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REVIEW

Triathlon related musculoskeletal injuries: The status of injury prevention knowledge

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Summary Triathlon is a popular participation sport that combines swimming, cycling and running into a single event. A number of studies have investigated the incidence of injury, profile of injuries sustained and factors contributing to triathlon injury. This paper summarises the published literature in the context of the evidence base for the prevention of triathlon related injuries. Relevant articles on triathlon injuries were sourced from peer-reviewed English language journals and assessed using the Translating Research into Injury Prevention Practice (TRIPP) framework. This review highlights the significant knowledge gap that exists in the published literature describing the incidence of injury, the profile of injuries sustained and evidence for the prevention of injury in triathlon. Despite the number of studies undertaken to address TRIPP Stages 1 and 2 (injury surveillance, aetiology and mechanism of injury), most triathlon studies have been limited by retrospective designs with substantial, and unvalidated, recall periods, inconsistency in the definitions used for a reportable injury and exposure to injury, or a failure to capture exposure data at all. Overall, the paucity of quality, prospective studies investigating the incidence of injury in triathlon and factors contributing to their occurrence has led to an inability to adequately inform the development of injury prevention strategies (TRIPP Stages 3—6) for this sport, a situation that must be rectified if gains are to be made in reducing the burden of triathlon related injury.

Contents

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Introduction

Since the mid 1970s participation in triathlon has steadily grown with 1500 members in 1982[1] to 58,073 nationally registered triathletes in the USA in 2005[2] and an estimated 160,000 triathletes participating in the 2005—2006 Triathlon Australia season.[3] There are currently 120 International Triathlon Union (ITU) affiliated national federations with triathlon awarded full medal status on the Olympic programme in 1994, making its debut at the 2000 summer games in Sydney, Australia.[4] Australian Triathlon Championship events are primarily run over four race distances: Sprint (750 m swim/20 km bicycle/5 km run), Olympic (1.5 km swim/40 km bicylce/10 km run), Long (2 km swim/80 km bicycle/20 km run) and Ironman (3.8 km swim/180.2 km bicycle/42.2 km run),[5] however variations of these distances often exist with the Half Ironman distance (1.9 km swim/ 90.1 km bicycle/21.1 km run) being a common example.

The increase in triathlon participation over the past 30 years has been accompanied by a rise in the number of papers reporting injury data over the varied triathlon race distances.[6—27] Given the rise in triathlon participation, and in published papers relating to triathlon injury, it would seem timely to review the literature describing the incidence of triathlon related musculoskeletal injury and the evidence base for prevention of injuries in this sport.

The Translating Research into Injury Prevention Practice (TRIPP) framework has recently been published with the aim to guide the conduct of research that will have ''real-world injury prevention gains'' in the sporting context.[28] The TRIPP framework describes a series of six steps necessary for providing an evidence base for injury prevention: injury surveillance, aetiology and mechanism of injury, identification and implementation of preventive measures, evaluation of the preventive measures under ideal conditions, understanding of the interventional context and finally evaluation of the effectiveness within the real world framework. This model is based on the four-stage model described by van Mechelen et al.[29] and the updated model provides a useful framework for assessing the status of the evidence base for the prevention of triathlon related injuries, enabling the strengths and weaknesses of current evidence to be addressed and to provide strategic recommendations for future work in this area.

Method

A search strategy to identify relevant triathlon specific articles was employed using electronic databases including MEDLINE, CINHAL, PubMed, PsychINFO and SPORTDiscus from 1974 to February 2007. The electronic databases were searched and further hand searches for relevant research studies were completed from the reference lists of identified articles. The searches undertaken used a variety of the following key words; triathlon, injury, injury prevention, epidemiology, incidence, risk factors, prevalence, overuse injuries, acute injuries and musculoskeletal injury. Only triathlon specific musculoskeletal injury studies published in peer-reviewed English language journals were included in this review as were case series of triathlon team cohorts. Case studies of individual injury presentations or review papers of triathlon injuries were excluded. Case studies were excluded as they present information on unusual presentations or treatment approaches and are not within the scope of a review investigating common injury profiles and associated risk factors in triathlon. Studies describing injury incidence or prevention in only the individual sub-disciplines (i.e. swimming, cycling running), outside the context of the combined training observed in triathlon, were excluded.

Results and discussion

Twenty-two relevant papers meeting all inclusion and exclusion criteria were identified. The TRIPP framework was used to assess and classify the relevant papers according to their contribution to the evidence base for the prevention of triathlon injury. A summary of the race distances, populations studied, methods of data capture and athletic status for each study is presented in Table 1. A more comprehensive table describing each study with added sections on the definition of a triathlon injury used in the study and the key results for the reporting of injury incidence and the main site of injury occurrence can be found in AppendixA.

TRIPP Stage 1: injury surveillance

The first TRIPP stage is injury surveillance, in which the extent of any problem must be identified and described in terms of incidence and severity of sports injuries[29] through the use of valid and reliable methodologies, and standardised injury and exposure definitions.[29,30] Scientifically rigorous studies provide knowledge on the incidence and the extent of any injury problem and when the injuries occur. Understanding when injuries occur, the body regions affected, severity of injury and the context in which they occur allows for appropriate targeting of investigations to determine key risks factors and the potential impact of injury on the individual and the community. Injury surveillance guides the prioritisation of injuries for investigation, informs the development of aetiological studies and injury prevention strategies, and provides a means for monitoring changes in injury incidence and patterns over time.

Incidence of triathlon related injuries

Injury incidence has been reported for triathlon in Olympic distance,[14] Ironman,[10,20,22,27] and for mixed distances of triathlons.[6–9,12,13,16–19,21,23–26,31] The incidence of injury reported in the triathlon literature has ranged from 37%[9] to 91%[20] of triathletes surveyed reporting at least one injury over the specified data capture period. When identified as a percentage of the total numbers of injuries reported, training injuries accounted for between 75% and 83% of reported injuries[13,16,23] while the percentage of injuries that occurred during competition ranged from 8% to 28%.[16,23] However, when injury rates have been reported in terms of hours of training or competition exposure, a higher rate of injury has been reported for competition (17.4 injuries per 1000 h of competition[17]), compared to training (0.7–5.4 injuries per 1000 h[9,17]).

Despite the figures for injury incidence presented, cautious interpretation of these results is warranted as the methods for reporting incidence have been inconsistent and the methods used to collect injury incidence data have generally been poor (Table 1 and Appendix A). The first TRIPP stage centres on the premise of providing ''high-quality injury surveillance information''[28] and most of the published triathlon studies to date have had substantial limitations.

Incidence rates require the determination of numbers of injury cases occurring over a prescribed time frame.[32] It is difficult to compare the incidences of triathlon injuries across studies for two major reasons. Firstly, the definition of injury used by each of the studies varied, preventing direct comparison of studies as the type and severity of injuries eligible for inclusion varied across the studies (Appendix A). Secondly, the duration of the data reporting period varied from 1 year or less[8,9,12] to the triathlete's entire participation history,[6,10,16] with some even failing to report a data capture duration[19,25,27] (Table 1). Even when the studies have used the same recall period,[8,15,19] there has been substantial variability in the incidences reported, probably due to the different definitions used for a reportable injury (Appendix A). Many of the papers presented used retrospective study designs, often with extensive recall periods without validation of self-reporting of injury information over these timeframes.[10,11,13,14,16,18,21,23] Previous research has indicated a decline in recall accuracy with increased detail requested over a 12 month period,[33,34] highlighting the issues with the recall periods used by many triathlon studies. The use of a prospective study design minimises the potential for recall bias as injury data are generally captured as they occur. Only two previous studies have investigated triathlon injuries using a prospective cohort design[12,17] and then only over limited timeframes of 8 and 13 weeks. Two recent Australian studies used prospective recruitment, but still required a retrospective recall of injuries sustained over the 10 week competition season investigation.[7,9]

Site of injury

The most commonly injured region reported has been the lower limb, with studies reporting that

Table 1 Overview of identified triathlon specific injury studies identifying the race distance, the study design employed, the population number studied and the athletic status of the population investigated

Study	Race distance	Study design	Population	Athletic status
Villavicencio et al.[6]	Mixed	Retrospective survey—lifetime	$n = 87$	Elite and non-elite
Burns et al.[7]	Not reported	Two retrospective surveys [6 months (pre-season) and 10 weeks (competition)]	$n = 131$ pre-season, $n = 128$ competition.	Elite and non-elite
Shaw et al.[8]	Not reported	Retrospective survey—12 month recall	$n = 258$	Elite and non-elite
Burns et al.[9]	Not reported	Two retrospective surveys [6 months (pre-season) and 10 weeks (competition)]	$n = 131$ pre-season, $n = 128$ competition.	Elite and non-elite
Egermann et al.[10]	Ironman	Retrospective survey—triathlon career	$n = 656$	Elite and non-elite
Clements et al.[11]	Not reported	Retrospective survey—3 year recall	$n = 58$	Elite and non-elite
Fawkner et al.[12]	Olympic distance to Ironman	Prospective study—13 weeks	$n = 56$[a]	Not reported
Cipriani et al.[13]	Not reported	Retrospective survey—10 year recall	$n = 52$	Non-elite club
Vleck and Garbutt[14]	Olympic distance	Retrospective survey—5 year recall	$n = 194$	Elite and non-elite
Manninen and Kallinen[15]	Not reported	Retrospective survey—12 month recall	$n = 92$	Non-elite club
Wilk et al.[16]	Not reported	Retrospective survey—triathlon career	$n = 72$	Non-elite club
Korkia et al.[17]	Long and short distance	Prospective study—8 weeks	$n = 155$	Elite and non-elite
Migliorini[18]	All distances	Retrospective case series (3 years).	$n = 24$	Elite
Collins et al.[19]	Other distance[b]	Retrospective survey—12 month recall and single event surveillance	$n = 257$	Elite and non-elite
O'Toole et al.[20]	Ironman	Retrospective survey—12 month recall	$n = 95$	Elite and non-elite
Williams et al.[21]	Short course, middle course and long course	Retrospective survey—triathlon career	$n = 332$	Not reported
Massimino et al.[22]	Ironman	Retrospective survey—unspecified recall	$n = 81$	Elite and non-elite
Ireland and Michelli[23]	Up to Ironman	Retrospective survey—triathlon career	$n = 168$	Not reported
Hiller et al.[24]	Olympic to Ironman	Single event surveillance	$n = 794$	Not reported
Levy et al.[25]	Not reported	Retrospective survey—unspecified recall	Triathletes: $n = 31$	Non-elite
Levy et al.[26]	Not reported	Retrospective survey—unspecified recall	Triathletes: $n = 31$	Non-elite
O'Toole et al.[27]	Ironman	Retrospective survey—unspecified recall	$n = 46$	Not reported

[a] Fawkner et al.[12] investigated a total of 98 participants ($N = 98$) from three sporting activities: women's field hockey, women's volleyball and triathlon.
[b] Collins et al.[19] investigated triathletes who participated in 1986 Seafair Triathlon: 1 km swim, 28 km cycle and 10 km run.

36%[21] to 85%[23] of all the injuries sustained by triathletes were to the lower limb. Within the lower limb, knee and ankle/foot injuries have been predominant with rates, as a percentage of all injuries reported, ranging from 14%[14] to 63%,[20] and 9%[15] to 35%,[10] respectively. Back and shoulder have also been identified as common sites of injury with reported levels as high as 72%[20] and 19%[10], respectively of all injuries reported in Ironman triathletes. Nevertheless, the extent to which these results may have been limited by the levels of detail and terminology used for injured body regions remains unclear. For example, the Burns et al.[9] questionnaire requested injury site information from respondents almost exclusively limited to the lower limb, hip and back, although their injury definition provided explicitly states ''... any bone or soft tissue problem ...''. The categorisation of injuries in the preceding example may have resulted in a over-reporting of lower limb injuries and under-reporting of upper limb injuries. Problems also exist in the triathlon injury surveillance literature due to injury site reported with injury type,[19] variations in reporting injuries either as grouped sites[10,20] or single sites,[17] and a lack of consensus between studies makes comparisons in determining the profile of the site of injuries sustained in triathlon difficult.

Severity of injury

Severity of injury is a measure of the impact of injury and is described on the basis of six criteria including: nature of injury, duration and nature of treatment, sporting time lost, working time lost, permanent damage and cost.[29] This information is important for describing the injury problem in detail, prioritisation of injury prevention activities on the basis of severity or impact, and for guiding research in the later stages of the TRIPP framework.

The nature of injury has often been misreported in the triathlon literature, commonly used interchangeably with mechanism of injury, or including mechanisms as categories of nature of injury.[9,13,14,16,19,20,27] The misreporting of injury is highlighted by studies that utilise overuse injuries as a category for nature of injury,[9,13] fail to report the nature of overuse injuries,[14,16,19,20] or refer to acute presentations such as muscle strains as overuse.[27] When the nature of injury has been reported it has mostly relied on self-reporting by the study participants. The reporting of nature of injury information by the study participants, i.e. people without clinical expertise could, account for the large ranges in injury types reported such as muscle/tendon injuries (30%[23] to 55%[17]), tendinitis (13% [18] and 25%[17]), ligament/joint injuries (6%[22] and 29%[10]), contusions and abrasions (51%[10]), and miscellaneous or ''other'' (23%[23] to 27%[17]). The validity and reliability of descriptions of injuries by the triathlete participants could be questioned as there is the possibility that the triathletes may not understand the difference between injury descriptors such as the differences between muscle/tendon or joint/ligament injuries. Of the papers identified in this review, seven provided specific injury diagnostic information reported by triathletes,[6,10,11,17,19,22,23] however only two studies used confirmed diagnosis by medical or allied health practitioners.[18,24] Validation of self-reporting of nature of injury information has not yet been undertaken in any study on triathlon injury and, combined with the inconsistencies in measurement methods for nature of injury, the overall quality of nature of injury information is poor.

The establishment of duration of recovery and treatment of triathlon injuries is important in the context of determining injury severity, estimation of costs and its impact on injury prevention programs. The reporting of injury treatment has been inconsistent with some studies only reporting the type of, if any, health professional seen[16,17,23] while another reported only the level of medical intervention as none, low, and hospital or higher.[10] An understanding of the health service usage of triathletes would enable a greater information base for prioritisation of injuries for aetiological investigations.

The impact of injury in terms of sporting and work time lost and permanent damage is another key indicator of the severity of injury. Retrospective reporting of injury impact found that 20% of all injured triathletes reported an injury severe enough to stop training or racing,[21] and injuries caused 17% to stop swimming, 26—75% to stop cycling and 42—67% to stop running when comparisons were made across levels of athlete participation.[14] A prospective trial found similar results where injuries caused running, cycling and swimming training to be stopped in 78%, 37% and 21% of injured athletes, respectively.[17] Injuries have been reported to be severe enough to stop training for all three training activities in 16% of cases and 17% of the injured research cohort missed a planned competition, while five injuries resulted in work absences.[17] Wilk et al.[16] reported that the injury caused an interruption to training in 78% of cases, an absence from a planned competition for 33% of cases, hindered daily activity for 64% of cases, and absence from work in 15% of cases. Only 4% of injuries resulted in permanent loss of function or impairment using a question that required self-determination by the sampled athletes.[16]

Quantifiable time off from training has been reported by a number of studies with O'Toole et al.[27] reporting an average of 2 months of lost training time for men and between one and two and a half for women, while Ireland and Micheli[23] report an average time off of 3 weeks with a range from 0 to 9 months. When time off was assessed relative to the individual sports of triathlon, club level athletes lost 13 ± 58 days (mean $\pm$ standard deviation) of swimming, 21 ± 65 days of cycling and 71 ± 174 days of running.[14] The reported duration of lost participation time was lower across all three activities for the elite and development groups.[14]

Overall, triathlon injuries appear to most commonly impact on running and cycling training (Appendix A). However, despite the findings reported, comparison of studies describing the impact of injury on training and racing is difficult due to the use of retrospective methods of data collection,[14,16,23] differences in the methods of measurement of this important aspect of injury severity,[14,16,23] and variability in the definition of a reportable injury.[14,16,17] Papers that have reviewed time off from injuries have failed to address whether this is cumulative over the sample period or for one discrete injury instance. For studies that reported actual time missed for all training, there is the potential for this to be misleading as many triathletes may modify their training and only stop activity in one of the three subdisciplines or may experience a carry-over effect from interdisciplinary training as indicated by Vleck and Garbutt.[14] The impact of continued training in the presence of an injury is unknown but could contribute further to injury severity and injury recurrence as previous injury has been associated with future injury occurrence.[7,9,17]

The impact of injuries on psychological wellbeing has not been studied in triathlon and only one study to date has reviewed the daily living impact of injuries on triathletes as part of a mixed population trial. De Longis et al.[35] reported significant increases in weekly hassles using a modified Daily Hassles Scale after an injury in a sample population of injured triathletes, hockey and volleyball participants, compared to a similar non-injured population.[12] The results of previous studies[12,16,17] suggest that the impact of triathlon related injuries may extend beyond training or competition interruptions, and further investigation is warranted in this area. To date, no study has been identified to establish the cost of triathlon injury to either the individual or the community.

Summary of evidence for TRIPP Stage 1: injury surveillance

Overall, the deficiencies in the provision of quality injury incidence data has been primarily due to many investigations using retrospective recall of injury information,[6–11,13–16,19–23,25,27] recall periods of greater than 1 year,[6,10,14] a failure to validate the self-reporting of injuries against appropriate medical diagnosis,[6,8–10,12–17,19–23,25–27] inability to differentiate between injuries sustained in training and competition,[6,8,11,12,14,15,20–22] the potential confounding of recurrent or multiple injuries,[7–9,17,19,20,23] selection biases for those athletes either with or without injury,[6] exclusion of traumatic injuries,[19] reporting of injuries for mixed race distance competitors without comparisons between groups,[6,18,23,25,26] comparatively small sample sizes,[6,11–13,15,16,18,20,22,25–27] the use of triathletes of mixed ability without comparing between groups,[6,11] gender comparisons based on disproportionate numbers,[10,15,17,19] incomplete response rates for surveyed populations (2–78%[6,8–10,13–17,19–21]) and failure to use standardised injury and exposure data definitions[6,8–12,14,16–21] (Table 1, Appendix A).

TRIPP Stage 2: establishing aetiology and mechanisms of injury

The second stage of the TRIPP framework highlights the need for ''understanding the aetiology of why injuries occur''.[28] Identification and understanding of injury aetiology, including mechanisms of injury, activity at the time of injury and risk factors for injury, is important to allow for appropriate targeting of prevention programs. Bahr and Krosshaug[36] suggested that the sum of intrinsic and extrinsic risk factors prepares the susceptible athlete for an inciting event resulting in injury. The nature of the intrinsic and extrinsic risk factors can only be ascertained through a broad interdisciplinary approach using various methodologies.[28,37] Injury surveillance is important in informing this stage. The limitations described for triathlon injury surveillance studies also impede the ability of the studies to accurately identify aetiological and risk factors contributing to the burden of injury. Nevertheless, the studies that have investigated risk factors, and their specific limitations, are summarised in the following sections.

Mechanism of injury and activity at time of injury

The injury rate in triathletes has been reported as greater than those observed in athletes who participated in only swimming, cycling or running[25,26] but similar to rates observed in runners,[9,13,17] but the cause of this variability in the rate of injury is unclear. The descriptors of overuse or traumatic injury causes have often been reported in the literature as mechanisms of injury. The reported incidence of traumatic injuries has ranged from 15%[22] to 56%[14] of injuries, and traumatic injuries have been further divided into mechanistic type actions such as twist and turn events, contact or collision and overstretching, accounting for 12%, 10% and 9% of reported injuries, respectively.[17] Overall, overuse has been the most commonly reported cause of triathlon injury across all levels of participation, ranging from 41%[17] to 91%.[20] However, studies investigating overuse injuries have often failed to provide a definition of an overuse injury[10,19,22,23] or have relied on the athlete's self-report of an overuse injury based on their interpretation of examples given.[9,14,16,17,19] The variability in the definitions of ''overuse'' used and the resulting lack of a clear consensus of what constitutes overuse provides limited evidence for informing injury prevention research and activities in the sport of triathlon.

When considering the activity at the time of injury, running has been identified as the activity most commonly associated with triathlon injury, especially for injuries to the lower limb.[9—21] An example is provided by Collins et al.[19] who reported that all self-reported stress fractures, plantar fasciitis, ankle and lower limb injuries in triathletes were linked to running activities. Cycling-related injuries have also been commonly described, accounting for 5%[9] to 50% of injuries reported,[21] while Egermann et al.[10] reported that of the all fractures sustained (12% of all injuries), 76% were attributable to cycling. Other authors have suggested that training or race sessions combining the elements of cycling and running contribute 5%[23] to 10%[18] to the injury incidence. Swimming related injuries have been reported less commonly in triathletes, accounting for 1%[9] to 12%[17] of reported triathlon injury cases.

Again, the limitations of the studies investigating injury provide a difficult climate for evaluating and comparing the reported mechanisms of injury in triathlon. Nevertheless, despite the limitations of surveillance studies to date, there does appear to be some consensus in the literature that non-traumatic injuries are common and that the disciplines of running and cycling are more commonly associated with injury than swimming. However, without adjustment for time spent participating in each of these activities, it is unclear whether the greater incidence of running and cycling related injuries, relative to swimming, is a product of greater participation (exposure) time spent in these disciplines rather than an increased risk of injury inherent in the specific activity.

Intrinsic and extrinsic risk factors

A number of intrinsic and extrinsic risk factors for triathlon related injury have been proposed in the literature. Intrinsic risk factors consist of the internal personal factors that may contribute to a sports injury, while extrinsic factors are all the external, environmental factors that could contribute to injury.[29] A summary of the existing evidence for the contribution of the proposed risk factors to triathlon injury is provided in Table 2. While psychological and nutritional factors have been proposed as potential contributors to the risk of triathlon injury,[13] these have not been formally investigated to date.

There have been twelve studies that have formally investigated an association between risk factors and injury incidence in triathletes[6—10,14,15,17,19—21,23] and only three of these have used a prospective study design[7,9,17] (Table 2). All three prospective trials found significant associations between some of the potential risk factors studied and triathlon injuries, but these positive associations were limited to previous history of injury,[9,17] years of triathlon experience[9] and a supinated foot type[7] (Table 2). Conflicting evidence has been reported between studies that have evaluated age,[6,9,10,15,17,19] gender,[6,10,15,17,19] anthropometric measures,[6,14,15,17,19] biomechanics,[7,15] training load,[6,8—10,14,15,17,19—23] warm-up and cool down participation,[9,17,23] athletic status,[6,8,17,19] triathlon competition distance,[17,21] participation in other sports[15,19] and triathlon experience[6,9,14,17,19,21] as possible risk factors for sustaining a triathlon related injury although the prospective studies undertaken to date have not found a significant association between age, gender, anthropometric measures, training load, warm-up and cool down, stretching, running surface and triathlon competition distance, and injury risk[7,9,17] (Table 2).

While a number of potential causative factors have been suggested in the triathlon injury literature, many have not been formally investigated to date. Of the risk factors formally investigated, many have only been investigated using retrospective designs which have significant limitations with respect to recall of exposure to potential risk factors, and an inability to determine whether the differences seen between injured and uninjured triathletes were pre-existing or the result of

Table 2 Summary of the existing evidence describing the aetiology of triathlon injuries and their prevention

Risk factor	Studies investigating factor	Evidence
Intrinsic		
Age	6, 9, 10, 15, 17, 19	±
Gender	6, 10, 15, 17, 19	±
Anthropometric characteristics	6, 14, 15, 17, 19	±
Triathlon experience	6, 9, 14, 17, 19, 21	±
Previous injury	6, 9, 17	+
Biomechanics	7, 15	±
Supinated foot type	7	+
Pronated foot type	7	−
Bike position and aerobar use	15	−
Extrinsic		
Training hours per week	6, 8, 9, 10, 15, 17, 20, 23	±
Running time	23	−
Cycle time	15, 23	−
Swim time	23	−
Training distance per week	9, 14, 17, 19, 20, 21, 22	±
Running mileage	9, 19	±
Cycle mileage	14, 19, 21	±
Swim mileage	14, 19	±
Training sessions per week	14, 17	±
Run sessions	14	+
Training intensity	14, 15, 17, 20, 22	±
Cycle pace	14	+
Training intensity	14, 15, 17, 20, 22	±
Training load increases	17	−
Presence of a coach	10, 19	−
Medical care	10	−
Warm-up and cool down	9, 17, 23	±
Stretching	15, 23	−
Strength training	15, 17, 19	−
Running surface	17	−
Athletic status	6, 8, 17, 19	±
Ironman performance	10	+
Triathlon competition distance	17, 21	±
Other sports	15, 19	±

Evidence: +, increasing susceptibility/risk; −, no increased susceptibility/risk; ±, possible/conflicting evidence.

injury. In addition, interpretation of the findings and direct comparison of studies is further limited by: (i) failure to provide a consistent injury definition, the use of injury self-reporting, failure to validate injury occurrence and training or race exposure; (ii) differences in the population groups (elite vs. age group), injury occurrence (training vs. competition), race distances, race details or any combinations of these factors and; (ii) Insufficient sample sizes to establish a relationship and failure to utilise an adequate prospective cohort design with appropriate power as required under the TRIPP Stage 2 framework.[28] Rigorous prospective cohort investigations are needed to determine the association between many of the proposed risk factors and the incidence of triathlon related injuries and to aid in the development of preventive strategies for triathlon participants.

TRIPP Stage 3: develop preventive measures

Once the extent of the injury problem has been identified, priorities for prevention have been set, and factors contributing to the occurrence of triathlon injury have been identified, the TRIPP framework suggests that the next stage involves the ''identification of potential solutions to injury problems and development of appropriate preventive measures''.[28] The development of preventive measures in triathlon has arisen from single event studies or reviews such as the Hawaiian Ironman World Championship event,[24,27,38,39] anecdotal experience of the important injury considerations for medical staff involved in triathlon[40–42] or a review of all conditions likely to be of concern during a triathlon event.[43–46] These papers have predominantly focused on secondary (early diagnosis, early treatment and improved prognosis of injuries) and tertiary prevention (reducing the likelihood of disability and prolonged sequelae of injuries) of injuries, such as ensuring adequate medical facilities are available to deal with athlete injuries or describing proposed treatment of triathlete injuries.[13,24,27,38–47]

While secondary and tertiary prevention strategies play an important role in reducing the burden of triathlon injury, the development of primary interventions aimed at reducing the risk of an injury occurring, or reducing the severity of an injury sustained, remain a high priority. Primary prevention strategies suggested in the literature include stretching,[13,18,22] warm-up and cool down participation,[9] pre-screening and weekly monitoring of triathletes,[42] the use of appropriate foot wear and shock absorption in running shoes,[13,20] appropriate usage of gear ratios while cycling,[18,41] appropriate and correct techniques for training and conditioning[13,47] and practising cycling to running transitions.[18] To date only the stretching, warm-up and cool down participation have been formally investigated, with no association to injury incidence found for stretching[17,23] and conflicting associations reported for warm-up and cool down[9,17,23] (Table 2). None of the other abovementioned strategies has been formally studied to determine whether they have any impact on the incidence and severity of injuries sustained by triathletes. Sound scientific investigations are required to determine efficacy of proposed prevention strategies for triathlon participants.

TRIPP Stages 4—6

Once prevention strategies have been developed, the final three stages of the TRIPP framework suggest incorporation of the scientific evaluation of the preventive strategy under ideal conditions, the translation of efficacious research into a real-world context and then, finally, implementation and evaluation of the preventive model under real-world conditions.[28] It is these final stages that have been largely ignored in the triathlon literature. The majority of widespread injury prevention behaviour in the sport has been implemented due to incorporation of community based preventive measures into the triathlon context and culture, and largely comes from policies developed by other organisations and government legislation to cover all recreational and sporting activities. For example, the Sports Medicine Australia heat policy[48] and mandatory wearing of bicycle helmets in Victoria, Australia.[49] The community policies, while active in the broader recreational context (i.e. bicycle helmet legislation in some countries), have not been specifically developed from research into the incidence and aetiology of triathlon injuries.

Conclusion

This review has highlighted the significant knowledge gap that exists in the published literature describing the incidence of injury, the profile of injuries sustained and evidence for the prevention of injury in triathlon. Despite the number of studies undertaken to address TRIPP Stages 1 and 2 (injury surveillance, aetiology and mechanism of injury), most studies undertaken to describe the incidence of injury, and risk factors for injury, in this sport have been limited by retrospective designs with substantial recall periods, inconsistency in the definitions used for a reportable injury and exposure to injury, or a failure to capture exposure data at all. Overall, the paucity of quality, prospective studies investigating the incidence of injury in triathlon and factors contributing to their occurrence has led to an inability to adequately inform the development of injury prevention strategies (TRIPP Stages 3—6) for this sport, a situation that must be rectified if gains are to be made in reducing the burden of triathlon related injury.

The identification of injuries and factors that contribute to their occurrence in the sport of triathlon is complicated due to the combination of running, cycling and swimming, multiple race lengths, both genders participating, the broad age range of participants, and differences in training regimes to appropriately prepare the athlete for their selected competition level and distance. Training regimes are complex and varied, providing a significant challenge for measuring exposure (i.e. time at risk) in this sport. Nevertheless, to progress injury prevention in triathlon, the first issue that must be addressed is the provision of quality injury incidence and profile of injury data, including the development of standardised approaches to measuring the injury definition, exposure, nature, mechanism and severity of injuries sustained. Perhaps the best approach to addressing these issues would be the development of a consensus statement for injury reporting and surveillance, a path successfully followed by other sports such as cricket[50] and football (soccer).[51] This approach would guide future studies, overcome the limitations of existing studies and provide the basis for tackling injury prevention in this sport. Without a systematic and staged approach to injury prevention in triathlon, improved safety of participation within the sport is unlikely.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.jsams.2007.07.009.

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