

**The UNC Triathlete Health and Fitness Survey:
An Epidemiological Cohort Study of Training Practices and Injury Patterns
in North Carolina Triathletes**

By

Joshua N. Tennant

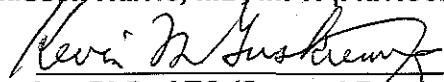
A Master's Paper submitted to the faculty of
the University of North Carolina at Chapel Hill
in partial fulfillment of the requirements for
the degree of Master of Public Health in
the Public Health Leadership Program.

Chapel Hill

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Russell Harris, MD, MPH (Advisor)



Kevin Guskiewicz, PhD, ATC (Second Reader)

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Introduction

The sport of triathlon is a physically demanding activity that has seen great growth in popularity among physically active individuals in recent years.²⁰ Because of the potential risks involved in training for and competing in triathlons, it is the responsibility of the public health and medical community to assess the safety issues with the intent of offering injury prevention methods for those involved with the sport.

Triathlon is traditionally composed of swimming, biking, and running—usually in that order. Lengths of triathlons vary, ranging from the sprint triathlon (0.5 mile swim, 12 mile bike, and 3.1 mile run) to the Ironman triathlon (2.4 mile swim, 112 mile bike, and 26 mile run). Intermediate lengths include the Olympic (1 mile swim, 24 mile bike, and 6.2 mile run) and half-Ironman (half the length of the Ironman) distances (**Table 1**). All such races are considered full triathlons.

The purpose of this paper is to: 1) provide a systematic review of the epidemiological injury literature concerning triathletes, 2) compare this body of literature to similar epidemiological survey studies in the component disciplines of swimming, cycling, and running, and 3) offer a study design to more accurately characterize the needs for injury prevention in triathletes based on lessons learned from existing literature.

Significance

History and growth of the sport

The tremendous growth of the sport since its inception in the 1970's, with large numbers of both new and experienced participants, warrants a careful examination of the causes of injuries in these athletes. Early swim-bike-run

triathlons began as a creative alternative for runners in California training for marathons and 10Ks. Organizers from the San Diego Track club intended the races, first held in San Diego's Mission Bay on summer evenings in 1974, to be entertaining and lighthearted breaks from constant running training regimens. Triathlon's popularity grew tremendously after the creation of the Ironman in Hawaii in 1978, with television broadcasts of the event beginning in 1980. While the Ironman remains the sport's most recognizable event, the average triathlete is more likely to participate in the more popular Olympic and Sprint distances.²

According to USA Triathlon, the governing body of the sport, the most recent estimate for U.S. triathlon participants is approximately 450,000 people. With the rapid growth of the sport in Europe and Asia over the past several years, the number of triathletes in the world is approaching 2 million people.²⁰

In the year 2005, the North Carolina Triathlon Series (NCTS), the largest triathlon series of its kind in the United States, had 11,000 online entries by 4,000 unique individuals. Sixteen races between the months of March and October comprise the series, including 11 Sprint, 3 Olympic, and 2 Half-Ironman distance events. The Endurance Development Series (EDS), a smaller North Carolina series designed for more novice triathletes, enrolled 2,050 unique participants in only its second year since beginning in 2004. The EDS consists of 12 races, 10 Sprint and 2 Olympic distance events, held between March and September.²³

This fast growing sport attracts 450,000 people in the United States and 2 million people worldwide, therefore begging the question of what the short and long-term risk of injury might be for the group of individuals which ranges in age from 6 to 90 years old.

Unique demands of the sport

The physical demands and health risks of the sport, given the perceived benefits of exercise, competition, and camaraderie of the sport, further emphasize the need for researchers to study the sport. With the current popularity of and influx of new participants to triathlon, it is important to consider the injury profile that is unique to multisport training and competition. While cross-training in several different disciplines may serve to reduce the stresses of repetitive over-training, the unique combination of swimming, biking, and running in a sustained training regimen or an intense endurance race may cause the triathlete to be more prone to certain types of injuries. Risk factors for injury may be multifactorial, classified as extrinsic (factors independent of the athlete) or intrinsic (factors inherent to the athlete).⁶

By identifying risk factors, we may be able to decrease the number of preventable injuries sustained by triathletes. We are seeking to better understand training regimens affect injury patterns within a temporal context, with the hope of identifying quantifiable relationships between training practices and patterns of injury. Such important information will serve to guide future practice of injury prevention for triathletes, coaches, and health care providers who care for injured and non-injured triathletes.

Inconsistent findings in previous studies

Inconsistencies exist within a body of literature that is based on surveys of varying quality and generally small sample sizes. The availability of online survey tools and an easily accessed large online triathlete population provided the impetus behind our investigation. As described in the following review of the literature, the current 15 published studies on the topic of triathlon injury largely lack the design and statistical power to guide future injury prevention practice.

Review of the literature

We conducted a systematic review of the literature to identify important patient-oriented factors that might be associated with increased injury incidence in persons training for and competing in triathlons.

Methods

Selection of Articles

The Medline (Pubmed) electronic database was searched for relevant studies published between 1974 and June 2006, limiting the search to human and English-only articles. The search terms “triathlon injury” yielded 26 non-review articles. In addition, use of the MeSH search terms “swimming injury overuse not diving not drowning,” “bicycle injury overuse,” “running musculoskeletal injury,” and “running injury overuse” yielded 136 human, English-only, and non-review studies. The primary reviewer (JT) also found an additional seven studies by manually reviewing the citation lists of pertinent studies and review articles.

The inclusion of swimming, bicycling, and running studies in the initial search was meant for comparison of these component discipline study results with triathlon study results. As discussed in the external validity assessment below, one must be aware that there is both value and limitation when comparing triathletes to swimmers, cyclists, and runners.

All abstracts were reviewed, and articles were excluded for a number of reasons (**Figure 1**). We limited the study design to epidemiological survey studies for our inclusion criteria. Because our study focus is on overuse musculoskeletal injuries, studies about triathlon were excluded if they had

physiological measures as their primary outcomes, such as hydration status, heart rate, VO2 max, hormone levels, hyperthermia, or blood enzyme activity levels pre- and post-activity. We excluded two case studies from the initial group of articles, and we included four studies^{12, 17, 19, 28} found from manual review of other study references. We proceeded with a total of 15 triathlon-related studies.

For research studies that examined swimming, biking, and running injuries, studies were excluded from further review if their focus was on a specific traumatic injury case series, such as ankle sprains, or specific age populations, such as pediatric or older runners. We excluded studies that included individuals in sports beyond running, swimming, or cycling. We also excluded five case reports from further review after analysis of their abstracts. No swimming studies fit our search criteria.

Upon further review of full-text articles, we included four triathlon-specific studies,^{12, 17, 19, 28} two running-specific studies,^{3, 9} and one cycling-specific study²⁶ found from a manual review of other study references. We excluded an additional two articles for a survey response rate of less than 10%,^{17, 21} and two other articles for not defining the number of individuals in their source population.^{6, 7} At the end of the selection process, we proceeded with critical appraisal of a total of 15 triathlon-related musculoskeletal injury studies: 8 triathlon-specific, 5 running-specific, and 2 cycling-specific injury survey studies (**Table 2**).

A Word on Study Design

Most of the studies in our literature review used the study design of a descriptive epidemiological survey study, which has been a commonly used method of describing injuries in sports medicine literature. The American Journal

of Sports Medicine, a top-tier journal in the sports medicine and orthopaedic field, includes the descriptive epidemiological study design as one of its 12 acceptable study designs. The inherent weaknesses of the study design include a lack of comparison group and an inability to measure associations between variations in training and injury types.

Several studies in this systematic review can be viewed as a foundation for developing further and more sophisticated research designs. A research plan for a randomized controlled trial is included in the discussion section below.

Moreover, we hope to combine a descriptive epidemiological survey with a prospective cohort study design for our current study. This will allow our study to reach a large number of individuals for descriptive epidemiological statistics, as well as providing comparisons between the cohorts of participants. Our survey will have more subjects than any of the previously published studies of amateur triathletes^{8, 10, 14, 15, 24, 25, 27, 28}. We optimistically hope that our study will enroll more study subjects than all studies in our systematic review combined (approximately 1500).

Appraisal of Literature Exploring Triathlete Injury Incidence

A. Data abstraction

The primary reviewer designed and used a standard data abstraction template to create a consistent method for my appraisal of each of the 8 triathlon injury survey studies and 7 running or cycling survey studies found in the literature review. The reviewer abstracted the following data from the included studies: study design, eligibility criteria, study population characteristics, sample

size, survey response rate, methods and measures of outcome assessment, and results (**Tables 3 and 4**).

B. Quality assessment

Internal Validity Ratings

Each of the 15 articles were classified according to study design (retrospective or prospective surveys) and given a quality rating. We assigned the quality ratings using a 0-3-point scale (0="poor", 1="fair", 2="good", 3="excellent") for each of four categories: selection of study populations, measurement methods and/or tools, statistical analysis, and overall reporting of results (**Tables 3 and 4**).

Selection of Study population

The quality rating of the study population selection for each article was based on 1) the description of the source population, and 2) how well the study population represented the source population.

In describing the source population, seven studies^{3, 10, 13-15, 24, 28} received fair or poor ratings, and eight studies^{8, 9, 16, 18, 22, 25-27} received good or excellent ratings. Studies received a rating of fair for inadequate description of inclusion criteria and suspect sampling techniques. Two studies received poor ratings, one for not describing a method of "random selection" of survey participants from a triathlete mailing list;²⁴ and the other for creating a pseudo-source population through media advertisements, for which the real source population could not truly be quantified.³ In contrast, studies received a "good" rating for source population if they limited their inclusion criteria to members of specific clubs or

teams,^{22, 25, 27} or if they included only single race finishers (instead of all race participants) in their source population.⁸ Four studies received a rating of excellent for defining their source population as participants in a race or event,^{9, 16, 18, 26} despite the generalizability drawbacks of such a method for an injury study (addressed in the external validity discussion below).

We rated the degree to which the study population represented the source population largely based on survey response rate, with additional consideration given to recruitment technique. Surveys with a response rate between 10% and 25% (surveys with response rates less than 10% were not reviewed) were universally given a rating of “poor” for not representing their source populations well.^{14, 18, 24} One study with a “fair” response rate had such a poorly defined source population that it was necessary to assign a rating of “poor” for its source population representation.³ A response rate between 26% and 50% yielded a quality rating of “fair” for three studies.^{8, 10, 27} Studies receiving a “good” rating were those with response rates of 51% to 75%.^{13, 15, 25, 28} Lastly, four studies (two running and two bicycling studies) received an “excellent” rating for a survey response rate of greater than 75%.^{9, 16, 22, 26} These four studies were unique in that participation was more strongly encouraged, either by coaches monitoring athletes²² or event organizers including the survey as a part of the event registration process.^{9, 16, 26}

Measurements

We rated measurement methods for each study according to the description of the measurement tool and identification of data collectors. Studies received a higher score if authors disclosed survey questions, topics, and designs, as well as a clear definition for injury. Because the individuals taking

the surveys served as their own data collectors, every study started at a baseline of “fair” for data collector rating. We gave a higher score to studies which used and identified data collectors beyond individuals taking surveys.

The quality of the description of the measurement tools was generally high for this group of studies. No study received a “poor” rating, as all of them defined to some degree the questions and topics of their survey. Two studies gave very cursory descriptions of the topics covered in their respective surveys and the methods of collecting data, for which each received a “fair” rating.^{15, 28} One of these “fair” studies, Manninen and Kallinen,¹⁵ piloted and reported their survey tool in an unpublished paper, which was not available for review. Four studies received an “excellent” rating for thorough description of the questions, topics, and administration methods of their surveys.^{9, 18, 22, 26} McKean et.al. gave a clear description of their survey, primarily using an online survey format, which included the use of passwords to ensure validity of the study population, email invites for publicity, and a system of creating a raffle-style drawing for incentives to increase participation.¹⁸ Another example of an excellent survey tool was that of Dannenberg et.al., which consisted of a pre-ride and post-ride bicycle injury with appropriately thorough and detailed survey questions.⁹ The remainder of the studies received a rating of “good” for sufficiently describing survey questions and methods, just not to the extent of the studies that received an “excellent” rating.

Studies received a higher rating for identifying collectors of study data. A baseline rating of “fair” was assigned to all studies, as the majority defined data collection only in terms of administration of a survey. Thirteen studies received a rating of “fair” for not defining data collectors beyond self-reporting individual survey participants.

Two studies received a rating of “good” for their identification of data collectors. Rauh, Koepsell, Rivara, *et al*²² used high school cross country coaches to collect daily data on high school cross country runners. Each of the coaches had received training for use of the measurement tool for athletes’ injuries and activity, which took approximately five minutes each day for each of the 23 coaches involved in the study. The study did not receive a rating of “excellent” because of the large number of data collectors, the variation between which could affect the precision of the measurement tool.

The study by Weiss²⁶ received a “good” rating because the author himself was intimately involved with the data collection and the event under evaluation. On the fifth day of an 8-day, 500-mile bicycle tour, the author administered the survey directly to his fellow tour-riders. If participants had questions about the survey, the author was able to provide direct answers while the participant took the survey. The author also cared for the medical needs of the tour riders, and he recorded incident injuries for use in his study data. The study did not receive an “excellent” rating because of the reliance on a survey method with untrained individuals.

Statistical Analysis and Confounding

We assessed the quality of statistical analysis for appropriate choice of statistical methods and the potential for confounding of the results. No study received the highest quality rating of “excellent”, as all study designs had a significantly high degree of inherent confounding.

Four studies received a quality rating of “good” for an adequate description of their statistical methods that included a consideration of confounding.^{10, 18, 22, 24} All four sets of authors used the best-described statistical

methods, including logistic regression in their analysis of possible confounding variables.

We assigned a quality rating of “fair” to the majority of the statistical analysis methods in our group of studies. Most of these authors did not include an assessment of confounding in their analysis, or at least did not clearly describe their analysis in the methods section of their papers. The majority of studies reported statistical tests used for analyzing descriptive statistics. Koplan *et al*¹³ received a “fair” rating, despite poorly reporting the methods of analysis. However, the study showed good results and an excellent analysis of differences between survey respondents and non-respondents, thus raising the quality to “fair”. One study analyzed data only in terms of percentages, ranges, means, and standard deviations, and for this it received a rating of “poor”.²⁷

Results

We rated the quality of reporting of results for each study, based on the use of p values or confidence intervals. Four studies received a rating of 3 (excellent) for thorough use of p values and confidence intervals.^{9, 10, 16, 24} The presentation of results in tables was difficult to interpret Williams *et al*, which received a rating of “fair”.²⁸ Wilk, Fisher, and Rangelli reported no p values or confidence intervals, giving it a quality rating of “poor”.²⁷ The remainder of the studies received a rating of “good” for adequate use of p values or confidence intervals.

Results

The results of our literature review are essentially a summary of the significant findings in each of the studies systematically reviewed, including

measured injury incidence, as well as association of training level, age, and athletic experience with injury.

Injury incidence rates

All studies reported incidence of injury, using percentage of injured participants or incidence rate as the measure of their findings. Because of the variety of survey designs employed in different studies, comparison of results is difficult among all the studies. Variability in the definition of injury and characteristics of study populations were the most obvious sources of incongruence between studies. For retrospective triathlete injury surveys, the reported incidence of injury (over varying amounts of time) included 15%,²⁸ 49%,⁸ 62%,²⁴ and 75%^{10, 25, 27} of survey participants. Korkia, Tunstall-Pedoe, and Maffuli¹⁴ reported a 37% injury rate over 8 weeks in their prospective survey study. In addition to percentages of participants injured, Egermann, Brocai, Lill, and Schmitt¹⁰ also reported an incidence rate of 0.711 injuries per 1000 exposure hours. Manninen and Kallinen¹⁵ did not report overall injury incidence, rather percentages of patients who had injuries of certain parts of their body (discussed further in the following section).

Running-specific and cycling-specific studies were also variable in measurement and reporting methods. Retrospective running studies reported injury rates of 46%¹⁶ and 35%,¹³ with one prospective study reporting an 85%³ injury rate. Rauh *et al*²² reported injury incidence in terms of "athletic exposures" (AEs), defined as time spent in practice or competition for high school cross country runners, with an overall injury incidence of 17.0/1,000 AEs. Of the two prospective cycling studies, Dannenberg, Needle, Mullady, and Kolodner reported 15.4 acute and 13.7 overuse injuries per 100,000 person-miles cycled,⁹

while Weiss reported percentages of participants with specific injuries, not overall rates (discussed below).²⁶

Location of injury

In the triathlon, running, and cycling studies reviewed, the most common location of injury in every study involved the lower extremity. Most triathlon-specific studies reported the knee to be the most common site of injury,^{8, 10, 15, 28} as well as single studies identifying the Achilles tendon²⁵ and the ankle¹⁴ as most common. The lower back, shoulder, thigh, and calf were also among more common injury sites in several studies.

Running and cycling studies reported similar findings to the triathlon studies. Rauh *et al*²² reported the shin (3.6 injuries/1,000 AEs), knee (2.5 injuries/1,000 AEs) and ankle (1.2 injuries/1,000 AEs) as the most common locations of injury among high school cross country runners. McKean, Manson, and Stanish reported that the knee (19.6%) and foot (16.2%) were the most common locations of injury for all runners in their study. Marti, Vader, Minder, and Abelin¹⁶ reported the lower leg (29.9%), foot/ankle (28.5%), and knee (27.9%) as the most frequently reported areas of injury amongst their 4,358 running survey participants. Koplan *et al*¹³ reported knee injuries (0.14 knee injuries per person-year of running) as the most common, and Bovens *et al*⁸ likewise reported frequent knee (25%) and lower leg (21%) injuries among runners in their studies. In bicycling studies, Dannenberg, Needle, Mullady, and Kolodner⁹ reported buttocks (42%), crotch (34%), and thigh (25%) injuries as most common. Weiss²⁶ reported buttocks (32.8%), knee (20.8%), and neck-shoulder (20.4%) injury as most frequent occurrences in his findings.

Cause of injury

In almost all triathlon studies, participants considered running as the most common cause of injury. Studies reported figures of 58.7-62.0%²⁵, 70%⁸, and 53%²⁸ for the percentage of injuries with a running etiology, with corresponding cycling etiology reported from each study as 15.9-34.5%, 12.5%, and 50%, respectively. In their study involving Ironman triathlon participants, Egermann, Brocai, Lill, and Schmitt¹⁰ reported cycling as the most common cause of injuries (54.8%), which one may attribute to the proportionally longer amount of time that Ironman distance triathletes spend training and competing on the bicycle. Williams *et al*²⁸ also reported a statistically significant relationship between cycling distance per week and injury incidence in their study population. Swimming was associated with the lowest number of injuries in every study; in fact, Shaw, Howat, Trainor, and Maycock²⁴ concluded that time spent swimming did not correlate with increase incidence of injury.

Some studies also allowed triathletes to report if the injury was caused by combinations of disciplines^{8, 28} or other activities.^{8, 27} Collins, Wagner, Peterson, and Storey described 167 injuries in 126 athletes, with 6.5% of those injuries caused by activities other than swimming, cycling, and running, and 8% of the injuries caused by a combination of running and another discipline or sport.⁸ Wilk, Fisher, and Rangelli reported that non-triathlon injuries prevented training or competition in 45.8% of survey participants.²⁷ Williams *et.al.* attributed several cases of injuries to multiple etiologies, but the authors did not specifically describe the injuries or combination of activities that led to the injuries.²⁸

Cause of Injury – Mechanism

Several studies also asked participants to report if their injuries were the result of overuse or trauma. Wilk, Fisher, and Rangelli²⁷ reported that 78.9% of injured participants had injuries attributed to “overuse”, and 33.3% had injuries due to trauma. Egermann, Brocai, Lill, and Schmitt¹⁰ used a slightly different definition for measurement, differentiating between fractures (11.9%), contusions/abrasions (51.1%), muscle/tendon injuries (33.1%), capsule/ligament injuries (29.0%), and chronic complaints (76.2%).

Running-specific studies generally showed a higher incidence of overuse injuries in their study populations. The findings of McKean, Manson, and Stanish showed that running more times per week increased the risk of injury for all age groups in their study, suggesting overuse as an important etiology for injury.¹⁸ Marti, Vader, Minder, and Abelin reported acute traumatic injuries to be 27% and overuse injuries to be 70%.¹⁶

In contrast to running studies, cycling-specific studies showed a higher incidence of traumatic injury compared to overuse injury. As mentioned previously, the study by Dannenberg, Needle, Mullady, and Kolodner showed 85 acute injuries (15.4 injuries per 100,000 person-miles cycled) and 76 overuse injuries (13.7 injuries per 100,000 person-miles cycled) during that particular bicycle tour, showing a slightly greater incidence of traumatic than overuse injury in their study population.⁹ The cycling-specific study by Weiss showed nine (8%) traumatic injuries, with two hospitalizations for traumatic injuries, but it did not report an overall injury rate for overuse injuries.²⁶

Training versus competition injuries

Two triathlon-specific studies considered the differences between injury rates during training for triathlons and during triathlon competitions. Egermann, Brocai, Lill, and Schmitt¹⁰ found a six-fold higher incidence of injury in triathlon competition compared to training in their population of Ironman triathletes. Korkia, Tunstoe-Pedall, and Maffuli¹⁴ reported similar findings in a study population of triathletes involved in shorter race distances, with injury incidence rates of 5.4 injuries per 1000 training hours and 17.4 injuries per 1000 competition hours.

Other reasons

The studies in our review considered several other covariates in their analyses of injuries. Six of the studies (including one running and one cycling study) found no correlation between injury incidence and age^{8, 13-15, 25, 26}, and x studies found that sex and injury incidence were not related^{8-10, 14, 15, 28}.

In contrast, several studies reported significant differences in injury related to age. Egermann, Brocai, Lill, and Schmitt¹⁰ reported a statistically significant greater incidence of fractures in older triathletes. Dannenberg, Needle, Mullady, and Kolodner⁹ reported a decrease in number of cycling injuries with age, hypothesized to be due to more cautious riding or developed resistance to injury. Additionally, McKean, Manson, and Stanish focused on the comparison of injury rates between runners under age 40 and runners over age 40.¹⁸ Their findings included a significantly greater overall injury rate, greater number of multiple injuries, and greater prevalence of calf, Achilles, and hamstrings injuries in older runners.

Two studies also showed significant differences in injury rates between males and females. Among high school cross country runners, Rauh *et al*²²

reported that girls had a significantly higher overall injury rate (19.6/1,000 AEs) than boys did (15.0/1,000 AEs) (incidence rate ratio: 1.3, 95% confidence interval: 1.0, 1.6). Weiss²⁶ also reported a significantly higher number of bicycling knee injuries for women compared to men in his study.

Several other independent variables were considered by various studies in our review. Egermann, Brocai, Lill, and Schmitt found that faster race performance time was associated with greater injury rate in Ironman triathletes¹⁰. Two studies with triathletes involved in shorter triathlons found no such association between performance level and injuries^{14, 25}. In congruence with both of these findings, Williams *et al*²⁸ reported a significant positive correlation of injury incidence with increasing triathlon race distance. Various studies found amount of total time training both positively^{15, 24, 25} and negatively^{8, 14} correlated with injury incidence.

Discussion

Summary of Internal Validity of Studies in the Systematic Review: Quality of Reviewed Data

The overall quality of the studies in our review was fair to very good, with total quality scores ranging between 6 and 15 on an 18 point scale. Of note, the five studies with the highest quality scores (12-15 points) were running and cycling studies^{9, 16, 18, 22, 26}, while none of the eight triathlon studies received a score above 10 points. The greatest weakness for all studies was the statistical analysis, as the descriptive survey study design has inherent weaknesses in its inability to adequately analyze confounding variables. Moreover, the lack of a

non-triathlete comparison group within all of the study designs diminished the meaning of each study's findings.

The description of the source population was a significant weakness for many of the studies, as some authors did not sufficiently describe which individuals were eligible to take their survey. The representation of the source population in the study population was also a problem, with poor quality largely determined by poor survey response rates.

Because all the studies relied on self-report, the quality of the data collection was generally rated "fair". Asking the location of an injury, while still subject to misinterpretation, seems less susceptible to incorrect reporting than asking triathlon or running survey participants to assess and self-report the cause of their own injuries. It was surprising to find that most of the studies asked participants to define injury causes in this way. If one can assume that these very physically-active adult study populations possessed greater than average knowledge about their own bodies, it may be possible to consider the self-report of injury as valid to some degree.

Summary and Analysis of Most Common Findings

The collective incidence of injury varied over a wide range among the studies analyzed. This seems understandable, given that each study focused on a relatively small group of athletes. Each study varied in its actual source population as well, ranging from elite professional Ironman participants to novice recreational athletes. Determination of injury incidence in triathlon participants would require a much larger population sampling that included all levels of athletes over a longer period of time in order to capture more accurate data.

Our review showed that overuse was the most common mechanism of injury in our cohort of studies, as one might expect. Triathlon is not a contact sport and it rarely involves rapid changes in direction (“cutting”-type maneuvers). It also does not involve the acute acceleration or deceleration actions seen in various non-contact ball sports. The potential for acute trauma in triathlon arises mostly from extrinsic factors such as terrain- and traffic-related incidents in the cycling and running portions of the event, which are usually tightly regulated in order to reduce such risk. This lack of predisposition towards situations favoring acute injury, coupled with the high-intensity repetitive motions involved in training and competition, naturally favors overuse as the primary mechanism of injury.

In the studies that differentiated between injuries during competition and training, the higher incidence of injury during competition also seems logical. Competitions generally involve athletes moving in close groups at high speeds, increasing the potential for injury by contact or bicycle crash. However, as noted above, racing safety regulations reduce such risk of acute traumatic injury. One therefore might consider an injury etiology of competitive strain or overuse. Most athletes exert themselves at a higher level during competition than during training, potentially pushing their bodies over a threshold for injury. Athletes also are often more likely to continue competing, in spite of a competition injury, in an attempt to “finish the race,” whereas such behavior is not as frequently seen during training. By failing to notice, ignoring, or dealing with an injury during competition, athletes likely place themselves at higher risk of worsening that injury or even sustaining other injuries.

It seems valid that the lower extremity, and specifically the knee, was the most common location of injury in the studies reviewed. With the exception of the swimming portions of the event (which often constitute the smallest fraction of

the overall race), triathlon does not place a high demand on the upper extremity. Sudden or awkward movements of the upper extremity are rarely, if ever, required in the course of training or competition. The lower extremity, on the other hand, bears most of the burden for the triathlete, as all three component disciplines place varying demands on the lower extremity in both training and competition. This pattern of injury is in fact similar to that of the general public, in whom leg and knee symptoms constitute the second-most common reason for visiting a physician*.

The association of most injuries with running in either training or competition also seems logical, especially when considered in conjunction with some of the other findings discussed above. Running is the only high-impact, full weight-bearing discipline in triathlon, as both swimming and cycling do not involve impact or weight-bearing. In competition, running is usually the final event of the three disciplines – making athletes potentially more at-risk for injury due to the collective effects of cumulative microtrauma, fatigue, and even the “final push” at or near the finish line.

External Validity of Findings from the Systematic Review:

Generalizability to Triathlete Populations

We did not quantify the external validity with quality scores for our analysis, but several general strengths regarding external validity existed for most of the studies. First of all, although several studies in our review used populations of German, British, or New Zealand triathletes, the results from these international studies are likely highly generalizable to American triathletes. With an international governing body, traditional swim-bike-run triathlon is fairly similar

* Number of Physician Visits for Musculoskeletal Conditions: 1999-2003. AAOS Database, 2003.

from country to country throughout the world. Second, although most of the study populations were predominantly male, the majority of participants in most triathlons are also male,¹ demonstrating congruence between study and source populations. For example, in 2005, 68% of USA Triathlon's 59,000 members were male.¹ We therefore expect studies to have generally more males than females, although the results of such studies may not be as generalizable to female triathlete populations. Lastly, inclusion of running and cycling survey studies allows a comparison of triathlon to its component disciplines, despite differences between the whole and its parts.

Several weaknesses existed in external validity for our group of studies. First, the source population of each study, because of limitations created by survey eligibility criteria, was a very small and unique group of people. In cases where the authors allowed only members of a few triathlon clubs^{14, 15, 25, 27} or participants in specific races^{8, 10, 28} to be included in the source population, the generalizability of the study may have been compromised with the narrower source population. As a specific example of this weakness, Egermann, Brocai, Lill, and Schmitt¹⁰ looked solely at Ironman triathletes in their source population. Such ultra-endurance athletes train and compete over distances five to twenty times that of typical amateur triathletes doing sprint or Olympic distance triathlons. The Ironman triathlete source population therefore may not be generalizable to the broader amateur athlete population. Likewise, studies of elite triathletes, who train and compete professionally at a high level, may not be generalizable to amateur or novice triathlete populations, who may only train a few days per week.

The inclusion of only race participants or race finishers in a source population is a major problem for external validity with any study dealing with injury. Individuals who are injured severely enough to miss the race would not be

included in the source population. The data from such studies^{9, 13, 16, 26, 28} would therefore underestimate prevalence or incidence (in studies using follow-up surveys) of injury, as a serious barrier to participation in an endurance athletics event would be musculoskeletal injury. Such a generalizability problem would only be magnified in studies that included only race *finishers* in their source populations, for the similar reason of missing individuals injured during a race.^{8, 10}

The external validity of pure swimming, cycling, and running studies for triathlete populations remains an obvious valid criticism, despite their each being a part of the sport. The injuries of triathletes, while similar to those of swimmers, cyclists, and runners, would involve more complex interactions of different disciplines both in training and competition that could exacerbate injury. Likewise, the theory exists that cross-training in different disciplines alleviates the musculoskeletal strain associated with constant training in the same discipline. One could argue, therefore, that a study with a pure long distance cycling tour population^{9, 26} or a pure running population^{3, 13, 16, 22} would not be generalizable to a triathlete population. Nevertheless, we included these discipline-specific studies in our analysis mainly for the purposes of 1) direct comparison with similar studies based only on triathlon, and 2) illustrating the paucity and lower quality of survey studies within triathlon.

Lastly, as is the case with almost all voluntary surveys, individuals who choose to participate in the survey may be different from those who decline. In general, it is not clear whether an injured or uninjured person might be more or less willing to take a voluntary survey about injuries. Yet even studies that did not use race participation or race completion as part of their source population eligibility criteria would be subject to missing individuals who suffered career- or season-ending injuries. Although these individuals would not fit inclusion criteria

(e.g., triathlon club membership) to be part of the source population, their exclusion is another significant weakness for the external validity of all 15 survey studies in our review.

Conclusion/Future Directions

As illustrated by our systematic literature review, some important findings about the patterns of musculoskeletal injury within triathlon and within each of its component disciplines have been previously investigated with some success. Although the existing studies are limited by the aforementioned weaknesses, our systematic evaluation of internal validity was generally favorable. It is particularly interesting that none of the triathlon-specific studies reached the same level of quality as the discipline-specific studies – suggesting that the quality of triathlon research can be improved. The generalizability of the findings of these studies to the overall population of triathlon participants may be limited, but at present no other better data exists. Future research into the musculoskeletal injury patterns in triathlon participants should consider both the successes and shortcomings of the currently available literature.

Current Research Study Proposal

Research Questions and Hypotheses

Our research questions primarily focused on whether there are significant associations between varying training levels, with regard to training distance and intensity (training pace, number of training sessions per week), and patterns of injury in triathletes. More specifically, 1) Is there an association between lower extremity overuse injuries and running training (distance and intensity)? 2) Is there an association between diagnosis of trochanteric bursitis or diagnosis of

lower back pain and cycling training (distance and intensity)? 3) Is there an association between shoulder injuries and swimming training (distance and intensity)? We hypothesized that we would be able to observe associations of specific injuries with measurable increases in training distance and intensity for specific training disciplines.

Secondary research questions include observing for associations between diagnoses of select traumatic and overuse injuries and individuals' experience in the sport; somatotype and anatomical factors such as height, weight, and body mass index; gender; and use of dietary supplements.

Materials and methods

Subjects

We administered the initial survey to 171 (as of 6/1/2006) triathletes in the North Carolina Triathlon Series (NCTS) and the Endurance Development Series (EDS) (see Dummy Table 3 for participant characteristics) over the period from March to October 2006. Eligible participants were any individuals between the ages of 18 and 75 who participated in any one of the 16 NCTS or 12 EDS triathlon races, which was approximately 6000 unique individuals for the 2006 triathlon season²³.

Pilot Study

We selected a group of about 20 individuals including triathletes, sports medicine physicians, and triathlon coaches to participate in a pilot survey, using the same basic survey design and software to be used in the actual survey. We measured the time it took for each individual to complete the survey, and we asked pilot participants to provide any comments or feedback about any survey

items or format issues. In addition to the pilot group, the primary investigator (JT) used cognitive feedback with two participants to gain insight into thoughts and feelings elicited during the process of taking the survey and made changes based on this feedback.^{4,5}

Instrument Design

Our study consisted of an initial online survey, followed by shorter monthly online follow-up surveys administered to each participant. We divided participants into cohorts, defined as the groups of participants who took the initial survey within in the same calendar month. The research team sent each participant a monthly email, personalized and confidential, with a link to each monthly follow-up survey. We used the professional subscription version of the online survey website SurveyMonkey.com for the 10 months of the study.

The initial survey consisted of approximately 100 questions and took most participants approximately 15 minutes to complete. Participants initially read a complete study description, including the background, purpose, and incentives for the study, as well as a required informed consent, without which participants could not proceed with the survey. The survey asked questions about past, present, and planned athletic and triathlon experience; swimming, cycling, running, and general training practices over the previous year, both during the competitive season and off-season; general medical conditions; injuries over the past three years to the toe/foot/ankle, lower extremity, torso, upper extremity, head/neck/back, with details on location, type, cause, mechanism, level of health care provider sought, method of treatment, time missed from training or competition, and the training disciplines stopped for each injury; quality of life assessment (short form-7); nutritional supplements, alcohol, and tobacco use;

demographic information (age, sex, height, weight, education level, marital status, occupation, race/ethnicity, and state of residence). We created the questions using the variety of formats allowed by the SurveyMonkey website. The Retired NFL Player Survey¹¹ served as a guide for creating our survey instrument.

The follow-up surveys were of a similar format to the initial survey, but consisted of approximately 30 questions and took about 5 minutes to complete. The survey asked about events since the individual had completed his or her last survey, such as triathlon race participation, training practices, and injuries.

At the end of each initial and follow-up survey, the survey thanked the participants and reminded them that we would contact them in approximately one month for the next follow-up. The survey then directed the finished participants back to the survey homepage.

Recruitment

Set-Up, Inc., the race organizer for the NCTS and EDS, put advertisements and links to the initial survey on its website (www.set-upinc.com), as well as links to the survey in prerace email reminders sent to race participants the week before each race in the series. Because 95% of NCTS and EDS race registrations were online registrations, most of the triathletes in these two series had access to the internet. UNC Orthopaedics also provided an email sign-up sheet at four of the NCTS races for people who had not seen previous advertisements or emails. Invitation to follow-up surveys was by email only.

As incentive for participation, we offered an end-of-study raffle for all participants, with one drawing for a grand prize of free race entry into all 2007 NCTS races, and ten drawings for gift certificates of \$25 each to local triathlon, running, and cycling stores. For each follow-up survey that an individual

completed, he or she received one additional entry into the raffle. For example, an individual who took the initial survey in March and completed a monthly follow-up survey every month until the end of the survey (October) would have received the maximum total of 8 raffle entries.

Statistical Analysis

All data will be downloaded from the on-line survey to an Excel spreadsheet, and then converted into an SPSS statistical software package (SPSS Inc., Chicago, IL). After the data is cleaned, Chi-square tests of association will be conducted to determine if significant relationships exist between the select injuries and the variables outlined in the research questions and hypotheses section. All hypotheses will be tested with an apriori P value of .05.

Results and Discussion

As of the publication of this Master's paper, we are continuing to collect data for this study. Our goal is to focus on promoting our survey, which we have trimmed to 10 minutes by eliminating questions we felt were not necessary to the aim of the study. Data collection will continue until the end of the triathlon season in October 2006, at which time we will analyze the data using the methods described.

As our review of the literature shows, the existing literature varies in quality, with most studies receiving an overall quality score of fair. We hope to contribute a study of "good" or "excellent" quality to the current body of literature. Upon analysis of our data, we expect to find that certain modifiable risk exist factors in the training regimens of triathletes, several of which athletes, coaches,

and clinicians could use in trying to prevent injuries in this population. Our study could potentially detect “training thresholds” for each discipline of swimming, cycling, and running at which certain injuries occur more frequently. Other items in our survey, while not our primary research questions, may lead us in important directions for future research.

Future Studies

One idea for a future study on this topic would be a clustered randomized trial design, wherein amateur triathletes are randomized to different training groups to assess the effect of training practices on injury incidence. The following section describes the protocol for one such idea of a clustered randomized trial.

The Effect of Training Regimen on Injury Incidence in Amateur Triathletes: A Clustered Randomized Trial Design

Main research question: Does the amount of running in an organized training program for amateur triathletes affect lower extremity overuse injury incidence over the course of a 9 month competitive triathlon season?

The research evidence is incomplete for this question. A Cochrane review of randomized trials exists for soft tissue overuse injuries in runners showed that modification of training schedules can have some impact on lower limb soft tissue injuries²⁹. Upon systematic review of the literature, the primary researcher (JT) found no randomized trials regarding athletic training regimen and injury incidence in triathletes. Significant results from such a study could help to guide clinicians, coaches, and athletes in designing training regimens that minimize overuse injury and optimize performance.

Secondary questions: Does an increased amount of running in an organized training program for amateur triathletes improve running performance and overall performance?

Parent population: Eligible persons for the study will be North Carolina Triathlon Series race participants from the last three years (approximately 6,000 individuals in 42 races).

Sample inclusion/exclusion: Participants must be between age 18 and 65; injury-free at beginning of study; and non-elite, age-group level participants who have competed in at least 5 triathlons (exclude novices). Exclusion criteria include having had a lower extremity overuse injury within the last 6 months that caused the individual to stop running for at least 1 week; and history of MI, cardiac arrhythmias, or other medical conditions that would limit participant's ability to participate in a strenuous exercise training program.

Sample size, availability: Survey study literature shows an incidence range of 0.711 to 5.4 injuries per 1000 training hours. Depending on ability to recruit study volunteers, a lower power, less sensitive sample size may be required. With $\alpha = 0.05$, and power of 0.8, the sample size needed to detect a 10% difference in injury incidence between the intense running group and the control (balanced swim, bike, and run) group would be 408 subjects for each arm. To detect a 20% difference with the same parameters, the sample size would be 103 for each arm. Calculations were done using the *sampsi* command from the STATA (College Station, Texas) software package.

Ethics: Besides anecdotal evidence, no randomized trial has been performed on this subject. Both the control and intervention cluster will be coached by a USA Triathlon certified coach, and both training regimens will be legitimate and safe for these endurance multisport athletes. Randomization will

reduce confounding, giving more scientific validity to the study. Incentives for participation will not be coercive, and informed consent will be provided by each participant. Although survey studies and anecdotal evidence suggest that running causes more overuse injuries than a balance of swimming, biking, and running, it is unproven whether a more intense running regimen, with the goal of improving racing performance, affects overuse injury incidence. Thus equipoise exists for this study.

Organization/monitoring: A primary investigator and group of co-investigators will comprise the research team, along with data collection and coaching from the certified coaches (1 coach per 25 athletes), clinical support from sports medicine physicians to assess and treat incident injuries, biostatistical support from biostatisticians and data managers, and administrative support for the study. A sponsor, such as a triathlon race organizer, would be included to help recruit subjects and provide incentives. Approval from an Institutional Review Board and monitoring from a Data and Safety Monitoring Board would also be a part of the study.

Randomization: Block randomization (using blocks of 4 and 8) would be performed by a computer, balancing the groups for baseline characteristics (see below).

Masking: Coaches and subjects cannot be masked, as this is a behavioral study. Investigators, clinicians (possibly, although they may need to know past training regimen to assess an injury), and biostatistical support could be masked.

Intervention/comparison: The intervention cluster will be the running-intensive training regimen group, which will do running workouts 4 days per week, biking 2 days per week, and swimming 2 days per week. The total of 8 workouts

would be done in 6 days, doing 2 workouts on two of the days (normal practice for many triathletes), with one day of complete rest per week. The control group would have a balanced workout regimen, with 2-3 days of running, 2-3 days of cycling, and 2-3 days of swimming per week. Again, this group would have a total of 8 workouts over 6 days, having combined workouts on two days, and one day of complete rest (see Appendix A). Both of these regimens would be considered reasonable by most triathletes competing at the age group racing category. Moreover, the “running intense” regimen would still be considerably less running than that of many recreational runners.

Compliance measure: Athletes will self-report to cluster coach in weekly online training and injury log. Coach will also be able to directly observe some of the workout sessions. Athletes will be encouraged to follow coaches’ recommendations. Subjects in both groups will be offered the incentive of free coaching (funded by study grants) for the duration of the year.

Follow-up procedures (including stopping): Comparative analyses between groups every 3 months. Stop study for adverse events or 50% or greater difference of injury incidence between intervention and control groups. Stopping requires contacting all coaches and subjects, with explanation of reasons for stopping.

Baseline measurements: Age, height, weight, sex, years doing triathlons, history of recent injuries, other medical conditions.

Outcome assessments (main outcomes, adverse events): Main outcomes will be incidence of overuse injuries of the lower extremity, as well as a measure of severity of injury (quantified by the length of time of athletic disability caused by the injury).

Injury will be defined as “as any musculoskeletal ailment that caused you to stop training for at least 1 day, reduce mileage, take medicine, or seek medical care”⁸. Any bursitis, tendonitis, stress fracture, muscle strain, or other overuse injury from the waist down, self-reported and assessed by the research study clinical staff, will be considered as a main outcome. Adverse events will be non-overuse injury or illness, including cardiac events, traumatic injuries, and other illnesses caused by athletic training.

Analyses: Non-inferiority trial will use ITT analysis. Baseline characteristics will be compared between control and intervention groups using Student's paired t-test. Compare variance of medians of primary outcome measurements (number of incident injuries in each group and number of days of disability caused by injuries in each group) using Wilcoxon Rank-Sum test. Confounding should not be an issue if true randomization occurs, as measured by baseline characteristics.

Appendix A: Sample training week for each study group

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Intervention (running intense) group	Run: 1 mile warm-up, 3 mile tempo run, 1 mile cool down	Swim: 2500 yds; Run: 4 miles	Bike: 25-35 miles	Swim: 2500 yds; Run: 4 miles	Bike: 25-35 miles	Run: 7 miles	Off
Control (balanced) group	Run: 1 mile warm-up, 3 mile tempo run, 1 mile cool down	Bike: 25-35 miles	Swim: 2500 yds; Run: 4 miles	Bike: 25-35 miles	Swim: 3500 yds	Bike: 25-35 miles; Run: 4 miles	Off

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Table 1: Triathlon Race Lengths

<u>Race Type</u>	<u>Swimming Length</u>	<u>Cycling Length</u>	<u>Running Length</u>
Sprint	500 meters	20 kilometers	5 kilometers
Olympic/International	1500 meters	45 kilometers	10 kilometers
Half-Ironman	1.2 miles	56 miles	13.1 miles
Ironman	2.4 miles	112 miles	26.2 miles

Note: In general, races are classified based on their running length. Lengths for each discipline can vary among races, especially at the sprint level, and some events may involve changes in the order of disciplines.

Figure 1: Results of literature search

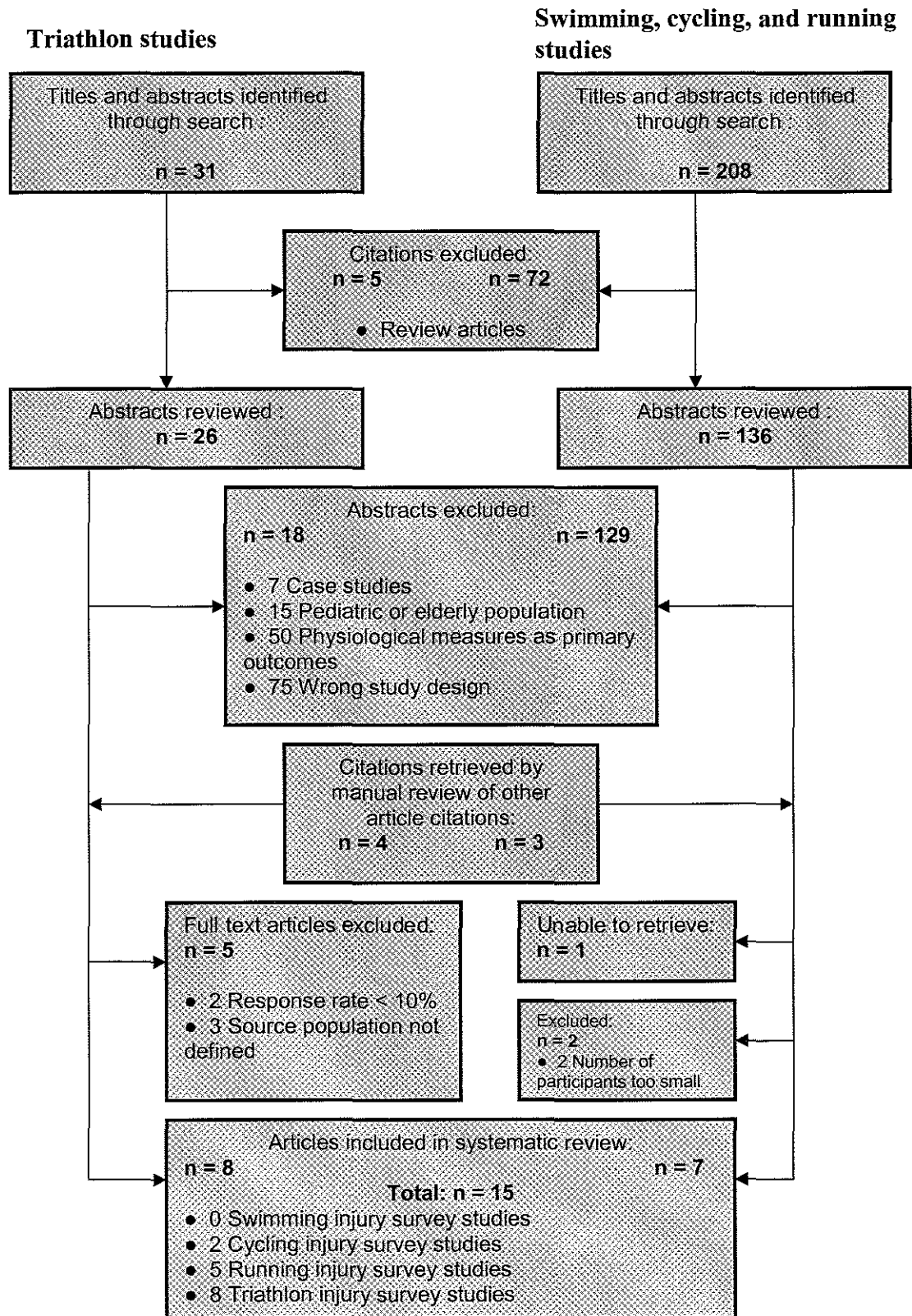


Table 2. Selected descriptive survey studies of injuries in triathletes.

Triathlon studies

Study Authors, Year	Study Design	Source Population	Study Population	Measurements	Significant Results/Outcome Measures																
Egermann, Brocai, Lill and Schmitt, 2002	Retrospective survey	German-speaking finishers in Ironman Europe 2000 (1833 eligible individuals), July 9 th , 2000 in Roth, Germany. No other description given.	656 responses (36%) used for final data analysis Sex: 588 (90%) men, 68 women Age: mean 35 y	Mail-in questionnaire distributed by race promoter to all German finishers of Ironman Europe 2000. Questions about demographic data, sport participation history, training data, and injury data answered by numbers and multiple choice.	74.8% (95% CI: 71.3-78.1) of all participants sustained at least one injury since starting triathlon 6.7 ± 4.1 years ago. Overall injury incidence: 0.711 injuries per 1000 exposure hours. Only significant risk factor for injury due to triathlon was race performance time; faster the race time, higher the risk of injury (OR = 0.766; 95% CI: 0.663 – 0.884). Most injuries (54.8%) attributed to cycling. 42.7% of athletes had a knee injury, 31.2% had a back injury, and 27.4% had an Achilles tendon injury 6-fold higher incidence of injury in triathlon competition compared to training.																
Vleck and Garbutt, 1998	Retrospective survey	Elite, developmental, and club male triathletes in specific clubs in Great Britain (194 eligible individuals)	116 responses (60%) used for final data analysis Sex: 116 (100%) men, 0 women Age: mean 27 y for elite and development, 35 y for club	Mail-in questionnaires distributed to triathletes with stamped reply envelopes. Athletes instructed to complete forms during a hard training week without taper when close to peaking for a major race. Subjects reported location of injuries and subsequent training days lost. Returns encouraged by personal contact, by a second questionnaire and personalized letter, and by telephone calls.	Overuse injuries occurred in 75.0% of Elite, 75.0% of Development, and 56.3% of Club triathletes. Most common and most severe injuries were located in the Achilles tendon, the lower back, and the knee. <table border="1" style="margin-left: auto; margin-right: auto;"> <thead> <tr> <th></th> <th>Elite</th> <th>Development</th> <th>Club</th> </tr> </thead> <tbody> <tr> <td>Running injuries:</td> <td>62.1%</td> <td>64.3%</td> <td>58.7%</td> </tr> <tr> <td>Cycling Injuries:</td> <td>34.5%</td> <td>25.0%</td> <td>15.9%</td> </tr> <tr> <td>P value:</td> <td><0.05</td> <td><0.05</td> <td><0.05</td> </tr> </tbody> </table>		Elite	Development	Club	Running injuries:	62.1%	64.3%	58.7%	Cycling Injuries:	34.5%	25.0%	15.9%	P value:	<0.05	<0.05	<0.05
	Elite	Development	Club																		
Running injuries:	62.1%	64.3%	58.7%																		
Cycling Injuries:	34.5%	25.0%	15.9%																		
P value:	<0.05	<0.05	<0.05																		

Collins, Wagner, Peterson and Storey, 1989	Retrospective survey	Race finishers in the Seafair Triathlon (July 20, 1986) (600 eligible individuals)	<p>257 responses (43%) used for final data analysis</p> <p>Sex: 197 (77%) men, 60 women</p> <p>Age: mean 32 y</p>	<p>Three-page questionnaire mailed to 600 out of 657 race finishers with questions about demographic data, training data, sport participation history, coaching, medical history, and injuries. Returns encouraged by second mailing to 25 non-responders, yielding 6 replies; T-shirt given to participants.</p>	<p>49% of respondents suffered a training-related injury serious enough to cause them to stop training at least 1 day, seek medical care, or take medicine.</p> <p>62% of injuries due solely to running; 8% running plus other; 12.5% cycling, and 11% swimming.</p> <p>Knee, shoulder, and ankle were most frequently affected.</p>
Korkia, Tunstall-Pedoe and Maffulli, 1994	Prospective training diary	Recreational, intermediate, and elite British triathletes (730 eligible individuals)	<p>155 responses (21%) used for final data analysis</p> <p>Sex: 124 (80%) men, 31 women</p> <p>Age: mean 34 y</p>	<p>730 questionnaires distributed to triathletes: 258 directly by one of the investigators or via club secretaries; 250 by the National Triathlon Coach at competitions; 222 via triathlon clubs.</p> <p>580 started the questionnaire. Returns through club secretaries or using self-addressed, stamped envelopes. Telephone calls to encourage non-responders.</p> <p>Questions about demographics, training data; 8 week detailed training and injury diary.</p>	<p>37% of respondents reported at least one injury over the 8 week period.</p> <p>Ankle/foot, thigh, knee, lower leg, and back were most frequent injury sites reported.</p> <p>Injury incidence rate: 5.4 injuries per 1000 training hours and 17.4 injuries per 1000 competition hours</p>
Williams, Hawley, Black, Freke and Simms, 1988	Retrospective survey	Participants in three triathlons of different lengths in New Zealand; 560 total questionnaires distributed	<p>332 responses (59%) used for final data analysis</p> <p>Sex: 251(76%) men, 81 women</p> <p>Age: mean 29 y</p>	<p>Mailed questionnaire randomly mailed to 200 short course, 200 middle course, and 160 long course triathletes via race directors</p> <p>Demographics, sport participation history, weekly training, and injuries (defined as feeling "...really uncomfortable...during training or racing" or if required "stopping training or pulling out of a race")</p>	<p>15% of triathletes surveyed reported injuries; 86% of these individuals had been involved with the sport for less than two years.</p> <p>53% of triathletes reported running as the activity associated with injury</p> <p>Knee was the most frequent site of injury (22%), followed by lower back (17%), and foot/ankle (14%)</p> <p>Greater number of injuries associated with long course compared to middle and short course distance triathlons.</p> <p>Good discussion section in this article.</p>

Wilk, Fisher and Rangelli, 1995	Retrospective survey	"150 members of the Tri-Miami Triathlon Division of the Miami Runner's Club were identified as the largest group of amateur triathletes that was easily accessible."	<p>72 responses (48%) used for final data analysis</p> <p>Sex: 41 (57%) men, 31 women</p> <p>Age: mean 38 y</p>	<p>Surveys mailed with 2 week follow-up post card and announcements at club meetings.</p> <p>24 survey items used to identify demographics, injuries, and the impact of injuries on training, racing, working, or daily activities.</p> <p>Questions were closed-end, fixed yes/no format.</p> <p>The term 'injury' was clearly defined.</p>	<p>75% of respondents suffered a musculoskeletal injury during training, 27.8% during competition.</p> <p>78.9% of injured participants had injuries attributed to "overuse", 33.3% had injuries due to trauma.</p> <p>Triathlon related injuries hindered daily activity 63.9% of the time, caused permanent loss of function 4.2% of time, and significant absence from work 15.3% of time.</p> <p>Non-triathlon injuries prevented training or competition 45.8% of time.</p>
Manninen and Kallinen, 1996	Retrospective survey	185 members of 10 Japanese triathlon clubs in Kinki, Chubu, and Kanto in March 1994	<p>92 responses (50%) used for final data analysis</p> <p>Sex: 70 (76%) men, 22 women</p> <p>Age: mean 31 y</p>	<p>Demographics, injuries (focus on low back pain) over the past year.</p> <p>Questionnaire piloted, found to have high test-retest reliability.</p> <p>Questionnaires mailed to representatives of the 10 clubs, who then distributed questionnaires to club members.</p> <p>Authors raise point of selection bias because uninjured triathletes do not participate in survey.</p>	<p>Low back pain (LBP) experienced by 32% of subjects over the previous year.</p> <p>54% of LBP lasted < 7 days, 19% lasted > 3 months.</p> <p>Knee (33%) was the most common site of injury, followed by back and shoulder.</p> <p>Theorize about LBP and triathlon training/competition.</p>
Shaw, Howat, Trainor and Maycock, 2004	Retrospective survey	Sample of 500 triathletes was randomly selected from the Triathlon Association of Western Australia's members' mailing list.	<p>258 responses (52%) used for final data analysis</p> <p>Sex: 190 (74%) men, 68 women</p> <p>Age: mean 35 y</p>	<p>Mail-in questionnaire, small prize offered as incentive.</p> <p>Questions about demographics, injuries (clearly defined), training practices</p>	<p>62% of individuals sustained at least one injury in the last triathlon season.</p> <p>30% sustained 1 injury, 22% sustained 2 injuries, 10% sustained 3 or more injuries.</p> <p>Triathletes who train for the longest and shortest periods of time tend to sustain injuries more often than those who train the intermediate lengths of time.</p> <p>Time spent on swimming training does not affect injury risk.</p>

Running studies

Study Authors, Year	Study Design	Source Population	Study Population	Measurements	Significant Results/Outcome Measures
Marti, Vader, Minder, Abelin, 1988	Retrospective survey	Male participants, residents of Switzerland, over the age of 16, in the 1984 Grand Prix 16 km road race in Bern, Switzerland.	4,358 responses (83.6%) used for final data analysis. Sex: 100% men Age: no mean age reported	Race participants received questionnaire in mail with race information. On race day, all participants were required to turn in the questionnaire, completed or not, in order to register for the race. Questions about training and injury over the previous 12 months; asked total number of kilometers run in the past year, years of running, type of shoes, usual running surface, use of orthotics, height, weight, medical visits, work absences, motivation for training and competing.	45.8% of participants had sustained "jogging" (German <i>joggen</i> means running) injuries in the past year. 14.2% of participants had required medical care. 2.3% had missed work because of injuries. Occurrence of injuries was independently associated with higher weekly mileage ($P < 0.001$), history of previous running injuries ($P < 0.001$), and competitive training motivation ($P = 0.03$). In 33 to 44 year old men, number of years of running was inversely related to injury incidence ($p = 0.02$). Achillodynia (11.6%) and calf muscle (8.9%) symptoms were the most commonly reported overuse injuries, occurring more with increasing mileage. Knee, lower leg, and foot/ankle were the most frequent general areas of injury. Acute traumatic injuries: 27%; overuse injuries: 70%.

<p>Bovens, Janssen, Vermeer, Hoeberigs, Janssen, and Verstappen, 1989</p>	<p>Prospective training and injury survey/diary</p>	<p>500 volunteers who responded to a newspaper ad in regional Netherlands newspaper for people with little or no running experience who wanted to train for a marathon in 1.5 years.</p>	<p>115 participants with no persistent injuries and little to no running experience; 73 (65%) completed their training diaries adequately for final analysis</p> <p>Sex: 83 (72%) men, 32 women</p> <p>Age: mean 35 y</p>	<p>Participants recorded training and injury (clearly defined) for 18-20 months in diary.</p> <p>Recurrent injuries not counted twice.</p> <p>Participants had all-day access to an experienced coach, with weekly group training sessions. Special attention was paid to preventive measures for all athletes.</p> <p>Study participants progressed through 3 phases, competing in a 15km, 25km, and 42km race at the end of respective phases.</p> <p>Training consisted of endurance, speed, and interval training.</p> <p>Reasons for dropouts (42 total) included lack of motivation, illness, vacation, and injury(14).</p>	<p>85% of study population (65 participants) reported at least one injury; 174 injuries reported overall.</p> <p>Increased incidence of injury over time in successive phases of training: 13%, 17%, and 18%, respectively.</p> <p>Related to exposure time, there was a decreased injury incidence over the total study period.</p> <p>Knee (25%) and lower leg (21%) were most common location of injury.</p> <p>Achilles tendon injuries localized more to left side.</p> <p>Chance of injury increased with running distance covered.</p> <p>P value < .05 considered significant.</p>
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<p>McKean, Manson, and Stanish, 2006</p>	<p>Retrospective survey</p>	<p>All participants in the Hood to Coast running relay in Oregon in August 2002, the largest running relay in North America, with approximately 12,300 participants.</p> <p>The 36 legs of the relay ranged from 3.9 to 8.2 miles.</p>	<p>2886 responses (23%) used for final analysis.</p> <p>Masters runners (≥ 40 years old): 34% of runners; 65% of these runners male</p> <p>Younger runners (<40 years old): 66% of runners; 50% of these runners male</p> <p>Overall age not reported.</p> <p>Overall sex: ~1587 (55%) men, 1299 women (based on calculations from rounded percentages)</p>	<p>Ninety-four (2712/2886) percent completed the survey electronically and 6% (174/2886) manually.</p> <p>The survey contained 27 questions including descriptive information about running experience, training patterns, shoe characteristics, orthotic use, injury patterns, and diagnosis. A running injury was defined as an event that affected the athlete's ability to train or race over the previous 1 year period.</p> <p>Each participant was required to log into the survey, using the assigned username and password. This ensured each participant could complete the survey only once.</p> <p>An email was also sent to the captains of each team of 12, informing them about the study and asking them to encourage their team to participate.</p> <p>As an incentive to participate in the study, runners who completed the survey were entered in a drawing for prizes.</p>	<p>The injury rate for the entire population was 46%.</p> <p>Significantly more masters runners (49%) were injured than younger runners (45%) ($P<0.05$).</p> <p>More masters runners suffered multiple injuries than younger runners ($P<0.001$).</p> <p>Significantly more masters runners were male, had 7 or more years of running experience, run more than 30 miles/wk, 6 or more times/week and wear orthotics than younger runners ($P<0.001$).</p> <p>The knee (19.6%) and foot (16.2%) were the most common locations of injury for both groups.</p> <p>The prevalence of soft-tissue-type injuries to the calf, achilles, and hamstrings was greater in masters runners than their younger counterparts ($P<0.001$).</p> <p>Younger runners suffered more knee and leg injuries than masters runners ($P<0.005$).</p> <p>Running more times/wk increased the risk of injury for both groups.</p>
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<p>Koplan, Powell, Sikes, Shirley, and Campbell, 1982</p>	<p>Retrospective survey</p>	<p>Sample of 1,250 men and 1,250 women randomly selected from participant list of the July 4, 1980 Peachtree 10-K roadrace in Atlanta, Ga (~ 25,000 participants); ~80% of race participants were men</p>	<p>1423 responses (57%) used for final data analysis.</p> <p>693 (49%) men and 730 women</p> <p>Age: mean 31 y</p> <p>Respondents vs. non-respondents (phone interview): 66 (91.7%) of 72 men and 32 (86.5%) of women</p> <p>nonrespondents differed significantly only from respondents by age (respondents older); more nonrespondents stopped running and had been hit by a thrown object.</p>	<p>Mail-in survey mailed in June 1981 to 2500 individuals. Remailed to non-respondents 6 weeks later.</p> <p>Random sample of non-respondents to both questionnaires given phone interview to determine if any differences between respondents and non-respondents.</p> <p>Questions about demographics, smoking, reasons for starting running, weekly mileage, hazard encounters, injuries, and response to injuries.</p>	<p>In one year after the 10K race, 35% of respondents incurred a musculoskeletal injury attributed to running.</p> <p>Knee was the most common site of injury (0.14 knee injuries per person-year of running).</p> <p>No confidence intervals or p values given for injury data.</p> <p>Good discussion about external validity.</p>
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<p>Rauh, Koepsell, Rivara, Margherita and Rice, 2006</p>	<p>Prospective injury incidence study</p>	<p>High school cross-country runners in Seattle, Washington during the 1996 cross-country season.</p>	<p>Cohort of 421 (86% of those approached) runners competing on 23 cross-country teams in 12 Seattle, Washington, high schools.</p> <p>No differences between participants and non-participants regarding gender.</p> <p>Sex: 235 (56%) boys and 186 girls</p> <p>Age: no mean age reported; presume all participants between 14 and 18 y</p>	<p>Investigators, with the help of coaches, collected daily injury and athletic exposure (AE) reports, a baseline questionnaire on prior running and injury experience, anthropometric measurements, and coaches' training logs.</p> <p>Injury clearly defined by authors: A running injury was defined as any reported muscle, joint, or bone problem/injury of the back or lower extremity (i.e., hip, thigh, knee, shin, calf, ankle, foot) resulting from running in a practice or meet and requiring the runner to be removed from a practice or meet or to miss a subsequent one.</p> <p>Injuries that occurred outside of practices and meets were excluded.</p> <p>Quadriceps angle measured by one of authors at beginning of study.</p>	<p>The overall incidence rate of injury was 17.0/1,000 AEs.</p> <p>Girls had a significantly higher overall injury rate (19.6/1,000 AEs) than boys did (15.0/1,000 AEs) (incidence rate ratio: 1.3, 95% confidence interval: 1.0, 1.6).</p> <p>Compared with boys, girls had significantly higher rates of injuries resulting in ≥ 15 days of disability.</p> <p>For the overall sample and for girls, Cox regression revealed that a quadriceps angle of $\geq 20^\circ$ and an injury during summer running prior to the season were the most important predictors of injury.</p> <p>For boys, a quadriceps angle of $\geq 15^\circ$ and a history of multiple running injuries were most associated with injury.</p> <p>The shin was the most common body part initially injured (3.6/1,000 AEs), followed by the knee (2.5/1,000 AEs) and ankle (1.2/1,000 AEs).</p>
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Bicycling studies

Study Authors, Year	Study Design	Source Population	Study Population	Measurements	Significant Results/Outcome Measures
Dannenberg, Needle, Mullady and Kolodner, 1996	Prospective survey	1638 recreational bicyclists who did a 6-day, 339-mile Cycle Across Maryland tour in 1994.	<p>1417 preride (87%) and 1140 postride (70%) responses (1068 for both, 65%) used for final data analysis</p> <p>Sex: 939 (68%) men, 449 women</p> <p>Age: mean 39 y</p>	<p>Information collected from race registration form, a preride survey, interviews of injured bicyclists during the tour, and a postride survey.</p> <p>Preride survey (37 questions): Mail-in questionnaire, mailed 1 month before ride, stamped envelope included; people who did not complete mail-in were asked to complete questionnaire at registration.</p> <p>Postride survey (13 questions): Mail-in questionnaire, waiting for participants when arrived home from race, stamped envelope included. Reminder postcards sent to non-responders.</p> <p>Questions about demographics, training practices, helmet use, bicycle riding history, bicycle equipment, crashes during tour (post), injuries during tour (post), other medical problems during tour (post).</p>	<p>85 acute injuries (15.4 injuries per 100,000 person-miles cycled) during tour. 2 injuries required ED transfer. No traumatic head injuries with 112 crashes.</p> <p>Acute injuries associated with history of racing (RR = 2.2, 95% CI: 1.3-3.7), and inexperience (RR = 1.7, 95% CI: 1.04-2.8), but not with sex, training, or prior injuries.</p> <p>76 (4.6%) overuse injuries (13.7 injuries per 100,000 person-miles cycled) treated by medical staff during tour.</p> <p>996 respondents (87%) reported aching or soreness during tour. Soreness/injury self-reported according to location on body.</p> <p>Buttocks (42%), crotch (34%), and thigh (25%) injury most common.</p> <p>37 (2.3%) riders treated for other medical problems (insect bites/stings, dehydration); (6.7 injuries per 100,000 person-miles cycled)</p> <p>Suggest more preride conditioning to prevent overuse injury.</p>

Weiss, 1985	Prospective survey	132 amateur bicyclists who participated in the 8-day, 500-mile Grand Canyon to Mexico Bicycle Tour in 1983.	<p>113 responses (86%), including all bicyclists who stopped riding before end of tour (3)</p> <p>Sex: 78 (69%) men, 31 women</p> <p>Age: mean 41 y</p>	<p>On day 6, after completing 372 miles, surveys distributed by author, who also provided treatment for injuries.</p> <p>Survey asked participant, according to location of injury, degree of disability cause by injury, from "no problem at all" to "so much that had to stop riding at some point."</p> <p>Questions about demographics, chronic medical conditions, injuries, demographics, bike, seat, and clothing type, time of bike ownership.</p>	<p>Buttocks pain (32.8%) was the most common symptom experienced by riders.</p> <p>Knee problems occurred in 20.7% of riders.</p> <p>Neck-shoulder pain occurred in 20.4% of riders.</p> <p>Groin numbness and palmar pain each occurred in 10% of riders, but were not a significant cause of disability for most riders.</p> <p>Foot/ankle symptoms and sunburn were less common problems.</p> <p>Nine (8%) traumatic injuries, two hospitalizations for injuries.</p>
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Table 3. Quality ratings for retrospective survey studies in systematic review. Each study was rated 0-3 for each category, with 0=poor, 1=fair, 2=good, 3=excellent.

Study Authors, Year	Source population Adequately Described?	Study Population representative of source population	Description Measurement tool?	Data collectors identified?	Appropriate analysis?	Results reported adequately, with P-values and/or CI?	Overall Quality Score
Shaw, Howat, Trainor and Maycock, 2004	0	0	2	1	2	3	8
Egermann, Brocal, Lill and Schmitt, 2002	1	1	2	1	2	3	10
Vleck and Garbutt, 1998	2	2	2	1	1	2	10
Manninen and Kallinen, 1996	1	2	1	1	1	2	8
Williams, Hawley, Black, Freke and Simms, 1988	1	2	1	1	1	1	7
Wilk, Fisher and Rangelli, 1995	2	1	2	1	0	0	6

* Rating of 0 = response rate of 10-25%; 1 = 26-50%; 2 = 51-75%; 3 = 76-100%

Table 3 (continued)

Study Authors, Year	Source population Adequately Described?	Study Population representative of source population	Description Measurement tool?	Data collectors identified?	Appropriate analysis?	Results reported adequately, with P-values and/or CI?	Overall Quality Score
Collins, Wagner, Peterson and Storey, 1989	2	1	2	1	1	2	9
Marti, Vader, Minder, and Abelin, 1988	3	3	2	1	1	3	13
Koplan, Powell, Sikes, Shirley, and Campbell, 1982	1	2	2	1	1 [†]	2	9
McKean, Manson, and Stanish, 2006	3	0	3	1	2	3	12

[†] Poor description of statistical methods, but good analysis of respondents vs. non-respondents.

Table 4. Quality ratings for prospective survey studies in systematic review. Each study was rated 0-3 for each category, with 0=poor, 1=fair, 2=good, 3=excellent.

Study Authors, Year	Source population Adequately Described?	Study Population representative of source population (response rate)?	Description Measurement tool?	Data collectors identified?	Appropriate analysis?	Results reported adequately with P-values and/or CI??	Overall Quality Score
Korkia, Tunstall-Pedoe and Maffulli, 1994	1	0	2	1	1	2	7
Rauh, Koepsell, Rivara, Margherita and Rice, 2006	2	3	3	2	2	3	15
Bovens, Janssen, Vermeer, Hoebregts, Janssen, and Verstappen, 1989	0	0	2	1	1	2	6
Dannenberg, Needle, Mullady and Kolodner, 1996	3	3	3	1	1	3	14
Weiss, 1985	3	3	3	2	1	2	14