IS ALREADY KNOWN ON THIS TOPIC

- ⇒ Women's Artistic Gymnastics (WAG) is associated with a risk of injury.
- ⇒ The most frequent injury location concerned the lumbar spine (13.5%), the knee (10.9%) and the wrist (9.4%), and the most common injury type was a sprain (19.0%), according to studies.
- ⇒ The high volume of gymnastics practice occurs within the gymnasts' growth period, a period of particular vulnerability of the musculoskeletal system.
- ⇒ Most current knowledge came from studies on the US university system, which differs from the high-level gymnasts approach.

WHAT THIS STUDY ADDS

- ⇒ An average of 91.4±6.5% of French high-level WAG belonging to the France Gymnastics National Centre of Saint-Etienne had at least one injury per season.
- ⇒ On average, each gymnast had 2.6±0.5 injuries per season.
- ⇒ The most frequent injury locations were the knee, the elbow and the ankle, and the most common type of injury corresponded to apophysis/physis pathologies.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

- ⇒ This very high injury prevalence and this potential negative health consequence of high-level sports support improving gymnastic injury risk reduction strategies. These strategies should focus on growth-related apophysis/physis pathologies, bone injuries, knee injuries and ankle sprains. National training centres should allow appropriate medical services and provisions to care for the gymnasts appropriately. Given the high number of injuries a gymnast can have during her career, it is also fundamental to take care of each injury and the gymnast appropriately by thinking about the long-term and potential consequences.

determined by a score corresponding to the addition of the difficulty presented and of the quality of the execution.¹ Thus, WAG requires and develops many physical capabilities, such as explosiveness, strength, flexibility, balance, coordination and proprioception. Still, it also

includes significant constraints on the musculoskeletal system during these activities, especially during impulses and landings.^{1 2}

WAG must be started early, around 3–6 years of age, to be done at a very high level.¹ This high-level activity or goal also involves a very high volume of gymnastics practice.¹ Indeed, from the age of 11, gymnasts sometimes do more than 30 hours of gymnastics per week for 48 weeks per year.^{1 3} In France, this intensive training is found among high-level gymnasts, who train mainly within French Gymnastics National Centres ('Pôles France'), which are structures recognised by the Sports Ministry and labelled by the French Federation of Gymnastics (<https://www.ffgym.fr>). These structures bring together the best French gymnasts with the aim of training for the French national teams.

Although gymnastics brings physical benefits such as increased bone density, reduced risk of osteoporosis, improved postural control and increased muscle strength,² the musculoskeletal constraints are major throughout a high-level career.⁴ They can lead to an increased risk of injury or potential impairments.⁴ Such as any sport, gymnastics is thus associated with a risk of injury.^{1 3 5–7} The prevalence of injuries in WAG seems to be related to the number of hours of training.^{6 8} Caine *et al*⁶ reported in a prospective study over 3 years that 76% of gymnasts had presented at least one injury responsible for a reduction or interruption of practice of at least 1 day. Vanderlei *et al*⁹ reported an annual prevalence of 1.3 injuries per gymnast. Among the National Collegiate Athletic Association, WAG was one of the sports with the highest incidence of severe injuries (1.4 per 1000 Athletic-Exposure).¹⁰ The most frequent injury location concerned the lumbar spine (13.5%), the knee (10.9%) and the wrist (9.4%), and the most common injury type was the ligament (sprain) (19.0%), according to studies.⁵ In addition, the very high volume of gymnastics practice occurs within the gymnasts' growth period, a period of particular vulnerability of the musculoskeletal system. Although these previous publications allow us to have a global overview of injuries in WAG,⁵ it is important to continue epidemiological studies on injuries in WAG because (a) injury epidemiology knowledge is the first step of the injury prevention sequence,¹¹ (b) recent publications on injuries in WAG are rare while the training, apparatus equipment, rules and scoring system have changed^{1 5} and (c) publications mainly concerned the US university system,⁵ which differ from high-level gymnasts, such as French high-level gymnasts (eg, lower ages matching with growth period, different apparatus and scoring system). Therefore, enhancing the understanding of injury epidemiology in high-level WAG is important for reducing the risk of injuries.^{5 11}

In this context, we aimed to determine the injury epidemiology in French high-level WAG.

METHODS

Study design and overall procedure

We conducted a retrospective analysis of injury data collected prospectively over six seasons from the 2014–2015 season to the 2019–2020 season among French high-level WAG from the French Gymnastics National Centre of Saint-Etienne ('Pôle France Gym de Saint-Etienne'; <https://www.gymnastique-féminine.fr>). This study was reported following the reporting guidelines from Strengthening the Reporting of Observational Studies in Epidemiology Sports Injury and Illness Surveillance.¹²

Population

The population was recruited from the WAG belonging to the France Gymnastics National Centre of Saint-Etienne during the selected period. We included in the study female gymnasts who started at least one season within the France Gymnastics National Centre of Saint-Etienne between the 2014–2015 and 2019–2020 seasons.

Patient and public involvement

There was no patient or public involvement. Gymnasts and the public were not involved in the study design and the conduction of the present study or the choice of outcome measures. However, these results should be considered patient/public involvement for further research or injury risk reduction development. A summary of the study results will be disseminated to the public.

Injury definition and data collection

This study defined an injury as any physical complaint concerning the musculoskeletal system that led to medical attention.¹² The exposure was the number of French high-level WAG female gymnasts who started at least one season within the France Gymnastics National Centre of Saint-Etienne per season between the 2014–2015 and 2019–2020 seasons. We also estimated the number of hours of gymnastic practice per season based on the estimated average number of hours of practice per week and the estimated number of weeks of gymnastic practice per season.

Data were collected prospectively by the same sports medicine physician. The physician collected, two times a year during the two annual regulatory medical surveillance consultations, anthropometric data: sex, age, height, body mass, average weekly training hours and estimated number of weeks of gymnastic practice per season. The physician collected the injury data prospectively throughout the six seasons during medical consultations concerning a somatic or another complaint. For each injury, the location, the type, the mode of onset and the consequence (modification/adaptation of sport, total stop of sport, imaging, surgery) were collected. No standardised data collection methods were used when the sports medicine physician collected the information during the medical consultations. Information from the

Table 1 Number, prevalence and incidence of injuries in Womens' Artistics gymnastics

Seasons	Gymnasts (n)	Injuries (n)	Average number of injuries per gymnast per season	Proportion of gymnasts who had at least one injury	Estimated number of hours of gymnastics practice	Estimated injury incidence rate per 1000 hours of gymnastics practice
2014/2015	16	51	3.2	100.0	24 650	2.1
2015/2016	21	43	2.0	81.0	29 745	1.4
2016/2017	17	49	2.9	88.2	21 600	2.3
2017/2018	19	55	2.9	94.7	27 265	2.0
2018/2019	20	42	2.1	90.0	28 226	1.5
2019/2020	18	45	2.5	94.4	26 034	1.7
Total	111	285			157 520	1.8
Mean (SD)	18.5±1.9	47.5±5.0	2.6±0.5	91.4±6.5	26 253±2877	1.8±0.3

paper and digital medical records (consultation letters and imaging results) was collected in an Excel spreadsheet. The injuries were then classified according to their location (head/face, shoulder, arm/forearm, elbow, wrist, hand, lumbar spine, other spine, pelvis/hip, ischium, thigh, knee, lower leg, ankle, heel, foot and other) and according to their type (joint, apophysis/physis, ligament, bone, muscle, tendon and other) using the classification from the International Olympic Committee.¹²

Statistical analyses

We performed a descriptive analysis using frequency and percentages for categorical data, means and SD for continuous variables. We also calculated an estimation of the injury incidence rate per 1000 hours of gymnastics practice. Analyses were performed using Excel (Office, Microsoft, 2021).

RESULTS

Population

A total of 43 French high-level WAG belonging to the France Gymnastics National Centre of Saint-Etienne over the six seasons from the 2014–2015 to the 2019–2020 seasons were included in this study. None of the gymnasts or their parents refused to allow their data to be used for this study. There was an average of 18.5±1.9 gymnasts per season, ranging from 16 to 21 (table 1). This represented 111 gymnast-seasons; some gymnasts participated in several consecutive seasons. The gymnasts were followed over 2.6±1.7 seasons on average: 18 gymnasts were followed for one season, 7 gymnasts were followed for two seasons, 5 gymnasts were followed for three seasons, 4 gymnasts were followed for four seasons, 5 gymnasts were followed for five seasons and 2 gymnasts were followed for six seasons. These two gymnasts' data have been collected from the 2014–2015 season to the 2019–2020 season, so during the entire duration of the study. Some gymnasts joined the structure before the 2014–2015 season, and others continued their careers after the 2019–2020 season.

At the inclusion, the average age of the gymnasts was 12.2±1.8 years; the average height was 143.7±9.0 cm and the average body mass was 35.3±7.5 kg. In the last studied season for each gymnast, the average age was 14.0±2.5 years, the average height was 149.9±9.5 cm and the average body mass was 42.1±9.4 kg. During the study period, the average reported number of weekly training hours was 30.2±2.8 hours per week.

Injuries

Over the six seasons, 285 injuries were collected. An average of 47.5±5.0 injuries per season (table 1). The average number of injuries per gymnast per season was 2.6±0.5, with a maximum of 3.2 in 2014–2015 and a minimum of 2.0 in 2015–2016 (table 1). On average, 91.4±6.5% of gymnasts had at least one injury per season (table 1). The estimated injury incidence rate was 1.8 injuries per 1000 hours of gymnastics practice (table 1).

The most frequent locations of injuries were the knee (16.1%), followed by the elbow (11.6%) and the ankle (11.6%) (table 2 and figure 1). The most frequent types of injuries were growth-related apophysis/physis pathologies (15.8%) and bone injuries (14.7%); the injury type was missing 35.1% of injuries (table 2 and figure 1). More than half of the injuries (56.5%) were of gradual onset, and 37.9% were of sudden onset; mode of onset was missing for 5.6%. Modification or adaptation of the practice was required following 88% of the injuries, while a total stop of gymnastics was required in 8.4% of injuries. Sixty-two per cent of injuries required imaging (radiography, ultrasound, scanner, MRI, scintigraphy). Surgical treatment was required for 11 (3.9%) injuries. The mean age at surgery was 14.8±1.3 years. The knee was the location the most frequently treated surgically (n=4; 36.4%); three of the four knee surgeries were anterior cruciate ligament reconstructions. The elbow was the second most surgical location (n=3 surgeries; 27.3%): two of the surgeries concerned osteochondritis of the capitulum with dislocation of an osteochondral fragment.

Table 2 Summary of injury locations and types (n (%))

	Joint	Apophysis/physis	Ligament	Muscle	Bone	Tendinopathy	Other	Not documented	Total
Face	1 (0.4%)								1 (0.4%)
Shoulder			1 (0.4%)			4 (1.4%)		9 (3.2%)	14 (4.9%)
Forearm/arm				3 (1.1%)			2 (0.7%)	1 (0.4%)	6 (2.1%)
Elbow	2 (0.7%)	12 (4.2%)		1 (0.4%)	3 (1.1%)	2 (0.7%)		13 (4.6%)	33 (11.6%)
Wrist			1 (0.4%)		2 (0.7%)	1 (0.4%)		11 (3.9%)	15 (5.3%)
Hand			3 (1.1%)		3 (1.1%)	1 (0.4%)			7 (2.5%)
Cervical/thoracic rachis				1 (0.4%)			1 (0.4%)	5 (1.8%)	7 (2.5%)
Lumbar rachis	3 (1.1%)			4 (1.4%)	9 (3.2%)		4 (1.4%)	8 (2.8%)	28 (9.8%)
Pelvis/hip	1 (0.4%)	4 (1.4%)		1 (0.4%)				7 (2.5%)	13 (4.6%)
Ischium		5 (1.8%)				1 (0.4%)		2 (0.7%)	8 (2.8%)
Thigh				3 (1.1%)		1 (0.4%)	1 (0.4%)	10 (3.5%)	15 (5.3%)
Knee	4 (1.4%)	14 (4.9%)	4 (1.4%)		3 (1.1%)	6 (2.1%)	2 (0.7%)	13 (4.6%)	46 (16.1%)
Leg				1 (0.4%)	8 (2.8%)	1 (0.4%)	1 (0.4%)	8 (2.8%)	19 (6.7%)
Ankle			18 (6.3%)		5 (1.8%)	2 (0.7%)	1 (0.4%)	6 (2.1%)	32 (11.6%)
Heel	1 (0.4%)	10 (3.5%)			2 (0.7%)	4 (1.4%)	1 (0.4%)	2 (0.7%)	20 (7.0%)
Foot	1 (0.4%)				7 (2.5%)	5 (1.8%)		5 (1.8%)	18 (6.3%)
Other							1 (0.4%)	2 (0.7%)	3 (1.1%)
Total	13 (4.6%)	45 (15.8%)	27 (9.5%)	14 (4.9%)	42 (14.7%)	28 (9.8%)	14 (4.9%)	100 (35.1%)	285 (100%)

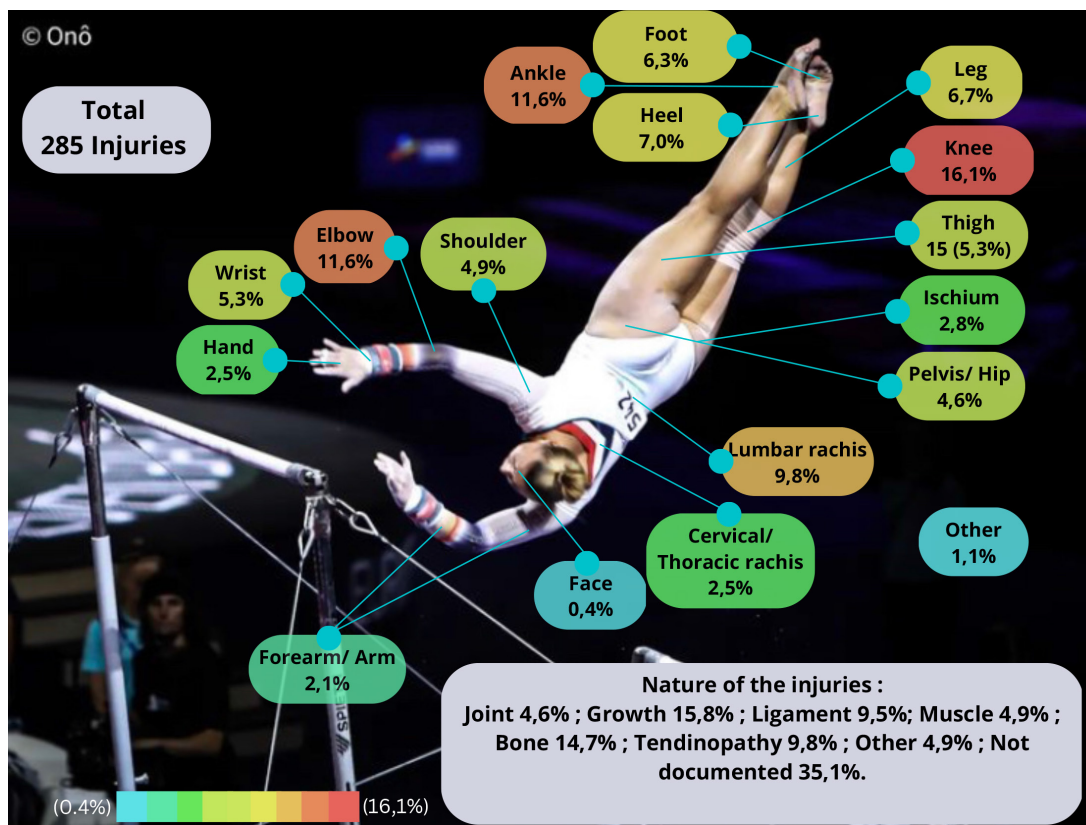


Figure 1 Characteristics of injuries (location and type) occurred by the Women's Artistic Gymnastics during the six seasons of follow-up.

DISCUSSION

The main results of our study were that (a) an average of $91.4\pm 6.5\%$ of French high-level WAG belonging to the France Gymnastics National Centre of Saint-Etienne had at least one injury per season, (b) on average, each gymnast had 2.6 ± 0.5 injuries per season and (c) the most frequent injury locations were the knee, the elbow and the ankle, and the most common type of injury corresponded to growth-related apophysis/physis pathologies.

The epidemiological data of injuries in WAG reported in our study agree with data from previously published studies on this topic.⁵ Caine *et al.*⁶ reported 2.5 injuries per gymnast in 1989. In 1995, Kolt and Kirkby¹³ reported 2.4 injuries per elite gymnast. However, in a systematic review, Campbell *et al.*⁵ in a systematic review, reported that these values varied from 0.3 to 3.6 injuries per gymnast per season. The injury prevalence (ie, the proportion of injured gymnasts over a defined period¹⁴) could also differ between studies according to the injury definition and the data collection methods. In our study, an injury corresponded to any physical complaint leading to medical attention. Injury prevalence could have been very different if we had kept a more practical look at injury consequences and defined injury as any complaint responsible for missing a part of a training or a competition.¹²

Our results confirmed that the lower limb was the most injured part of the body. The knee (16.1%) and the ankle (11.6%) were the most affected joints by WAG, in agreement with previously published studies: 10.9% and 12.0%, respectively, according to Caine *et al.*⁶ and 14.6% and 31.8%, respectively, according to Kolt and Kirkby.¹³ Four per cent of injuries required surgical treatment in our sample of gymnasts, in agreement with the 6.7% reported by Kerr *et al.*¹⁵ and 4.7% by Caine *et al.*⁶

Our study's population differed from those mainly studied in previously published articles on WAG, representing a major strength of the present study. Indeed, most previous studies mainly focused on university gymnastics⁵ and, therefore, gymnasts over 18, in contrast with our average age of 12.2 years at the inclusion in the study. Although the results are close to the previously reported results,⁵ the two populations are quite different. We studied a younger population of gymnasts. Consequently, our study's greater prevalence of growth-related apophysis/physis pathologies is consistent. Growth-related apophysis/physis pathologies were not mentioned in most epidemiological studies concerning a population of university gymnasts, whereas in our study, it was the most frequent injury type. This has already been reported in competitive trampolines gymnasts, with growth-related apophysis/physis pathologies associated with the adolescent growth spurt and with higher weekly training loads.¹⁶ This is of great importance given the potential consequences in the short, middle and long terms of these specific injuries on the musculoskeletal systems (physical aspect) and psychological and societal aspects. This deserves future studies to continue to

improve WAG health protection. As practical approaches, following suggestions from trampolines gymnasts, education of coaches to identify periods of rapid growth and monitor training load could help.^{16 17} Our population and the university categories' training and competition habits differed. In particular competitions in the university categories, there is a competition every weekend between January and April with fewer weekly training hours. Another difference was the mode of injury onset: in our study, 37.9% of injuries were considered acute, whereas 59.4% were acute, according to Caine *et al.*⁶ This could be probably due to the difference in training and competition characteristics. In addition, Caine *et al.*⁶ reported a greater proportion of injuries occurring during competition.

As strengths, we can also report that this work constitutes one of the first studies evaluating the epidemiological of injuries in WAG concerning top-level gymnasts in Europe. The scientific literature has reported little information on this topic and population.⁵ This study focused on six gymnastics seasons, which is a relatively long period. Gymnasts aged from 10 to 19 were recruited, which allows us to look at the growing period corresponding to specific injury risks and morphological changes.

Regarding limitations, we must acknowledge that exposure to the gymnastic activity (training and competition) was not prospectively collected, the reported values of exposure and injury incidence rate are estimation based on the estimated average number of hours of practice per week and the estimated number of weeks of gymnastic practice per season. Time-loss from sports due to injuries was not evaluated. However, in this sport, the total arrest from sport is very rare. There are often training adaptations (eg, eviction of certain motion or apparatus, reduction of training intensity or volume).¹ The event (eg, vault, beam) during which the injury occurred and the injury mechanism and circumstance (training or competition) have not been collected. The injury data collection was not performed initially with a research objective; the sports medicine physician did not use a standardised method to collect injury data. The injury type was missing for about a third of injuries. This could be explained by the fact that the prospective data collection was not performed with a research aim. For future studies, physicians should do their best to determine a precise injury diagnosis (including at least location and type) for each injury event. This justifies the need to continue the injury data collection in high-level WAG by improving the methods, for example, by following the consensus statement from the IOC for epidemiological data collection in sports¹² and thus (a) using a standardised report form to prospectively collect injury data with injury circumstance, mode of onset, mechanism, location, type, apparatus, time-loss/adaptation, (b) performing the needed imaging to make the full diagnosis, (c) following the gymnasts until recovery to have the exact duration of injury consequences and (d) collecting training and competition exposure to gymnastics. Finally, the COVID-19 pandemic impacted the analyses of this study in terms of injuries. The successive



confinements and the general health context have led to prolonged interruptions in training and the mass cancellation of competitions over the 2019–2020 sports season.^{18 19}

Practical implications can be suggested based on the present results. Given the high prevalence of injuries in this population (about 90% of gymnasts had at least one injury per season) and their consequence on the training and competition (88% lead to modification or adaptation of the training), there is a need to improve the injury prevention strategies. This can be scientifically done by following the injury prevention sequence¹¹ and thus promoting scientific projects on the most ‘relevant’ injuries (eg, growth-related apophysis/physis pathologies, bone injuries, knee injuries, ankle sprains) and developing injury prevention measures based on all available knowledge from previous and new scientific studies and experience of gymnastics athletes, coaches, athletes and health professionals. Focusing on growth-related pathologies and the specificity of the youth athlete in maturation seems relevant, probably by taking an example of other sports and approaches.^{20 21} It seems important that these injury prevention measures are co-constructed by all the stakeholders to improve their adherence and be multifactorial (physical, psychological and societal) to match the complex and multifactorial nature of injuries.²² Then, given the high number of injuries per year, there is a need to have appropriate medical services and provisions to take care of the gymnasts appropriately. Given the high number of injuries a gymnast can have during her career, it is also fundamental to take care of each injury and the gymnast appropriately by thinking about the long-term and potential consequences.²³ The gymnast and their entourage indeed have a project towards performance in gymnastics, but there is a need not to forget the entire life, including post-high-level life. And finally, injuries can have consequences on mental health, which should be explored and managed in high-level gymnasts.^{24 25}

CONCLUSIONS

We reported that almost all French high-level WAG had at least one injury per season, with about 2.6±0.5 injuries per season per gymnast, and certain injury patterns were more frequent. Given this very high injury prevalence and that gymnastics, and high-level sports in general, can cause physical, psychological and social sequels,²³ there is a need to improve injury risk reduction strategies in gymnastics.

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Contributors SC and PE conceived the study. PE performed the data collection. SC performed the data extraction. SC and PE performed data analyses. SC and PE drafted the manuscript. All coauthors contributed substantially to interpreting the results, provided important revisions and approved the manuscript. All authors

understand that they are accountable for all aspects of the work and ensure the accuracy or integrity of this manuscript. PE acts as guarantor of the study.

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Competing interests PE is an associate editor for the *British Journal of Sports Medicine* and for the *BMJ Open Sports and Exercise Medicine*.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval This study involves human participants and the present study was reviewed and approved by the Saint-Etienne University Hospital Ethics Committee (IRB32N232016/CHUSTE). All gymnasts, as well as their parents for those under 18 years old, were informed about the study aim and procedure, that their data were used for research, and about their rights to refuse that their data be used for research. The ethical committee required no signed informed consent.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available upon reasonable request. Data are available upon reasonable request. Requests for data sharing from appropriate researchers and entities will be considered on a case-by-case basis. Interested parties should contact one of the author Pascal Edouard (pascal.edouard@univ-st-etienne.fr).

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