Review

Balancing the risk of injury to gymnasts: how effective are the counter measures?

R M Daly, S L Bass, C F Finch

Abstract

***Background*—To minimise injury risk and maximise gymnastics performance, coaches, parents, and health professionals working with young gymnasts need to understand and practise safe gymnastics.**

***Aims*—To (*a*) identify the various injury counter measures specific to gymnastics, (*b*) critically review the literature describing each injury prevention measure, and (*c*) assess, using available risk factor and injury data, the weight of evidence to support each of these counter measures. Specific recommendations for further research and implementation strategies to prevent injury and improve safety are also given.**

***Methods*—The relevant literature was identified through the use of Medline (1966 to May 1998) and SPORT Discus (1975 to May 1998) searches, hand searching of journals and reference lists, and discussions with key Australian gymnastics organisations.**

***Results*—The key gymnastics injury counter measures identified in this review include coaching (physical preparation, education, spotting, and performance technique), equipment, and the health support system (medical screening, treatment, and rehabilitation). Categorisation of the type of evidence for the effectiveness of each of these counter measures in preventing injury showed that most of it is based on informal opinion/anecdotal evidence, uncontrolled data based studies, and several prospective epidemiological studies. There is no evidence from formally controlled trials or specific evaluation studies of counter measures for gymnastics.**

***Conclusions*—Although gymnastics is a sport associated with young participants and frequent high volume, high impact training, there is a paucity of information on injury risk factors and the effectiveness of injury practices. Further controlled trials are needed to examine the extent to which injury prevention counter measures can prevent or reduce the occurrence of injury and re-injury. Particular attention should be devoted to improving training facilities, the design and testing of apparatus and personal equipment used by gymnasts, and coaching and the role of spotting in preventing injury.**

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Keywords: gymnastics; injury prevention; counter measures; effectiveness; coaching; equipment

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Although there is increasing evidence that children are becoming more sedentary and less fit,[1] the number of children and adolescents involved in organised sporting activities such as gymnastics, tennis, and swimming has actually increased.[2] Although the long term risks associated with involvement in organised sport during the period of growth and development are still obscure, concern has been expressed over a potential epidemic of both acute and chronic overuse sports injuries.[3 4]

Adolescence appears to be associated with the highest incidence of injury, which may be partially due to the growth process itself inducing an imbalance between strength and flexibility.[5] There is also evidence that the growth plate cartilage is less resistant to repetitive stress than adult articular cartilage, and that the ligaments of children are stronger than the cartilage and bone to which they are attached.[5 6] This may result in an increased likelihood of injury to the open epiphysis. Gymnastics as a potential cause of injury is of particular concern because of participation by children and the frequent high impact loading associated with both training and competition.

Gymnastics as a sport has enjoyed a boom in popularity over the last 20 years, which may reflect the increased publicity and television coverage given to the sport at events such as the Olympic Games. The sport of gymnastics began with the ancient Greeks and Egyptians, where it was used as a means of discipline and physical conditioning for young men being trained for warfare.[7] Today, it is both a recreational and organised sporting activity, in which there are six major disciplines: men's artistic gymnastics, women's artistic gymnastics, rhythmic sportive gymnastics, sport aerobics, trampoline sports, and general gymnastics. Within each of these disciplines, there are three main levels of gymnastics activity: recreational, competitive, and elite. At present, the vast majority of competitive participants are children. This is probably because of the widely held belief that to achieve success at the highest level, training and competition should begin before puberty when a small lean physique is likely to convey a performance advantage. It is not uncommon for elite gymnasts to start training from as early as five or six years of age, and to train for between 20 and 40 hours a week all year round.[8 9]

Since the mid 1970s, competitive gymnastics has undergone a dramatic transformation with respect to the complexity of manoeuvres performed and the age at which gymnasts start training.[10] Both coaches and gymnasts have become more ambitious and creative, and consequently, the range and number of risk elements incorporated into gymnastics routines have increased substantially.[11] More children are starting gymnastics from an earlier age and maintaining an extremely high level of training throughout the years of growth and development. Consequently, it has been suggested that the increased involvement and difficulty of skills practised from an early age may be associated with an increased risk of injury.[12] Most elite gymnasts do not pass through childhood and adolescence without injury, and the risk of injury increases with longer practice time and the degree of difficulty of the routines.[13]

Although a number of safety practices are widely adopted to prevent the occurrence and recurrence of gymnastic injuries, the effectiveness of these preventive measures has received little attention. Given the cost of treatment for injury rehabilitation, the loss of sports participation time, and the risk of long term or even permanent disability, it is important that injury counter measures be identified to reduce the occurrence, recurrence, and severity of injuries associated with sports participation. The aim of this review was to (*a*) identify the various injury counter measures specific to gymnastics, (*b*) critically review the literature describing each injury prevention measure, and (*c*) assess, using available risk factor and injury data, the weight of evidence to support each of these counter measures. Specific recommendations for further research and implementation strategies to prevent injury and improve safety are also given.

Methods

The information for this article was obtained using the WinSPIRS 4.0 Silverplatter Electronic Reference Library at Deakin University. This library contains a number of search engines, including Medline (from 1966 to May 1998) and SPORT Discus (from 1975 to May 1998) which were used to obtain most of the information for this review. Discussions with key Australian gymnastics organisations and hand searching of journals and reference lists were also carried out. The keywords and phrases used to search the literature included "gymnastic" and one or a combination of the following words: injury, training, prevention, conditioning, strength training, flexibility, preparticipation screening, equipment, technique, education, coaching, spotting, medical treatment, and rehabilitation. The literature search for the relevant material did not discriminate between males and females or the different levels of gymnastics. The material reviewed was restricted to the English language.

Injuries in sport, such as those that occur during gymnastics, generally result from the culmination of a pre-existing condition and/or a particular set of circumstances.[12] A multifactorial chain of events usually results in the incident leading to an injury during sport. Three phases are identifiable as points of intervention: before the event, the event, and after the event.[12] Injury counter measures are measures aimed at preventing or reducing the risk of injury. It has been suggested that injury counter measures can be targeted at the three phases in the chain of events leading to an injury. Gymnastics injury counter measures can therefore be equated to primary (before the event), secondary (event), and tertiary (after the event) prevention,[14] as shown in table 1.

Although few counter measures specific for gymnastics have been formally shown to actually prevent injury, the key counter measures identified in the literature pertain to coaching (physical preparation, education, spotting, and performance technique), equipment, and the health support system (medical screening, treatment, and rehabilitation). The evidence for each specific counter measure in these categories will be discussed according to the level of supportive evidence. On the basis of this assessment, recommendations are made for improving the safety of gymnastics and for further counter measure research and development. The classification for the strength of the type of evidence showing the effectiveness of each counter measure is based on a grading scale developed and previously published by the authors.[15] This grading system should be regarded as a continuous scale. Randomised controlled trials of the effectiveness of the performance of a counter measure in the field is rated as the best scientific

Table 1 Counter measures to prevent or control gymnastics injuries

Level of prevention	*Potential counter measures*
Primary (pre-event)	• Adequate warm up and stretching before and after gymnastics sessions • Good physical condition appropriate to the specific demands of gymnastics • Attention to equipment factors—for example, appropriate matting • Screening programmes to identify at risk gymnasts and corrective actions • Coaches and spotters • Education of gymnasts, coaches, and parents • Facilities design
Secondary (event)	• Equipment design and maintenance • Facilities design • Personal protective equipment—for example, hand guards
Tertiary (post-event)	• Prompt first aid and medical attention • Adequate first aid facilities • Full rehabilitation before returning to participation

evidence. In the absence of randomised controlled studies, the highest level of proof for the effectiveness of a gymnastics counter measure is provided by prospective cohort studies. This is followed by data based (uncontrolled) studies, which includes case series, cross sectional, retrospective cohort designs, and information from routine surveillance systems that document the incidence of injury over time. Biomechanical research includes description of equipment design and testing and development of standard testing procedures. This type of research is often performed under conditions that are artificially controlled, which may not be representative of the actual gymnastics environment or conditions. Anecdotal reports of injuries and their prevention and comments based on informed or expert opinion are considered the lowest level of proof.

Results

COACHING

Physical preparation

As with most sporting pursuits, a conditioning programme is recommended to prepare the gymnast for the environment anticipated in competition and reduce the potential for injury.[16] Gymnastics is a demanding, multifaceted sport with many different performance requirements. The different competitive events, which last from only a few seconds (the vault) to about 90 seconds (the floor routine), require a combination of speed, strength, endurance, agility, flexibility, and power. Previous research has estimated that gymnasts obtain up to 80–90% of their energy needs from anaerobic sources, with minimal energy from aerobic pathways.[17] More important with regard to injury risk is the fact that both the upper and lower extremities of gymnasts are subjected to frequent, high impact, weight bearing activities.

Competitive gymnastics training generally proceeds in systematic phases with varying demands on the athlete during the different phases. The typical approach to training consists of the following phases: general preparatory; specific preparatory; precompetitive; competitive.[18] At present, no gymnastics specific studies have investigated the association between injury prevention and physical conditioning. Sands *et al*[19] conducted a five year prospective cohort study of gymnastic injuries in female college gymnasts, and reported that the onset of training after an enforced break, routine performance, and competitions resulted in more gymnastics injuries (total or new injuries per exposures across five years) than any other training demands. Furthermore, the authors suggested that the high incidence of injury during the initial preparatory phase of training and routine development may result from the shock of increased work demands after a period of reduced training and high levels of fatigue when performing long sequences of skills.[19] Consistent with these findings, the results of two other prospective studies reported an increased incidence of injury after enforced breaks.[20 21] Together, these studies provide indirect evidence that poor physical preparation or conditioning may be associated with an increased risk of injury.

> Speed, strength, power, agility, and flexibility form an integral component of gymnastics training and performance. However, most of the evidence for the effectiveness of a general conditioning, strength, or flexibility programme for preventing injuries is based on informed opinion, fundamental training principles from other sports, and epidemiological research.

To avoid or diminish the occurrence of injuries in gymnastics, it is claimed that the initial subtle indicators of injury should be effectively managed by instituting a training strategy favouring a gradual acquisition of skill.[4] Caine *et al*[4] suggested that training should be performed in a cyclically progressive manner so that the dose of load bearing or training intensity is not increased in a stepwise fashion. A conditioning programme becomes potentially hazardous when a coach or gymnast quantifies achievements by defined percentages of improvement within specific time intervals.[22] This can result in a large or sudden increase in the training load or intensity, predisposing the gymnast to injury. The results of a seven month epidemiological study designed to identify physical parameters predisposing gymnasts to injury showed that the duration and frequency of workouts in the clubs with the highest rates of injury were significantly greater than in those with no injuries (20–30 hours a week *v* 4–6 hours a week).[23] Although injury data were collected by questionnaire, the authors concluded that fatigue was a major factor contributing to injury in those clubs with gymnasts training in excess of 20 hours a week. Furthermore, they recommended that weekly practice sessions be interrupted by rest or light days and that daily sessions include hourly rest periods. Lindner and Caine[24] also used questionnaires and interviews to obtain injury information from 178 competitive female gymnasts over three years. They concluded that long practice sessions on a single apparatus and lapses in concentration were key factors associated with gymnastics injury. The results of a recent 18 month epidemiological study showed that, when exposure time to injury was considered, subelite gymnasts reported a higher injury rate than elite participants.[25] The authors suggested that this may have been due to lower levels of physical conditioning in the subelite participants.[25] Although cause and effect cannot be established from the results of these studies, together they provide further indirect evidence that a conditioning programme may help to reduce the risk of injury in gymnastics.

There is a general consensus within the gymnastics community that strength training forms an integral component of the gymnast's training schedule. Kirkendall[17] estimated that almost 60% and 30% of the movements performed by male and female gymnasts respectively involve supportive tasks (supportive holds, momentary support, and passing support during movement) all of which require a high degree of muscular strength and/or power for their successful execution. Unfortunately, few studies have examined the effectiveness of a specialised strength training programme on injury prevention in gymnastics. Colby and Fricker[26] introduced a back exercise programme for the Australian Institute of Sport women's gymnastics squad to protect, stretch, and strengthen the lumbar spine. It was performed at least three times a week during the warm up for 12 months. To examine the effectiveness of the programme, a comparison was made between the number of injuries in the 12 months before and the 12 months after the intervention. Although the number of gymnasts followed each year was small (12 and 11 respectively), back injuries as a group accounted for 32.3% of all injuries in the first year and 25.6% in the second year. Comparison of injury rates for the two years showed a decline in the overall injury rate per gymnast per year from 4.3 in the first year to 3.5 in the second year. Further analysis of the results showed a new back injury rate per month of 1.4 in the first year and 0.5 in the second year. In the light of these findings, the authors concluded that there was a trend for the exercise programme to prevent back injuries in female gymnasts. Unfortunately, they failed to consider the exposure time of the gymnasts to the risk of injury, and only those injuries brought to the attention of the doctor or physiotherapist were reviewed.

Advocates of strength training for gymnasts suggest that certain fundamental training principles should be considered when designing a strength training programme. One of the most important principles is that the training programme should consist of activities similar to the specific demands associated with the various gymnastics apparatus or manoeuvres.[17 27] There is some suggestion that the countless elements, combinations, and routines performed during training are unlikely to develop or maintain an adequate level of strength for advanced gymnastics.[28] It has also been suggested that strength training be maintained during both the competitive and non-competitive developmental periods.[4] There is some suggestion that inconsistent strength training may explain the decline or plateau in gymnastics performance and high incidence of injury during the preparatory phase of training in some gymnasts.[28] Another important principle of gymnastics specific strength training is that a greater emphasis is placed on maximising muscle strength from minimal muscle size, given that the power to body weight ratio is an important performance determining factor.[28]

Loss of concentration and inattentiveness have been shown to be associated with gymnastics injuries, particularly in children and adolescents.[23 24] Therefore, adequate rest and recuperation are considered essential to prevent fatigue and lapses in concentration. In addition, it is recommended that strength training is separated from periods devoted to skill learning. However, it has been suggested that the two components be integrated so as to develop the necessary strength and power for the correct technical performance of a skill.[28] With insufficient strength, gymnasts often learn a skill with one technique only to have to relearn it with further advancements in strength.[28]

A prescribed regime for the activities performed before and after practice and competition is an essential strategy for injury prevention in gymnastics. There is evidence to suggest that insufficient warm up may leave muscles and other skeletal structures unprepared for the forthcoming performance.[29] Although specific warm up procedures have been described for gymnastics,[30 31] no studies appear to have formally investigated the relation between injury prevention and warm up in gymnastics. After gathering injury information on competitive female gymnasts for three years, Lindner and Caine[24] found that most strains in young elite female gymnasts occurred during the first hour of practice, suggesting that the cause was insufficient warm up.

Both poor and excessive flexibility or hypermobility have also been suggested as risk factors for injury.[32] In the sport of gymnastics, there is an obvious need for flexibility given the complexity of manoeuvres required for high level performance. The consensus is that both static and proprioceptive neuromuscular facilitation stretching techniques be used to stretch all the major muscle groups, with special attention devoted to the typically non-weight-bearing upper extremities. However, little information exists on the effectiveness of a flexibility programme in preventing gymnastics injuries. In a retrospective study of 40 female gymnasts aged 10–21 years, Steele and White[33] found that injury proneness was associated with poor shoulder flexion and high lumbar back extension. Unfortunately, it was unclear whether the flexibility status of the gymnasts was a cause or consequence of injury, because all measures were taken only after the injury had occurred. Kirby *et al*[32] compared the flexibility of 60 competitive female gymnasts with 35 non-athletic controls to investigate the association between flexibility and the incidence and severity of gymnastics injuries. All injury information was obtained by interview. Although the overall flexibility of the gymnasts was greater than that of the controls, except for a positive association between toe touching ability and lower back pain, there was no clear link between flexibility and gymnastics injury. Unfortunately, this type of study design does not allow one to establish the sequence of events between risk factor(s) and injury.[34] Further randomised controlled trials are needed to establish the relation between flexibility and gymnastics injury.

After training and competition, it is common practice for gymnasts to perform a cool down routine. Although no studies appear to have investigated the relation between the practice of cool down and injury risk in gymnastics, Borsa and Lephart[35] suggested that an effective cool down may accelerate recovery, maintain or improve flexibility, and reduce the potential for exercise induced muscle soreness.

Education

Education is an integral component of injury prevention. The Australian Sports Injury Prevention Taskforce emphasised how the education of coaches and trainers can have a significant role in preventing injury.[36] In addition, well educated gymnasts are more likely to detect and avoid potential injurious situations and learn general preventive measures.[4 22] Educating gymnasts with regard to their physical capacity to execute a skill and increasing their understanding of important principles of general conditioning, warm up, and flexibility may not only reduce the likelihood of injury but also improve performance.

At every level of gymnastics, the coach plays a crucial role in preventing injuries and maintaining the physical development and mental well being of gymnasts. The coach's roles range from being a communicator and educator, to being a psychologist and provider of medical care when appropriate. For residential gymnasts living away from home, the coach may become a "substitute" parent, and thus an important role model during the critical years of development. Unfortunately, many coaches have little knowledge of child development and the influence they have on young aspiring gymnasts.[37]

To reduce the potential for injury, the coach has a responsibility to maintain an up to date knowledge of training techniques and important principles related to the safety and health of athletes.[38] All gymnastics coaches are required to partake in formal coaching education and professional development courses. The level of education among coaches is an important variable when considering predictors of injury. No formal controlled studies have reported a direct link between coaching behaviour or technique and injury risk in gymnastics. In a nine month study of 873 club level gymnasts, there was no detectable relation between injury rates and the number of instructors with or without safety certification or those working part time or full time.[39] Furthermore, results from both prospective and retrospective studies were unable to establish a relation between injury rates and the student/instructor ratio.[23 39 40] However, others have suggested that poor coaching techniques, in which gymnasts are subjected to long practice sessions with few rotations that lead to lapses in concentration and inattentiveness,[24] may be associated with an increased risk of injury.

Coaches must appreciate that they are in a unique position of trust and are important role models for young gymnasts. Willingness to please and loyalty may inspire gymnasts to accept excessive demands from the coach, which may be potentially harmful to the gymnasts' health and well being. There is some suggestion that a gymnast's self esteem can be significantly affected by the coach's feeling, attitudes, and behaviour toward team mates.[37] Coaches should make every effort to create an environment where gymnasts feel secure in sharing any discomforts they may have, either in anticipation of a particular manoeuvre (emotional effect) or after a particular manoeuvre (physical aspect). Gymnasts who feel good about themselves are usually more focused when training and more apt to feel personally safe.[41] Thus, psychological factors are likely to play an important role in relation to the predisposition of injury in gymnastics. In partial support of this notion, Kolt and Kirkby[42] reported that life stress was a significant predictor of injury in 162 elite and non-elite competitive female gymnasts who completed a questionnaire covering personal, training, and injury data. While further studies are needed to examine the influence of psychological factors on injury prevention in gymnastics, it is essential that appropriate care be taken to balance the risk of gymnastics participation with the potential rewards.

Spotting

For both inexperienced and competent gymnasts, spotting is a safety technique designed to assist with the execution of a skill, develop confidence, and reduce the possibility of injury. Poor spotting or no spotting has been suggested as a risk factor for gymnastics injuries.[4 23 24 39 43 44] Although there is no doubt that spotting is important in the early stages of skill learning and the progression of gymnastics skills, information on the effectiveness of spotting with regard to injury prevention is conflicting. In a prospective study of club level gymnastics injuries, Pettrone and Ricciardelli[23] reported that 65% of injuries occurred in the presence of a spotter, which they suggested may be because gymnasts attempt more difficult tasks when assisted by a spotter. In contrast, results from a three year prospective study of competitive female gymnasts showed that, for 85% of all injuries, no active spotter was present.[24] Similar results were reported in a retrospective study investigating 32 elbow injuries in 30 female gymnasts, where about 60% of all injuries in gymnasts occurred when the spotter was not present.[44] After following club level gymnasts for nine months, Weiker[39] also noted that a large proportion (78%) of all injuries occurred without spotting, and concluded that spotting versus non-spotting was the most significant controllable factor in determining the rate of injury. Unfortunately, most of these studies failed to consider the exposure time of the gymnasts to the risk of injury. Therefore, the finding that a high percentage of injuries occurred when a spotter was not present is perhaps expected given that the exposure to injury risk when a spotter is not present is greater than with a spotter. Pettrone and Ricciardelli[23] stated that the injury rate per unit time spent with spotters was lower than the same rate without spotters. However, in the light of the lack of formal evidence and the widespread use of spotting as a potential preventive measure, further controlled studies are needed to investigate the effectiveness of spotting for preventing gymnastics injury.

Performance technique

Correct technique in terms of landing strategies and body posture appears to be essential for optimal gymnastics performance and injury prevention.[45] On the basis of a small case series of 11 female gymnasts who sustained 12 knee

> Despite the widespread use of spotting as a safety technique to assist gymnasts in learning skills, to correct body position, and to develop confidence, further controlled trials are needed to evaluate its effectiveness for preventing injury.

injuries, Hunter and Torgan[46] reported that most of these injuries were sustained during dismounts, especially twisting dismounts from apparatus. Two prospective studies that attempted to examine the mechanism(s) of gymnastic injury reported that dismounts from apparatus were often associated with injury.[20 23] Caine *et al*[20] reported that more than a third of sprains (35.7%) occurred during the dismount, although only 19% of all injuries were classified as sprains in this study. These results indicate that many gymnasts may have trouble satisfying both performance and safety objectives when attempting to land with certain gymnastics skills.[47] Although Priest and Weise[44] suggested that gymnasts who received formal instruction on how to fall early in their career may suffer fewer injuries, the effect of formal instruction on how to fall on injury rates has not been formally investigated.

Owing to the high impact nature of gymnastics, participants must learn to effectively dissipate the large forces and moments applied to the body during landing. In a study examining landing forces after a jump from different heights, McNitt-Gray[48] found that, compared with elite gymnasts, recreational athletes changed their landing strategy to dissipate impact forces over a longer period as impact velocity increased. From these findings, it could be argued that the scoring system used to assess gymnastics performance may need to be reviewed to reduce the magnitude of impact forces imparted to the musculoskeletal system. In support of this contention, Russell *et al*[49] suggest that the rules be changed to de-emphasise "sticking landings" because of the apparent increase in anterior cruciate ligament injuries and the low hamstrings to quadriceps strength ratio in some elite gymnasts. Given that the rules are unlikely to be altered, further research is needed to investigate the influence of different landing strategies on both the magnitude of impact forces and the prevention of injury in gymnastics.

Poor posture has also been considered to be one factor contributing to injuries in gymnastics.[50] The way in which the body is held during both static and dynamic movements can unduly stress skeletal structures through the maldistribution of forces and body weight over structures that are not suited to the various tasks.[50] Poor posture can result from muscular weakness, skeletal deformity, carelessness, and general laziness.[50] A common example of poor posture in gymnastics is excessive arching of the lower back. Pain in the lumbar region of female gymnasts is often associated with hyperextension activities.[51] This is not unexpected in the light of the results from one study which found that maximum lumbar hyperextension in female gymnasts during selected movements—for example, front and back walkovers and back handspring—occurred close to the time that peak impact forces were sustained by the hands or feet.[52] Although there is some suggestion that maintaining a proper technique during training can effectively reduce forces across the lumbosacral spine,[53] it is recommended that gymnasts with known spinal pathologies or a history of low back pain avoid high impact activities associated with excessive hyperextension.

EQUIPMENT

A number of injuries in gymnastics appear to be related to the misuse or inappropriate use of safety devices and equipment.[50 54] At present, foam rubber landing mats, tumbling mats, crash pads, landing pits, protected beams, and salto and twisting belts are used to help reduce the magnitude of forces imposed on the musculoskeletal system and prevent injury.[11] Unfortunately, the development of the sprung floor and spring beams, thicker landing mats, and fibre glass rails to prevent injury has been associated with a trend towards an increase in the difficulty of manoeuvres and risk in the skills performed.[4]

The International Gymnastics Federation has developed specifications for the equipment and landing surfaces used during sanctioned gymnastics competitions to ensure uniformity of apparatus and equity for participants.[55] Although the original focus of these standards was on the geometric proportions of equipment and landing surfaces, the mechanical properties of apparatus have recently been scrutinised by standardised rigid body impact testing.[56] Such rigid tests quantify the impact between inanimate objects in a repeatable and precise manner, although they fail to assess the strategies that gymnasts may use when interacting with different surfaces.[57] The high incidence of injury to the lower extremities of gymnasts associated with foot first landings reflects the need to examine the interaction between the gymnasts and different landing surfaces,[39 40 46 58] especially given that a common mechanism of injury involves dismount landings from apparatus.[20 23 46 59]

Data from a case series study of 30 female gymnasts with 32 elbow injuries showed that thicker landing mats, the presence of spotters, and formal instruction on how to fall may reduce the chances of serious elbow injury.[44] Unfortunately, the nature of this type of study design does not allow one to calculate absolute risks of injury, nor test the hypotheses on the cause of injury. For example, the finding that approximately two thirds of the elbow injuries sustained by the gymnasts occurred when landing on a thinner mat or the floor is perhaps expected given that most landings during training are likely to be on thin mats. Despite these limitations, Goldstein *et al*[60] suggested that using thicker mats during competition may reduce mechanical loading on the spine. In a controlled study of nine female gymnasts, McNitt-Gray *et al*[57] showed that mat composition (soft versus stiff) did not affect the magnitude of peak vertical ground reaction forces. Despite this finding, others have suggested that mats that bottom out to the ground, gaps between landing mats, and hard tumbling surfaces are factors that may also predispose gymnasts to injury.[50]

No formal studies have examined the effectiveness of gymnastics equipment, particularly matting, on injury prevention. However, one investigation using an instrumented drop mass system, in which weights of varying magnitude were dropped from different heights, found that peak vertical ground reaction forces were reduced by at least 50% with the use of a mat and sprung floor combined, compared with a mat placed directly on a concrete floor.[61]

Poorly equipped and/or designed training facilities are also considered to be risk factors associated with gymnastics injuries.[4 39 40 50 62] In an epidemiological study of over 6000 female gymnasts, Bale and Goodway[62] reported that most of the facilities in which the injured gymnasts trained were poor (32%) or only adequate (44%); the lowest percentage of injured gymnasts trained in superior facilities (24%). In contrast, the results of a retrospective study showed that injury rates were no different for clubs with five or more safety devices compared with those with only one or two pieces of safety equipment.[40] The authors suggested that clubs with the highest rate of injury, although having a considerable number of safety devices, may not use this safety equipment. However, there were no data to support this statement. Caine *et al*[4] suggested that the higher incidence of injury in poorly equipped clubs may be because gymnasts and coaches at well equipped clubs attempt more difficult manoeuvres that would not have been considered if the appropriate facilities were not available. Although not directly related to training facilities or equipment design, Lindner and Caine[24] found that equipment failure did not contribute to any injuries in 178 female gymnasts followed for three years.

Injuries and/or pain to the wrist have become a major problem leading to loss of participation time and decreased gymnastics performance.[63 64] The importance of elucidating practical and effective counter measures for the prevention of wrist injuries is highlighted in the study by Mandelbaum *et al*,[63] who found that 88% of male and 55% of female collegiate gymnasts suffered wrist pain during practice or competition. For male gymnasts, the pommel has been implicated as the main contributor to wrist injuries.[63] Previous research has shown that the wrist is exposed to repetitive forces of up to twice body weight during this activity.[65 66] To reduce the potential for wrist injury, padded vaults and foam beam covers have been put forward as possible intervention strategies to absorb the forces imparted to the wrist.[63] It has also been suggested that the development of an ulnar variance wrist brace could restrict the degree of wrist extension or hyperextension on certain apparatus, such as the vault and pommel.[63] It is claimed that this may transfer or distribute the load more evenly over the joint surfaces so as to help absorb some of the compressive forces imparted to the upper extremities.[63] The effectiveness of a wrist brace on injury prevention in this sport is currently under investigation.

> Safety devices and protective equipment are designed to reduce the magnitude of impact and frictional forces imposed on the musculoskeletal system and thereby the potential for injury. However, no formal controlled studies have evaluated the effectiveness of matting, sprung floors, hand guards, padded vaults, or other protective devices for preventing gymnastics injuries.

In skeletally immature gymnasts, wrist pain is often the first sign of growth plate changes at the wrist.[63] Several studies in growing elite gymnasts have reported changes to the distal radial epiphyses, including widening of the growth plate, cystic changes on the metaphyseal region and "beaking" of the distal aspect of the epiphysis, positive ulnar variance and/or premature closure of the growth plate.[63 67–70] Because of the potential for long term damage, it has been recommended that biannual radiographs are performed on gymnasts with continued wrist pain.[71] It is also recommended that gymnasts gradually increase weight bearing support to avoid overloading the wrist at an early age. Wrist strengthening and flexibility exercises should also be performed before and after a workout, and swinging and support events should be alternated during workouts.[4 67] It is also suggested that gymnasts with continued wrist pain discontinue any activity that puts significant stress on the wrist, until the activity can be performed without pain.[4] Further studies are required to ascertain whether the aforementioned recommendations may prevent or reduce the recurrence of wrist injuries in young gymnasts.

Hand guards or dowel grips have become popular among high level gymnasts as the number and difficulty of manoeuvres requiring high angular velocities on apparatus such as the high bar have increased. The development of the hand guard, a leather strap with three finger holes at one end and a strap which wraps around the wrist at the other, has enabled gymnasts to train for extended periods on apparatus such as the high bar because of a reduction in the frictional forces acting on the hands.[72] Although the influence of hand guards on injury prevention remains to be established, one case report of injury to the distal radial epiphysis in a male gymnast advises caution in the use of dowel hand grips in skeletally immature gymnasts.[73] Yong-Hing *et al*[73] speculated that a chronic injury to the distal radial epiphysis in one 13 year old gymnast was due to the tensile forces produced during swinging with the use of dowel grips. Although cause and effect cannot be established from this study, a separate investigation showed that hand guards allowed greater tensile forces to act across the wrist during giant swings on the high bar compared with bare hands alone.[72] As a result, the authors suggested that a redesign of the guards may help to alleviate the potential for injury from forces transmitted by the dowel grips.[72]

Injuries associated with dowel grips usually occur when the grips used by the gymnasts become locked on the bar as the gymnast's momentum continues on through the skill being performed.[74] Others have suggested that grip lock injuries may be caused by grips that are too large, worn, stretched, or slide up the wrist.[74] It has been suggested that injuries could be prevented by careful maintenance of the equipment to ensure that the grips are in good order and fit the gymnast's hand properly.[7]

HEALTH SUPPORT SYSTEM

Medical screening

Medical and musculoskeletal screening programmes are often implemented to identify physical characteristics that may predispose a gymnast to injury.[75] The results from an 18 month epidemiological study of injuries in elite and subelite female gymnasts showed that for each injury, subelite gymnasts reported missing a significantly greater number of training sessions than their elite counterparts.[25] The authors proposed that elite gymnasts may continue to train with and through their injuries, which could be partly attributed to pressure from coaches to continue training to avoid deconditioning.[25] In the light of these findings, it was suggested that periodic musculoskeletal screening may assist with the identification and early diagnosis of injuries that could be aggravated by further training, and allow an appropriate rehabilitation programme to begin. Caine and Lindner[76] also recommended that each gymnast has a preparticipation physical examination before entry into competitive gymnastics, before any change in competitive level, and before returning to training after injury. However, there is no formal evidence to support the role of a medical screening programme for reducing the risk of injuries in gymnastics. Nevertheless, there appears to be a general consensus that the success of a musculoskeletal screening programme for preventing injury is dependent on periodic assessments during participation and that corrective actions be adopted to address identified problems. Large scale studies reporting results of preparticipation physical examinations in high school athletes indicate that one out of every ten athletes screened has an existing problem that merits either exclusion, further evaluation, or rehabilitation before participation.[77] Furthermore, these examinations may be the only periodic health examination for many young athletes.

Support for the potential role of a musculoskeletal screening programme in gymnastics is highlighted by studies that have reported growth plate injuries to the distal radial epiphysis[63 67 69] and an increased injury risk associated with periods of rapid growth in high level gymnasts.[20] The implementation of a screening programme during the so called growing years could help to identify potential skeletal disorders in young gymnasts. In the light of the high incidence of injury and repeat injuries in gymnastics, the preparticipation physical examination may also help to identify gymnasts with previous injury who need further rehabilitation before participation.

> Despite recommendations that periodic musculoskeletal screening may assist with the early identification and management of gymnastics injuries, support for the role and cost effectiveness of a medical screening programme for reducing the risk of injuries is lacking.

Treatment and rehabilitation

Early management of injuries is important in the prevention of re-injury and exacerbation of the current injury. Re-injury is a common problem in gymnastics. One study reported a re-injury rate of 33% in highly competitive female gymnasts.[20] Although it has been suggested that re-injury can be minimised with adequate and appropriate rehabilitation,[78] no studies appear to have investigated the effect of a rehabilitation programme on the incidence of re-injury in gymnastics. Because of the demanding nature of competitive gymnastics, Ryan[79] cautioned that the return of gymnasts to 95% of normal strength, coordination, and flexibility after injury may be insufficient to prevent re-injury, although data to support this contention are lacking. Others have suggested that cross training may offer an alternative means of training and rehabilitation for the injured athlete[80]; conversely there has been some suggestion that cross training may be counterproductive or even dangerous for the athlete.[81] There is also some suggestion that gymnastics clubs should allocate sufficient funds to employ physiotherapists or sports trainers (at least on a part time basis) to help in the early detection and management of gymnastics injuries.[4] However, further studies are needed to investigate the cost effectiveness of trainers or physiotherapists for preventing injuries in gymnastics.

Discussion

Many injury counter measures can be implemented to help reduce the risk of injury in the sport of gymnastics. Effective prevention of gymnastics injuries needs to be based on an understanding of the inherent nature of the sport, its participants and the external environment. Table 2 summarises the extent to which the effectiveness of these counter measures has been formally evaluated or measured. It is clear from this table that most evidence for the potential of counter measures to reduce gymnastics injury is based on anecdotal or informed opinion, uncontrolled data based studies, and several prospective cohort studies. Controlled trials are considered to provide the best scientific evidence, but there is no information for the effectiveness of gymnastics injury counter measures based on randomised controlled studies or actual evaluation of counter measures in the field setting.

Informal opinion as to the knowledge of the demands of gymnastics as a sport suggests that the development of a general conditioning,

Table 2 Summary of the type of evidence for the effectiveness of counter measures against injury in gymnastics (numbers are reference numbers)

Counter measures	Anecdotal or informed/expert opinion	Biomechanical/ experimental research	Data based studies (uncontrolled)	Prospective studies
Coaching				
Physical preparation				
General physical conditioning	4,9,19,20,23,25,38,49,50,82,83,87	—	—	23
Strength training	4,7,10,20,28,50,59,67,71,88	—	—	26
Adequate warm up, flexibility, and cool down	4,7,10,20,23,24,50,67,71,85,88	—	32,33	—
Education				
Education of coaches and gymnasts	4,38,44,67	—	44	39
Coaching techniques and student/instructor ratio	4,10,20,23,24,25,38,50,58,59,62,64,72,85	—	40,64	23,24,39
Spotting	4,7,10,11,39,43,58,62,85,86	—	44	23,24,39
Performance technique				
Landing technique(s) and posture	20,38,44,46,48,49,50,59,84,85,88	48,57,84	44,46	20,23,24
Equipment				
Facilities, equipment design and maintenance	4,50,62,72,74,85,87,89	61	40,44,74	24,39
Use of safety equipment (matting, padding)	4,11,19,38,44,50,60,63,67,71,84,85,88	57,84	40,44	19,23,24,39
Personal protective equipment (dowel grips or handguards)	7,71,72,73,74,85	72	73	—
Health support system				
Medical screening	4,9,10,20,25,49,71,83	—	—	—
Appropriate treatment and rehabilitation	20,62,63,67,71,82,83,85	—	—	—

strength, and/or stretching programme would help to reduce the risk of injury, especially before resumption of training or after an enforced break due to injury. Although there is a general consensus that a general conditioning and/or sport specific strength or flexibility programme should form an integral component of a gymnastics programme, only one small prospective study has evaluated the effectiveness of a strength and stretching programme for preventing gymnastics injuries.[26] Despite the reported benefits of this programme for reducing back injuries in female gymnasts, it is important to consider that only those injuries brought to the attention of the doctor or physiotherapist were reviewed, and the exposure time of the gymnasts to the risk of injury was not considered. Furthermore, it was not possible to determine whether the reduction in the number of back injuries was due predominantly to the effects of the strength training or stretching component of the programme.

Although there is an obvious need for flexibility in the sport of gymnastics and poor flexibility has been suggested as a risk factor for injury, no formal controlled studies have examined the effectiveness of a specific stretching programme for preventing gymnastics injuries. The highest level of evidence for the effectiveness of flexibility in reducing injury is based on several retrospective and cross sectional studies, which provide limited evidence for a cause and effect relation. Most of the evidence for the effectiveness of a stretching, general conditioning, or strength training programme for preventing gymnastics injuries is based on informed opinion or fundamental training principles and experience from other sports. Further large scale trials are needed to examine the optimal intensity, duration, and nature of a conditioning, strength training, or stretching programme for preventing injuries during the various phases of a typical yearly training cycle.

Spotting is considered a vital adjunct to assist performance in learning skills, to correct body position, and to enable gymnasts to develop confidence. The level of evidence for the effectiveness of spotting as a preventive injury measure is based primarily on informed or expert opinion. Although the results from several epidemiological studies of injury patterns have shown that a large proportion of gymnastics injuries occurred without spotting,[23 24 39 40] the level of evidence provided by these studies is limited because the exposure time to injury, which is likely to be greater when the gymnasts are unassisted, was not considered. In the light of the widespread use of spotting as a potential injury preventive measure, further research into its effectiveness is required.

Education of coaches and gymnasts and coaching techniques and/or behaviours are considered crucial in the prevention of gymnastics injuries. However, there is no formal evidence for the effectiveness of these counter measures for preventing injuries in gymnasts. The results of several prospective epidemiological studies examining the association between education and/or coaching behaviours and techniques and injury prevention have produced mixed results. Most of the evidence supporting the effectiveness of education and coaching techniques or behaviours as injury preventive measures is based on informed opinion, anecdotal evidence, and uncontrolled data based studies. Unfortunately, such studies provide limited evidence for a cause-effect relation because they are not able to establish the sequence of events between risk factor(s) and injury.

Correct technique in terms of landing strategies and body posture are also considered essential to prevent gymnastics injuries. Both epidemiological and biomechanical research support the notion that dismount landings and the associated high impact forces imparted to the musculoskeletal system may contribute to injury in gymnastics. However, no controlled trials investigating the influence of formal instruction on how to land or the influence of different landing techniques or strategies on injury rates have been conducted.

The frequency, duration, and intensity of training loads, and the difficulty of skills and increased emphasis on the performance of aerial manoeuvres, will always produce some risk in gymnastics. The use of personal and protective equipment (dowel grips, hand guards, matting) to safeguard gymnasts from injury is one counter measure that has received considerable attention. One controlled laboratory based biomechanical study reported that the use of landing mats and a sprung floor can reduce peak vertical ground reaction forces, and may therefore reduce the potential for injury.[61] However, it is difficult to extrapolate the results from this study to the field setting because it does not assess different strategies used by gymnasts when interacting with different surfaces. Most of the evidence for the effectiveness of personal and protective equipment to prevent gymnastics injuries is based on expert or informed opinion, which appears to arise from epidemiological research into the pattern and/or mechanism(s) of gymnastics injury. Few studies have formally evaluated the effectiveness of matting, sprung floors, hand guards, padded vaults, foam beam covers, or other protective devices for preventing injury. Further studies are needed to examine the load distribution characteristics of equipment and landing surfaces, and particular attention should be paid to the gymnast and measuring the physical stresses on joints, muscles, and tendons during selected gymnastics movements that have been associated with the highest risk of injury.

Hand guards or dowel grips were introduced into gymnastics to cope with the increased performance capabilities of gymnasts and to reduce frictional forces acting across the hands. However, the use of hand guards needs to be fully evaluated in a controlled trial in the light of results from one biomechanical study showing that they allowed greater forces to act across the wrist than bare hands.[72] The effectiveness of these grips for preventing injury needs to be evaluated as a matter of priority given their widespread use by gymnasts and the reported incidence of shoulder problems, wrist pain, and injury to epiphyseal growth plates of skeletally immature gymnasts.

Future research directions

It is evident from the studies reviewed in this article that there is a lack of formal controlled evaluations or scientific evidence for the effectiveness of preventive measures for reducing the occurrence of injuries and re-injury in gymnastics. Further studies are needed to understand the causes of gymnastics injuries so that randomised controlled or prospective cohort studies can be designed to evaluate the effectiveness of potential gymnastics counter measures. However, in the light of the gaps in current knowledge, specific recommendations for future counter measure research and development include:

- research into the influence of general and gymnastics specific physical conditioning programmes and the role of strength training in gymnastics injury prevention;
- investigation into the optimal duration and frequency of warm up, stretching, and cool down as an injury prevention measure;
- greater attention to testing the load distribution characteristics of equipment and landing surfaces; in addition, a formal assessment of the effect of different types of protective matting and padding is needed;
- further research into the development and design of dowel grips or hand guards for preventing wrist and hand injuries in gymnasts;
- continuing biomechanical research into the mechanism(s) of gymnastics injury and the influence of different landing strategies and techniques on injury prevention;
- investigation into the role of education for both coaches and gymnasts to improve their knowledge about injury prevention strategies;
- additional research into the role of spotting as an injury prevention measure;
- investigation into coaches' skills, attitudes, knowledge, and behaviour in relation to injury risk;
- formal evaluation of preparticipation screening programmes and an investigation into the role of health care personnel and rehabilitation programmes on the incidence of injury and re-injury.

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Multiple choice questions

1 The highest level of proof for the effectiveness of injury counter measures is provided by:
(a) cross sectional studies
(b) randomised controlled trials
(c) retrospective cohort studies
(d) prospective cohort studies

2 Despite the lack of formal evidence for the effectiveness of strength training for preventing gymnastics injuries, it is recommended that:
(a) strength training consists of activities specific to the demands associated with the various gymnastics apparatus
(b) strength training is maintained during both the competitive and non-competitive periods
(c) greater emphasis is placed on maximising muscle strength from minimal muscle size
(d) all of the above

3 In which of the following circumstances is spotting required?
(a) only with young and inexperienced gymnasts to enable them to develop confidence
(b) only when gymnasts are learning new and difficult manoeuvres
(c) at all stages to assist with learning skills, to develop confidence, and to correct body position
(d) during training but not competition

4 Which of the following statements are correct?
(a) hand guards or dowel grips allow greater tensile forces to act across the wrist during swinging manoeuvres compared with bare hands alone
(b) peak vertical impact forces can be reduced by at least 70% with the use of a sprung floor compared with a mat alone
(c) soft landing mats have been shown conclusively to result in lower peak vertical impact forces compared with stiff landing mats
(d) all of the above

5 It is recommended that a preparticipation physical examination is administered to all gymnasts:
(a) before entry into competitive gymnastics
(b) before any changes in competitive level
(c) before returning to training after injury
(d) all of the above

Essay questions

1 You have been instructed to review the safety measures of an elite gymnastics program. What factors would you assess and what recommendations would you make?
2 Discuss the role and benefits of a physical conditioning programme for the prevention of injury in gymnastics?

Take home message

Evidence for the effectiveness of counter measures, including coaching (physical preparation, education, spotting, and performance technique), equipment, and the health support system (medical screening, treatment, and rehabilitation), in preventing gymnastics injury is based largely on informal and anecdotal opinion and results from uncontrolled data based and epidemiological studies. Formally controlled randomised trials are needed to confirm the extent to which key injury prevention counter measures can prevent or reduce the occurrence of (re)injury.