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Gymnastics Injuries

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Abstract

Objective: The purpose of this chapter is to review the distribution and determinants of injury rates as reported in the pediatric gymnastics injury literature, and to suggest measures for the prevention of injury and directions for further research. **Data sources:** An extensive search of Pubmed was conducted using the Text and MeSH words ‘gymnastics’ and ‘injury’ and limited to the pediatric population (0–18 years). The review focused on studies using denominator-based designs and on those published in the English language. Additional references were obtained from hand searches of the reference lists. Unpublished injury data from the USA Gymnastics National Women’s Artistic Gymnastics Championships during 2002–04 were also analyzed. **Main results:** Comparison of study results was compromised due to the diversity of study populations, variability of injury definition across studies, and changes in rules and equipment across years. Notwithstanding, this review of the literature reveals a reasonably consistent picture of pediatric gymnastics injuries. The incidence and severity of injuries is relatively high, particularly among advanced level female gymnasts. Body parts particularly affected by injury vary by gender and include the ankle, knee, wrist, elbow, lower back, and shoulder. Ankle sprains are a particular concern. Overuse and nonspecific pain conditions, particularly the wrist and low back, occur frequently among advanced-level female gymnasts. Factors associated with an increased injury risk among female gymnasts include greater body size and body fat, periods of rapid growth, and increased life stress. **Conclusions:** Above all, this overview of the gymnastics injury literature underscores the need to establish large-scale injury surveillance systems designed to provide current and reliable data on injury trends in both boys and girls gymnastics, and to be used as a basis for analyzing injury risk factors and identifying dependable injury preventive measures.

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Introduction

Gymnastics has enjoyed resurgence in participation and a rise in spectator popularity in recent decades largely due to an increased emphasis on girls’

sports, the inherent athleticism of gymnastics, and some important personalities who captured the public attention via astonishing performances in competition [1]. Associated with this increased participation is an earlier age of entry and specialization in the sport. Elite female and male gymnasts may initiate training for their sport as early as ages 6 and 9 years, respectively, with peak performance being 10 or more years away. During this period, the degree of difficulty of maneuvers practiced and performed, and the volume and intensity of training increases dramatically.

The increased participation in gymnastics is encouraging because physical activity clearly provides many health-related benefits to those who participate. However, the increased involvement and difficulty of skills practiced at an early age and continued through the years of growth, with the volume or intensity of training required to be competitive, gives rise to concern about the risk and severity and long-term effects of injury to the young gymnast. Indeed, most gymnasts do not pass through their years of training and competition without incurring injury [2].

The purpose of this chapter is to review integratively and comprehensively the distribution and determinants of injury rates as reported in the pediatric gymnastics injury literature, and to suggest measures for the prevention of injury and directions for further research. Data collection focused on the English literature; however, foreign publications that have been translated were also included. Data collection was limited primarily to published articles and reports and was conducted using Pubmed (keywords = gymnastics and injury). Relevant articles cited in the literature retrieved were also located (i.e., ancestry approach). In addition, unpublished data collected at the USA Gymnastics National Women's Artistic Gymnastics Championships during 2002–04 were also included to provide a more complete picture, given the relative paucity of published literature on injuries affecting national-level competitors.

Our search was limited to denominator-based designs including cross-sectional, retrospective, and prospective studies. The gymnastics injury literature is replete with epidemiological data, yet too few studies have focused on the pediatric population of gymnasts, especially male gymnasts. Additionally, most of the studies are descriptive in nature and few have sought to analyze risk factors or injury prevention measures [2]. Furthermore, the following methodological shortcomings among the cohort studies restricted the potential to interpret and compare their findings through a common statistical treatment:

- diversity of study populations;
- instability of study results due to relatively short periods of data collection in some studies;
- insufficient sample size to warrant risk factor analysis in some studies;
- low response rates, short- and long-term recall bias, and response motivation bias associated with the frequent use of questionnaires;

- nonrandom selection or convenience samples (i.e., the possibility that some schools or clubs most concerned with safety may be the ones to consent to involvement in an epidemiological study of injuries); and
- variability in injury definition across studies.

In addition to these methodological shortcomings, comparison of results across studies and years may be further complicated by changes in rules and equipment. Every 4 years, for example, rules are changed that affect the way judges score gymnasts, the way coaches train gymnasts, and the way gymnasts prepare their minds and bodies. Additionally, women's artistic gymnastics frequently changes its equipment to increase the difficulty of skills that a gymnast can perform and to decrease the forces on the body. The use of resi-mats, square foam pits and shredded loose foam pits, for example, have helped to decrease the physical stress on the gymnasts landing their skills. Changes in equipment and rules may lead to different injury patterns and risk of injury.

Incidence of Injury

Participation Level

A comparison of injury rates reported in prospective and retrospective injury studies is shown in table 1. Study samples include both female and male recreational [3–5], club [3–18], and high school gymnasts [6, 19]. Overall, there were seventeen studies reporting on injuries affecting female gymnasts and six studies on male gymnasts. Review of table 1 indicates that most injury rates were calculated with reference to participant-seasons and therefore do not account for individual differences in exposure to injury risk. A meaningful comparison across these studies, both within and between genders, is, therefore, difficult.

As shown in table 1, exposure-based injury rates (i.e., number of injuries/1,000 h) for club-level female gymnasts reported in studies using the same definition of injury (i.e., any damaged body part that would interfere with training) range from 1.4 to 3.7 injuries per 1,000 h [9–13, 15, 17]. Only one study reported an injury rate relative to the number of athletic-exposures. Caine et al. [13] reported a rate of 8.5 injuries per 1,000 athletic-exposures, which notably is quite similar to that reported for female collegiate gymnasts in the USA [20].

Injury Characteristics

Injury Onset

A percentage comparison of injury onset in girls gymnastics is shown in table 2 [3, 4, 7, 9–14, 16, 17, 21, 22]. A review of these data indicate that the

Table 1. A comparison of injury rates in girls' and boys' gymnastics (adapted from Caine [2] and Caine et al. [27])

Study	Design pros/retro (P/R)	Data collection interv/question (I/Q)	Duration of injury survival	Number of injuries	Sample Number of participants (1 participant = 1 gymnast participating in one season)	Sample Number of teams	Rate Number of injuries per 100 participant seasons	Rate Number of injuries per 1,000 h of exposure	Rate Number of injuries per 1,000 athletic exposures*
Females									
<i>Recreational</i>									
Pettrone and Ricciardelli [3]	P	Q	7 months	33	2,016	15	1.6		
Goodway et al. [4]	P	Q	1 year	7	5,929		0.1		
Lowry and Leveau [5]	R	Q	11 months	128	3,042	14	4.2		
<i>Club</i>									
Garrick and Requa [6]	P	Q	1 season	16	72	3	22.2		
Weiker [7]	P	Q	9 months	95	766 ^a	6	12.4		
Vergouwen [8]	P	I	3 seasons	353	42		840.5		
Pettrone and Ricciardelli [3]	P	Q	7 months	29	542	15	5.3		
Caine et al. [9]	P	I	1 year	147	50	2	294	3.7	
Goodway et al. [4]	P	Q	1 year	93	725		12.8		
Lindner and Caine [10]	P	QI	3 seasons	90	362	5	24.9	0.5	
Bak et al. [11]	P	Q	1 year	41	46		89	1.4	

Table 1 (continued)

Study	Design pros/retro (P/R)	Data collection interv/question (I/Q)	Duration of injury survival	Number of injuries	Sample Number of participants (1 participant = 1 gymnast participating in one season)	Sample Number of teams	Rate Number of injuries per 100 participant seasons	Rate Number of injuries per 1,000 h of exposure	Rate Number of injuries per 1,000 athletic exposures*
Kolt and Kirby [12]	PR	Q	18 months	349	64	17	364	3.3	
Caine et al. [13]	P	I	3 years	192	79 ^b	1		2.5	8.5
Lowry and Leveau [5]	R	Q	11 months	260	370	14	70.3		
Steele and White [14]	R	Q	2 seasons	146	268	9	54.5		
Backx et al. [15]	R	Q	7 months		220			3.6 ^c	
Dixon and Fricker [16]	R	I	10 years	325	162	1	200		
Kolt and Kirby [17]	R	Q	1 year	321	162	18	198	2	
<i>High School</i>									
Garrick and Requa [6]									
1973–75	P	IQ	2 seasons	39	98		39.8		
1973–74	P	I	1st			3	56.0 ^d		
1974–75	P	Q	2nd			2	28		
Garrick and Requa [6]	P	Q	1 season	73	221	12	33		

McLain and Reynolds [19]	P	I	1 season	11	24	1	45.8
Males							
<i>Recreational</i>							
Lowry and LeVeau [5]	R	Q	11 months	1	377	14	0.3
<i>Club</i>							
Weiker [7]	P	Q	9 months	10	107 ^e	6	9.3
Kerr [18]	P	Q	8 months	61	24	2	254 ^f
Lowry and LeVeau [5]	R	Q	11 months	16	21		76.2
Dixon and Fricker [16]	R	I	10 years	247	121	1	204
<i>High School</i>							
Garrick and Requa [6]	P	I	2 seasons	5	18	1	13.9
McLain and Reynolds [19]	P	I	1 season	8	20	1	40

*An athletic exposure (A-E) is one athlete participating in one practice or game in which the athlete is exposed to the possibility of athletic injury.

^aIncluding 477 recreational gymnasts.

^bTotal number of participants during 3 years (mean duration = 17.5 months).

^cRates include data from 25 male gymnasts.

^dThis rate was inflated due to high incidence of trampoline injuries; trampoline was eliminated as a scholastic event after this year.

^eIncludes 70 recreational gymnasts.

^fIncludes data from 8 female gymnasts.

Table 2. A percent comparison of injury onset in girls' gymnastics (adapted from Caine [2] and Caine et al. [27])

Study	Study design P/R	Number of injuries	Number of participant seasons*	Injury onset	
				Sudden	Gradual
<i>Club</i>					
Weiker [7]	P	95	766	42.9	57.1
Pettrone and Ricciardelli [3]**	P	29	2,558	17.7	82.3
Goodway et al. [4]	P	93	725	48	52
Caine et al. [9]	P	147	50	55.8	44.2
Lindner and Caine [10]	P	90	362	21.9	78.1
Bak et al. [11]	P	98	115	39	61
Kolt and Kirkby [12]	P	349		35.8	64.2
Caine et al. [13]	P	192	159	40.6	59.4
Steele and White [14]	R	146	268	33	67
Dixon and Fricker [16]	R	325	162	36.9	63.1
Jones [21]	R			38	62
Mackie and Taunton [22]	R	279		44	56
Kolt and Kirkby [17]	R	321	162	41.7	58.3

*A participant season is one gymnast participating in one season.

**Includes data on recreational gymnasts.

majority of injuries were of sudden onset in nature (range = 52.0–83.4%). The pattern of injury onset injuries may vary according to the competitive level. For example, studies of Australian gymnasts [12, 17] report that elite gymnasts are characterized by a significantly greater proportion of chronic injuries than subelite gymnasts. In the Eugene study [13], where 82/147 (55.8%) injuries were gradual onset, gymnasts were highly competitive and trained 20–27 h weekly.

The pattern of injury onset may also vary by injury location. For example, in one study [13] the majority of wrist and low back injuries were gradual onset while most ankle injuries were sudden onset injuries.

Injury Location

Identification of commonly injured anatomical sites is important because it alerts sports medicine personnel associated with gymnastics teams to areas in need of special attention. A percentage comparison of injury location reported girls club and high school gymnastics studies is shown in table 3 [6, 9–14, 23, 24]. A review of the prospective data in this table indicates that the lower extremity was the most frequently injured body region for club-level gymnasts

Table 3. A percent comparison of injury location in girls' club and high school gymnastics (adapted from Caine [2] and Caine et al. [27])

Number of injuries	Club: Prospective studies							Club: Retrospective studies					High School studies	
	Garrick	Weiker	Caine	Lindner	Bak	Kolt	Caine	Steele	Kerr	Dixon	Kolt	Homer	Garrick	Garrick
	[6] 16	[7] 95	[9] 147	[10] 90	[11] 46	[12] 64	[13] 192	[14] 146	[23] –	[16] 325	[17] 321	[24] 49	[6] (mixed)	[6] (interscholastic)
<i>Head</i>	6	3.2	0.7	4.1	2.4	1.1	1.6	1.4		1.5	0.6	2	3	7.7
Skull		2.1		1								2		
Face		1.1		2.1										
Teeth		0		1										
<i>Spine/Trunk</i>	0	7.5	15	16.7	9.8	17.2	19.2	13.7		22.3	17.8	24.4	13	43.6
Neck	0	1.1	0.7	6.3			4.2	2.7		3.9		4.1		
Upper back	0	0	0.7	3.1			1	0		2.4				
Lower back	0	6.4	12.2	5.2			13.5	11	13	13.3		20.3		
Ribs	0	0	0.7	2.1			0.5	0		2.1				
Stomach	0	0	0.7	0					0				0.6	
<i>Upper extremity</i>	25	18.1	20.5	22.9	17.1	20.9	21.4	14.4		21.7	22.7	18.3	36	12.8
Shoulder		1.1	0.7	4.2			4.2	0		1.2				
Arm		0	0.7	1			0.5	0.7		0				
Elbow		5.3	4.8	7.3			3.7	4.8		8.5		4.1		
Forearm		1.1	0.7	0			1	0		0.6		2		
Wrist		6.4	9.5	5.2			9.4	7.5		6		10.2		
Hand/Fingers		4.2	4.1	5.2			2.6	1.4		5.4		2		
<i>Lower extremity</i>	69	70.2	63.7	54.1	61	59	57.8	69.1		55.3	57.3	54.9	48	35.9
Pelvis, hips		2.1	2.7	1			2.1	1.3		4.5		6.1		
Thigh		1.1	8.7	1			4.2	1.3		3		2		
Knee	19	24.5	14.3	19.8			10.9	18.5	15	10.9		12.2	7	5.1
Leg		8.5	6.8	0			5.2	7.5		1.5				
Ankle	25	19.1	21.1	20.8			12	22	29	16		16.3	10	10.3
Heel/Achilles		4.2	5.4	4.2			10.9	0		6.9		18.3		
Foot/Toes		10.6	4.7	7.3			12.5	18.5	12	11.5				

(range = 54.1–70.2%) followed by the upper extremity (range = 17.1–25%), and spine/trunk (range = 0–43.6%). The retrospective data suggest a similar injury distribution except that injuries appear somewhat evenly distributed among the spine/trunk (range = 13.7–24.4%) and upper extremity (range = 14.4–22.7%) regions. The most frequently injured body part in the spine/trunk was the lower back in both prospective and retrospective studies. Common injury locations in the upper extremity were the wrist, elbow and hand/fingers. The ankle was typically the most often injured body part in the lower extremity followed by the knee.

Three prospective [7, 18, 25] and one retrospective [16] study report injury location data on young male gymnasts. In these studies the upper and lower extremities were injured most often, followed by the spine/trunk and head. However, only two of these studies provide complete data [16, 25]. The proportion of injuries affecting the upper (range = 36.4–53.4%) and lower (range = 32.8–43.1%) extremities was quite similar. In the most extensive and well-documented study of male gymnasts [16], the proportion of upper extremity injuries (53.4%) was greater than the proportion of lower extremity (32.8%) injuries.

In all of the studies of young male gymnasts, the shoulder was injured most often (range = 16.8–19%) followed by the wrist (range = 8.4–13.8%) and ankle (range = 9.7–13.9%). These findings differ from those of girls' gymnastics and may reflect the different types of apparatus used in men's gymnastics that place greater physical demands on the upper body.

Situational

Injury Rates in Practice versus Competition

It is not surprising that more injuries occur during practice than competition since more time is spent training than competing. In girls' gymnastics studies [3, 6, 9–11, 13, 23] the percentage of all injuries that occur in practice varies from 79 to 96.6%. In contrast, the proportion of injuries occurring in competition varies from 3.4 to 21% [3, 6, 9–11, 13, 23]. However, when the number of injuries is computed with reference to exposure data, injury rates are greater during competition than training for (7.4 vs. 2.4 injuries/1,000 h) [9]. This finding may be explained by the fact that gymnasts are better protected in training than in competition because of landing in foam pits, spotting, and softer mats [26]. Nerves and time pressures may also be contributing factors.

Unpublished data on injuries sustained by competitors at the 2002, 2003, and 2004 USA Gymnastics National Women's Artistic Gymnastics Championships are summarized in table 4. Definition of injury was any gymnastics-related condition that required treatment by the USAG Medical Staff. These included both acute and overuse conditions. Perusal of table 4 reveals that 27.6–80% of the junior and from 62.5 to 70% of senior gymnasts, respectively, were treated for

Table 4. Injuries treated at the 2002–04 USA Gymnastics National Women’s Artistic Gymnastics Championships

Diagnosis	2002 Junior	2002 Senior	2003 Junior	2003 Senior	2004 Junior	2004 Senior	Total	Per cent
<i>Apophysitis</i>							[5]	
Osgood-Schlatter disease			1		2		3	3.4%
Sever’s disease		1	1				2	
<i>Contusion</i>							[5]	3.4%
Calcaneous						1	1	
Foot			1				1	
Iliotibial band				1			1	
Metatarsal			1				1	
Toes			1				1	
<i>Dislocation</i>							[1]	0.7%
Elbow		1					1	
<i>Fracture</i>							[13]	8.9%
Fibula (stress fracture)		1					1	
Ischial tuberosity (avulsion)		1					1	
Metacarpal				1	1		2	
Metatarsal (stress reaction)		1					1	
Phalanx		1					1	
Phalanx (Salter-Harris III)						1	1	
Spondylolysis		1		1			2	
Talus		1	1			1	3	
Tibia tubercle (avulsion)			1				1	

Table 4 (continued)

Diagnosis	2002 Junior	2002 Senior	2003 Junior	2003 Senior	2004 Junior	2004 Senior	Total	Per cent
<i>Impingement</i>							[2]	1.4%
Ankle				1			1	
Shoulder						1	1	
<i>Laceration/Rip</i>							[5]	3.4%
Hand			1				1	
Toes			1	3			4	
<i>Muscle Spasm/Tightness</i>							[8]	5.5%
Calf		2					2	
Gluteus						1	1	
Quadriceps		2		1			3	
Paraspinal		1		1			2	
<i>Nonspecific pain</i>							[21]	14.4%
Low back		1	6	3	3	5	18	
Lumbar facet syndrome				1		1	2	
Thoracic myalgia				1			1	
<i>Osteochondritis dessicans</i>							[2]	
Knee					1	1	2	
<i>Overuse (Muscle/Tendon)</i>							[26]	17.8%
Achilles tendonitis			1		1	2	4	
Bursitis				1			1	
Costochondritis						1	1	
Epicondylitis (elbow)				1			1	

Medial tibial stress syndrome				3		8	11	
Patellar tendonitis				1		1	2	
Planter fascitis	1					1	2	
Rotator cuff tendonitis						3	3	
Sesamoiditis				1			1	
<i>Respiratory problem</i>							[2]	1.4%
Infection			1				1	
Pharyngitis				1			1	
<i>Sprain (ligament)</i>							[40]	27.4%
Ankle	3	5	5	3	5	3	24	
Cervical			1				1	
Elbow	2						2	
Foot	2		2			1	5	
Knee				1		3	4	
Sacroiliac joint			1	2			3	
Wrist			1				1	
<i>Strain (Muscle/Tendon)</i>							[12]	8.2%
Achilles	1						1	
Adductor					1		1	
Forearm						1	1	
Groin			1				1	
Hamstring		1		2		1	4	
Hip flexor			3				3	
Quadriceps					1		1	
<i>Torn cartilage</i>							[3]	2.1%
Medial knee meniscus				2		1	3	

Table 4 (continued)

Diagnosis	2002 Junior	2002 Senior	2003 Junior	2003 Senior	2004 Junior	2004 Senior	Total	Per cent
<i>Torn tendon</i>							[1]	0.7%
Achilles						1	1	
Total number of injuries	9	20	31	32	15	39	146	
Total number of participants	29	20	25	28	20	35		
Number of injuries/100 participants	31	100	124	114.3	75	111.4		
Total number of injured gymnasts	8	14	18	20	12	27		
Percent of injured gymnasts	27.6%	70%	72.0%	62.5%	80%	69.2%		

injuries at the various championships. The most common injury types were sprains (27.4%), overuse conditions (17.8%), and nonspecific pain (14.4%). The most common injury locations were the ankle (16.4%), low back (12.3%), and lower leg (7.5%). Overall, 16 injuries (11%) required surgery. The most common surgeries were for fracture repair ($n = 4$), anterior cruciate ligament reconstruction ($n = 3$), and meniscus repair ($n = 3$). Injury rates ranged from 31 to 124 injuries per 100 participants.

Action or Activity

Most reported data on events associated with injury in girls' gymnastics are flawed because they include both sudden and gradual onset injuries [27]. That is, it is difficult to determine whether gradual onset injuries are specifically related to maneuvers in a given event. Additionally, most injury data on events are expressed as percentage values, which do not account for differential gymnast exposures among the various gymnastics events [27]. One study which reports exposure-based acute injury rates for events in girls' gymnastics indicates that floor exercise is the event with the highest injury rate among club-level female gymnasts [9]. Notably, floor exercise also had the highest frequency of injury during the international competitions between 1983 and 1998 [28].

Only one study reported events associated with injury in boys' gymnastics. Lueken et al. [25] reported 345 injuries affecting club level gymnasts attending the U.S. Olympic Training Center over a 15-year period. Floor exercise was most often associated with injury (24.9%), followed by still rings (19.2%), horizontal bar (16.9%), parallel bars (16.4%), pommel horse (14.7%), and vault (7.9%).

Chronometry

Time of practice

Three studies [9, 10, 13] report a relatively high frequency of injuries occurring early in practice, suggesting the possibility of a qualitatively or quantitatively insufficient warmup for the gymnasts studied. Other possible explanations include the possibility that appropriate progressions were not provided and that gymnasts may practice difficult skills earlier in practice when they are most fresh. Of note, one study [9] reported that 7 of 12 acute competition injuries occurred during the first half-hour of competition, which was during the timed warmup.

Time of Season

Several injury studies report the time of season when injury occurs in girls' gymnastics [9, 13, 16, 23]. These studies report a relative increase in injury rates:

- Following periods of reduced training such as a short vacation or recuperation [9, 13] – perhaps due to an increased workload demands [26];

- During competitive routine preparation [13] – perhaps due to increased fatigue during performance of longer combinations and routines and/or hurried attempts to prepare routines with skills, which are not thoroughly learned [29]; and
- During the weeks just prior to competition [9, 23] – perhaps due to a heightened competitive anxiety or stress [23], or performing skills which are not thoroughly learned.

Injury Severity

Injury severity can span a broad spectrum from abrasions to fractures, to those injuries that result in severe permanent functional disability or even death. In the gymnastics literature, injury severity is usually indicated by one or more of the following: injury type, time loss, surgery, and clinical outcome.

Injury Type

A percentage comparison of injury types sustained by female participants in recreational [5], club [3, 5, 6, 9, 10, 12, 13, 17], and high school [6] gymnastics is shown in table 5. Sprains (range = 15.9–43.6%) and/or strains (range = 6.4–31.8%) are consistently among the three most common injury types for these gymnasts. Other common injury types include contusions, fractures, and overuse injuries. There were no corresponding data for young male gymnasts.

Lower Back

As shown in table 3, the low back is typically the most frequently injured body part in the spine/trunk region of female gymnasts. The young gymnast engaging in strenuous training and competition places demands on the lower back unparalleled in most other sports. Demands on the gymnast's back include repetitive flexion and hyperextension postures during vaulting, dismounts, and somersaults. In addition to the hyperlordotic postures, vertical impact loading occurs as the gymnast lands on both feet during dismount activities [30]. It is the chronic repetitive flexion, hyperextension, rotation, and compressive loading of the spine during these activities that may cause injuries to the spinal elements [31, 32]. The spine, as with the rest of the skeleton, is at greater risk of injury during the adolescent growth spurt [33].

Table 6 summarizes radiographical data on specific injuries and conditions involving the lower back of female and male gymnasts [34–45]. Common injury sites reported include the vertebral bodies, intervertebral discs, and pars interarticularis. Common problems reported include back pain, radiographical

Table 5. A percent comparison of injury types in girls' gymnastics (adapted from Caine [2] and Caine et al. [27])

Level/Study	Number of injuries/ particular season	Abrasion	Concussion	Contusion	Dislocation	Fracture	Inflammation	Laceration	Nonspecific	Sprain	Strain	Other
<i>Recreational</i>												
Retrospective study												
Lowry and Leveau [5]	128/3042	0	0	27.3	1.6	3	11.7	2.3	0	32	21.9	0
<i>Club</i>												
Prospective studies												
Garrick and Requa [6]	16/72			0		31.2				15.9	16.2	18.7
Pettrone and Ricciardelli [3]**	29/542	0	0	9.7	6.4	27.4	8.1	0	0	41.9	6.4	0
Caine et al. [13]	147/50	0	0.7	4.1	0.7	3.4	10.2	0	40.1	19	17.7	4.1
Lindner and Caine [10]	90/362	2.2	0	6.5	4.3	4.8	6.5	1.1	11.8	19.4	11.8	9.7
Kolt and Kirkby [12]	349/-	0	0	6	0.6	8.3	17.9			29.7	23.2	14.3
Caine et al. [9]	192/159	0.5	0.5	8.9	0.5	1.6	3.1	1.6		19.3	31.8	29.2
Retrospective studies												
Lowry and Leveau [5]	260/370	0	0	34.2	1.5	8.1	13.8	0	0	41.9	6.4	0
Kolt and Kirkby [17]	321/162			3.1	1.6	8.4	15.3			29.6	20.6	21.4
<i>High school</i>												
Propective study												
Garrick and Requa [6]												
1 year (mixed study)				4.1		8.2				39.7	31.5	16.4
2 year (interscholastic study)				20.5		0				43.6	17.9	17.9

*A participant season is one gymnast participating in one season.

**Includes data for recreational as well as club gymnasts.

Table 6. Cross-sectional studies of lower back conditions affecting young female and male gymnasts (adapted from Caine [2] and Caine et al. [27])

Study	n	Age	Level	Condition/Diagnosis
Jackson et al. [34]	100	14	regional	Bilateral L5 pars interarticularis defects (11%), 6 of the 11 cases had coexisting spondylolisthesis at L5
Rossi [35]	132		olympic	32.8% spondylolysis; 8.9% spondylolisthesis
Ohlen et al. [36]	64	11.9	club	Low back pain in 20% of the subjects
Sward et al. [37]	26	16–25	national	19.2% spondylolysis, 4/5 with existing spondylolisthesis
Rossi and Dragoni [38]	417	15–27	competition	16.31% spondylolysis
Tertti et al. [39]	17 F	8–19	district, national and international	Sacrilization of L5 (5.9%), Scheuermann's disease (5.9%), spondylolysis at L5 (5.9%)
	18 M	8–14 yrs	district, national and international	Sacrilization of L5 (11.1%), Scheuermann's disease (11.1%), disc degeneration (5.6%)
Hellstrom et al. [40]	26 F	14–25	nationally ranked	Scoliosis (11.5%), spondylolysis (19.2%) with coexisting spondylolisthesis in 4 of the 5 cases, abnormal configuration of the vertebrae (15.4%), disk height reduction (3.8%), Schmorl's nodes (11.5%), apophyseal abnormalities (15.4%)
	26 M	16–25	national	Scoliosis (19.2%), spondylolysis and spondylolisthesis (11.5%), abnormal configuration of the vertebrae (38.5%), disc height reduction (11.5%), Schmorl's nodes (26.9%), apophyseal abnormalities (11.5%)
	30 M/F	16–25	nonathletes	Scoliosis (3.3%), spondylolysis (3.3%), coexisting spondylolisthesis (3.3%), spina bifida occulta (13.3%), abnormal configuration of the vertebrae (10%), disk height reduction (6.7%), Schmorl's nodes (40%)
Sward et al. [41]	26 F	14–25	national	65.4% had moderate or severe pain; 42.3% radiological abnormalities of the thoraco-lumbar spine
	26 M	16–25	national	84.6% had moderate or severe pain; 42.3% radiological abnormalities of the thoraco-lumbar spine
Goldstein et al. [42]	8 F	25.7	national	Spondylolysis (12.5%); abnormal disk (62.5%)
	14 F	16.6	elite	Spondylolysis (21.4%); abnormal disk (21.4%)
	11 F	11.8	pre-elite	Spondylolysis (9.1%); abnormal disk (0)
	11 F	18.6	swimmers	Abnormal disk (9.1%)

Table 6 (continued)

Study	n	Age	Level	Condition/Diagnosis
Sward et al. [43]	26 F	14–25	national	Abnormalities of the anterior aspects of the vertebral ring apophyses (30.8%)
	26 M	16–25	national	Abnormalities of the anterior aspects of the vertebral ring apophyses (19.2%)
Soler and Calderson [44]	112	14.3	top-level	Spondylolysis (17%)
Szot et al. [45]	52 M	15–31	national	Radiological changes of the spinal column (65.8%) (i.e., fracture and deformation of vertebral bodies, degeneration of the intervertebral discs, degenerative changes of the intervertebral articulations)

abnormalities of the vertebral bodies including abnormal configuration (flattening, wedging, and increased sagittal diameter), Schmorl's nodes and apophyseal changes, increased degenerative disc changes, and damage to the pars interarticularis with resultant spondylolysis (prevalence = 5.9–32.8%) and spondylolisthesis.

In the past, women's gymnastics focused on extreme reclination of the lumbar spine (e.g., frequent walkovers with extremely extended lumbar spine), which is believed to relate to the relatively high prevalence of spondylolysis in this sport [31]. In contrast, women's gymnastics has recently concentrated on a fixed and well-controlled spinal movement with forward flexed spine during landing, which may result in a decreased risk of spondylolysis [2, 31]. The repeated trunk flexion when landing from various heights, however, may create biomechanical compression forces sufficient to damage the anterior aspects of the spine. Anterior vertebral fractures and other anterior spine problems are now more common than the posterior problems seen during the era of contortionistic spine positions in poses, walkovers and limbers [31, 33, 46–51].

Upper Extremity

Unlike most other sports, in gymnastics, the upper extremities are used as weight-bearing limbs causing high impact loads to be distributed through the elbow and wrist. Considering the upper extremity's ill-adapted design for weight-bearing, it is not surprising that it is the second most frequently injured body region. As shown in table 3, the wrist is the most frequently injured site in the upper extremity of female gymnasts followed by the elbow. In male gymnasts, the shoulder has been the most frequently injured upper extremity body

part followed by the wrist. However, wrist injuries and conditions have been the focus of many cross-sectional reports for both male and female gymnasts.

Table 7 briefly summarizes data from cross-sectional studies of injuries and conditions involving the wrist of female and male gymnasts. Wrist pain is a common complaint among gymnasts, with prevalence estimates ranging from 46 to 87.5% [52–55]. Eight cross-sectional studies [45, 52–60] report prevalence estimates of radiographical abnormalities consistent with distal radius physal-stress reaction in 10–85% of gymnasts.

A concern voiced in the literature is that gymnastics training may inhibit radial growth in female gymnasts [61]. Although case studies have established the presence of premature closure of the distal radius among female gymnasts [62–65], there are currently few data which provide prevalence or incidence estimates for this condition. However, in one cross-sectional study of Chinese opera students (training included gymnastics) there were 2 cases (2/77 or 2.6%) of early partial closure of the distal radial growth plate [59]. In another study involving 18 top-level Chinese gymnasts, the nature and frequency of growth-plate conditions were monitored radiographically over 9 years [66]. During that period, 6/18 (33.3%) of the girls developed progressive pathology leading to ‘hindered radial growth’ and a ‘relatively lengthened ulna’.

Lower Extremity

The lower extremity is also a site of tremendous physical loading in gymnastics. This involves the repetitive jarring impact of vault takeoffs and dismounts from a variety of heights and during tumbling activities. A review of the data in table 3 shows that the lower extremity is actually the region most affected by injury in girls’ gymnastics. Yet surprisingly, there are no published prevalence data on lower extremity injuries affecting female or male gymnasts. However, two cohort studies report inversion ankle injuries are the most frequent lower extremity injury followed by Sever’s disease [16, 22]. Ankle sprains were also the most common injury sustained by gymnasts participating in the USA Gymnastics National Women’s Artistic Gymnastics Championships during 2002–04 (see table 4).

Catastrophic Injury

The worst case scenario in gymnastics is catastrophic injury. The recently publicized spinal cord injuries of national-level gymnasts Sang Lan of China and Julissa Gomez of USA [67, 68] focused public attention on the potential for catastrophic injury in gymnastics. The limited incidence data shown in table 8 suggest that catastrophic injury is a relatively infrequent occurrence among high school male and female gymnasts [69, 70]. However, there is a conspicuous absence of research reporting rate data for catastrophic injuries affecting

Table 7. Cross-sectional studies of wrist injuries and conditions affecting young female and male gymnasts (adapted from Caine [2] and Caine et al. [27])

Study	n	Age	Level	Diagnosis/Condition
Auberge et al. [56]	57 F	14–17	junior national	Chronic osteoarticular lesions involving the distal radial growth plate (85%)
	41 M	17–33	junior national	Chronic osteoarticular lesions involving the distal radial growth plate (80%)
Szot et al. [45]	41 M	15–31	national	Distal radial epiphyseal irregularities (58.5%)
Roy et al. [57]	26 F	9–14	class II	Minimal widening and irregularity of the distal radial growth plate (30.8%)
Caine et al. [52]	39 F	12.6	III, II, I	Minimal widening and irregularities of the distal radial physis (10%)
	21 M	12.6	IV, III, II, I	Definite changes of subchondral sclerosis, physeal widening, marginal new bone formation, and distortion of the distal end of the radius (4.8%)
DeSmet et al. [58]	156 F (not fused)	15.9	national	Enlargement of the distal radial growth plate with irregular borders in 10% of the cases; at baseline, 23 of 50 gymnasts had wrist pain
Chang et al. [59]	176 M/F (77 F, 99 M)	11–16	Chinese Opera students	Unfused group: 10 girls (14.3%) and 32 boys (32.3%) showed stress-related changes of the distal radial growth plate; 23 cases show early partial closure of the distal radial growth plate
De Fiori and Mandelbaum [53]	52 M/F (32 F, 20 M)	11.8	club level	38 (73%) reported wrist pain within the past 6 months; gymnasts with wrist pain were older, trained at a higher skill level, trained more hours per week, and began training at an older age
De Fiori et al. [54]	44 M/F (27 F, 17 M)	11.6	nonelite	11 gymnasts (25%; MF) showed radiographical evidence of stress injury to the distal radial physis

Table 7 (continued)

Study	n	Age	Level	Diagnosis/Condition
De Fiori et al. [60]	47 M/F (21 F, 26 M)	5–16 yrs	club level	Wrist pain was reported by 57% (27 of 47) of the gymnasts; 81% (24 of 27) reported wrist pain both at study onset and one year later; 42% of subjects with wrist pain reported that symptoms interfered with training
Di Fiori et al. [55]	59 MF (28 F, 31 M)	9.3	club level	Wrist pain was reported by 56% (33 of 59) of the gymnasts, with 45% (15 of 33) describing pain of at least 6 months; 51% of the gymnasts (30 of 59) had a finding of stress injury to the distal radial physis of at least a grade 2

Table 8. A summary of catastrophic injury rates in high school gymnastics (adapted from Caine [2] and Caine et al. [27])

Study	Duration	Injuries	Condition	Rate*, Number of cases/injures per 100,000 male participants	Rate*, Number of cases/injures per 100,000 female participants
Clarke [69]	3 years (1973–75)	1 F 1 M	permanent ^a permanent ^a		
National Center for Catastrophic Sports Injury Research [70]	21 years (1982–2003)	1 M/F 8 M/F 4 M/F	fatal nonfatal ^b serious ^c	1.15 2.3 1.15	0 1.1 0.55

^aRefers to permanent disability, including death, secondary to spinal cord injury.

^bPermanent, severe functional disability such as quadriplegia.

^cNo permanent severe functional disability, but severe injury.

club-level gymnasts. This finding is a concern given the escalation of difficulty and combination ratings in gymnastics; also, because the vast majority of competitive gymnasts participate at the club level.

Notably, several recent longitudinal studies of injuries affecting club-level female gymnasts report no catastrophic injuries [9, 10, 12, 13, 16]. In contrast, a national spinal cord injury registry in Japan revealed 23 spinal cord injuries to competitive gymnasts during 1990–92 [71], and between 1985 and 1997 there were 6 competitive gymnasts with spinal cord injuries treated at the Orthopedic Department at the University of Heidelberg [72].

Time Loss

A commonly used measure of injury severity is the duration of restriction from training and competition. Time loss due to injury is difficult to measure in gymnastics because injured gymnasts, depending on the severity of injury, tend to continue to train on selected apparatus with some skill or movement modifications. In addition, there are many possible subjective and objective factors that may influence performance time lost due to injury (e.g., personal motivation, peer influence, coaching staff reluctance or encouragement, approaching competition). This bias is minimized when numerical definitions are used [73].

Data from two studies of club-level female gymnasts using the same injury definition [9, 13] indicate that advanced-level participants experience a greater proportion of severe (>21 days time loss) injuries than beginning-level girl gymnasts. Similarly, several studies report that mean time loss per injury is greater for advanced- than beginning-level female gymnasts [9, 12, 17].

Clinical Outcome

Re-Injury

A high frequency of re-injury suggests an underestimation of the severity of the primary injury, inadequate rehabilitation, and/or premature return to training or competition [12]. There are few data on percentage or rate of re-injury among female gymnasts. In three cohort studies involving female gymnasts, percentage of injuries that were re-injuries ranged from 24.5 to 32.3% [9, 10, 12]. Cross-tabulation of re-injury with injury onset in two studies [9, 12] suggests that the majority of re-injuries affecting club-level gymnasts are chronic injuries.

Residual Symptoms

Two studies investigated former top-level female gymnasts for back pain and radiological changes [74, 75]. Both studies reported no significant differences in back pain between gymnast and control groups; however, the prevalence of radiological abnormalities was greater in gymnasts than controls in one study [74]. Maffuli et al. [76] reported the long-term follow-up (mean = 3.6 years) of lesions of the articular surface of the elbow joint in a group of 12 gymnasts (6 females, 6 males). In this group there was a high frequency of osteochondritic lesions, intra-articular loose bodies, and precocious signs of joint aging. Residual mild pain in the elbow at full extension occurring after activity was present in 10 patients, and all patients showed marked loss of elbow extension compared with their first visit.

Nonparticipation

Several case series studies have reported ‘career-ending’ injuries affecting the elbow [76–78] and low back [50] of young gymnasts. In a 10-year cohort study of Australian elite gymnasts, 7 females and one male (8/116) retired as a result of injury [16]. In this study, injuries that resulted in retirement included chronic rotator cuff injury, navicular stress fracture, loose bodies in the ankle joint, medial and lateral meniscus lesions, anterior cruciate ligament rupture, and osteochondritis of the elbow joint. In three cohort studies [9, 12, 79] from 16.3 to 52.4% of dropouts were injured when they withdrew from participation, thus implicating injury as a likely contributing factor in the decision to retire from gymnastics.

Injury Risk Factors

An important part of gymnastics injury epidemiology is the identification and analysis of factors that contribute to the occurrence of gymnastics injury.

These factors (i.e., the *why*) are commonly referred to as risk factors and may be classified as either intrinsic or extrinsic. Intrinsic factors are individual biological and psychosocial characteristics predisposing a gymnast to the outcome of injury. Extrinsic risk factors are factors that have an impact on the gymnast while she is participating in her sport, for example training methods or equipment.

Results of gymnastics risk factor studies are summarized in table 9 and discussed below with reference to intrinsic or extrinsic factors [3, 4, 9, 12, 13, 17, 23, 80–83]. The information provided should be interpreted cautiously due to the methodological problems and study differences described earlier. Further, risk factors may interact differently with the categories of injury onset, a possibility which was not accounted for in most of the studies reviewed. The risk factors identified should be viewed as initial steps in the important search for predictor variables and may provide interesting characteristics for manipulation in other experimental designs.

Intrinsic Factors

Physical Characteristics

Analytical cohort studies indicate that in comparison with uninjured or low-injury-risk gymnasts, the injured or high-injury-risk gymnasts are characterized by greater body size (height and weight), age, and body fat [80–82]. In one of these studies [80], however, measurements were taken after injury occurred, thus invoking the possibility that an injury itself caused the observed difference. Additionally, exposure patterns in injured and uninjured gymnasts were not identified as a basis for determining reasons for injury occurrence.

It is possible that factors such as greater height, weight and age tend to characterize older gymnasts with more years training and involvement in higher levels of training and competition. Older gymnasts may be more likely to sustain injury because of more complex and difficult skills and greater accumulated exposure to training.

There are some data which suggest that somatotype may relate to risk of injury. One study [80] reported mesomorphy to be negatively related to injury. However, as mentioned previously, these analyses were based on the injury data obtained retrospectively (before injury occurred). Additionally, comparing only one somatotype component may give a misleading interpretation of the role of overall somatotype, as the relative dominance of components may vary from one gymnast to another. Nonetheless, it seems reasonable to expect that gymnasts characterized by a somatotype most congruent to the physical demands of their sport would also be most protected from injury. Notably, Caine et al. [13] reported that gymnasts who lost the most time from training due to injury were also characterized by body types which were least typical of female gymnasts.

Table 9. A comparison of results arising from analytical cohort studies (adapted from Caine [2] and Caine et al. [27])

Study	Duration	Design	Method	n	Purpose	Results														
Steele and White [80]	2 years	retrospective	questionnaire	40 F	<p>To determine whether high and low injury groups could be identified</p> <p>To identify injury predictors</p>	<p>High and low injury risk gymnasts could be classified with 70% and 79% accuracy, respectively; significant differences ($p < 0.05$ or better) were found in the following variables:</p> <table><tr><td>weight</td><td>high > low</td></tr><tr><td>height</td><td>high > low</td></tr><tr><td>age</td><td>high > low</td></tr><tr><td>mesomorphy</td><td>high < low</td></tr><tr><td>quetelet index</td><td>high > low</td></tr><tr><td>shoulder flexion</td><td>high < low</td></tr><tr><td>lumbar extension</td><td>high > low</td></tr></table> <p>Variables associated with injury risk ($p < 0.05$ or better): weight (+), mesomorphy (-), lumbar curvature (+), age (+), and height (-)</p>	weight	high > low	height	high > low	age	high > low	mesomorphy	high < low	quetelet index	high > low	shoulder flexion	high < low	lumbar extension	high > low
weight	high > low																			
height	high > low																			
age	high > low																			
mesomorphy	high < low																			
quetelet index	high > low																			
shoulder flexion	high < low																			
lumbar extension	high > low																			
Kerr and Minden [23]	2 years	retrospective	questionnaire	41 F	To determine whether selected psychological variables (trait anxiety locus of control, self-concept, and stressful life events) were related to the number and severity of injuries	Moderately strong relationship between stressful life events and injury number ($r = 0.53$; $p < 0.01$) and between stressful life events and injury severity ($r = 0.53$; $p < 0.01$)														

Pettrone and Ricciardelli [3]	7 months	prospective	questionnaire	542 F	To identify physical parameters which predispose the athlete to injury	Duration and frequency of workouts in clubs with high injury rates were significantly greater ($p < 0.05$) than in clubs with low injury rates (20–30 hours/week vs. 4–6 hours/week)
Caine et al. [13]	1 year	prospective	interview	50 F	<p>To identify the nature of the relationship between injury status and selected host and environmental factors</p> <p>To determine the extent to which group classification into high and low injury risk groups could be predicted</p>	<p>No significant canonical relationship between the limited selection of predictor variables and the injury measures ($p = 0.11$); separate multiple regression tests ($p < 0.05$) showed maturation rate associated with injury rate (+) and competitive level associated with time loss (+)</p> <p>The results of discriminant analysis involving the criterion variable injury rate were not significant ($p = 0.10$); for the criterion variable individual proportion time loss, the groups were significantly different ($p < 0.05$) and could best be distinguished as a result of the contribution of competitive level (high > low) and</p>

Table 9 (continued)

Study	Duration	Design	Method	n	Purpose	Results
Goodway et al. [4]	1 year	prospective	questionnaire	6,654 F	To gain statistical verification for trends identified by descriptive means	maturation rate (high > low). In whole sample 84.6% of high risk and 69.3% of low injury risk gymnasts were correctly classified Trends associated with increased injury risk: higher competitive level, smaller less well-equipped facilities, and lower gymnast/coach ratio
Lindner and Caine [81]	3 years	prospective	interview	68 F	To distinguish injured from uninjured gymnasts To identify injury predictors	In whole sample 85.2% of uninjured and 75.6% of the injured gymnasts were correctly classified; the best discriminating component variables were age/body size (injured > uninjured), gymnastic-specific flexibility (varied by competitive and age levels) and body fat (injured > uninjured) Significant predictors ($p < 0.05$) of the injury measures (injury rate, time lost, previous injuries) were identified among the anthropometric and performance

Lindner and Caine [82]	3 years	prospective	interview	68 F	To distinguish high from low level competitive gymnasts	components, but were specific to the components and various age and competitive levels. Overall, training hours/week was a positive predictor of time lost ($p < 0.01$)
Kolt and Kirkby [17]	12 months	retrospective	questionnaire	162 F	To determine the number, site, and type of injury Incurred by elite and sub-elite female competitive gymnasts	In whole sample, 80% of low level and 100% of high level gymnasts were correctly classified; time loss due to injury ($p < 0.001$) and number of previous injuries were greater ($p < 0.05$) for high level gymnasts Injury rate for elite gymnasts (per 1,000 h) was lower than sub-elite gymnasts ($p = 0.03$) Distribution of injuries was significantly different ($p = 0.001$) with a higher proportion of elite gymnasts reporting tendonitis and growth plate injuries
Kolt and Kirkby [83]	12 months	retrospective	questionnaire	162 F	To assess the role of life stress, competitive anxiety, self esteem, and locus of control in injury	Life stress was a significant predictor of injury for the overall sample and for the nonelite gymnasts

Table 9 (continued)

Study	Duration	Design	Method	n	Purpose	Results
Kolt and Kirkby [12]	18 months	prospective	questionnaire	64 F	To compare injury rates in elite and sub-elite gymnasts	Rates per 1,000 h training were lower for elite than sub-elite gymnasts ($p = 0.01$)
Caine et al. [9]	3 years	prospective	interview	79 F	To estimate the relative risk of injury in competition versus training among beginning and advanced gymnasts	The RR of injury during competition relative to practice was 2.69 (95% CI: 1.53, 4.75; $p < 0.001$). The relative RR during competition was 0.47 for beginners (95% CI: 0.07, 3.42) and 4.34 for advanced gymnasts (95% CI: 2.39, 7.88; $p = 0.035$)
DiFiori et al. [60]	1 year	prospective	interview	21 F 26 M	To determine the prevalence and characteristics of wrist pain among young, nonelite gymnasts	Multivariate analysis revealed that adolescent gymnasts between 10 and 14 years of age were significantly more likely to report wrist pain than those who were either above or below this age range ($p = 0.03$) either above or below this age range ($p = 0.03$)

It is believed that the growth spurt is associated with an increased risk of injury [84–86]. Caine et al. [13] reported that injury rate was almost twice as great for female gymnasts experiencing rapid compared to stable growth (as indicated by Tanner stages), regardless of competitive level. Similarly, DiFiori et al. [60] reported that male and female gymnasts between 10 and 14 years of age were significantly more likely to report wrist pain than those who were either above or below this age range. However, these findings await confirmation from an analysis of individual longitudinal growth records and injury rates.

Motor Characteristics

One study [81] reported speed (–), balance (–), endurance (+) and flexibility (+) as significant injury predictors among club-level female gymnasts; however, these were not significant at all age and competitive levels studied. Additionally, the number of gymnasts in each age and competitive level were small thus limiting the precision of analysis within subgroups.

One study [80] reported that the high injury risk was associated with a relatively low shoulder flexion and high lumbar extension. Once again, these measures were taken after the injury occurred, thus the possibility that the injury itself caused the observed difference. In addition, as mentioned above, exposure patterns in injured and uninjured gymnasts were not identified as a basis for determining reasons for injury occurrence. No doubt success in gymnastics depends on a certain minimum of joint looseness, yet flexibility is specifically difficult to define and its relationship to injury remains conjectural.

Psychosocial Characteristics

An intriguing, but relatively unexplored area of injury research in gymnastics, is the role of psychosocial factors in injury occurrence. In one study [23], a moderately strong positive relationship between the number of stressful life events and injury number and severity was reported. In a more recent study [83], life stress was a significant predictor of injury in elite and nonelite competitive female gymnasts who completed a questionnaire covering personal, training, and injury data. In both of these studies, however, the psychosocial measures were taken after the injury occurred, thus invoking the possibility that the stress profiles of the gymnasts were different at the time of injury.

Extrinsic Factors

Exposure

The results of analytical studies are inconclusive as to whether injury rates are greatest at advancing levels of training and competition [9, 12, 13, 17]. Two studies report significantly lower injury rates in elite compared to sub-elite

gymnasts [12, 17]. In contrast, when proportion time loss and injury rate were used as criterion variables [13], the analysis resulted in a significant effect and competitive level surfaced as best discriminator between high and low injury risk gymnasts. In a recent study [9], the relative risk for injury among advanced gymnasts was 1.47 times greater than a beginning group. When the advanced group was divided into training versus competition time, the RR of injury compared to the beginning group was not inflated in training ($RR = 0.97$) while it is much higher during competition ($RR = 4.22$).

Suggestions for Injury Prevention

The aim of this overview of the gymnastics injury literature was to provide epidemiological information that would be useful to minimize injury morbidity and prevent injury to young athletes through an understanding of how, where, and why injuries occur in the sport. Arising from this integrative review of the gymnastics injury literature are the following injury patterns:

- higher rates of injuries among advanced-level gymnasts in some studies [7, 9, 13, 22];
- the most frequently injured body parts: shoulder, wrist, elbow, lower back, ankle and knee [6, 7, 9, 11, 13, 16, 18, 25];
- higher rates of injuries in competition, especially among advanced-level gymnasts [9];
- floor exercise is characterized by the highest rate of injury [9];
- most injuries are acute [3, 4, 7, 9–12, 14, 17, 21, 22, 27]; however, there is some evidence that advanced-level or heavily trained gymnasts incur more overuse conditions than their less-advanced peers [12, 13, 17];
- national level gymnasts incur relatively high rates of injury associated with competitions; the most frequently treated injury conditions at these competitions were sprains, overuse injuries and nonspecific pain and common injury locations were the ankle, low back, and lower leg [unpubl. data];
- a relatively high frequency of injury during the early part of practice or during timed warmup for competition [9, 10, 13];
- increased rates of injury following periods of reduced training, during competitive routine preparation, and during the weeks just prior to competition [9, 13, 23];
- sprains and strains are the most common injury types [3, 5, 6, 9, 10, 12, 13, 17];
- a high prevalence of overuse injuries affecting the spine and wrist of both male and female gymnasts [33–63];

- catastrophic injuries appear to be infrequent outcomes of high school gymnastics participation [69, 70]; however, there are no rate data on this injury type among club-level gymnasts;
- time loss associated with injury is greater for competition than for practice injuries, and greater for advanced- than beginning-level gymnasts [9, 12, 13, 17];
- about one in four injuries is a re-injury [9, 10, 13]; there is some evidence that most re-injuries are chronic injuries [9, 13];
- little is known about the long-term effect of gymnastics injuries; however, there is evidence that history of back and elbow injury is related to persistence of symptoms following retirement [74–76];
- injury is a reason for dropping out for some gymnasts, perhaps as many as one in ten [9, 13, 16, 18]; and
- factors shown to be associated with increased risk of injury include: greater body size, age, and body fat [80–82]; periods of rapid growth [13, 60]; life stress [23, 83]; and, in some studies, advanced levels of training and competition [9, 13].

Suggested preventive measures arising from the studies reviewed in this chapter are listed in table 10 according to study design. Recommendations are referenced to indicate source and any available supporting evidence. As indicated in the table, most of the suggestions were derived from descriptive data and await confirmation from more controlled epidemiological study, including evaluation for their effectiveness in preventing injuries.

In closing, it is important to emphasize that the prevention of gymnastics injury is a complex phenomenon which requires interaction among gymnast, coach, gymnastics governing body and medical support staff. A multidisciplinary team including coach, athletic trainer, psychologist and physician is essential to optimizing the preventive strategies.

Suggestions for Future Research

An important purpose of this chapter has been to identify methodological weaknesses in the literature and provide suggestions for further research. This is an integral component of the ‘epidemiology of gymnastics injuries’ because informed decisions related to the establishment of injury prevention programs depend on accurate and reliable data. Above all, this overview of the gymnastics injury literature underscores the need to establish national injury surveillance systems designed to provide current and reliable data on injury trends in boys and girls club-level gymnastics.

Table 10. Suggestions for injury prevention (adapted from Caine [2])

Preventive measures	Type of evidence	
	Cross-sectional	Cohort
<i>Coaching – Education</i>		
Require coaches to meet a minimum level of qualification		Weiker [7]
On the importance of protecting gymnasts from premature attempts to execute advanced maneuvers		Clarke [69]
<i>Coaching – Physical Preparation</i>		
Provide specific stretching and strengthening exercises – particularly for the Achilles tendon, hamstring and quadriceps muscles		Mackie and Taunton [22]
Maximal conditioning of those muscles used for spinal and abdominal strengthening to avoid chronic back conditions	Soler and Calderon [44]	Garrick and Requa [6]
Conditioning programs to prevent muscle strains associated with the short bursts of running in floor exercise and vaulting		Garrick and Requa [6]
Coach should not emphasize gymnastics-specific flexibility (splits, leg raises) before extent flexibility at various joints is adequately developed		Lindner and Caine [10]
Encourage wrist strengthening and flexibility exercises to help protect the wrist against chronic injury	Caine et al. [52]	
Teach and practice correct landing techniques to prevent fractures and dislocations of the upper extremity		Mackie and Taunton [22]
Ensure adequate warmup		Caine et al. [13]; Pettone and Riccardelli [3]
Recognize the existence or potential for growth plate injury and the importance of referring the gymnast for medical evaluation as soon as symptoms occur	Caine et al. [52]	Kolt and Kirkby [12,17]
Pain is a signal in an important process and should be regarded as a warning, not something to get used to; ‘no pain – no gain’ is inappropriate	Jackson et al. [34]; Caine et al. [34]	Caine et al. [13]

Conditioning specifically designed to ‘smooth the transition’ from skill training to routine training (e.g., ergometer interval training, anaerobic conditioning, and weight training)	Caine et al. [52]	
Ensure the technically correct performance of movements to avoid unnecessary overloading of the spine	Soler and Calderson [44]	
<i>Coaching – Training</i>		
Alternate loading types during workouts; for example alternate swinging and support movements so as to reduce stress on the wrist	Caine et al. [52]	
Train gymnasts in a cyclically progressive manner so that the [3]	Caine et al. [52]	Pettrone and Riccardelli
gymnastis not increasing the dose of load bearing in a progressive stepwise fashion but rather in a cyclical manner; every escalation is followed by a decrease in overall load for a week’s time, followed by another increase, thereby allowing reparative time for connective tissue structures		
Reduce duration of rotations and increase their number per workout to avoid lack of concentration and inattentiveness; avoid training when concentration is poor		Lindner and Caine [10]; Mackie and Taunton [22]
Reduce training loads during periods of rapid growth	Caine et al. [52]; DeFiori et al. [55]*	Caine et al. [13];* Lindner and Caine [81]* DiFiori et al. [60]
Avoid conditions in which the gymnast is allowed merely to go through the motions of a skill without a specific assignment requiring the gymnast’s attention		
Spotting should be used more extensively during practice and obligatory during high-risk events		Lindner and Caine [10]
Availability of well-trained spotters		Bak et al. [11]; Weiker [7]

Table 10 (continued)

Preventive measures	Type of evidence	
	Cross-sectional	Cohort
<i>Equipment</i>		
Encourage use of personal protective equipment (e.g., dowel grips, handguards)	Caine et al. [52]	
Increase thickness of landing mats during practice and competition		Goldstein et al. [42]
Re-evaluation of the criteria of the scoring system for competition		Bak et al. [11]
<i>Health Support System – Screening</i>		
Administer a preparticipation physical examination (PPE) to each gymnast prior to entry into competitive gymnastics, before any change in the competitive level, and before returning to practice following injury	Soler and Calderson [44]	Kolt and Kirkby [12,17]; Caine et al. [13]
Biannual musculoskeletal screening and, when indicated, AP radiographs of the wrist to rule out stress changes of the growth plate		Steele and White [80]*
Periodic physical examination focusing on epiphyseal areas of growing gymnasts such that injuries to these areas can be diagnosed at an early stage and modifications made to the training program to assist in the recovery process		Kolt and Kirkby [12,17]
<i>Health Support System – Treatment and Rehabilitation</i>		
The physician should heighten awareness and encourage extra vigilance on the part of coaches during the period of routine preparation and competition given the increased rate of injury during these periods	Caine et al. [9]	
Gymnastic clubs include within their cost structure sufficient funds to hire an athletic trainer or physical therapist, at least on a part-time basis.	Caine et al. [52]	Jackson et al. [34]; Kolt and Kirkby [12]; Garrick and Requa [6];

The functions of this individual should include the following:

- early detection of developing stress injuries
- identify potential injury-provoking practices
- liaison between gymnasts, coaches, and physician
- oversee the development of special rehabilitation programs for injured gymnasts identified in the PPE

Caine et al. [9]

Caine et al. [9]

Treatment of chronic injuries before they become disabling

Steele and White [80]*

The Sport

Re-evaluation of competition rules and the performance environment
given the high incidence of injury linked with competition

Caine et al. [9]

*Derived from an analytical study.

In particular, injury surveillance systems could provide the needed and on-going descriptive data related to important epidemiological ‘targets’ or areas that merit closer scrutiny. Targets for further study identified in this literature review include the following:

- injuries that cause restriction or loss of participation for extended periods of time (e.g., >7 days);
- injuries that require surgery or are otherwise severe in nature (e.g., concussions);
- injuries that are catastrophic;
- re-injuries;
- injuries that may affect skeletal growth;
- injuries that occur during or following warm-up;
- injuries that occur in the weeks just prior to competition;
- injuries that occur during competition; and
- long-term follow-up of gymnastics injuries.

In addition to injury surveillance systems, in-depth epidemiological studies are needed. A critical aspect of the proposed research is the precise determination of exposure patterns in injured and uninjured gymnasts as a basis for determining reasons for injury occurrence. As this review of the gymnastics injury literature has shown, few injury risk factors have been subjected to statistical tests for correlation or evaluated for predictive value. And there have been no studies published that were designed to determine the effectiveness of specific injury prevention measures. Although the institution of a preventive strategy on the basis of clinical practice or descriptive epidemiological data may still prevent injury, the most reliable suggestions for injury prevention are believed to emerge from experimental or quasi-experimental research [9].

Examples of questions or issues that have arisen from this review of the gymnastics injury literature and which may help direct further analytical research initiatives include the following: Why is the risk of injury in competition so much higher than training, especially among advanced-level gymnasts? Do some psychosocial factors increase the risk of competition injury and can these factors be controlled or eliminated? Can an increased risk of injury during periods of rapid growth be confirmed with reference to growth velocity data? If so, what can be done to reduce this increased risk of injury? What is the relationship between poor technique and risk of injury? What factors are associated with increased risk of the nagging chronic injuries experienced by gymnasts? Can these factors be controlled or eliminated? What are the long-term effects of gymnastics injuries? And, would a well-designed pre-season conditioning and proprioceptive balance training program help to reduce the risk of lower extremity injuries?

In closing, it is important to stress that it is only through concerted collaborative efforts that optimal results could be achieved. The research team should include the coach, athletic trainer, physician, and epidemiologist who interact in a very dynamic and fluid manner. In addition, it is important to emphasize that every effort should be made by the research team to establish an open and trusting dialogue with gymnasts and their parents. Only when this could be achieved, could an adequate database be established.

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