Sports and Recreation Injury Prevention Strategies:
Systematic Review and Best Practices

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I. INTRODUCTION

Canadian children and youth spend a considerable amount of time participating in sports and recreation activities. On average, children between the ages of 5 and 12 years spend 18 hours on physical activity every week, while those between 13 and 17 years-of-age average 15 hours (CFLRI, 1998). Soccer, swimming, hockey and baseball are the most popular sports among active Canadian children. The benefits of sport and recreational activity for children and youth are numerous, including physical fitness, motor skill acquisition, improved self-esteem and the development of teamwork and leadership skills.

Participation in these activities does carry some risk however, particularly the danger of suffering an injury. Unintentional injuries are the leading cause of death in children and adolescents in Canada, and a major cause of morbidity (Canadian Institute of Child Health, 1994). Evidence has shown that injuries are not unlucky “accidents” but predictable events that are in most cases preventable (Rivara and Grossman, 1996). A recent article from the United States found that the largest source of child medical spending after birth are injuries, estimated at $12 billion (U.S.) per year (Miller, Lestina and Galbraith, 1995). In Canada, $4.2 billion (Cdn.) was spent on treating unintentional injury in 1995 (SmartRisk). Thus in addition to saving lives, injury prevention has great potential to save money.

Young Canadians spend a considerable portion of their leisure time engaging in sports and recreational activities. Therefore it is not surprising that injuries during these activities account for a large proportion of all injury cases reported in the Canadian Hospitals Injury Reporting and Prevention Program (CHIRPP) (Minister of Public Works and Government Services Canada, 1997). Sports and recreational injuries, both organized and informal, account for relatively few deaths (approximately 6% of deaths to those under age 20). However, these activities are associated with 17% of all hospitalized injuries, and 19% of emergency room visits to hospitals participating in CHIRPP (Minister of Public Works and Government Services Canada, 1997).

While estimates of the magnitude of sport and recreational injury are available, they are limited by how injury is defined in most administrative databases. This is particularly true for death and hospitalization data. The most comprehensive studies are based on European data. An eight-year study of hospital emergency room visits in Harstad, Norway found that the vast majority of injuries occurred in people between 10 and 30 years-of-age (Ytterstad, 1996). Team sports accounted for two-thirds of the injuries, soccer injuries being the most frequent. Based on these findings, it was concluded that prevention of sport injuries in general and more specifically soccer injuries should be given high priority. Similar results were found in a population survey conducted in a Swedish community, which found that the majority of injuries occurred in team sports: soccer (38.9%), followed by basketball/volleyball/handball (10.9%), and bandy/hockey (9.2%) (Lindqvist, Timpka and Bjurulf, 1996). These findings also suggested that children and youth are at high risk for these injuries because of higher levels of exposure to these activities and the physiological and biomechanical changes occurring in the human body at these ages (Lindqvist, Timpka and Bjurulf, 1996). Data from a 1988-89 Colorado study examining the etiology of school-related injuries, also support this theory (Lenaway, Ambler and Beaudon, 1992). The authors found that formal and informal organized sports accounted for 53% of all reported injuries.

Until recently, data related to sports and recreational injuries to children and youth in Canada have not been available. An initial perusal of the literature found few studies. A school-based study of elementary and secondary students in Vancouver, British Columbia found that sports injuries were the most frequent cause of injuries among secondary school students (Sheps and Evans, 1987). In a 1998 telephone survey using random digit dialing in Alberta, authors estimated that there were 11 sports and recreational injuries per 100 people annually (Mummery, Spence, Vincenten et al., 1998). More than half of the total estimated injuries were attributed to seven activities: ice hockey, baseball, basketball, soccer, jogging, cycling, and volleyball.

Even based on the limited data available, it is obvious that the prevention of sports injuries has merit on two fronts. First, increasing physical activity holds promise for reducing the risk of cardiovascular disease as well as other health benefits. Thus the reduction of injuries related to sport and recreational activities has significant implications for public health. Secondly, although the majority of sports injuries are not severe enough to require hospitalization, they are frequent and have a major economic impact in terms of both direct medical costs (treatment and rehabilitation) and indirect costs (lost productivity by parents taking time off to care for injured children).

Assessing the best prevention strategies for a sports or recreational injury requires a full understanding of the factors that contribute to both the occurrence of these injuries and the uptake of, or compliance with, potential prevention strategies. One of the challenges in current injury prevention is the gap that exists between what is known about these factors and the use of that information in developing and evaluating prevention strategies and/or policies. Prevention strategies can take the form of education and awareness raising activities (e.g., skill building sessions, public awareness campaigns), engineering modifications (e.g., new equipment design) or the setting and enforcement of policy (e.g., rules of competition). They can be targeted at participants, parents, coaches or the community at large. Injury theory and common sense suggest that the majority of sports and recreational related injuries can be prevented by:

1. Ensuring that design, development and maintenance of sports and recreation equipment and facilities meet safety standards;
2. Promoting the wearing of protective gear in both informal and organized sports and recreational activities;
3. Adapting playing rules to the participants with respect to age, etc.

Actual evidence, however, is less plentiful and the views on what environmental modifications, standards, protective equipment and playing rules are needed varies between participants, parents, coaches and officials. Further, much of what already exists in the way of standards, equipment and rules for children and youth is based on studies of adults.

To address these questions, researchers at Plan-it Safe: the Child and Youth Injury Prevention Centre at the Children's Hospital of Eastern Ontario and the British Columbia Injury Research and Prevention Unit initiated a collaborative research project in January 1998. A systematic review of published and unpublished Canadian and International literature on the evaluation of strategies to prevent injury in selected sports and recreational activities was selected. This method was selected over other approaches as it uses a methodical approach to comprehensively identify relevant literature, hence minimizing selection bias, and makes explicit the methods used to conduct the review (Chalmers and Altman, 1995). Key aspects of a systematic review include a well-formulated review question; explicit inclusion criteria; identification and inclusion of all relevant evidence; description of the methodology used to conduct the review; and an effort to explicitly link resulting recommendations to the evidence. Although two systematic reviews related to sports and recreational injury prevention had been conducted previously in Australia and the U.S., one addressed protective equipment only, one was not specific to children and youth, and neither examined the issue from the Canadian perspective (Dowswell, Towner, Simpson et al., 1996, Harborview Injury Prevention and Research Center, 1997).

The goal of this project had three components: to examine existing evidence on the effectiveness of current prevention strategies in selected sports and recreational activities; to determine the applicability of this evidence to children and youth and to the Canadian setting; and to make recommendations related to best practice (policy and programming) and future research needs in this area. The specific objectives were to:

1. Describe the evidence and quality of evidence on the effectiveness of strategies used to prevent injury during sports and recreational activities.

2. Develop and widely disseminate two reports – a *Technical Report* describing the review methods used, the results of the synthesis of evidence and a series of recommendations related to future research and best practice, and a *Best Practices Guide* providing evidence-based practice and policy recommendations for those involved in or responsible for ensuring safe participation in the selected sports and recreational activities.

II. METHODS

SYSTEMATIC REVIEW PROTOCOL

The protocol for this review was developed from previously tested "systematic review" methods, including explicit and reproducible procedures for systematically identifying and selecting studies, grading the strength of evidence, and extracting information. Adaptations to the protocol were made to suit the particular needs of this project in consultation with experts.

SELECTION OF SPORT AND RECREATION INJURY AREAS

Sports and recreational activities for this review were selected by two methods: (1) an analysis of the incidence and severity of pediatric sports and recreational injuries presenting to emergency rooms at the Children's Hospitals in Vancouver and Ottawa; and (2) discussions with a panel of experts from injury prevention, epidemiology and sports medicine. The Canadian Hospital Injury Reporting and Prevention Program (CHIRPP) database was analyzed for sport and recreational injuries in children and youth. Lists were produced of the top sport and recreation areas by ranking injury frequency and severity (a severe injury was defined as an extended stay in the emergency room or hospitalization). An individual list was produced for each hospital to examine regional differences and then the two lists were combined.

In combination, the searches identified twenty-five activities: trampoline, downhill skiing, soccer, snowboarding, inline skating, baseball, basketball, football, ice hockey, horseback riding, swimming, ice skating, ringette, field hockey, roller hockey, rugby, golf, gymnastics, martial arts, track and field, sledding, skateboarding, wrestling, volleyball, street hockey. Because cycling is listed in CHIRPP as a method of transportation, not as a sport or recreational activity, it was not identified in the search. The investigators and expert panel thought that cycling, as a major cause of injury, should be covered in this review. General sport and physical activity were also added to ensure that multiple-sport or non-sport-specific prevention strategies (e.g., stretching) would be picked up by the electronic searches. The final activity list included twenty-seven sport and recreation activities.

SEARCH OF ELECTRONIC DATABASES TO IDENTIFY PUBLISHED LITERATURE

An electronic search strategy was developed in collaboration with a librarian with extensive experience in conducting systematic reviews. A search filter (a series of subject-related keywords used to extract potentially relevant articles from a computerized database) was first developed and tested for baseball (randomly selected as a test case). Attempts were made to refine this initial search until any additional refinements excluded one or more previously identified potentially relevant articles. Eight electronic databases were then repeatedly searched using the broad filter previously developed with the addition of search terms for each specific sport (including cross-cultural synonyms – e.g., softball and baseball). The databases searched were Medline, Psychinfo, CINAHL, Current Contents, HealthSTAR, Sportdiscus, the Cochrane database for Systematic and Complete Reviews, the Cochrane Controlled Trials Registry and EMBASE. All databases were searched from the earliest records available for all languages and age groups, and for all sports with the exception of cycling, where only articles after 1996 were included[1].

In order to reduce the number of duplicates identified due to either the similarity between identified sport areas (e.g., softball and baseball) or terms common to more than one sport (ice skating and in-line skating), several of the sports were pooled during searching. A total of twenty different searches were run: trampoline, soccer (football, rugby), snowboarding, skating (ice and inline), baseball, basketball, hockey (ice, street and ringette), horseback riding, sledding and skateboarding, downhill skiing, wrestling, martial arts, golfing, gymnastics, volleyball, track and field, swimming, cycling and general sport. All searches identified at least one potentially relevant study.

The results of each of the separate database searches were collected in a separate Reference Manager (RM) database. Sport-specific databases were then created by first capturing those references from Medline and then adding references from successive computerized databases in the order listed above. Each reference identified was tagged with an added keyword that reflected the sport search and computerized database from which it was identified. Once created, each sport-specific database was hand-checked for duplicates. Priority for retaining duplicates was given to those retrieved by Medline and then to each successive database in the order of capture.

Due to the broad nature of both the search strategy and the content of some articles, many duplicates were retrieved. To address this, all sport-specific databases were subsequently collapsed into one large database in order to identify any duplicate references between the twenty sport-specific databases. One copy of the reference was held in the most appropriate sport database, and all others were deleted. The twenty sport-specific databases were then recreated using the sport keywords. Accuracy of each sport-specific database was also checked during the selection of potentially relevant articles. If inappropriately categorized references were found, they were moved to the sport-specific database that most accurately reflected their content.

SELECTION OF ELIGIBLE ARTICLES

One member of the research team screened each citation in the 27 sports-specific databases, including the abstract when available, using broad criteria. When examining an abstract for inclusion, it was required to: (1) pertain to unintentional injury in one of the twenty-seven identified sport and recreational areas; and (2) involve the evaluation of an injury prevention strategy or if not specifically stated, an indication that it might possibly involve one. If no abstract was available, information was taken from the article title. For inclusion as potentially relevant, an article title needed to: (1) refer to unintentional injury in one of the twenty-seven

[1] Only cycling-related articles after 1996 were included in the search; however the review included all articles identified by the Harborview Injury Prevention and Research Center (HIPRC), which had already conducted a systematic review of cycling studies up to 1996.

identified sport areas; and (2) clearly indicate that it was an evaluation of an injury prevention intervention. Selection of articles meeting these criteria was not dependent upon the source of the article. However, if a title met the first criterion but did not contain clear reference to evaluation, the document source was checked. If the source was found online at the Mulford Library website, the citation was marked for potential relevance. If the source was not listed, it was not marked for further review.

Hard copies of all potentially relevant articles were sought and retrieved. If articles were not available from local libraries in either Ottawa or Vancouver, they were ordered through CISTI (Canada Institute for Scientific and Technical Information). Articles not available through any of these sources were ordered through inter-library loan services at a local library. A cut-off date for receiving articles ordered through inter-library loans was set for a minimum of four weeks after the last of the articles were ordered, allowing a reasonable amount of time for articles to arrive. This was a somewhat arbitrary timeline and in the end, all articles that did not arrive prior to commencement of write-up of the final report were considered unavailable and excluded from the review.

All potentially relevant articles were screened for inclusion using a set of pre-determined relevance criteria. A document was included if it:

- Addressed sport and/or recreation unintentional injury prevention (IP);
- Addressed IP in one or more of the 27 specific sport and recreational areas (cycling-related articles were limited to those published after 1996);
- Evaluated the effectiveness of either (a) an educational IP program/strategy (b) a policy/regulation/legislative change (c) a community organization effort (d) environmental, equipment or product modifications;
- Contained either (a) injury incidence (b) injury severity (c) uptake of risk-reducing behaviors (d) uptake or compliance with IP measures;
- Contained a control group in its methodological design or used other comparative measures.

In addition to the relevance criteria cited above, the relevance form developed also asked reviewers to indicate if the article was Canadian in origin. This was not recorded for the purpose of assessing relevance, but to provide an idea of the amount of Canadian research in these areas. The relevance form was piloted on a random sample of fifteen potentially relevant articles. Seven members of the research team completed the relevance form for each of the pilot articles and results were compared. Disagreement was resolved by discussion, and changes to the relevance form were made. Once the form was finalized, all English and French language articles identified as potentially relevant were independently reviewed by two of the team members. Any disagreements were resolved by discussion between the two reviewers and when necessary, a third reviewer made the final decision.

One refinement was made to the relevance criteria after implementation. A number of studies were identified in which the outcome was a “biomechanical” measure related to injury (e.g., a force such as torque, resistance or absorption). Although the research team agreed that these studies might add to the comprehensiveness of the review, they were excluded because biomechanical research had not been specifically addressed in the search strategy. The decision to exclude biomechanical studies was an attempt to ensure that bias was not introduced in the search and that the quality of the review was maintained.

It was necessary to alter the relevance protocol for foreign language articles other than French due to a lack of readily available reviewers capable of translating as well as the high cost of translation (e.g., $400 per article). If the title and abstract were available in English, assessment of relevance was attempted using the information available. If not available, individuals who read the language were sought and relevance forms were completed in consultation with a research team member. Twenty-two relevance forms were completed for foreign language articles. Only when an individual who read the language could not be located, or if there was no abstract with the first 250 words of the methods or results, was an article abstract actually translated. One team member then completed the relevance form from these translations.

Hand searching of additional sources was conducted to identify potentially relevant studies not captured in the electronic database search. Sources for hand searching included the reference lists of: a) all relevant articles b) all "review" articles identified c) sport injury textbooks published after 1990 d) a series of sport injury systematic reviews published by the MONASH Injury Prevention Centre in Australia and e) the table of contents from the American Journal of Sports Medicine. In addition, if an identified sport did not have representation in the list of relevant articles, 10% of the potentially relevant articles for that sport were randomly selected and the reference lists hand-searched. Finally, after the list of relevant articles was compiled, all volumes of any journal that was the source of at least 10% of the articles were also hand searched for additional articles. Any article identified through the hand searching process was first checked against those pulled in the electronic search before retrieval, in order to avoid duplication.

Letters were sent to Canadian Sport Organizations requesting information on any published or unpublished reports (gray literature) for the 27 areas covered by the review. These requests did not yield any potentially relevant reports.

DATA EXTRACTION

A data extraction tool was developed for each of the research designs to extract bibliographical details and descriptive data about each study. Extracted information included:

- Year of publication;
- Country in which the study was conducted;
- Sport studied;
- Descriptions of type of activity (e.g., competitive versus non-competitive);
- Study design;
- Study time period;
- Study aim;
- Population(s) studied;
- Setting;
- Intervention approach;
- Primary outcome(s);
- Sample size;
- Key study results.

For each relevant study, reviewers attempted to abstract the primary outcome, the intervention and relevant results. If the primary outcome was unclear, an objective selection of the outcome to report was made by determining which outcome seemed to be the most telling or serious (e.g., helmet use would be more telling than helmet ownership; death is a more serious outcome than hospitalization, etc.). Piloting of the data extraction forms was done in three stages (in conjunction with piloting of quality assessment forms - see section 1.7). Each of the first two stages involved extracting data from three randomly selected articles and in the final stage, six articles chosen to represent each of the study designs was included (RCT, Non-Equivalent Control Group Design, Cohort, One-Group Pre-test Post-test Design, Case Control, and Time Series). At each phase of the pilot, team members independently completed the data extraction forms and results were compared. Disagreements were resolved through group discussion and changes were made until consensus was met.

QUALITY ASSESSMENT

The quality, or strength of reporting, of each relevant study was assessed to determine the strength of evidence provided. Articles were first grouped by study design as per data extraction. RCTs were evaluated using the quality assessment tool developed and validated by Moher, Jadad et al. (1996). Since no practical tools existed to evaluate the remaining study designs, quality assessment forms were developed. First the research team completed an extensive Medline literature review on Quality Assessment instruments to identify relevant articles. The search detected 258 potentially relevant articles, which was reduced to 53 after an initial review. A full-text review revealed 18 instruments that could be used to assess the quality of studies other than RCTs.

A list of questions addressing quality of reporting and internal and external validity of non-RCT study designs was extracted from the 18 instruments. Some questions were general and applied to all study designs while others were specific to a particular study design. The resulting list of questions was sent out for review by an international multidisciplinary panel of experimental design and methodology experts. Based on their recommendations, an initial quality assessment protocol was developed for each study design. These drafts were reviewed and redundant or irrelevant questions were removed.

The resulting quality forms were pilot tested in three steps. Each of the first two steps involved piloting the forms using three randomly selected articles. Changes were made to the forms after each of these pilots. For the third stage, six randomly selected articles chosen to represent each of the study designs were reviewed. For each stage of testing, team members independently completed the quality assessment forms for the selected studies, and group results were compared and discussed. Any disagreements were resolved though group discussion, and final revisions were made.

DATA EXTRACTION AND QUALITY ASSESSMENT OF INCLUDED STUDIES

After all relevant articles had been identified, they were divided by sport. Due to limited resources and consideration of the limited value of synthesizing a small number of articles, only those sports with three or more relevant articles were included for further analysis. Thus eight of the 27 identified sports were put through data extraction and quality assessment (baseball, basketball, cycling, skiing, football, hockey, rugby and soccer). A pair of reviewers was assigned to each of the included sports, and these two reviewers independently completed the data extraction and quality assessment forms. The pairs then met and any disagreements were resolved through discussion. The final forms, with answers agreed upon by both reviewers, were submitted for entry into an electronic database. Once all data were entered, each reviewer pair was responsible for synthesizing the data and writing the sport reports, including the development of research, practice and policy recommendations for their assigned sport. Abstracted information was put into tables to facilitate synthesis and recommendations.

In addition, totals for each subsection of the quality assessment scores, quality of reporting, internal validity, and an overall score were calculated. The overall score was converted to a percentage value and the quality of each study was rated using the following three-point scale:

- 0% - 49% = Poor;
- 50% - 89% = Moderate;
- 90% and greater = Good.

These ranking scores were incorporated into the results summary tables for each sport. Post-hoc statistical analysis was calculated to determine the inter-rater reliability of the quality assessment.

EXTERNAL CONSULTATION PROCESS

Once draft chapters for each of the sports with four or more relevant articles were complete, they were distributed to the Expert Advisory Panel for comment. In addition, the national organizations for each of these sports was contacted and a series of questions on injury prevention and safety measures currently recommended in Canada was asked. The responses to these questions were integrated into the results of the systematic review.

STATISTICAL ANALYSIS

Statistical analysis was conducted on the data extraction and quality assessment to test reliability of the reviewers making the measurements. Four of the sports were randomly selected to be tested for the data extraction. Eight questions from the data extraction were selected as representative of the data extraction questions. A Kappa was calculated to determine the degree of consistency between the reviewers using Cohen's method.

The reliability of the quality assessment was assessed with multiple statistical measures. A reliability analysis was calculated for reporting, internal validity, and total quality assessment to ascertain the strength of each individual question. A factor analysis was also completed to assess trends within the quality assessment and to determine if particular questions accounted for a significant degree of the variance.

The confidence interval was set at 95% ($p < 0.05$) for all tests. All calculations were completed on Statistical Package for Social Sciences (SPSS) 9.0.

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III. RESULTS

The detailed searches of the eight electronic databases identified 21,499 articles meeting the initial search criteria. An additional 124 articles were identified through hand searching. A review of the abstracts from each article identified 795 potentially relevant articles. One hundred and seventeen of these met the strict inclusion criteria and were judged to be relevant to this review. All of the relevant studies were published in English. Relevant articles were only found for 17 of the original 27 sport and recreational activities. Only eight of the original sports/activities had three or more relevant articles and were included in this systematic review: Alpine Skiing, Baseball, Basketball, Bicycling, Football, Ice Hockey, Rugby and Soccer. Overall the quality of the relevant studies was found to be low, with approximately 52% rated as poor, 47% as moderate and only 1% as good. One of the objectives of this review was to assess injury prevention interventions among Canadian youth and children. However, only seven (6%) of the articles were of Canadian origin. Therefore wherever possible a Canadian perspective is presented on injury prevention, but most of the research is based on populations from other countries. The remainder of this report consists of the individual reports for each of the eight sports with three or more relevant articles.

Table III.I Total Potentially Relevant and Relevant Articles and Number of Canadian Articles

	Potentially Relevant	Relevant	Potentially Relevant Canadian	Relevant Canadian
Alpine Skiing	91	10	1	0
Baseball	39	4	2	0
Basketball	14	3	0	0
Bicycling	31	12	11	0
Football	159	47	5	1
General Sport	189	2	12	0
Gymnastics	10	1	2	1
Horseback Riding	20	1	0	0
Ice Hockey	65	8	27	5
Inline Skating	17	2	1	0
Martial Arts	13	2	1	0
Rugby	35	5	1	0
Skating	23	2	1	0
Soccer	44	4	1	0
Swimming	28	1	0	0
Volleyball	9	1	0	0

The three primary reasons for articles to be excluded were: the studies did not address sport and/or recreation unintentional injury prevention; the studies did not evaluate the effectiveness of an injury prevention strategy, intervention or program; or the study investigated biomechanical factors.

IV. REVIEW OF ALPINE SKIING INJURY PREVENTION STRATEGIES

Alpine skiing is one of Canada's most popular sports, due to long winters and the abundance of snow and mountains. However, there is some suggestion that because of the cost of participating (equipment and access), skiing-related injuries are more likely to occur in higher economic strata of the population (Faelker, Pickett & Brison, 2000).

Due to the nature of alpine skiing, injury risk is related to the high speeds and potential for impact with immovable objects, level of ski ability (due to the typical mixed abilities of skiers on a ski slope), equipment and the environment. Alpine ski injuries tend to be related to a twisting fall, impact with an obstacle or collision with another skier. The types of injuries seen are typically lower extremity injuries with a historic trend suggesting a shift from ankle fractures and sprains to severe knee injuries because of changes in skiing equipment in the last two decades.

Lower extremity injuries tend to be the result of twisting falls, while upper extremity and head injuries are due to impact. Upper extremity injuries are estimated to account for between 13% and 36% of all downhill-related injuries. Internationally, thumb sprains (rupture of the ulnar collateral ligament as the result of impact with the snow during a fall) account for the largest proportion of upper extremity injuries, followed by fractures and dislocations of the shoulder as a result of either a fall or a pole becoming entangled in bushes (Soma, Mandelbaum, Watanabe & Hanft, 1996).

A case series of spinal injuries in Canada found that skiers received spinal injuries when landing incorrectly from a jump or skiing out of control into trees. One-third of these fractures resulted in paralysis, and two thirds had associated major injury of the extremities, chest, abdomen, or head (Reid & Saboe, 1989).

In an international review of alpine skiing injury rates in 1996, Soma et al. found the studies reviewed suggested a decline in injury rates and that the current injury rate could be estimated to be 3.2/1000 skier days for skiers of average ability. They also reported that based on prospective surveys of downhill skiing-related injuries, reported incidence rates appear to be on the decline attributed to improved grooming of ski hills, preparation and education of skiers and ski equipment. None of the prospective studies in the international review were Canadian.

An analysis of CHIRPP data for the pediatric sites in Ottawa and Vancouver found that skiing injuries ranked eighth in terms of frequency of emergency room visits related to sports and recreational activities. Skiing injuries ranked first, however, in terms of frequency of hospitalization, representing 13% of children and youth presenting at emergency rooms with a sports and recreational related injury (Scanlan et al., 2000).

Risk factors for skiing can be classified as relating to the skier, the equipment or the skiing environment. Skiier-related factors such as skiing ability and experience appear to be related to injury, with rates of injury in beginner skiers being 2 to 9 times higher than experienced skiers (Hauser, Asang & Müller, 1985). Further studies comparing injury rates between children and youth suggest that skiers under 11 years-of-age have the same incidence of injury as adults, but "teens" aged 12-16 years are more prone to injury (Blitzer, Johnson, Ettlinger et al., 1984; Garrick & Requa, 1979). This may reflect increased risk-taking in this age group.

In the area of equipment, the reduction in lower extremity injuries as the result of twisting falls can be attributed to great strides in ski equipment design. Two major improvements have been the development of quick release bindings and mid-calf height boots. However, despite these advances, certain types of knee injury (anterior cruciate ligament [ACL] sprains) have not benefited from the advances in ski bindings and may conversely have increased in frequency (Soma et al., 1996).

Results

The searches of computerized databases found 1500 alpine skiing-related studies, of which 70 were found to be potentially relevant. Twenty-one additional potentially relevant studies were identified as a result of hand searching. Eleven of the 91 potentially relevant articles (12%) met the relevance criteria. Of the 80 non-relevant studies, the main reasons for exclusion were a lack of evaluations (55%), not addressing injury prevention (16%), not having a comparison group (14%), and the lack of an injury-related outcome measure (6%) (includes those examining biomechanical measures). Only one Canadian article was found, but it did not meet the relevance criteria. Eight of the 11 relevant articles were found as a result of hand searching. This was initially a concern as it suggested that the search strategy had not been effective, but all of these articles came from the proceedings of a series of skiing-specific research meetings that did not appear in the computerized databases. Of note, three of the articles dealt with the same data set collected in the 1984/85 ski season (Bouter, Knipschild & Volovics, 1989a; 1989b; Bouter & Knipschild, 1991). The first two articles examine binding function and ability and physical condition, respectively. The third is essentially a summary of the findings of the first two, with a discussion of the implications of the results for health education. For the purposes of this review, only the first two are included in the analysis.

Of the remaining 10 relevant studies, all but one were conducted in the 1980s. All dealt with non-organized, non-competitive skiing. The majority (70%) were case control studies examining injury data from ski patrols, local clinics or hospitalizations and correlating it to specific risk factors (Bouter, Knipschild & Volovics, 1989a; 1989b; Ekeland, Holtmoen & Lystad, 1989; Hauser, Asang & Müller, 1985; Lystad, 1989; Shealy, 1993; Ungerholm & Gustavsson, 1985).

There were only three studies with prospective designs - two RCTs and a non-equivalent control group design (Jorgensen, Fredensborg, Haraszuk & Crone, 1998; Hauser, 1989; Damoiseaux, de Jongh, Bouter & Hospers, 1991). All three examined the impact of a specific strategy on risk-taking and in particular on binding setting adjustments.

When quality was examined, two studies were judged to have moderate quality of reporting and the remainder were of poor quality. Average quality score for the case-control studies was 6.4/18 (range 3-12.5), the nonequivalent control group 5.5/14 and the two RCTs, 0/5 and 1/5. None of the prospective studies addressed the biases introduced by their study designs.

Only one study exclusively targeted children and/or youth (Ungerholm & Gustavsson, 1985), although children were included within the sample for five others (Damoiseaux et al., 1991; Jorgensen et al., 1998; Hauser, 1989; Lystad, 1989; Ekeland et al., 1989).

Environmental Interventions

EQUIPMENT

Six of the relevant studies (60%) focused on ski bindings, their adjustment and risk of injury. Five of the case-control studies examined the association of properly adjusted ski bindings to injury and in particular, lower extremity equipment-related (LEER) injury.

One study found that skiers with non-release bindings were 3.3 times more likely to sustain a lower extremity injury than those with release bindings (Bouter et al., 1989b), and two found that skiers who performed binding release self-tests were less likely to sustain an injury than those who did not (Ekeland et al., 1989; Lystad, 1989). Two of the case-controls found that skiers with bindings at higher than recommended settings were at greater risk of injury (Ungerholm & Gusavsson, 1985; Hauser et al., 1985). Hauser et al. (1985) went on to discuss the need for and importance of developing standard binding settings for children and youth.

The only prospective study examining equipment was an RCT examining the impact of actual testing and proper fitting of ski bindings on ski injuries (Hauser, 1989). Skiers were recruited through advertisements in the media and then randomly allocated to have their bindings tested and properly fitted or to serve as controls. The primary outcome of interest was self-reported injury collected using postcards, which were completed and mailed back to investigators. The data collected also included a measure of exposure (skier days) to allow for more accurate estimates. Investigators found that the actual number of falls, injury events, and lower extremity injuries were significantly lower in the group whose skis had been adjusted than among the control group ($p < 0.01$). They also examined thumb injuries using a special bow grip pole in a sub-set of skiers and found that 2.8% of those using the special pole reported thumb injuries as compared to 4.0% of controls (actual numbers were not presented). The limitations of the study were not discussed.

None of the studies addressed the issue of helmet use to decrease the risk of head injury, an intervention that is becoming increasingly popular, especially for children.

None of the studies examined environmental factors such as pitch of hills, number of obstacles, depth of powder, etc. Lack of data on these factors in epidemiological studies makes it difficult to assess their importance.

Educational Interventions

Two of the case-control studies examined the impact of ski lessons on risk of injury (Boulter et al., 1989a; Shealy, 1993). Both studies found no overall association between risk of injury and ski lessons. However, the results from the Netherlands suggested that beginners may benefit from lessons (Boulter et al., 1989a). Boulter et al. (1989a) also examined the impact of practicing on an artificial slope, a ski gymnastics class, warming up before skiing and general physical condition. There was no association between the artificial slope and ski gymnastics, general physical conditioning decreased risk, and warming up appeared to increase injury risk. None of the prospective studies assessed the impact of ski lessons on ski-related injuries.

Two of the three intervention studies evaluated strategies to increase the proportion of skiers with properly adjusted bindings (Jorgensen et al., 1998; Damoiseaux et al., 1991). In addition they examined increases in awareness of the importance of properly adjusted ski bindings and the proportion of skiers conducting self-tests to assess binding adjustment.

Jorgensen et al. (1998) evaluated the impact of a 45 minute instructional video that concentrated on the significance, testing and adjustment of release bindings to prevent injury and included how-to information on self-testing. Buses of skiers on their way to the ski hill were randomized to receive the video during the trip or to serve as controls. No process measures were reported, making it difficult to assess how many of the participants actually attended to the video. The primary outcome of interest was self-reported injury collected by questionnaire on the return trip. The strategy appeared to be successful with an overall decrease in injuries of 30% between experimental and control buses and an 85% decrease in injuries among beginners. Further, there were fewer falls and knee injuries among the experimental group, and they were also more likely to self-test their bindings.

Damoiseaux et al (1991) conducted a 2x2x2 factorial study examining delivery options for the key message – " have your bindings adjusted." Participants, recruited at ski fairs across the Netherlands, all planned to ski during the 1987/88 ski season. Eight groups of approximately 145 participants received either a fear-arousing or neutral message delivery via cassette or pamphlet either one or three weeks before their next ski trip. There was also a control group of 136 participants' who received nothing. The outcome of interest was self-reported binding adjustment and was collected by mailed questionnaire following participants' ski holidays. There was no overall difference between experimental and control groups. However, the fear-arousing approach appeared to independently impact binding adjustment with a higher proportion of those receiving this approach to messaging reporting that they had had their bindings adjusted. The authors acknowledge that it is not reasonable to expect an occasional leaflet or cassette to have a permanent effect on the behavior of skiers and it is difficult to prove that a health education intervention can reduce the number of injuries. Finally, they conclude that the results of the study are not adequate to develop a mass media campaign as the target audience was undifferentiated.

Discussion

Little research has been done in this area, particularly in regards to children. Only one of the studies included in this review specifically addressed injuries in children. One of the obvious areas to examine further would be that of equipment in children's skiing. Advances in equipment are driven by elite athletes and the speed with which advancements in ski equipment have occurred over the last number of years may mean that much of the evidence from the studies in this review is now outdated.

It would also be of interest to examine environmental factors in injury incidents involving children versus adults to assess whether there is a difference. Any differences would probably be related, at least in part, to skiing ability. Given the suggestion that ski lessons may be valuable to beginning skiers, the majority of whom are children and youth, this strategy should receive further evaluation. It may be reasonable to evaluate measures to enforce the “skier code of responsibility”, so that when there are skiers of mixed ability on the ski hill, those with greater control are more mindful of those with less.

Only one of the studies included was even judged to be of moderate quality. This makes it difficult to assess the strength of evidence for the effectiveness of the strategies evaluated. Research in this area could benefit from stronger study design and certainly this review identified gaps in the research done to date. However based on the evidence available, there are some recommendations that can be made to participants and some policies that should be in place at ski hills. Recommendations are summarized below.

Recommendations

Research

- Develop a set of ski equipment standards for children and youth (e.g., appropriate binding settings for children);
- Conduct a prospective evaluation of the impact of ski lessons for children and youth, and in particular, quantifying the number of hours of skiing needed or skill level to no longer be considered ‘a beginner’;
- Evaluation of the impact of ski helmets (particularly for children and youth) in preventing injury;
- Further evaluation of public awareness campaigns designed to increase awareness of the importance of properly adjusted bindings;
- Evaluation of a policy requiring separation of skiers by level of ski ability;
- Conduct a study examining the relationship of hill environment to injury.

Practice

- All skiers should wear a helmet to prevent head injuries;
- Ski equipment should be appropriate to the level of ability of the skier;
- Ski bindings should be adjusted by a professional at the beginning of the ski season;
- Children and youth should be taught how to conduct a ski binding self-test and should conduct these tests at the beginning of each ski day;
- Parents should consider enrolling beginning skiers in lessons and restricting them to beginner ski hills until a reasonable number of ski hours have been obtained;
- Inexperienced skiers should be supervised until they have mastered basic skills (e.g., a controlled snow-plow).

Policy

- Until such time as a rigorous evaluation of ski lessons is conducted, ski lessons should continue to be recommended by ski hill management and school boards supporting ski trips - in particular for beginning skiers;

- Until such time as a rigorous evaluation of ski helmets is conducted, the use of helmets specifically designed for skiing should continue to be required by ski hill management for children taking lessons, and be required/recommended by school boards supporting ski trips especially for beginning skiers (children and youth).

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Table 1: Alpine Skiing Study Characteristic

First Author	Study Design	Quality Rating	Year of Publication	Country	Study Time Period	Funding
Jorgensen	RCT	Poor (0/5)	1998	Denmark	Weeks 7 and 8 of 1995 ski season	Not reported
Hauser	RCT	Poor (1/5)	1989	Germany	1982/83, 1984/85 and 1985/86 ski seasons	German Ski Federation and Int. Assoc. for Safety in Skiing
Damoiseaux	Non-Equivalent Control Group	Poor (5.5/14)	1991	Netherlands	Winter 1987-88	Not reported
Bouter (1989a)	Case Control	Poor (6.5/18)	1989	Netherlands	1984-85 ski season	Not reported
Bouter (1989b)	Case Control	Poor (5/18)	1989	Netherlands	1984-5 ski season	Not reported
Ekeland	Case Control	Moderate (8/18)	1989	Norway	1985-86 ski season	Norwegian Confederation of Sport and Norwegian Council for Science and the Humanities
Hauser	Case Control	Poor (3/18)	1985	Germany	January – April 1982	German Ski Federation and Int. Assoc. for Safety in Skiing
Lystad	Case Control	Poor (5/18)	1989	Norway	1982/83 to 1986/87 ski seasons	Not reported
Shealy	Case Control	Poor (5/18)	1993	USA	1988-89 and 1989-90 ski seasons	Not reported
Ungerholm	Case Control	Moderate (12.5/18)	1985	Sweden	1982-83 ski season	Two foundations and University

Table 2: Alpine Skiing Study Design

First Author	Study Aim	Study Setting	Study Participants/ Targets	Participant Selection/ Recruitment
Jorgensen	Investigate the effect of an instructional video on skiers' behavior, injury risk and type and severity of injury.	Ski bus tours from Denmark to France	Skiers in buses traveling from Denmark to ski hills in France (5-61 years; ø=24.3 years)	Skiers in randomly selected ski tour buses in Weeks 7 and 8 of the 1995 ski season.
Hauser	Estimate the injury risk difference in skiers with a correct binding setting compared to skiers with an average binding setting.	Ski areas around Munich Germany	Skiers from the area around Munich	Self-selection following advertising in local media; randomly allocated into intervention and control groups.
Damoiseaux	Evaluate the effectiveness of an educational message targeting skiers binding adjustments (compared eight ways of delivering the message).	Dutch skiers	Skiers = 18 years attending ski fairs in the Netherlands and planning to ski during the 1987/88 ski season	1288 skiers who volunteered at a ski fair to participate in a telephone survey on the subject of skiing and safety. 136 selected as controls, remainder randomly distributed to one of eight intervention groups.
Bouter (1989a)	Determine whether binding adjustment on both skis among injured skiers differs from non-injured skiers and whether binding release is less frequent during incidents leading to LEER compared to non-LEER injury.	Dutch skiers	Cases were injured skiers who claimed medical costs related to a ski trip; controls were uninjured skiers from same source	Cases selected from insurance company claims records; controls chosen by taking next available claim from an uninjured skier for non-medical reasons (e.g., loss or theft of ski equipment).
Bouter (1989b)	Determine the relation of ability and physical condition to injury risk in downhill skiing.	Dutch skiers	Cases were injured skiers who claimed medical costs related to a ski trip; controls were uninjured skiers from same source	Cases selected from insurance company claims records (fractures, dislocation, ruptured ligament and a sample of less severe injuries); controls chosen by taking next available claim from an uninjured skier for non-medical reasons (e.g., loss or theft of ski equipment).
Ekeland	Identify risk factors in alpine skiing to generate data for preventive measures.	Four Norwegian ski resorts (Hemsedal, Hovden, Oppdal and Trysil)	All skiers	Cases were injured skiers presenting to local physicians at the local medical center. Controls were randomly selected skiers from lift lines in the same skiing areas throughout the season.
Hauser	Identify special risk groups among skiers (of interest to this systematic review, those related to equipment and binding settings).	Bavarian skiing area (Garmisch-Partenkirchen)	All skiers	Cases were skiers brought to clinic at the ski area. Controls were a random selection of skiers at the ski area interviewed as they approached from the parking lot during the same time period.

Table 2: Alpine Skiing Study Design (*continued*)

First Author	Study Aim	Study Setting	Study Participants/ Targets	Participant Selection/ Recruitment
Lystad	Not stated by authors.	Norwegian skiing area (Hemsedal Skicenter)	All skiers (skiers ranged in age from 3-70 years)	Cases were lower extremity equipment-related (LEER) and non-LEER injured skiers presenting to physicians at a ski centre; controls were a randomly selected group of non-injured skiers from lift lines during different parts of each season and over the five seasons.
Shealy	Explore protective factors in downhill skiing and snowboarding (this systematic review examined the results for downhill skiers).	15 ski areas in the United States	All skiers	Cases were injured skiers at one of the 15 ski areas as reported in Ski Patrol incident reports; controls were a random sample of non-injured skiers selected to be representative of the skiing public in terms of general composition and activity.
Ungerholm	Explore risk factors related to lower extremity injury in skiers ≤ 16 years, including binding adjustment.	Swedish skiing area (Lindvallen, Sälen)	All skiers ≤ 16 years	Cases were skiers who suffered an injury to the lower extremity (LE) and were transported to the emergency medical office in the skiing area. Controls were a random selection of skiers from two representative lift queues (4-5 selected each day throughout the ski season).

Table 3: Alpine Skiing Intervention

First Author	Intervention Type	Details of Intervention	Frequency Duration	Primary Outcome Measure	Outcome Collection Method
Jorgensen	Education	An instructional video focused on how to get started in skiing and advice on injury prevention, especially the significance, testing and adjustment of the release binding and including the self-release test.	45 minute	Injury incidence – a physical disability sustained while skiing, that bothered the skier for > 24 hours and required a modification in behavior.	Self-completed questionnaire on return bus trip and contact with SOS International for injured skiers not returning on bus.
Hauser	Equipment	Ski binding testing and set properly by Landesinstitut fur Arbeitsschutz (according to IAS specification 80) - specifics of intervention not reported.	One-time intervention	Injury incidence	Mailed questionnaire
Damoiseaux	Education	A health education intervention with the central message “Have your ski bindings adjusted in a ski shop with the aid of a test device” distributed varying three conditions: *medium* (leaflet or cassette); *moment of receiving* (1 or 3 weeks before departure on ski vacation; *approach* (fear-arousing or neutral delivery of message).	One-time intervention	Mean binding adjustment score 1=not adjusted 2=self-adjusted 3=adjusted in ski shop 4=adjusted in ski shop and pretested	Telephone interview

Table 3: Alpine Skiing Intervention (*continued*)

First Author	Intervention Type	Details of Intervention	Frequency Duration	Primary Outcome Measure	Outcome Collection Method
Bouter (1989a)	Equipment	Exposure of interest is adjustment of ski bindings.	Unclear	Release of both ski bindings Recent binding adjustment	Mailed questionnaire
Bouter (1989b)	Education	Exposures of interest were training on artificial ski, ski gymnastics, physical conditioning, sports participation and ski lessons.	Unclear	5 behaviors of interest (potential protective factors)	Mailed questionnaire
Ekeland	Education/ Equipment	Exposures of interest were self-release testing binding and ski instruction.	Unclear	Prior self-release testing of bindings Formal skiing instruction in the current season	Cases – interview by physician Controls – interview on the slope
Hauser	Equipment	Exposure of interest is binding adjustment tested by modern marker setting device.	Unclear	Mean release torque of both left and right bindings	A modern Marker setting device
Lystad	Equipment	Exposure of interest is self binding release test		Proportion conducting self-test of binding release	Cases – interview by physician in doctor office Controls – interview with same questions as controls on ski slopes
Shealy	Education	Exposure of interest is ski lessons.	Unclear	Ever taken ski lessons	Cases – ski patrol report and/or supplemental data form Controls - interview
Ungerholm	Equipment	Exposure of interest is ski release bindings (toe and heel mechanisms deviation from IAS-80 reference system).	Unclear	Toe mechanism release forces (mean deviation from norm) Heel mechanism release forces (mean deviation from norm)	Binding release testing

Table 4: Alpine Skiing Results

First Author	Intervention Group	Results per group	P-VALUE	Conclusion
Jorgensen	Video on bus (*n* = 243) No video on bus (*n* = 520)	39 injuries/243 skiers who viewed video (16%) 119 injuries/520 skiers who served as controls (23%) 21.3 injured skiers per 1000 skier days in video group 30.6 injured skiers per 1000 skier days in control group	p = 0.038 $p < 0.05$	Injuries were seen in 16% of skiers in the video group versus 23% of skiers in the control group – a reduction of 30%. The video group was less likely to have to seek medical attention and/or reduce their amount of skiing. The video's impact appeared to be higher among beginner skiers.
Hauser	Pre-season binding test/ adjustment (*n* = 460) Control (*n* = 690)	81/460 (17.6%) with 1+ injuries 169/690 (24.5%) with 1+ injuries 0.7 LEER injuries/ 1000 falls 2.4 LEER injuries /1000 falls	$p < 0.01$ $p < 0.01$	Significant differences between skiers with proper binding setting and improperly set bindings. This was seen overall and in lower extremity injuries where the difference was 3.5 fold.
Damoiseaux	Cassette, one week, fear Cassette, one week, neutral Cassette, three weeks, fear Cassette, three weeks, neutral Leaflet, one week, fear Leaflet, one week, neutral Leaflet, three weeks, fear Leaflet, three weeks, neutral Control	2.94 2.76 3.06 2.97 3.05 2.83 3.08 2.94 2.86 Fear had a significant effect (F(1,939) = 5.6	 $p < 0.05$	A fear-arousing approach to the message increased adjustment behavior score irrespective of timing of message or medium of delivery. Recommend leaflet for practical reasons, three weeks prior to ski trip to allow time for skier to have bindings adjusted and a fear-arousing message, but only when precise directions as to how to prevent the health problem are provided.

Table 4: Alpine Skiing Results (*continued*)

First Author	Intervention Group	Results per group	P-VALUE	Conclusion
Bouter (1989a)	Males LEER cases (*n* = 136) Non-LEER cases (*n* = 129) Females LEER cases (*n* = 204) Non-LEER cases (*n* = 103) Controls	Two bindings 30% vs. 50% OR=1.0 One binding 27% vs. 23% OR=2.1 No release 33% vs. 13% OR=3.2 Two bindings 18% vs. 34% OR=1.0 One binding 29% vs. 22% OR=2.7 No release 46% vs. 28% OR=3.3		Non-release of bindings during an injury incident was associated with a higher risk of lower extremity (LE) injury. For males, the risk of LE injury was 3.2X higher (95% CI 1.6-6.5) in non-release and for females, 3.3X (95% CI 1.7-6.5). No relationship was found between time of last binding adjustment and injury risk between injured cases and controls, or between LE and non-LE injured cases.
Bouter (1989b)	Injured skiers (*n* = 572) Controls (*n* = 576) Training on artificial ski slope Course on ski gymnastics Not in good physical condition Instruction on 1 or 2 ski holidays (injured skiers *n* = 157; controls *n* = 132) Instruction on 3+ ski holidays (injured skiers *n* = 366; controls=432)	5% vs. 6% OR 1.5 (0.8,2.8) 21% vs. 19% OR 1.9 (0.7, 1.6) 29% vs. 36% OR 0.7 (0.5,0.9) 78% vs. 91% OR 0.4 (0.2,0.9) 36% vs. 35% OR 1.1 (0.7,1.6)		No evidence could be demonstrated for a preventive effect of a pre-holiday course in ski gymnastics, training on an artificial ski slope or good physical conditioning. The latter may even be a risk factor. A preventive effect for formal instruction was found only among skiers who had gone on winter ski holidays for the first or second time.
Ekeland	Formal instruction during current season Injured skiers (*n* = 289) Controls (*n* = 311) Self-release of bindings test LEER injured skiers (*n* = 112) Controls (*n* = 310)	Skiers taking formal instruction during the current season were significantly underrepresented among injured skiers (OR 0.56). Self-release test bindings were significantly more apt to release during the accident than bindings not tested (46% vs. 60%) .	$p = 0.02$ $p = 0.02$	Skiing instruction seemed to protect against injuries and all beginners ought to attend ski school classes. Prior release testing of bindings reduced the risk of sustaining a LEER injury. All bindings should be actuated in all directions each day before skiing.

Table 4: Alpine Skiing Results (*continued*)

First Author	Intervention Group	Results per group	P-VALUE	Conclusion
Hauser	Relative deviation from IAS (%) Tibia fracture (*n* = 16) Knee ligament injury (*n* = 35) Non-LEER injury (*n* = 112) Control (*n* = 825)	 146% 84% 70% 51%		Binding settings of skiers with sprained knees were distinctly higher than those with non-LEER injuries or controls and lower than those with fractured tibias. This may be related to cheaper equipment and/or increased likelihood to rent equipment which is not normally set according to function and setting values.
Lystad	Self-test of bindings LEER injured skiers (*n* = 371) Non-LEER injured skiers (*n* = Control skiers (*n* = 379)	 38% 59% 59% The proportion performing self-test in both injury groups declined over the five years.		During the timeframe of this study skiers became less aware of the importance of performing self-test of bindings. This suggests the need for continuous information about skiing safety and the role of self-test of bindings.
Shealy	Ski lessons Injured skiers (*n* = 21,817) Control (*n* = 2318)	 69.4% 74.1% $X^2 = 0.33$	 *p* = NS	There was no evidence that taking a skiing lesson is associated with a reduced risk of injury.
Ungerholm	Toe Mechanism Lower extremity injury [LE] (*n* = 31) Control [C](*n* = 183) Heel Mechanism Lower extremity injury [LE] (*n* = 31) Control [C](*n* = 183)	LE Right foot +114% (SD 82%) Left foot +117% (SD 96%) C Right foot +64% (SD 75%) Left foot +70% (SD 89%) LE Right foot +28% (SD 72%) Left foot +28% (SD 65%) C Right foot +23% (SD 56%) Left foot +24% (SD 55%)	$p < 0.01$ NS	The release force of the toe mechanism deviated markedly from the IAS-80 reference system for both groups. The deviation was even more pronounced for the injury group. The heel mechanism showed a moderate deviation in both groups, without a significant difference between them. Recommend toe release set loosely as possible. Risk of sustaining an injury was not related to who had adjusted bindings or where they had been adjusted.

V. REVIEW OF BASEBALL INJURY PREVENTION STRATEGIES

In Canada, both baseball and softball are very popular sports. According to Softball Canada, there are 400,000 players in registered leagues and an estimated 3 million people in Canada playing, but not registered. Baseball is one of the four most popular sports among children between the ages of 6 and 14. Results from the 1992 General Social Survey indicate that 14% of children (20% of males) aged 6-10 play baseball, as do 16% of children (25% of males) aged 11-14 (Sport Canada, 1994).

Walk, Clark and Seefeldt in their 1996 review of baseball and softball epidemiology state that injury rates in baseball vary widely, reflecting the variety of ways that baseball injuries are reported. With softball injuries, data collection and injury definitions are also inconsistent resulting in a lack of data to compare injury rates in youth softball.

The published literature reports acute injuries such as fractures or abrasions to a much greater extent than it does chronic or overuse injuries (Walk, Clark and Seefeldt, 1996). In this same review, injuries among young baseball players were found to most frequently involve abrasions, sprains and fractures. The location of injuries occurred most frequently to the upper extremity, followed by the spine and trunk. For softball, the patterns of injuries were found to be less clear, as only three studies addressed this issue.

The review also identifies overuse injuries to elbows and shoulders among youth baseball players as prevalent. As well, eye injuries among youth in baseball are reported as frequent and often severe, but poorly studied. Baseball is a leading cause of sports-related eye injuries and of hyphemas, a condition requiring hospitalization (Larrison, Hersh, Kunzweiler et al. 1990). The most frequent mechanism involves blows to the eye by a ball (Fountain and Albert, 1988).

An analysis of CHIRPP data on 1324 baseball injuries to children 1-19 years-old found that 39% of the injuries had occurred in an organized context, and 62% in an informal context (Health Canada, 1997). The head and neck as well as the upper limbs accounted for 42% and 34% of the injuries, respectively. Facial lacerations and hematomas were the most frequent injuries, followed by fractured or dislocated fingers (6%) and sprained ankles (5%).

An analysis of 1997 CHIRPP data from BC's Children's and Women's Health Centre and from the Children's Hospital of Eastern Ontario found that 221 (5%) of the 4387 pediatric sport and recreational injuries were due to baseball (Scanlan & Olsen, 2000). This ranked sixth out of 65 sports and recreational activities.

Both fatal and non-fatal catastrophic injuries have been reported in the literature related to both baseball and softball play. Walk, Clark and Seefeldt (1996), refer to ten reported cases, which involved children and youth between 4 and 14 years. Seven of the ten cases involved a pitched ball and 3 involved a batted ball. Seven of the ten injuries involved a blow to the chest, with the remaining three resulting from a blow to the head.

Studies reveal that more injuries occur in games than in practices when participant hours are included in the calculations (Walk et al., 1996). Studies of younger baseball players also found that they were more likely to be hit by pitched balls while batting (Grana, 1985; Grana, 1980; Hale, 1967). A commonly suggested cause of arm injuries in young baseball pitchers is poor pitching mechanics; positioning the elbow more horizontally is thought to increase the chances of injury.

Walk, Clark and Seefeldt (1996) identified the most frequent events associated with injuries at the youth level. These were being struck by a thrown or batted ball, injuries occurring while players were trying to catch the ball and sliding injuries. A 1967 study by Hale reported data on the percentage of injuries among youth players occurring at different positions: pitcher (5%), catcher (16%), first base (5%), second base (6%), third base (5%), shortstop (5%), outfielders (14%), runners (17%), and batter (22%). This information, although very outdated, suggests that closer attention should be paid to injuries among batters. Walk, Clark and Seefeldt comment that injuries in baseball and softball by position have been understudied and should receive further attention.

Environmental factors associated with risk of injury in baseball include the condition of the field and its surroundings, and the type of base used (Walk et al., 1996).

Results

Our search of electronic databases identified 37 potentially relevant articles. Two additional articles were identified through hand searching. Of the 39 articles, 4 were deemed relevant and are included in this review. Studies were excluded for the following reasons:

- 9 studies were excluded because they did not address injury prevention;
- 15 studies were excluded as they did not address any of the types of intervention outlined in the relevance criteria;
- 7 studies were excluded because their outcome measures were biomechanical;
- 1 study was excluded as it was unavailable.

One of the five relevant studies (Janda, 1988) was a brief report in the Journal of the American Medical Association which reported findings that were published in more detail in the American Journal of Sports Medicine in 1990. It was this publication that was used in this review. The four remaining studies were all prospective cohorts from the United States. Two of the studies focused on baseball, one focused on softball and the fourth looked at both. Both males and females were the targets in three of the studies and gender was not reported in the fourth. All were conducted in organized settings and reflected competitive activity. Two of the studies were conducted in a community sport club setting, one with collegiate and professional minor league teams and the fourth study with a variety of recreational, inter-collegiate, inter-scholastic, and intramural softball and baseball teams. Only one study (Pasternack, 1996) focused entirely on youth. Two included youth in the overall sample of participants, who ranged in age from 18 to 55 years-old (Janda, 1990) and 15-48 years-old (Sendre, 1994). Janda (1993), did not report age of study participants.

All four studies examined environmental strategy, with three of the four assessing the effectiveness of break-away bases in reducing injuries. The fourth study addressed both personal protective equipment (the use of a batting helmet with a face-mask) and equipment (reduced impact ball). The quality assessment for the three break-away base studies were moderate (Janda et al., 1993; Sendre et al., 1994; Janda et al., 1990). The study on protective equipment was poor (5/14) (Pasternack et al., 1996).

Environmental Interventions

BREAK-AWAY - BASES

Three of the studies compared the effectiveness of break-away bases versus standard bases in minimizing injuries. Janda et al. (1993) studied the effectiveness of break-away bases on sliding-related injuries in collegiate and professional baseball players. Nineteen teams within the National Collegiate Athletic Association (NCAA) and professional minor league baseball utilized break-away bases and were followed over a two season period. Break-away bases were used by all the teams during their home games. Four hundred and ninety-eight games were played on stationary bases and a total of 10 injuries were sustained. The same teams played 486 games on break-away bases with two sliding injuries. The incidence of sliding-related injuries were reported at 2.01 per 100 games for the stationary bases and 0.41 per 100 games for the break-away bases representing an 80% reduction in the number of sliding-related injuries among teams using break-away bases ($p < 0.05$). The authors recommended that break-away bases should be mandatory for both recreational and high-performance baseball.

Similarly, Janda et al. (1990) examined sliding injury rates among recreational softball players. Both male and female participants between the ages of 18-55 years in a summer recreational league were followed over two seasons. The incidence of sliding-related injuries was reported at 1/13.9 games (7.2%) for games on stationary bases compared with 1/316.5 games (0.3%) for games on break-away bases. For every sliding injury on a break-away base field, there were 22.7 injuries on the stationary base field representing a 98% reduction. The results were statistically significant ($p < 0.001$). The authors recommended the mandatory use of break-away bases for recreational softball leagues.

Sendre, Keating, Hornak and Newitt (1994) compared the use of the Hollywood Impact Base (HIB) to the use of standard stationary bases on the incidence of sliding-related injuries among 15-48 year-old, male and female softball and baseball players. All teams in Central Michigan agreed to use either the HIB or the standard base. Teams were selected to ensure inclusion of players of varying age, skill and intensity level. Participating teams, who ranged from recreational to intercollegiate varsity teams, were followed over a two-year period. The study reported one injury with HIBs and 4 injuries with standard bases. This represents 1 injury per 38.8 games (2.6%) for stationary bases as compared to 1 injury per 1285 games (0.08%) with HIBs. This finding was significant at the $p < 0.01$ level. The authors concluded that the injury rate with the HIB compared favorably with reported break-away base injury rate.

FACE MASKS

Pasternack, Veenema, and Callahan (1996) studied injury patterns among two Little League baseball organizations and assessed the impact of two types of safety equipment. Face masks were assessed among 9-12 year-olds and a reduced impact ball in seven and eight year-olds. In both organizations, team managers collected data over the course of one season using an injury survey form. The players aged 9-12 years-old using a batting helmet with a face mask had 4 ball-related facial injuries (in 21,486 player-hours) as compared to 3 ball-related facial injuries (in 39,522 player hours) among those using helmets with no face masks. The 8 year-olds playing with the reduced impact ball had 1 ball-related injury (per how many player hours) compared to 2 injuries for those playing with a regular ball. Injury rates and statistical testing were not reported for either intervention. The authors reported that a significantly greater number of ball-related facial injuries occurred on the defensive positions compared to offensive positions and concluded that face-masks on batters would only partially reduce the incidence of ball-related facial injuries. This study was the only one to specifically address baseball injuries among youth.

Discussion

The three cohort studies addressing break-away or Hollywood Impact Base provide good evidence that a modified base is more effective than a standard base in preventing sliding injuries in both baseball and softball at varying levels of play. Whether the HIB is as effective as break-away bases is unknown. However, none of these studies included children aged less than 15 years; thus the impact of base changes among younger players is also unknown. The evaluation of face masks and reduced impact balls was conducted on younger children; however the authors failed to present enough information on their findings to allow conclusions about the effectiveness of these two interventions to be drawn. Clearly, there is room for additional intervention evaluation research in the baseball and softball area relating to preventing injuries among children and youth.

Extensive literature is available on the topic of problems associated with the repetitive action of throwing a baseball among young pitchers (Walk, Clark and Seefeldt, 1996). These authors state that changes have occurred in rules to limit the number of innings that young pitchers are allowed to pitch. The authors suggest that continuing reports of arm and shoulder injuries among pitchers reflect an ongoing problem in this area.

Recommendations

Research

- Better surveillance of baseball injuries in children and youth, particularly in softball, where there has been very little research on the patterns of injury among children and youth. Conduct longitudinal studies to document overuse injuries frequencies in youth and children;
- Additional analyses of injury patterns in younger players. Particularly injuries occurring at different levels of play and differences between position played;
- Evaluate interventions such as modified playing rules or equipment (e.g., modified bases to prevent sliding injuries or reduced pitching schedules to prevent overuse injuries) aimed at younger players;
- Ascertain the frequency of pitchers/in-fielders being struck by a hit ball or the bat (or pieces of it) to determine if rule or equipment changes are necessary to prevent injury in specific positions;

- Investigate the effectiveness of educational strategies such as modified rules and skills, and sport-specific training programs for younger players; for example, safe sliding techniques or training programs to prevent overuse injuries.

PRACTICE

- Break-away bases should be used in softball and baseball at all levels of play.

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Table 1: Baseball and Softball Study Characteristics

First Author	Study Design	Quality Rating	Year of Publication	Country	Study Time Period	Funding
Janda (1993)	Prospective cohort	Moderate (12.5/17)	1993	USA	2 seasons	Not reported/unclear
Janda (1989)	Prospective cohort	Moderate (11.5/17)	1989	USA	2 seasons: 1986-87	Industry
Pasternack	Prospective cohort	Poor (5/17)	1996	USA	1 season: 1994	Not reported/unclear
Sendre	Prospective cohort	Moderate (12.5/17)	1994	USA	1990-1991	Industry

Table 2: Baseball and Softball Study Design

First Author	Study aim	Study Setting	Study Participants/ Targets	Participant Selection/ Recruitment
Janda (1993)	Study the effects of break-away bases within collegiate and professional baseball teams (on sliding-related injuries).	College/University (Varsity)	Sport/recreation participants Age, gender not reported	19 teams, minor league, college and university in US and Canada.
Janda (1989)	Compare injury rates focusing in softball games using break-away bases vs. those using stationary bases.	Community Sport Club	Sport/recreation participants Male and female 18-55 years	College students, labourers, executives, physicians
Pasternack	Determine injury patterns among youth baseball players and assess the value of 2 types of safety equipment.	Community Sport Club	Sport/recreation participants Male and female 7-18 years	Not reported
Sendre	Compare the frequency of base-running injuries associated with the Hollywood Impact Base (HIB) with those of the standard stationary base. Looks at both softball and baseball.	College/University (Varsity and Intramural) Community League	Sport/recreation participants Male and female 15-48 years	All teams in Central Michigan area (interscholastic, intercollegiate recreational and intramural) agreeing to use HIB or standard base.

Table 3: Baseball and Softball Study Intervention

First Author	Intervention Type	Details of Intervention	Frequency Duration	Primary Outcome measure	Outcome Collection Method
Janda (1993)	Environmental	Involved Product/Engineering modification or other movable equipment used: Break-away bases --all teams exposed during home games.	N/a	Injury rates	Sport association Or team records
Janda (1989)	Environmental	Involved Product/Engineering modification or other movable equipment used: Half of the games were played with break-away bases.	N/a	Incidence of sliding injuries (rates)	Hospital records Doctor diagnosis Other methods
Pasternack	Environmental	Approach involved Personal Protective Equipment worn by participant: Face Mask—compared group wearing batting helmet with face mask vs. group with no face mask. Involved Product/Engineering modification or other movable equipment used: Reduced impact ball—compared group using reduced impact ball vs. group who used a regular ball.	N/a	Ball-related facial injuries (incidence)	Sport association or team records
Sendre	Environmental	Involved Product/Engineering modification or other movable equipment used: two types of bases were installed on fields—HIB and standard bases.	N/a	Sliding-related injury incidence	Sport association or Team records Other methods

Table 4: Baseball and Softball Study Results

First Author	Intervention Group	Results per group	*p-value*	Conclusion
Janda (1993)	1(*n* = 498 games) 2 (*n* = 486 games)	2.01/100 games 0.41/100 games	$p < 0.05$	80% reduction in number of sliding-related injuries among teams using break-away bases.
Janda (1989)	1 (*n* = 633 games) 2 (*n* = 627 games)	1/13.9 games (7.2%) 1/316.5 games (.3%)	$p < 0.001$	Ankle injuries predominated – 24/45 injuries. For each sliding injury on break-away bases, there were 22.7 injuries on stationary bases.
Pasternack	1 (*n* = 21,486 player hrs) (*n* = 6855 player hrs) 2 (*n* = 39,522 player hrs) (*n* = 15,779 player hrs)	Face mask – 4 injuries No face mask – 3 injuries	No Statistical tests	Batting helmet with face mask – 4 ball-related facial injuries. Batting helmet only – 3 ball-related facial injuries. No statistical tests. Total number with outcome = 4.
Sendre	1 (*n* = 33,153 athlete exposures) 2 (*n* = 3999 athlete exposures)	Injury in 0.08% of games (0.003% injury rate in 33,153 athlete exposures) Injury in 2.6% of games (0.10% rate in 3999 exposures)	$p < 0.05$	Use of HIB significantly reduced injury rates.

VI. REVIEW OF BASKETBALL INJURY PREVENTION STRATEGIES

Basketball is one of the most popular sports among young people in Canada today. However, it is also the highest contributor to sport and recreation-related injuries. Among sport-related injuries for children and youth, basketball ranks first, according to both national and provincial CHIRPP (Canadian Hospital Injury Reporting and Prevention Program) data (over 14% of all sport/recreation-related injuries) (Goulet & Regnier, 1997). Based on 1992 General Social Survey data, young Canadians in the older teenage age group do participate in sport and recreation in large proportions with 89% of males and 64% of females reported participating in sport regularly (Ministry of Supply and Services, 1994). Older teenagers are underrepresented in the data set because they often attend general rather than pediatric hospitals. Further, it is reasonable to conclude that those sports and recreation activities that are most frequently participated in by the older age group are underrepresented as well. There is very limited epidemiological data regarding basketball because there are notable variabilities in the study design, data collection methods and injury definitions. They are: a) studies conducted for a relatively short periods of time b) the available retrospective and prospective studies deal with dissimilar groups of age and athletic abilities c) most studies are missing the exact number of males, females, and basketball players within a population of athletes (Zvijac & Thompson, 1996).

Since denominator data is not available for exposure or levels of participation, one needs to bear in mind when interpreting these results that the frequency of injury due to these sports may reflect the popularity and level of participation in that sport, and not a direct comparison of levels of risk between different sports. However, the frequency of injuries still represents a need to direct prevention efforts to the sport activities producing the greatest burdens of injury.

In 1993, hospitals participating in CHIRPP reported 2,831 emergency room visits following basketball injuries. Among 10 to 19 year-olds basketball was the leading cause of injury. Of those for which the mode of practice was known, the majority occurred during organized activities (Goulet & Regnier, 1997). The most frequent injuries were sprains (40%) and fractures or dislocations (26.5%). The upper limbs (50%) were most often affected, followed by the lower limbs (36%). According to a recent analysis of 1997 CHIRPP data from two Canadian pediatric hospitals, 12% of basketball injuries resulted in advice only, 15% resulted in treatment and follow ups, 3% led to short stays while just over 4% were admitted. Further analysis revealed that 12% of the injuries were superficial, 8% open wounds, 13 % fractures, 20% sprains and strains while nearly 8% were head injuries.

Further analysis shows that fingers were the body part most often involved in the injury (33.7%); the injury was usually associated with improper pass and reception. Falls and collisions were the circumstances involved in 74.3% of injuries. In an organized context, basketball has the second highest percentage of sports and recreation injury (20%) by age, sex and type of activity. In an informal context, basketball has the highest percentage of sports and recreation injury (15.9%) by age, sex and type of activity. Broken down by gender, boys in the 15-19 age group had the highest injury rate, while girls 10 to 14 were most frequently injured (32%) (Goulet & Regnier, 1997).

Results

Upon a search of computerized databases, fourteen potentially relevant articles were identified. Ten of the articles were written in English, three in French and one in Spanish. None of the articles were Canadian. No additional articles were identified through subsequent hand searching. Of the 14 articles identified, three met the inclusion criteria and are included in this review. All three were written in English. Most articles were excluded because they lacked an evaluation of an intervention strategy.

All three of the relevant articles found were randomized controlled trials (RCTs) conducted in the USA. One was conducted and reported in 1973 while the other two were conducted in 1991 and published shortly thereafter. All three studies focused on competitive play among either intramural college or military cadet athletes. Two of the three studies reported age means; 20.6 years (Barrett et al., 1993) and 19.25 years (Sitler et al., 1994). One study did not supply age-related data (Garrick & Requa, 1973). One of the studies (Barrett et al., 1993) was assessed to be fairly high quality based on the Jadad scale (3/5); however, the other two studies both scored 0/5.

Environmental Interventions

SHOE DESIGN AND PROPHYLACTIC TAPING

All of the studies examined equipment-related interventions designed to reduce injury to the ankle; one also examined knee sprains. Barret et al., (1993) examined whether wearing high-top and inflatable air chamber shoes resulted in fewer ankle sprains compared with wearing low-top shoes. Garrick and Requa (1973) attempted to define the relationship between ankle and knee sprains to the practice of prophylactic taping and strapping. Sitler et al. (1994) sought to determine the efficacy of a semi-rigid ankle stabilizer in reducing the frequency and severity of acute ankle injuries.

Barrett and colleagues (1993) recruited 622 male and female subjects from a college intramural program through flyers and newspaper advertisements. Subjects were then stratified by previous history of ankle sprains and randomized into one of three groups. They were then provided and fitted with either a low-top shoe, a high-top shoe or a high-top shoe with an inflatable air chamber. These shoes were to be worn during all season games, but no other time. Outcome measures of interest were incidence and severity of ankle sprains defined as causing functional limitation or stoppage. There were no significant differences found among the different groups after 39,302 minutes of play and 1833 player games.

The second RCT (Garrick & Requa, 1973) divided 2562 participants from a college intramural program into one of three groups whose ankles were either: not taped; taped with foam under-wrap and adhesive tape; or taped and additionally *J flex* wrapped with an elastic material prior to play. Further, participants were noted as having self-selected the use of either low- (n = 1914) or high-top (n = 630) running shoes for the season. Outcomes of interest included ankle and knee sprains that necessitated stoppage of play. The lowest incidence of ankle sprains was reported among the group with taping and high-top shoes (6.5/1000 games), followed by the low-top and tape group (17.6/1000 games). Injury incidence among both groups with no taping was considerably higher as were the low-top shoes/no tape (33.4/1000 games) and hi-top shoe/no tape groups (30.4/1000 games). However these differences were not statistically significant.

The third RCT (Sitler et al. 1994) assigned a sport stirrup ankle stabilizer to the treatment group of male military cadets (*n* = 789) while the control group (*n* = 812) remained unstabilized over three seasons. All players underwent a preparticipation exam to determine ankle injury stability and injury history. The same type of high-top basketball shoe was worn by all players. Outcome measures were defined as acute trauma to ankle ligaments resulting in the athletes' inability to participate in basketball for at least one day. Subjects experienced a total of 13,430 athlete exposures. Use of ankle stabilizers significantly reduced the frequency of ankle injuries across all player positions. However, reduction in ankle injuries depended on how the injury occurred (those who wore braces had fewer contact injuries). Severity of ankle injury and frequency of knee injuries were not reduced with ankle stabilizer use.

Discussion

There was some discussion that the use of new shoes may protect against sprains. Anecdotal evidence exists among professional basketball players, who generally wear new shoes each game or every few games. It is believed that the new shoes provide good lateral support and help prevent sprains. Barrett and colleagues suggested that this may have had an impact on their study as each player was provided new shoes and that the games were generally shorter in duration, and that the season was short in duration (6 weeks) (Barrett et al., 1993). The injury rates for this study were considerably lower than reported in previous studies.

There was no evidence from these studies that an increase in knee sprains results from the use of ankle support.

It is important to remember that the growing child is in a unique phase of development which puts them at risk for developing a number of problems including increased risk of sport-related injuries. Problems with coordination, even among previously well-coordinated athletes can be extreme (Larkins, 1991). None of the studies in this review included children, however CHIRPP data indicates that girls aged 10-14 have the highest injury rates resulting from basketball. Additional research must focus on children and youth playing the sport.

Historically, the majority of the athletic injury research did little more than provide descriptive information of existing injury patterns. Unfortunately, these descriptions fell short of pointing out the most efficient methods for improving programs of injury prevention. In addition, they did not indicate causal relationships, which must be understood before intervention techniques are established to reduce the incidence of injury (Mueller & Blyth, 1982).

The number of ankle injuries among the military cadet intramural group was significantly reduced with the use of ankle stabilizers. The incidence of injury and the player position were independent of ankle stabilizer use. Severity of ankle injuries was not significantly reduced with ankle stabilizer use (Sitler et al., 1994).

A recent systematic review published by the Cochrane Library (an international collaboration to review and summarize health care research) on the prevention of ankle ligament injuries reviewed five studies of young adults (mostly males) evaluating the use of semi-rigid orthotic devices or ankle braces (Quinn et al., 1998). Two of the studies were on basketball injury prevention. This review found “good evidence for the protective effect of these devices for athletes involved in sporting activities considered to be at high risk for ankle injuries”.

Recommendations

Research

- Future studies must clarify findings on a broader range of basketball players specifically younger players participating both recreationally and competitively;
- A large part of the published research literature on the prevention of sport injuries is aimed at organized athletics and as opposed to the casual recreational participant, which is how many children participate in sports and recreational activities. Research is needed in these areas to gain better understanding of how children are injured in non-organized settings and what can be done to effectively reduce these types of injuries;
- Sport injuries will never be totally eliminated. However, sports injury research has already resulted in rule changes, equipment standards, improved coaching techniques and better conditioning of the athletes. If continued progress in sports injury prevention is to be made, reliable data is imperative. Persistent surveillance of sports injury data is essential;
- Assess the impact of rule changes (i.e., limiting which players can attempt to gain possession of a rebounded ball) at reducing acute injuries in children and youth;
- Determine if any basketball injuries are the result of unsafe playing surfaces and assess the effect of court and facility maintenance on injury rate;
- Investigate the effect of equipment modifications, such as lighter basketballs, at reducing the force and injury potential of ball-player contact in children and youth;
- Research effectiveness of protective eye wear to prevent eye injury;
- Sample size required for clinical study should be determined a priori.

Practice

- The use of ankle stabilizers or high-top shoes and ankle taping can reduce the incidence of ankle injuries in basketball players;
- Encourage pre-season conditioning to prepare the athlete for competition and reduce the possibility of injury;
- Playing surfaces must be well-maintained and kept clear of debris or obstructions and conditions should be monitored;
- Ensure that the design, development and maintenance of sports and recreation equipment and facilities meet recognized safety standards and monitor the effects on injury reduction.

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Table 1: Basketball Study Characteristics

First Author	Study Design	Quality Rating	Year of Publication	Country	Study Time Period	Funding
Barrett	RCT	Moderate (3/5)	1993	USA	2 month intramural season	Reebok
Garrick	RCT	Poor (0/5)	1973	USA	Jan-Feb 1972 and 1973	Johnson & Johnson
Sitler	RCT	Poor (1/5)	1994	USA	1990-91 Season	Aircast Inc.

Table 2: Basketball Study Design

First Author	Study Aim	Study Setting	Study Participants	Participant Selection/Recruitment
Barrett	Examine whether wearing high-top and inflatable air chamber or low-top shoe results in fewer ankle sprains compared with wearing low-top shoes.	College Intramural Program	Sport/rec participants (20.6 year mean age)	Participants from college intramural basketball program (44% of population)
Garrick	Attempt to define the relationship between ankle and knee sprains to the practice of prophylactic taping and strapping.	College Intramural Program	Sport/rec participants (gender not reported)	Participants from college intramural basketball program
Sitler	Determine the efficacy of a semi-rigid ankle stabilizer in reducing the frequency and severity of acute ankle injuries occurring during basketball.	Military Academy Intramural Program	Sport/rec participants (males, 19.25 mean age)	Participants from US military cadets intramural basketball program

Table 3: Basketball Study Intervention

First Author	Intervention Type	Details of Intervention	Frequency / Duration	Primary Outcome Measure	Outcome Collection Method
Barrett	Environmental (personal protective equipment – shoe design)	Subjects were stratified by previous history of ankle sprains into 3 groups and by randomization. All participants were provided and fitted with a new pair of Reebok basketball shoes for all games during one season.	2 month study encompassing 1833 player games	rates of ankle injury; severity of ankle injury	Sport association, team records, Athletic Trainer
Garrick	Environmental (personal protective equipment – prophylactic taping)	Participants were either not taped, taped with foam underwrap and adhesive tape and a 3rd group taped, J-flexed and additionally wrapped with an elastic material prior to play.	2 month study repeated over 2 successive years	ankle sprains, knee sprains severity	Sport association and team records
Sitler	Environmental (personal protective equipment – use of sports stirrup ankle stabilizer)	Assignment of an ankle stabilizer to the treatment group vs. the nonbraced group over 3 seasons (2 years).	3 intramural seasons during each of the 2 years	incidence of ankle injury structural ankle injuries	Doctor diagnosis

Table 4: Basketball Study Results

First Author	Intervention Group	Results per Group	*p-value*	Conclusion
Barrett	(1) High-top shoes (*n* = 208); (2) high-top shoes with air chamber (*n* = 203); (3) low-top shoes (*n* = 158)	Total ankle sprains = 15. 7. Group 1 = 7 injuries, Group 2 = 1 injuries, Group 3 = 4 injuries. No significant differences in severity or incidence by shoe type.		There was no difference between high and low-top basketball shoes in the prevention of ankle sprains.
Garrick	Taped (*n* = 1163), Untaped (*n* = 1107), J-flexed and taped (*n* = 292)	Lowest incidence of ankle sprains were: (1) taping and high-topped shoes 6.5/1000 games; (2) no taping and low-top shoes 33.4/1000 games; (3) no tape and high-top shoes 30.4/1000 games; (4) low-top and tape 17.6/1000 games).	$p = 0.25$	The group offered the combination of prophylactic taping plus a high-topped shoe exhibited the lowest incidence of ankle sprains.
Sitler	Braced (*n* = 789), Nonbraced (*n* = 812)	46 ankle injuries total. Overall injury rate 3.4 per 1000 exposures. 11 injuries occurred among group 1 and 35 in group 2.	(x^2=12.29 $p < 0.01$)	The relative risk of sustaining an ankle injury was approximately three times as great for control subjects as for braced subjects. However severity of injury was not reduced with ankle stabilizer use.

VII. REVIEW OF BICYCLING INJURY PREVENTION STRATEGIES

Bicycling is a very popular activity among Canadian children and youth. In the 1994 National Population Health Survey, 62% of parents with a child aged 14 years or younger, and 49% of parents with a youth aged 15-19 reported that their child rode either a bicycle or tricycle (Pless & Millar, 2000). For children under 12 years-of-age, this percentage ranged from 66% in British Columbia to 59% in Quebec. No differences were seen in bicycle use between urban and rural residence for this age group, however use did decrease as household income decreased.

Bicycling injuries are an important issue as they can have very serious consequences. The circumstances associated with fatal injuries to cyclists are different from those associated with non-fatal bicycling injuries. In Canada between 1990 and 1992, 96% of the 46 bicycling-related deaths and 20% of bicycle-related hospitalizations among children and youth under the age of 20 involved a collision with a motor vehicle (Health Canada, 1997). The majority of bicycle-related hospitalizations are the result of falls and collisions with immovable objects. In the ten-year period ending in 1995, 137 bicyclists died in British Columbia. In 1997, 872 persons were injured in bicycle collisions with motor vehicles. Injuries were most common among two age groups of cyclists: those aged six through 15 and those aged 21 to 40 years-of-age (Insurance Corporation of British Columbia, 1998).

Overall, the causes of bicycle-related injuries tend to be a fall (losing control or balance, swerving to avoid a hazard), collision with an immovable object (road hazard, curb, parked vehicle, tree), collision with a moving object (motor vehicle, other cyclist, pedestrian or animal) and malfunction of the bicycle (Canadian Hospital Injury Reporting and Prevention Program [CHIRPP], 2000; Friede, Azzara, Gallagher & Guyer, 1985). In 1993, 76% of CHIRPP bicycle-related cases were described as a fall or loss of control (Health Canada, 1997). Eight percent were the result of a collision with a motor vehicle, 5% a collision with something other than a motor vehicle and just over 2% involved equipment failure.

Minor injuries such as lacerations and abrasions are the most common type of injury, while head injuries are the most severe. Emergency room data from CHIRPP indicate that 53% of bicycling injuries reported in 1993 were abrasions or lacerations, 26% were fractures and 7% were head injuries (Health Canada, 1997). Data from the United States estimate that head injuries account for 62% of bicycle-related deaths, 67% of bicycle-related hospital admissions and 33% of bicycle-related emergency room visits (Centers for Disease Control, 1995). The 1988 Canadian General Social Survey identified bicycle injuries as the second leading cause, after hockey injuries, of restricted-activity days due to sports activities in persons older than 15 years (Millar & Adams, 1991).

Cyclist-risk factors include age, gender, helmet use and training. Older children and youth are more likely to die as a result of a bicycling injury than younger children. Explanatory factors from a US study include riding at higher speeds and the highest involvement with motor vehicles (Baker, Li, Fowler & Dannenberg, 1993). US studies have also found that males are injured more frequently than females but this difference greatly diminishes when exposure (number of trips or miles ridden) is controlled for, and the risk of head injury following a crash does not vary by gender (Hazinski, Francescutti, Lapidus, Micik & Rivara, 1993).

Injury rates are the highest during months with good weather, in daylight hours and on weekends. Data from the US and Australia have identified that 10 PM to 6 AM is period of greatest risk, when 5% of trips result in 26% of all deaths. Factors during this period are poor visibility of the cyclist, fatigue and alcohol use on the part of both the motorist and cyclist (Baker et al., 1993; Hoque, 1990). Data from Ontario support these findings. (Rowe, Rowe & Bota, 1995; MacKay, Reid & Howard, 2001)

A systematic review and analysis of bicycle-related injury prevention strategies was conducted by the Harborview Injury Prevention and Research Center (HIPRC) in 1997. In their review, the HIPRC examined:

- The effectiveness of helmets;
- The impact of legislation and community education campaigns on helmet use and injury;
- The impact of protective clothing on injury and bicycle lights;
- Bicycling education;
- Alcohol use;
- Age restrictions for street travel;
- Road/path design;
- Speed limits;
- The removal of road hazards on bicycle crashes and injury.

Their findings are summarized below.

The biggest preventable risk factor for bicycle head injury is failure to wear a bicycle helmet. Many studies have looked at the protective effect of helmets, with the most compelling evidence coming from the summary provided by the HIPRC systematic review where eight case control studies estimated helmets to be 70-88% protective against head and brain injury and 65% protective against facial injury to the upper and mid face (Thompson, Rivara & Thompson, 1989, 1996; Thompson, Nunn, Thompson & Rivara, 1996; Maimaris, Summers, Browning & Palmer CR, 1994; Thomas, Acton, Nixon, Battistutta, Pitt & Clark, 1994; McDermott, Lane, Brazenore & Debney, 1993; Spaite, Murphy, Criss, Valenzuela & Meislin, 1991; Thompson, Thompson, Rivara & Wolf, 1990).

Despite the effectiveness of helmets, they are not consistently worn. Helmet use around the world varies greatly. Recent data from Ontario and British Columbia estimate helmet use to be between 50-70% depending on the sub-population being observed (Foss & Beirness, 2000; MacKay, Klassen & Cushman, 1998). Education of bicycle helmet effectiveness in preventing head injury is one method used to increase and/or sustain bicycle helmet use. These interventions can be either community-based, school-based, physician-based or some combination of these settings. The HIPRC review found seventeen studies addressing educational approaches to increasing helmet use (Farley, Haddad & Brown, 1996; Jaffe & Tamir, 1996; Hatziandreu et al., 1995; Liller, Smorynski, McDermott, Crane & Weibley, 1995; Parkin et al., 1995; Morris, Trimble & Fendley, 1994; Rivara et al., 1994; Rourke, 1994; Dannenberg, Gielen, Beilenson, Wilson & Joffe, 1993; Parkin et al., 1993a; Towner & Marvel, 1992; Morris & Trimble, 1991;

Bergman, Rivara, Richards & Rogers, 1990; Stutts & Hunter, 1990; DiGuiseppi, Rivara, Koepsell & Polissar, 1989; Wood & Milne, 1988; Berchem, 1987).

They found these strategies, when done properly, have been successful. An important element appears to be the participation of parents, and two studies (Liller et al., 1995; DiGuiseppi et al., 1989) suggest that children are more likely to wear helmets if their riding partners - adults or children - are also wearing helmets. The most effective interventions have a broad scope that includes media announcements, bike rodeos and helmet discounts. Helmet subsidies have been found to be effective in increasing helmet use among low SES children. Campaigns that are too narrowly focused (providing helmets in emergency departments, schools, and from pediatric offices) have not been particularly successful in reducing injury (Parkin et al., 1993b; Cushman, Down, MacMillan & Waclawik, 1991; Pendergrast, Ashworth, Durant & Litaker, 1992).

Another way to promote helmet use has been to make it mandatory through the administration or rules and legislation. Helmet use has been mandatory for bicycle races in Canada since the 1980s and most bicycling clubs and organizations require helmets for club rides. Helmet legislation is in place in four Canadian provinces and has been most effective where it applies to all ages. The HIPRC systematic review found five studies examining the impact of legislation (Ni, Sacks, Curtis, Cieslak & Hedberg, 1997; Cameron, Vulcan, Finch & Newstead, 1994; Cote et al., 1992; Vulcan, Cameron & Watson, 1992; Ozanne-Smith & Sherry, 1990). The results suggest that legislation is effective in increasing helmet use and that the effect is not heavily dependent on enforcement (Dannenberg, Gielen, Beilenson, Wilson & Joffe, 1993; Cote et al., 1992). Further, parental and peer use of helmets supplements any direct enforcement by police (in all cases warnings served as the only enforcement). However, legislation appears to be most effective when it is preceded by a well-coordinated helmet promotion campaign.

Rather than replicate the systematic review and analysis of bicycle-related injury prevention strategies conducted by the HIPRC, it was decided to add to their results with articles published after 1996. The HIPRC search parameters differed from this review in that the former focused exclusively on children and adolescents 19 years-of-age or younger, while this review included all studies regardless of the age of the target population.

Results

The search for studies subsequent to 1996 found 393 articles, of which 28 were identified as potentially relevant. In addition, three more potentially relevant studies were identified through hand searching. Of these 31 articles, only twelve met relevance criteria. Over half of the 19 found to be non-relevant (58%) were excluded because they were not evaluations of a prevention strategy. Other reasons for exclusion were that articles were not subsequent to 1996 (21%), did not discuss injury prevention (11%) or were not received by the study cut-off (11%). Similar to the HIPRC review, this review found that much of the research in this area has been descriptive.

Of the 12 relevant articles, eight of the studies were from the U.S. and the rest were from Australia, Sweden, Israel and Canada (Table 1). There were three randomized controlled trials, four nonequivalent control group studies, three type II pre-post studies, one prospective cohort and one case-control study. All twelve studies looked at informal non-competitive bicycling.

Eight of the twelve studies examined community campaigns to increase helmet use (Table 2). Two of the twelve addressed the impact of legislation alone and a third looked at the combination of legislation and education. The last two examined the impact of school-based bicycle skills training. All of the studies focused on increasing helmet use among children.

Similar to the studies included in the HIPRC review, it was found that the studies included here were evaluated to be poorly designed, inadequately analyzed, or both. For example, allocation and analysis were rarely done at the same level. The three randomized controlled trials scored either 1 or 2 out of 5 on the Jadad scale. The average scores for the various designs were 6/14 for studies with a nonequivalent control group design (range 4.5-7.5), 12/17 for cohort studies, 13/18 for case-control studies and 9/14 for pre-post test designs.

The strategies covered by the relevant articles included were educational and legislative (Table 3). The educational strategies fell into two categories: school-based bicycling skills education, and education on the effectiveness of helmets in preventing head injury as part of either institution-based or broader community education campaigns. The legislative strategies include legislation at the state level, alone or in conjunction with educational activities.

Educational Strategies

BICYCLING SKILLS EDUCATION

Carlin, Taylor and Nolan (1998) conducted a case-control study to evaluate the possible benefits of a one-time school-based bicycle safety education program in Australia called *Bike Ed*. The course content included safe rider skills, traffic knowledge and basic bicycle mechanics and was conducted in three stages - classroom teaching, practical skills, maintenance and a road test, including a traffic situation. The 148 cases were children over nine years-of-age presenting to two emergency departments with bicycle-related injuries; 130 controls were located through random digit dialing among the same population. The adjusted bivariate analysis showed no significant association between *Bike Ed* exposure and injury risk. The odds ratio of 1.57 (0.91 to 2.71) did suggest that *Bike Ed* exposure actually increased risk of injury and further analysis showed that this was particularly the case for boys, younger children, children whose parents had a lower educational background, children in families where other members do not bicycle and where parents do not place restrictions on where the child may ride.

Macarthur et al. (1998) conducted a randomized controlled trial to assess the effectiveness of a skills training program, the *Can Bike Festival*, in improving safe bicycling behavior, knowledge and attitudes. Our review examined the behavioral outcomes only. The intervention involved a one time 90-minute educational session conducted at six activity stations - two related to equipment and four to bicycle handling - on a playground by trained instructors in a 1:6 instructor to child ratio. Grade 4 students from six elementary schools participated in the program (73 in the intervention group; 68 in the control group). At both baseline and follow-up, there were no significant differences between the groups on the frequency of safe bicycling behavior, including straight line riding, coming to a complete stop, shoulder checking or reported helmet use. The authors concluded that this brief skill training intervention was not effective in improving safe bicycling behavior.

HELMET EDUCATIONAL CAMPAIGNS

Seven of the studies addressed increasing helmet use through educational campaigns. Intervention setting, target population, and nature and length of interventions differed substantially between studies. Three were reasonably broad campaigns: one was conducted in two rural towns in Texas (Logan et al., 1998), one targeted a county in Sweden (Ekman, Schelp, Welander & Svanstrom, 1997) and the third included all of Israel (Ressler & Toledo, 1998). The remainder were specific to a smaller setting: one was set in six public health clinics (Kim, Rivara &Koepsell, 1997); one in nine elementary schools in central Texas (Hendrickson & Becker, 1998); one in eighteen *Head Start* pre-school programs in Washington State (Britt, Silver & Rivara, 1998); and one in two elementary schools in Virginia (Watts, O'Shea, Flynn, Trask & Kelleher, 1997).

The intervention in three of the studies evaluated both education and provision of helmets at reduced or no cost. Logan et al. (1998) evaluated the impact of an all day educational program that included safety education, the distribution and fitting of free helmets, a bike rodeo and a six-month incentive program. All students in two rural towns participated. Although helmet use did increase during the campaign from 3% to 30%, this increase was only temporary and by the end of the six-month incentive, only 5% of children were wearing helmets. The results of this study are further limited by the absence of a control group.

Kim et al. (1997) examined whether helmet cost-sharing was better at promoting helmet use than free helmets. Six public health clinics were randomized to provide educational messages and distribute either free helmets or request a $5.00 donation. The analysis was based on the 506 of the children who received a helmet and whose parents were sent a questionnaire collecting data on the child's subsequent bicycling and helmet use. The authors found no significant difference in use by helmet distribution method (odds ratio (OR) 1.36 [0.77-2.41]).

Watts et al. (1997) examined a similar question among elementary school students. Two schools, matched on demographic variables, were chosen. A self-report questionnaire collected data on helmet ownership and use at baseline and one month post-intervention. Students at school A received a bicycle safety program and school B received the same program plus any students without helmets at baseline were provided with free helmets in conjunction with the safety program. When helmet use among children at school B was examined during the follow-up period, children who received a free helmet were more likely to wear it (61%) than those who had already owned one (43%). Overall, a significantly higher proportion of students at follow-up 'always' used a helmet (46%) as compared to at baseline (38%). However, a breakdown showed that the significant increase was due to an increase in 'always' helmet use at school B (42% pre-intervention versus 55% post-intervention), where free helmets were distributed. While the authors concluded that the distribution of free helmets had increased their use, they cautioned that the follow-up period of one month may not have been long enough to allow for novelty of the free helmet to wear off.

Britt et al. (1998) targeted pre-school aged children with the rationale that the earlier helmet use was established the better. The intervention was a multifaceted bicycle helmet program for low-income children that included:

- Classroom activities;
- Education of parents at a minimum of five home visits during the year;

- Distribution and fitting of free helmets;
- A bicycle skills and rodeo event and a policy requiring children to wear helmets while riding on school grounds.

Helmet use was observed during home visits and again two to three weeks post-intervention. The relative risk of helmet use at follow-up was 1.47 (1.16-1.85) and the authors concluded that the program was successful in increasing helmet use.

Hendrickson and Becker (1998) used a conceptual framework based on the PRECEDE model to assess predictors of helmet use among low-income fourth graders. Nine schools were randomized to one of three conditions: a classroom intervention involving a video, helmet distribution and fitting and discussions around the importance of helmet use and a take home worksheet; the classroom intervention plus a parental intervention involving a telephone call to encourage parental reinforcement; and a control group.

Self-reported helmet use was measured at baseline, immediately following the intervention and one-month after intervention. Helmet use increased 55% in intervention schools as opposed to a 16% increase in control schools. Helmet ownership, participation in either of the educational interventions, belief that helmets protect and participation in the parental intervention group accounted for 72% of the variance.

Ekman et al. (1997) examined the combination of local, regional and national information targeting helmet use on injuries among Swedish children aged 15 years or less. The analysis examined the additive impact of bicycle helmet discount programs and general community safety programs in one target county that was already intervening in child health-care and education settings and with parents. Helmet use and injury rates in the target county were compared to three other counties. Two of these had interventions in child health-care and education settings and with parents, and the third had similar programs to the target county. The four areas being compared did not have equal injury rates at baseline. The two intervention counties had injury incidence rates twice as high as the control areas at baseline that fell to levels similar to the control areas following the additional interventions.

Ressler and Toledo (1998) used functional theory to develop, pilot and implement a nation-wide social marketing campaign aimed at increasing children's bicycle helmet use in Israel. The targets for the program were children aged 5 to 15 years (with an emphasis on 5-10 year-olds) and their parents. The campaign was piloted in 1993, then expanded and run intensely in June 1994 and to a lesser degree for the rest of that summer. The pilot program included a 50-second music video clip and the integration of bicycle helmets into regular programming on a national cable system targeting children and four 18-second spots for parents encouraging helmet use. The expanded program added a second video clip for TV and cinema advertising involving a campaign song, expansion of the integration of bicycle helmets into children's programming, a public awareness campaign using billboards, buses and bus stops and children's magazines, information to schools, bike rodeos and demonstrations, distribution of T-shirts, reflective stickers, key chains and free or discounted helmets. Observations of helmet use were conducted in 1993 after the pilot, and again in 1994 following the main campaign. Additionally, parents of children in the target age group were randomly selected and interviewed on children's helmet ownership following the pilot in 1993 and again in 1994. Observed helmet use increased from

7% to 22% in children <10 years, from 8% to 16% in children and youth aged 11-18 years and from 8% to 11% in adults. There was no change in the proportion of parents who reported that their child owned a helmet between the 1993 and 1994 surveys. Anecdotally, the authors also reported that helmet sales in the country had risen from several hundred in 1992, to several thousand in 1993, to nearly 20,000 in 1994. This number doubled with the repeat of a further enhanced campaign in 1995. Ressler and Toledo concluded that exposure to the full campaign was associated with an increase in helmet use – particularly in the target age groups and that the use of the functional theory appeared to have resulted in the development of an effective social marketing campaign.

Regulatory Interventions

Three studies evaluated helmet legislation. Two examined legislation alone (Shafi et al., 1998; Ni, Sacks, Curtis, Cieslak & Hedberg, 1997) and a third examined legislation with and without a preceding educational campaign (Abularrage, DeLuca & Abularrage, 1997).

HELMET LEGISLATION

Ni et al. (1997) used multiple measures of helmet use to evaluate the impact of the Oregon law requiring cyclists 15 years and younger to wear a helmet. Helmet use was measured pre-law and post-law using four measures: state-wide observations, middle school observations, classroom self-report surveys and a state-wide adult telephone survey. State-wide observations of youth saw an increase in helmet use from 24.5% to 49.3%; middle school children's helmet use was observed to increase from 20.4% to 56.1%; self-reported "always" use of helmets increased from 25.8% to 76.0% and parental reported child's "always" use of helmets increased from 36.8% to 65.7%. The authors conclude that the law had increased helmet use and that although helmet use estimates differed, all estimates showed similar degrees of pre-law and post-law change. However, half of child cyclists were still not wearing helmets and Ni et al. suggest the need for additional promotional activities to increase usage rates.

Shafi et al (1998) conducted a retrospective cohort study of bicycle crash victims from 1993 to 1995 to assess the impact of the 1994 New York State bicycle helmet law requiring children under 14 years-of- age to wear a helmet. The charts of all bicycle crash victims admitted to a regional pediatric trauma centre between 1993 and 1995 were reviewed. The authors found a 13-fold increase in helmet use among admitted children following the introduction of the helmet law (2%-26%). Further, the analysis suggested that although the proportion of children suffering head injury pre- and post-law as similar, there was a significant decrease in skull fractures and a protective trend against intracranial injuries. They concluded that the increase to 26% is inadequate and suggest the addition of community-wide education and subsidization of helmet cost.

HELMET EDUCATIONAL CAMPAIGNS AND HELMET LEGISLATION

Abularrage et al. (1997) evaluated the impact of both legislation and an educational campaign. A one-week borough-wide educational campaign was implemented prior to the enactment of a bicycle helmet law requiring helmet use among children aged 1-14 years in New York State in May 1994. Baseline helmet observations were conducted in 4-block areas centred around 14 randomly selected schools in Queens County (intervention) and 12 randomly selected schools in Kings County (control). The intervention consisted of four components: distribution of an educational package through local schools, distribution of helmet prescriptions by local pediatricians, ads in local newspapers and a bicycle helmet day at the local medical centre. On June 1st, the state bicycle helmet law came into effect. Follow-up observations were conducted at the baseline sites from July 19-August 8, 1994. Helmet use increased from 4.7% to 13.9% in the intervention group and decreased from 5.6% to 4.2% in the control group. The authors concluded that legislation alone is inadequate to ensure helmet use.

Discussion

Combining the twelve studies published since 1996 with the results of the systematic review conducted by the Harborview Injury Prevention and Research Centre (HIPRC) suggest that strategies to increase bicycle helmet use continue to be the focus of most interventions.

The six additional studies evaluating education strategies alone continue to support the notion that multifaceted campaigns are the most effective. Further, there is additional evidence that long-term intervention is needed in order to get helmet use into the realm of social norm. A one-time program does not lead to sustained increases in helmet use. Moreover, the addition of the studies from this review provide increased evidence that older children and youth are not as compliant with campaign messages. There is therefore still a need to evaluate the effectiveness of helmets in different age groups of cyclists.

Although a number of the studies included in this review had helmet fitting as one aspect of their campaign, none of them examined helmet fit as an outcome. A study published since this review's literature search estimates that improperly fitted helmets may double the risk of head injury (Rivara, Astley, Clarren, Thompson & Thompson, 1999). Further research is needed to evaluate the roles of helmet fit and retention in overall protection and the effectiveness of strategies to improve fit. Bicycle-related facial injuries also continue to be common and other than mountain biking helmets, for which no evaluation studies were found, current helmet designs offer no protection to the lower face, jaw, mouth and teeth. Helmets with a facial bar or similar protective piece may greatly reduce these injuries. The feasibility, acceptability and effectiveness of these enhanced safety designs should be examined.

Evidence on the effectiveness of bicycling skills education remains mixed. This review adds two studies to this area, both of which suggest that one-time skills education sessions have little or no impact. However, one was retrospective in nature, and the second used self-reported helmet use as an outcome. A large-scale randomized trial linked to injury as an outcome, may be the only way to provide needed evidence in this area. The other important issue related to bicycling skills education is an exploration of the necessary frequency and duration of intervention to bring about a reduction in injury.

This review failed to find studies to address the other gaps identified by the HIPRC. It did not add to the evidence for the use of bicycle safety equipment such as lights and reflectors. While it is intuitive that cycle lights should decrease collisions, further evidence is needed. Further, this systematic review also failed to provide any additional studies examining environmental modification and engineering solutions to construct safer roads with wide shoulders and minimal hazards or separate lanes. The HIPRC review found two studies, the results of which were both inconclusive. Due to the paucity of studies in this areas, a wide variety of designs to separate bicycles from motor vehicle traffic remain to be evaluated.

Finally, one emerging area of injury is injuries due to contact with handlebars in the event of a bicycle crash. No intervention studies addressing this issue were found.

Recommendations

Research

- Develop a surveillance system to ascertain where and when bicycling injuries are occurring;
- Evaluate the role of bicycle lights and reflectors in decreasing bicycle collisions;
- Evaluate the role of bicycle/rider fit in injuries resulting from a loss of control;
- Evaluate environmental modifications designed to separate cyclist from motor vehicle traffic (e.g., bicycle lanes, bicycle pathways);
- Further evaluation of bicycle skills training, with stronger designs and thought to frequency and duration of interventions;
- Evaluation of the effectiveness of helmets in different age groups of cyclists (e.g., small children);
- Develop age-specific guidelines for children and youth and suggest appropriate environments for them to cycle in;
- Evaluate the role of helmet fit and helmet retention in overall protection;
- Evaluate the feasibility, acceptability and effectiveness of enhanced helmet designs to protect the lower face, jaw, mouth and teeth;
- Investigate the impact of bicycle lanes on injury rates;
- Evaluation of the role of handlebars as a cause of injury.

Practice

- Bicyclists should wear a CSA approved helmet;
- Bicyclists should ride only proper-fitting bicycles to prevent overuse injuries and decrease injuries resulting from loss of control of the bicycle;
- Bicyclists wishing to increase performance should consider as appropriate to their type of cycling (e.g., mountain biking versus road racing): bicycle fit, stretching and strengthening exercises, use of padded gloves and handle bars, and properly fitted and padded bicycle pants.

Policy

- Community campaigns should be based on research data, focus on carefully selected target age groups, include the use of bicycle helmets (through discounts or donation) in addition to other strategies and have a built-in evaluation component (including a control group where possible);

- Community awareness and educational campaigns should be part of the pre-law phase when helmet legislation is introduced;
- Long term awareness campaigns are necessary to move helmet use into the realm of social norm.

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Table 1: Bicycling Study Characteristic

First Author	Study Design	Quality Rating	Year of Publication	Country	Study Time Period	Funding
Hendrickson	RCT	Poor (1/5)	1998	USA	Not reported	CDC
Kim	RCT	Poor (1/5)	1997	USA	Mar – Aug 1993	CDC and Seattle Dept. of Public Health
Macarthur	RCT	Moderate (2/5)	1998	Canada	Jun – Sep 1995	Ontario Ministry of Transportation
Abularrage	Non-Equivalent Control Group	Moderate (7/14)	1997	USA	May – Aug 1994	Not reported
Britt	Non-Equivalent Control Group	Moderate (7.5/14)	1998	USA	1995/96 and 1996/97 school years	NIPC, CDC
Ekman	Non-Equivalent Control Group	Poor (4.5/14)	1997	Sweden	1978 –1993	National Institute of Public Health
Watts	Non-Equivalent Control Group	Poor (5/14)	1997	USA	Not reported	Not reported
Shafi	Prospective Cohort	Moderate (12/17)	1998	USA	Jan 1993 – Dec 1995	Not reported
Carlin	Case Control	Moderate (13/18)	1998	Australia	Apr 1993-Jan 1996	PHRDC, MRC
Logan	Type II Pre-Post Test	Moderate (10/14)	1998	USA	Sep 1995 – Jun 1996	CDC
Ni	Type II Pre-Post Test	Moderate (9/14)	1997	USA	Jul 1993 – Jun 1995	NIPC, CDC
Ressler	Type II Pre-Post Test	Poor (5/14)	1998	Israel	Summer 94	Not reported

Table 2: Bicycling Study Design

First Author	Study Aim	Study Setting	Study Participants/ Targets	Participant Selection/ Recruitment
Hendrickson	Determine relationships among PRECEDE model prediction and self-reported helmet use among fourth graders from low-income, non-urban schools.	Elementary school	Sports/rec. participants (Grade 4 students)	Children attending nine low-income schools in eight non-metropolitan Central Texas counties.
Kim	Determine whether asking for a $5 donation for bicycle helmets, compared with distribution free of charge, and an educational intervention from public health clinics would affect helmet use among children receiving helmets.	Health care setting and participants homes	Sports/rec. participant (6-12 years)	Children whose parents/guardians accompanied them to a clinic for immunizations, minor illness, well child care or dental care at six public health clinics in Seattle-King County.
Macarthur	Evaluate the effectiveness of a skills training program (Can Bike Festival) in improving safe cycling behavior, knowledge and attitudes in young children.	Elementary school and general community	Sports/rec. participants (Grade 4 students)	Grade 4 students attending a convenience sample of six elementary schools in a borough of metropolitan Toronto.
Abularrage	Measure the effect of an organized bicycle helmet educational campaign in a multiracial population timed to coincide with the introduction of a statewide bicycle helmet law.	General community plus elementary school, health care setting	Sports/rec. participants (1-14 years) Parents/caregivers	All child bicyclists observed during specified data collection periods in four-block sections around randomly selected elementary and junior high schools in two counties in New York State.
Britt	Evaluate the effectiveness of a multifaceted bicycle helmet promotion program for low-income children attending Head Start preschool enrichment programs throughout Washington state.	Pre-school	Sports/rec. participants (3-4 years)	Children attending preschool "Head Start" programs in Seattle, Washington with $\geq$5 home visits per school year as part of their policy.
Ekman	Examine the effectiveness of the combination of local, regional and national information on helmet use and bicycle injury in 5 Swedish communities.	General Community plus pre-school, elementary school, health care settings and parent groups	Sports/rec. participants (< 15 years) Parents General community	Not reported
Watts	Determine whether: (1) bicycle safety programs increase helmet use; (2) children who are given a free helmet use their helmets more than children who receive their helmet from another source; and (3) free helmet distribution with a bicycle safety program is more effective in increasing helmet use than a safety program alone.	Elementary school	Sports/rec. participants (5-12 years)	All children at two elementary schools with matched demographic variables.

Table 2: Bicycling Study Design (*continued*)

First Author	Study Aim	Study Setting	Study Participants/ Targets	Participant Selection/ Recruitment
Shafi	Assess the impact of state legislation on helmet use in children admitted to a trauma center following bicycle crashes.	Health care setting	Sports/rec. participants < 14 years-of-age (mean age 7±0.7 years)	All children admitted to a regional trauma centre between 1993 and 1995 as the result of a bike crash.
Carlin	Evaluate possible benefits of a school-based bike safety education program ("Bike Ed") on the risk of bicycle injury in children.	Elementary school	Sports/rec. participants (9-14 years)	Children presenting to two emergency rooms as the result of a bicycle-related injury.
Logan	Determine the effect of a bicycle helmet give-away program on helmet use among children.	Elementary school	Sports/rec. participants (5-8 years)	All school children in Kindergarten-Grade 8 in two rural Texas towns.
Ni	Evaluate an Oregon law requiring bicyclists younger than 16 years-of-age to wear a helmet and to compare methods of measuring helmet use.	State population	Sports/rec. participants (< 16 years-of-age) Parents	Statewide observational survey: 13 sites throughout Oregon. School observational survey: students attending 33 randomly selected middle schools throughout Oregon. Classroom self-report survey: Grade 4, 6 and 8 students attending 33 randomly selected middle schools throughout Oregon Behavioral risk factor survey: randomly selected households using random digit dialing and a 3-stage sampling technique.
Ressler	Use functional theory to develop, pilot and implement a nationwide social marketing campaign aimed at increasing children's bicycle helmet use.	Population	Sports/rec. participants Parents	Observers in 15 towns and cities throughout Israel observed bicyclists helmet use. Children in 25 classrooms at a convenience sample of eight schools selected to provide a good geographic and demographic distribution. A random sample of 400 households using a multistage cluster sampling of 50 statistical areas and door to door recruitment.

Table 3: Bicycling Study Intervention

First Author	Intervention Type	Details of Intervention	Frequency Duration	Primary Outcome Measure	Outcome Collection Method
Hendrickson	Education	Classroom instruction only: video, main physiology, discussion on 'how a head injury could change your life'. Classroom instruction, parental intervention: above interventions plus telephone intervention with parents providing information to encourage reinforcement of helmet use.	Two classroom periods – duration not specified One telephone call – duration not specified	self-reported helmet use	In class questionnaire
Kim	Education	Helmet with a $5 co-payment plus education component (written suggestions, buttons and posters for staff, activity books and brochures for families). Free helmet plus education component	Once per child - duration not specified	parent-reported helmet use	Mailed questionnaire
Macarthur	Education	Introductory level course in bicycle safety: 6 stations (2 equipment, 4 bike handling) on playground by trained instructors with 1:6 instructor to child ratio.	Two hour program	straight line riding complete stop shoulder checking	Observation
Abularrage	Education/ Legislation	Community campaign consisting of distribution of educational pack at schools (contained letter, bookmark, fact sheet, coupon, and entry postcard); distribution of prescription for bicycle helmets by local pediatrician; ads in local newspapers; and "Bicycle Helmet Day" at local medical centre. State helmet law for children 1 to 14 years-of-age.	One week campaign; ongoing state law	observed helmet use	Observation
Britt	Education	Classroom instruction to children; education of parents; educational materials; distribution and fitting of helmet; bike rodeo; and policy requiring helmet use on school grounds.	Unclear	observed helmet use parent-reported helmet use	Observation Parent interview
Ekman	Education	Helmet campaign: helmet discount program, prescription info and media.	Unclear	annual change in hospitalizations due to bicycle injury	Hospitalization data
Watts	Education	Bicycle safety program, with and without distribution of free helmets.	Unclear	self-reported helmet use	Questionnaire
Shafi	Legislation	State-wide legislation requiring children younger than 14 years-of-age to wear a helmet while riding a bicycle.	Implemented June 1, 1994 – ongoing	helmet use at time of injury head injury incidence	Chart review

Table 3: Bicycling Study Intervention

First Author	Intervention Type	Details of Intervention	Frequency Duration	Primary Outcome Measure	Outcome Collection Method
Carlin	Education	Bike Ed course: covers aspects of safe riding skills, traffic knowledge and skills, and basic bicycle mechanics. 3 key stages: (1) classroom traffic rules; (2) practical skills and maintenance; (3) road test with traffic situation.	Unclear	validated exposure to school-based bicycle safety program (*Bike Ed*)	Personal interview of child and at least one parent.
Logan	Education	School-based campaign: safety education, free helmet, bicycle rodeo plus an incentive program for helmet use involving posters and draw for prizes.	One day school-based campaign plus six month incentive program	observed helmet use	Observation
Ni	Legislation	State-wide law requiring children younger than 16 years-of-age to wear a helmet while riding a bicycle on public property or be subject to a $25 fine.	Implemented July 1, 1994 – ongoing	observed helmet use self-reported helmet use parent reported helmet use	Observation (statewide and at middle schools) In class questionnaire (middle schools) Telephone survey
Ressler	Education	A comprehensive social marketing program including: two 50-second music video clips for TV and cinema advertising; integration of bicycle helmets into regular programming on a national cable system targeting children; four 18-second spots for parents encouraging helmet use; ads on billboards, buses, bus stops and in children's magazines; information to schools, bike rodeos and demonstrations; and distribution of T-shirts, reflective stickers, key chains and free or discounted helmets.	Intense campaign in June 1994; less intense over remainder of summer	observed helmet use parent-reported helmet ownership	Observation Personal interview

Table 4: Bicycling Study Results

First Author	Intervention Group	Results per group	*p-value*	Conclusion
Hendrickson	Classroom instruction only (*n* = 163) Classroom instruction plus parental intervention (*n* = 142) Control (*n* = 102)	Hierarchical regression to predict bicycle helmet use immediately after the educational intervention F=217.71, df=4/332 $p < 0.0001$		72% of the variance in predicting helmet use for the fourth graders was explained by helmet ownership (p = 0.000), belief that helmets protect your head (p = 0.000), being in either intervention group (p = 0.019) or being in the parental intervention group (p = 0.039)
Kim	Co-payment helmet plus education (*n* = 180) Free helmet plus education (*n* = 243)	147/180 (81.7%) 186/243 (76.5%) Crude OR 1.36 [0.77, 2.41] OR adjusted for income 1.66 [0.94, 2.92]	p = 0.20	Helmet use was not significantly different among children whose parents were asked for a small co-payment compared to those who received helmets free. Use of co-payments can increase helmet use by increasing the number of helmets available to give to low-income children.
Macarthur	Bike Skills Education Program [B] (*n* = 73) Control [C] (*n* = 68)	Straight line riding Pre B = 0.65 C = 0.51 Post B = 0.90 C = 0.88 RR 1.54 [1.32, 1.79] Complete stop Pre B = 0.92 C = 0.82 Post B = 0.90 C = 0.76 RR 0.96 [0.86, 1.06] Shoulder check Pre B = 0.01 C = 0.00 Post B = 0.00 C = 0.02 RR 1.11 [0.07, 17.38]	 p = 0.24 p = 0.78 p = 0.09 p = 0.23 p = 1.00 p = 1.00	The skills training program was not effective in improving safe cycling behavior.

Table 4: Bicycling Study Results (*continued*)

First Author	Intervention Group	Results per group	*p-value*	Conclusion
Abularrage	Legislation (pre *n* = 342; post *n* = 312) Legislation plus education (pre *n* = 276; post *n* = 316)	Pre 19/342 (5.6%) Post 13/312 (4.2%) Pre 13/276 (4.7%) Post 44/316 (13.9%)	$p < 0.001$ $p < 0.10$	A significant increase in helmet use above legislation alone was demonstrated after a campaign and distribution of education material.
Britt	Multifaceted educational program (baseline *n* = 230; follow-up *n* = 247) Control (baseline *n* = 71, follow-up *n* = 48)	Baseline 99/230 (43%) Follow-up 219/247 (89%) Baseline 30/71 (42%) Follow-up 29/48 (60%) RR 1.47 [1.16, 1.85]		The provision of a multifaceted educational program and distribution of individually fitted free helmets by Head Start staff to preschool children resulted in a doubling of observed helmet use.
Ekman	Information within child health-care and staff and parental information and educational strategies PLUS bicycle helmet discount programs and general community safety programs Information within child health-care and staff and parental information and educational strategies.	Skaraborg -3.1% [-4.0, -2.3] Kristianstad -3.4% [-4.1, -2.7] Uppsala -2.9% [-4.5, -1.2] Sörmland -2.2% [-3.3, -1.2] Västmanland -1.1% [-3.1, +1.0] All of Sweden -1.4% [-2.5, -0.3]		Percent annual change in mean incidence/1000 children did not change significantly in Skaraborg as compared to other counties or Sweden as a whole. However, during the timeframe of the study, bicycle-related hospitalization in Skaraborg decreased to the level of the remainder of the country.
Watts	(1) "Always" wear helmet (pre *n* = 926; post *n* = 684) (2) Free helmets (*n* = 57) Existing helmets)*n* = 234) (3) Bike safety program alone (pre *n* = 434; post *n* = 367) With helmet distribution (pre *n* = 492; post *n* = 317)	Pre 38% Post 46% X2 = 7.89 (df=1) Free 61.4% Existing 43.4% X2 = 5.84 (df=1) No difference in helmet use pre to post Pre 42% Post 55%	 $p = 0.005$ $p = 0.016$ p = NS $p < 0.001$	Bicycle safety programs and free helmet distribution may increase the consistent use of helmets in elementary school children. However, the authors caution that increases reported were collected only one month after the bicycle safety program and there may have been a lapse back to previous behavior with a longer follow-up period.

Table 4: Bicycling Study Results (*continued*)

First Author	Intervention Group	Results per group	*p-value*	Conclusion
Shafi	Helmet Legislation (numbers not provided) Head injury Helmeted [HC] $n = 31$ Not helmeted [NHC] $n = 177$	Helmet use pre 2% Helmet use post 26% Head injury HC 21/31 (68%) NHC 107/177 (61%) Concussion HC 20/31 (65%) NHC 77/177 (44%) Skull fractures HC 0/31 (0%) NHC 23/177 (13%) Intracranial inj. HC 1/31 (3%) NHC 19/177 (11%)	$p <$ 0.00001 p = NS $p = 0.031$ $p = 0. 02$ p = NS	Legislation is an effective way of increasing helmet use in children. While there was no difference between HC and NHC in overall head injury incidence, there was evidence that helmet use reduces the severity of head injury. A higher proportion of HC suffered concussions alone and helmets appeared to be protective against skull fractures. A trend was observed toward reducing intracranial hemorrhages, cerebral contusions and diffuse cerebral edema.
Carlin	Exposure of interest “Bike Ed” Bicycle Safety Education Program Injured bicyclists ($n = 106$) Community controls ($n = 97$)	Crude OR 1.65 [0.89, 3.07] Adjusted OR (age, sex and income) 1.63 [0.84, 3.16]		There was no evidence that the *Bike Ed* bicycle safety education program decreases the risk of bicycle injury in children. May increase risk in some children (perhaps due to inadvertent encouragement of risk-taking or bicycling with inadequate supervision).
Logan	Bicycle helmet giveaway and incentive program Gr. K-6 Baseline $n = 122$; 2 weeks post $n = 38$; 9 mos. post $n = 30$ Gr. 7-8 Baseline $n = 25$; 2 weeks post $n = 5$; 9 mos. post $n = 10$	Pre 4/122 (3%) 2 wk post 13/38 (34%) 9 mos. post 2/30 (7%) Pre 1/25 (4%) 2 wk post 0/5 (0%) 9 mos. post 0/10 (0%)		The bicycle helmet giveaway increased helmet use temporarily in the Grades K-6 but was not enough to sustain it. The program had no impact on Grades 7-8.

Table 4: Bicycling Study Results (*continued*)

First Author	Intervention Group	Results per group	*p-value*	Conclusion
Ni	Helmet Legislation Statewide obs. Pre $n = 1610$ Post $n = 1703$) School obs. Pre $n = 558$ Post $n = 437$ Student reported helmet use Pre $n = 7088$ Post $n = 7417$ Parent reported child helmet use Pre $n = 961$ Post $n = 476$	Pre 394/1610 (24.5%) Post 840/1703 (49.3%) Pre 114/558 (20.4%) Post 245/437 (56.1%) Pre 1042/7088 (14.7%) Post 2919/7417 (39.4%) Pre 373/961 (36.8%) Post 332/476 (65.7%)	$p < .01$ $p < 0.01$ $p < 0.01$ $p < 0.01$	Although the law increased helmet use, half of child bicyclists are still not wearing helmets. This indicates a need for additional promotion of helmet wearing.
Ressler	Observed helmet use Pre <10 years $n = 324$ Pre 11-18 years $n = 687$ Pre >18 years $n = 1211$ Post <10 years $n = 407$ Post 11-18 years $n = 581$ Post >18 years $n = 1111$ Parent reported child helmet ownership $n = 362$	7% helmet use 8% helmet use 8% helmet use 22% helmet use 16% helmet use 11% helmet use 19%		Exposure to the full campaign was associated with an increase in helmet use in the target age groups. The increase in helmet use by adults of only 3% indicates that the largest changes in use occurred among the campaign's target group and as such, functional theory appears to have resulted in an effective social marketing campaign.

VIII. REVIEW OF FOOTBALL INJURY PREVENTION STRATEGIES

Football is one of the most popular sports in North America, with thousands of athletes participating and millions of fans watching the game. Exact participation rates in Canada have not been reported, but Football Canada reports approximately 90 000 members (Football Canada website http://www.footballcanada.com). Participation rates in the U.S. were estimated at 1.5 million high school and 75 000 college athletes in 1992 (Andrish, Bergfeld, & Romo, 2000; Mueller, Zemper, & Peters, 1996). Although the sport is still primarily played by males, there are a growing number of females now participating.

Despite football's popularity among athletes and spectators, injury rates are very high among participants. Mueller et al. (1996) cite two primary factors for the high injury rate in football:

1. Increased participation has produced an increase in the total number of injuries;

2. The inherently violent nature of the game, the physically demanding aspects of the game and the speed, strength and size of the players combine to make football a high-risk sport.

High school football injury rates of between 11.8% and 81.1% have been reported in the literature (Andrish et al., 2000; Mueller et al., 1996). In College athletes, injury rates have been reported between 6.1 and 11.1 per 1000 Athlete-Exposures (A-E) (Mueller et al., 1996). An A-E is defined as one athlete participating in one game or practice where he is exposed to the possibility of injury. Re-injury is also very common among these athletes. It has been reported that 60% of high school athletes with an injury will suffer a subsequent injury, while only 40% of athletes that have not been injured will suffer an initial one (Mueller et al., 1996).

The most common injuries among football players are strains, sprains and contusions (Andrish et al., 2000; Mueller et al., 1996). Being a contact sport, most of the injuries resulting from football are acute in nature. Injuries to the lower extremity are the most common in competitive football, with medial collateral ligament sprain or tear being the most frequent lower extremity injury (Mueller et al., 1996). Upper extremity injuries, especially to the shoulder, hand and fingers are also very common (Mueller et al., 1996). Although less frequent, injuries to the head and neck are not unusual in football. Because of the potentially serious ramifications, much research has investigated the cause and prevention of these injuries.

Recent reports from the 1999 NCAA Injury Surveillance indicate an increase in concussion injury (4.2 per 1000 A-E) over the last four years (National Collegiate Athletic Association, Injury Surveillance System Report, 1999). Game injury rates were reported at 44.9 per 1000 A-E. (National Collegiate Athletic Association, 1999). "The knee, ankle and upper leg were the most prevalent body parts injured in football practices, accounting for 43% of all injuries. The knee, ankle and shoulder injuries accounted for 49% of all reported game injuries" (National Collegiate Athletic Association, 1999).

Results

The review of electronic databases identified 131 potentially relevant articles. A manual search of reference lists discovered an additional 28 potentially relevant articles. A total of forty-seven studies met the inclusion criteria. Thirty-eight of the included studies were identified from the electronic databases and the remaining nine from the hand search. The primary reasons that the other studies were excluded are: studies were not relevant (38); no intervention was studied (58); and the study consisted of biomechanical research (13). All but one of the studies were conducted in the U.S.A., with the remaining study being from Canada. The articles were published between 1969 and 1996 and all were written in English. Sixteen of the articles were published prior to 1979, eighteen between 1980 and 1989 and twelve between 1990 and 1999.

Of the forty-seven studies, six were randomized controlled trial design, two used a nonequivalent control group design, twenty-one were prospective cohorts, four were retrospective cohorts, four were time series studies, and ten used a one-group pre-test post-test protocol. Eight of the studies investigated the effect of educational interventions, seven the effect of regulatory interventions, and thirty-four investigated environmental interventions (two studies had dual interventions). The subjects for all studies were involved in organized, competitive football.

These studies investigated a number of research hypotheses. A review of the papers identified the following research objectives:

1. Six studies investigated differences in injury rates on natural playing surfaces compared to artificial turf;
2. Six studies examined the impact of safety equipment on injury rates in athletes wearing various types of helmets and mouth-guards;
3. Four studies investigated the influence of pre-season training and warm-up on the incidence of football injuries;
4. One study investigated the effect of warm-up and stretching on injury incidence;
5. One study researched the effect of stress management on injury rates;
6. Fourteen studies investigated the impact of prophylactic knee braces on lower extremity injury rates, particularly injuries to the medial collateral ligament (MCL);
7. Four studies examined methods of reducing catastrophic football injuries, particularly to the head and neck;
8. Seven studies researched the effect of cleat design on injury rates;
9. One study investigated the effect of coaching experience on injury rates;
10. Three studies researched the effect of regulation changes on injury;
11. Three studies researched the effect on injury rates in touch football by using different playing surface, equipment and officiating.

The quality assessment scores for the RCT studies ranged from 0/5 to 3/5. The quality ratings for all other study designs were 18 at poor, 22 at moderate, and only 1 receiving a good rating.

Environmental Interventions

SHOE & CLEAT DESIGN

The design of modern football shoes and cleats is continually evolving. Several decades ago, team physicians and trainers recognized a relationship between cleat design and the incidence of lower extremity injury. Subsequently, considerable research has focused on developing a shoe that provides the traction required in football while minimizing the risk of injury. In 1969, Rowe conducted a prospective cohort study investigating several shoe and cleat designs on lower extremity injury rates in 1325 high school varsity football players. He concluded that the low-cut shoe with the disk heel was the safest shoe at the time. Only a small population wore soccer style cleats in this study so no conclusions could be made, but Rowe hypothesized this shoe may be even better at preventing injury. This study was rated poor on the quality assessment.

Torg and Quedenfeld (1973) reported the impact of changing from traditional football cleats (seven spikes 0.75” long and .375” in diameter) to soccer cleats (fourteen spikes 0.375” long and 0.5” in diameter) in two articles. The single research study documented knee injuries in two high school leagues playing on natural turf in the 1968 to 1970 playing seasons. A marked decrease in the incidence and severity of knee injuries in athletes wearing the soccer style cleats was found. The number and severity of ankle injuries was also reduced in one of the study leagues. Authors concluded that a traditional cleat design was a factor in the development of knee and ankle injuries in all levels of organized football. They recommended that football shoes should meet the following specifications: (1) molded synthetic sole, (2) minimum of fourteen cleats per shoe, (3) minimum cleat diameter of 0.5”, and (4) maximum cleat length of 0.375.

Cameron and Davis (1973) studied the effect of a unique cleat design, the swivel shoe, on injury incidence. The swivel shoe had moveable forefoot cleats mounted on a 360º turntable. This nonequivalent control group study tested the number of knee and ankle injuries in high school athletes wearing cleated shoes (n = 2055), heel plate (n = 52), soccer shoes (n = 266) and swivel shoes (n = 466). The study quality was rated as poor. Considerably fewer injuries were noted in the swivel shoe group (see table II). The authors concluded that “the most effective method of preventing rigid cleating and the resulting dangerous position was by wearing a shoe combining a cleatless heel and swivel cleats.”

Table VIII-I. Percent of athletes with knee or ankle injuries, from Cameron & Davis (1973)

	Cleated Shoe	Heel Plate	Soccer Shoe	Total – Control	Swivel Shoe
Knee	7.88	5.77	5.27	7.54	2.14
Ankle	8.46	7.69	5.64	8.14	3.00
Total	16.34	13.46	10.91	15.68	5.14

Blyth and Mueller (1974b) conducted a prospective cohort study investigating the relationship between injury rate and the type of protective equipment worn. They recorded injuries from forty-three North Carolina high schools in the 1969 to 1972 seasons. In the first phase of the study, they compared the rates of lower extremity injuries when wearing football and soccer cleats. They initially discovered higher incidence of injury in the soccer shoe group. However, poor field maintenance prevented the authors from determining if the injury rate was the result of cleat type or field conditions. Several of the schools were randomly selected to have their fields resurfaced and properly maintained. The rate of knee and ankle injuries was reduced when athletes wore soccer shoes on a well-maintained field. The authors report an injury rate of 0.213 in athletes playing on poor field,; 0.148 for athletes on resurfaced fields and football cleats, and 0.115 for those wearing soccer cleats on resurfaced fields.

In 1996 Lambson et al. (Lambson, Barnhill, Higgins, 1996) completed a prospective study (quality assessment was moderate) evaluating the effect of cleat design on the incidence of anterior cruciate ligament (ACL) injury. They studied four modern cleat designs:

1. Edge design with multiple small cleats pointed inferiorly and on the peripheral margin (n = 2231);
2. Flat cleats on the forefoot similar to soccer shoes (n = 832);
3. Seven screw-in cleats (n = 46);
4. Pivot disk composed of a large circular disk on the forefoot with one spike in the centre (n = 10).

The study demonstrated that the Edge design produced significantly greater surface resistance ($p < 0.05$) and was associated with a significantly greater incidence of ACL injury (0.017%) than the other three styles combined (0.005%). The authors concluded that modern football shoes, which produce high surface friction and enhance foot fixation, maybe at least partially responsible for knee ligament injuries. They recommended the use of non-Edge design shoes to prevent major knee injuries.

PROPHYLACTIC BRACING

The knee is the most commonly injured area in competitive football players (Mueller & Blyth, 1974). The MCL is particularly susceptible to injury. Prophylactic knee bracing has been investigated in many studies as a means to reduce the frequency and severity of knee injuries in football.

Many studies have noted a positive impact on injury rate when athletes wear preventive knee braces. The effectiveness of prophylactic knee bracing was studied by Hansen et al. in a 1985 retrospective cohort study (Hansen, Ward, Diehl, 1985). They reviewed the medical charts of the USC football teams for the 1980 to 1984 seasons. They reported that 11% of athletes not wearing a brace suffered a knee injury compared to only 5% of those wearing a brace. The researchers concluded that the Anderson Knee Stabler was beneficial in preventing collateral ligament and meniscus injuries. Shaw and Brubaker (1987) noted a similar benefit in high school athletes. They recorded fewer injuries and lost days in athletes wearing a single hinge McDavid Knee Guard. The quality assessment for both studies was poor.

Schriner (1987) also reported a reduced incidence of knee injuries in high school football players using protective knee braces in a prospective cohort study published in 1987. He monitored 1796 athletes from 25 schools over two twelve-week football seasons and found significantly fewer knee injuries from lateral force in braced players ($p < 0.01$). Schriner states that approximately

85% of football knee injuries resulted from lateral forces. There was no difference detected between the groups in terms of injuries from hyperextension or posteriorly inflicted forces.

In 1987 Quillian et al. (Quillian, Simms, & Cooper, 1987) investigated the ability of the Anderson Knee Stabler (a double hinged alloy brace) to prevent injury in one high school team over two seasons. Subjects were randomly assigned to the brace ($n = 50$) or non-brace group ($n = 50$). There were significantly fewer knee injuries ($p < 0.01$) and MCL injuries ($p < 0.05$) in the brace group than the non-brace group. The authors concluded that the brace group sustained fewer and less severe injuries than the non-brace group. This RCT study quality was rated as 1/5.

Further evidence that braces are effective at preventing knee injuries in intramural high school football players was reported by Sitler et al. in 1990 (Sitler, Ryan, Hopkinson, et al., 1990). In a prospective randomized study (quality rating was 2/5) of 1396 athletes, the use of unilateral-biaxial knee braces (DonJoy Orthopedics Protector Knee Guard, DonJoy Inc.) significantly reduced the frequency of injury ($p = 0.005$). The trend did not continue when player position was factored into the analysis. The number of injuries was significantly reduced in defensive players using a brace ($p = 0.005$) while no difference was noted in offensive players ($p > 0.05$). The severity of knee injury was not reduced by wearing the brace and no difference in the incidence of ankle injury existed between the groups.

A unique knee brace with double uprights and polycentric hinges was tested by Brodersen and Symanowski in a prospective cohort study published in 1993. In 1982 the Iowa State University implemented a protective knee orthosis program. The medical records for the 1979 through 1987 seasons were examined to ascertain differences in injury rates. They discovered that the unbraced players had 18% more knee injuries ($p < 0.001$) and more severe injuries ($p < 0.001$) than braced players. The study quality was rated as poor.

NCAA athletes were also studied by Albright et al. (Albright, Powell, Smith. 1994) in their investigation of MCL injuries in a prospective cohort of 987 subjects. The position, string, type of session and daily brace wear was recorded for each athlete. Noticeable differences in the rates of injury for braced and non-braced knees was noted in almost every position during practice. When position, string and session were factored into the analysis, a statistically insignificant trend towards lower injury in the brace group was noted. The results, although inconclusive, demonstrated a trend towards lower incidence of MCL injuries in athletes using a protective knee brace and the authors recommended further research. The study quality was moderate.

While there are several studies that reported a decreased incidence and severity of knee injury in athletes wearing a prophylactic brace, many studies found the opposite effect. Hewson at al. in 1986 found no statistical difference in total knee injuries or MCL injuries between the brace and non-brace test groups (Hewson, Mendini, Wang, 1986). The researchers evaluated the ability of the Anderson Knee Stabler to prevent injury in the University of Arizona football team over four seasons. Decreased recovery time for injured athletes in this study was attributed to improved treatment protocols, not the prophylactic braces. The authors concluded that there was no improvement in knee injury prevention from wearing a prophylactic brace.

The Anderson Knee Stabler brace was also tested by Rovere et al. in a 1988 retrospective cohort study (Rovere, Haupt, Yates, 1988). The incidence of knee injury was greater when all players of the Wake Forest University football team wore a prophylactic brace. The rate of injury was 6.1 per 100 players in the non-brace period and 7.5 per 100 in the brace period. ACL injuries were also more common in the brace condition. The use of an Anderson Knee Stabler as a prophylactic brace was not recommended by the authors.

Tietz et al. also did not recommend braces to prevent knee injuries in collegiate football players (Tietz, Hermanson, Kronmal, et al., 1987). In a prospective cohort study of 71 teams in the 1984 season and 61 teams in the 1985 seasons, authors determined that players using the brace had significantly higher rates of injury ($p < 0.001$). No differences were detected in injury rate when position of the player and playing surface were factored into the analysis.

In 1988 Grace et al. investigated the impact of both a single-hinged and double-hinged prophylactic knee brace on high school football athletes (Grace, Skipper, Newberry, et al., 1988). The nonequivalent control group study recruited 247 athletes who wore a single-hinged brace and 83 who wore a double-hinged brace. These subjects were height, weight and playing position matched with control subjects. Subjects with the single-hinge knee brace suffered significantly more knee injuries ($p < 0.001$). A non-significant trend towards more injuries in the double-hinge group was also noted. There was also a dramatic increase in the number of foot and ankle injuries in athletes wearing braces ($p < 0.01$). The quality of this study was rated as good.

Zemper's (1990) prospective cohort study, investigated the effect of prophylactic bracing on injury rate in 6229 collegiate football players. The results indicated a slight increase in the number of knee injuries in the braced athletes ($p < 0.05$). The braces appeared to have no effect on reducing the incidence or severity of MCL injuries nor was any difference noted between various brands of braces. They further noted that wearing a knee brace did not affect the rate of ankle injuries, and that more development work is required before prophylactic bracing will have a significant effect reducing knee injury.

Deppen and Landfried's (1994) study (quality rating was moderate) of 524 high school football players found no statistically significant differences between the braced and non-braced groups ($p > 0.05$). Based on the results of the study and the expense associated with prophylactic bracing, the authors recommended that sports medicine practitioners not advocate the use of these braces.

Only one study included in this review investigated the efficiency of prophylactic bracing and taping for preventing ankle injuries. In a study of 297 college athletes, Rovere et al. (Rovere, Clarke, Yates et al. 1988) found a significantly lower incidence of ankle injury when wearing an ankle stabilizer compared to taping ($p = 0.0006$). They concluded that the stabilizers were not only more effective at preventing injury but also much more cost efficient than taping.

FOOTBALL EQUIPMENT

Knee injuries, while the most common, are not the only injuries suffered by competitive football players. Football players rely heavily on protective equipment to reduce the rate and severity of injuries .

A RCT by Kaufman and Kaufman (1984) found that use of a new mouth-guard design (Mandibular Orthopedic Repositioning Appliance) reduced the severity of all injuries, the incidence of knee injury, increased strength and was reported to have higher satisfaction compared to a regular mouth-guard (Kaufman & Kaufman, 1984). Unfortunately, the authors did not explain the mechanism by which the MORA reduces knee injuries. Quality of the study was rated at 3/5.

Robey's study published in 1972 investigated the injury rate of three helmet types (suspension, combination suspension/padded, and padded) based on fit and condition of the helmet. He found that players wearing the suspension helmets had the lowest concussion rate while those wearing the padded helmets had the highest. Within the suspension helmet group there was no difference in injury rate and the quality or fit of the helmets. The combination helmets were associated with more injuries when they were 'too small'. There was no relationship between helmet quality and injury. Finally, padded helmets in 'good' condition that fit 'too large' were associated with the lowest concussion rate within this category. The quality of the study was rated poor.

Mueller and Blyth's (Blyth & Mueller, 1974b, Mueller & Blyth, 1974) prospective cohort study investigated the influence of multiple factors on the development of football injuries in 8776 athletes over four seasons. Included in the investigation was the evaluation of various makes of helmets and shoulder pads. Although differences in injury rates were noted among the different brands of helmets, no significant difference was detected between the type of helmets (suspension, combination suspension/padded and padded). Similar to the helmets, some differences in shoulder injury were noted with different brands of shoulder pads. In addition to the protective quality of the equipment for the wearer, the authors also investigated the effect of equipment on other players. Prior to "spearing" (leading with the head) rules being implemented within football, several researchers discussed the tackler's risk of head and neck injuries while spearing. Blyth and Mueller report that the risk of injury is even greater for the recipient of the tackle. The helmet was responsible for almost half of the injuries resulting from a "blow by an object". Football shoes were responsible for 23% of the injuries while the shoulder pads accounted for 15%. Improperly fitted equipment accounted for 49% of the injuries in the "ill-fitting, broken or defective" category while broken equipment was responsible for 44% of cases. The authors also discovered that new helmets and shoulder pads were not associated with a reduced rate of injury. This study emphasized the importance of well-maintained and well-fitted equipment in injury prevention.

In 1977 Andrish et al. (Andrish, Bergfeld, Romo, 1977) published a prospective cohort study on the use of a semi-elastic neck strap that attached the back of the helmet to the shoulder pads in an effort to reduce forced cervical flexion while an athlete is tackling or blocking. The rate of neck injury was monitored in a group of 135 athletes at the US Naval Academy. Ten percent of the athletes wearing the neck strap sustained a cervical injury while 26% of those not wearing one suffered an injury. The quality of this study was rated as poor.

A more recent study on helmet design by Zemper (1994) (study quality was moderate) found reduced frequency of concussion in athletes wearing a Riddell M155 helmet and an increased rate in those wearing the Bike Air Power helmet. This study emphasized the fact that although football equipment has dramatically improved over the decades, further research is required to continue developing better gear and evaluating the effectiveness of current equipment. Unfortunately, there is a dearth of research on current football equipment.

PLAYING SURFACE

Since the introduction of artificial playing surfaces in the 1960's, there has been a great debate over which surface is responsible for more injuries; natural or artificial turf. Initial reports indicated that artificial turf produced more injuries and a few new injuries (i.e., turf toe).

In 1972, Bramwell et al. (Bramwell, Requa, & Garrick, 1993) published a prospective cohort study examining the number and severity of injuries suffered by 26 high school football teams playing on natural and artificial surfaces. The quality rating of the study was moderate. A significant difference in injury rates (0.52 injuries per game on natural turf compared to 0.76 for artificial, $p < 0.01$) were noted between playing surfaces. The number of serious injuries was virtually identical between the surfaces.

Larson and Osternig (1974) discovered a considerable difference in the incidence of both olecranon and prepatellar bursitis in Pacific-8 conference players. Of all the cases of prepatellar bursitis reported by the athletic training staff, 82% were reported on artificial turf (an equal number of teams used artificial and grass surfaces). A similar trend was noted in olecranon bursitis with 87.5% of injuries occurring on artificial turf. The authors recommended the use of neoprene and foam knee and elbow sleeves to dissipate the forces associated with playing football to reduce the incidence of bursitis.

Seventy-three high schools were followed by Adkison et al. in a 1974 prospective cohort study of the relationship between surfaces and injuries (Adkison, Requa, Garrick, 1974). Statistically more injuries were detected on the artificial surfaces ($p < 0.05$). Within the artificial turfs, the players had significantly more injuries on Astroturf fields than on Tartan Turf. Study quality was rated as poor.

Keene et al. found opposite results in a study that employed retrospective and prospective questionnaires (study quality was moderate) for university football players (Keene, Narechania, & Sachtjen, 1980). The results indicated that there was no difference in the total number of injuries suffered on the different playing surfaces. Significantly more scrapes ($p < 0.001$) and sprains ($p < 0.01$) were reported by athletes on the Tartan Turf. However, significantly more torn ligaments were reported while playing on grass playing fields ($p < 0.05$).

Powell, in a 1987 prospective cohort study, found a higher incidence rate of injury in players on AstroTurf compared to grass. He calculated that if an NFL team were to play all of its games on artificial turf, it would incur an average of one to four additional injuries and one to two more major knee or foot/ankle injuries through the season. He stated that the higher rate of injury on artificial turf could be the result of numerous factors including: "player position, tackling and blocking, rushing or passing, and the shoe-surface coefficient of friction." The quality of this study was rated as moderate.

Powell and Schootman completed a more rigorous study in 1992 on knee injury rates in the NFL according to the playing surface used by the athletes. In the study, the severity of injury, position, and the situation at the time of injury were all controlled for. There were significantly more players with knee injuries on the AstroTurf. When knee injuries were categorized as ACL or MCL injuries, only the ACL were significantly more common on AstroTurf.

Educational Interventions

PRE-SEASON TRAINING

Cahill and Griffith (1978) investigated the benefit of a pre-season training program to reduce the incidence of knee injuries in high school football players over eight years. Previous study had indicated that a majority of knee injuries occurred very early in the season prior to the third game of the year, with a considerable portion of them resulting before the first game. A pre-season conditioning program was developed to prepare the athletes for the rigors of competitive football. The training program consisted of "total body conditioning through cardiovascular stressing, acclimatization to heat, weight training, flexibility drills and agility exercises." The study documented the number and severity of knee injuries in athletes that either did or did not participate in a pre-season training routine. Early season injuries were reduced in the pre-season conditioning group by 68% ($p < 0.01$). There was no significant difference after the third game. There was also a significant reduction in knee injuries ($p < 0.01$) and surgical knee injuries ($p < 0.01$). The authors concluded that a pre-season training program reduced the early season knee injuries, the total number of knee injuries and the severity of those injuries that did occur. The study quality was rated as moderate.

Cahill et al., in a study rated of moderate quality, further investigated the effect of pre-season training by adding a third study group to the original data (Cahill, Griffith, Sunderline, et al., 1984). In the previous report, the athletes in the pre-season conditioning group were closely monitored. In the second study, the same conditioning program was implemented, but coaching or medical staff did not monitor the athletes during the pre-season training routine. As before, significant reductions in injury rates were observed in the group participating in pre-season training. No differences were detected between the supervised and unsupervised athletes and the authors concluded that direct supervision during pre-season training was not required to reduce injury rate in high school football players.

Hamstring muscle strains are common injuries among power athletes. They are often difficult to treat and have a high re-injury rate. In 1984, Heiser et al. investigated the ability of a prophylactic training program to prevent hamstring injuries in collegiate athletes (Heiser, Weber, Sullivan, et al., 1984). The training program was introduced in the 1978 – 1982 seasons and the injury rates and recovery times were compared to athletes playing in the 1973 – 1977 seasons. Prior to 1978, the football players (group I) underwent a training program that consisted of a supervised winter running program and self-designed year-long stretching, running and weight-lifting routines. Athletes that suffered a hamstring injury in this group were treated with rest, ice and elevation and by the third day light jogging was instituted. Once the athlete demonstrated adequate speed and agility, they were allowed to return to play. Beginning in 1978, athletes (group II) were required to participate in a supervised winter running program and staff-designed year-long stretching, running and weight-lifting programs. Baseline isokinetic testing of the thigh muscles was also performed on this group. Those athletes that did not have hamstring strength at least equal to 60% of the quadriceps strength were required to complete an isokinetic strengthening program to improve the hamstring strength. Athletes within group II that suffered an injury were treated initially with rest, ice and elevation. High-speed isokinetic exercise was started on the third day. They were allowed to begin jogging when hamstring peak torque reached 70% of baseline and returned to play once 95% was reached. The number of hamstring injuries was significantly reduced from 7.7% of athletes in group I to 1.1% of group II athletes ($p = 0.005$). The number of re-injuries also dropped from 31.7% in group I to 0 in group II ($p < 0.1$). The authors concluded that isokinetic testing and strengthening of hamstring muscle injuries could prevent recurrences by ensuring that an athlete had regained near-normal strength prior to returning to athletics. Study quality was rated as moderate.

In 1997 Gorse et al. conducted a prospective cohort study investigating the effect of introducing pool workouts on pre-season injuries (Gorse, Mickey, & Bierhals, 1997). Five hundred and nineteen NCAA Division III football players were followed over five years. All athletes in the 1991 and 1992 seasons completed a post-practice conditioning program (running and sprinting) on an artificial turf field. The athletes in the 1993 to 1995 seasons alternated post-practice conditioning between turf running/sprinting and kickboard swimming. Thirty-five percent of the turf group suffered a pre-season injury compared to only 13% in the turf and swim group ($p < 0.001$). The turf group also suffered significantly more quadriceps ($p = 0.4$) and hamstring ($p < 0.0001$) injuries.

WARM-UP AND STRETCHING

Performing a warm-up routine prior to practice or competition is common practice for most athletes. In 1992, Bixler and Jones conducted a project investigating the effect of a post-halftime warm-up on third quarter injury rates. Subjects in the intervention group completed a three-minute warm-up and stretching routine following the halftime break. The authors found that ligament sprains and muscle strains were the most common injuries among all the athletes. In the control group these injuries occurred most often in the third quarter. The warm-up group had significantly fewer third quarter sprains and strains ($p < 0.05$) although no difference in total number of injuries was noted. The authors concluded that a post-halftime warm-up and stretching routine may help prevent third quarter sprains and strains. The quality of the study was rated as poor.

STRESS MANAGEMENT

In 1991, Davis studied the effect of progressive relaxation techniques on injury rate and athletic performance. In a pre-test/post-test study of one Division I NCAA football team, the athletes performed ten minutes of progressive muscle relaxation followed by sports imagery five times per week during pre-season training and twice per week during the regular season. Davis reported a 33% reduction in serious injury and an improvement in team performance for the two seasons that included the stress management training. A rating of “poor quality” was applied to the study.

Regulatory Interventions

REGULATIONS

Mueller and Blyth published two time series reports (1986 and 1987) (study quality was poor for the 1986 study and moderate for the 1987 study) on the incidence of catastrophic head and neck injury and changes related to equipment and rules. Research indicated that the highest rate of injury occurred during 1965 to 1974 when players began wearing full face-masks and helmets. The feeling of safety that these players felt lead to increased contact during tackling or blocking being made with the head or face mask. One hundred and sixty-two head and 42 spine fatalities were recorded during that decade. In 1976, a change in football rules made it illegal to “butt block”, “face tackle” or “spear.” Additionally, the National Operating Committee on Standards for Athletic Equipment (NOCSAE) established a safety standard for football helmets in 1978. As a result of these regulatory changes, 69 head and 14 cervical deaths were recorded in the decade of 1975 to 1984. The authors concluded that these regulation changes coupled with improved medical care and physical conditioning programs and instruction on the proper execution of tackling and blocking considerably reduced the incidence of head and cervical injuries.

Torg et al. also noted a decrease in cervical injuries following the 1976 rule changes (Torg, Truex, Quedenfeld, et al., 1979). Prior to 1976, the well-designed modern helmet provided a great deal of protection and a feeling of relative security for the athletes. Their review of the National Football Head and Neck Injury Registry found a decrease from 115 cervical spine injuries in 1976 to 84 in 1977. The number of permanent quadriplegias also decreased from 35 to 19 over the same time period. This study was rated as poor quality.

In a subsequent study by Torg et al. (Torg, Vegso, Sennett. 1987), the incidence of severe head and cervical injury was monitored through the 1984 season. The authors noted a general increase in intracranial hemorrhage from 1976 to 1984. The increased head injuries was thought to result from the use of computerized axial tomography (CAT) and the improvement in the ability to accurately diagnose these injuries. For evidence of this theory, the authors note that although more injuries were diagnosed, the death rate from cranio-cerebral injuries was relatively constant over the same 9-year period. The rate of cervical injury decreased markedly following the implementation of spearing rules. The incidence of cervical injury was 6.5 per 100 000 high school and 29.3 per 100 000 college football players in 1975. In 1976 there was a slight increase in injury rate but in the following years injury rates dropped to 3.9 and 6.66 per 100 000 high school and college players respectively.

COACHES

Blyth and Mueller, in their 1974 prospective cohort study (study quality was poor) of North Carolina high school football, examined the influence of factors such as a coach’s playing and coaching experience, age and education on the occurrence of injury (Blyth, Mueller. 1974a). The following trends were identified by the authors:

- Teams with coaches under age 30 had the highest rate of injury while those with coaches over 45 had the lowest;

- The number of years of playing experience a coach had did not affect the team's injury rate. However, those coaches with only high school experience had teams with the highest injury rate among players, while those with both high school and college or just college had teams with the lowest rates;
- Teams that had coaches with a degree in physical education had similar injury rates as those whose coaches had degrees in other disciplines, but teams whose coach had a master's degree (regardless of field of study) had lower injury incidence among players;
- The more assistant coaches a team had the fewer injuries it suffered;
- Schools that used limited-contact training programs had lower injury rates and a better-than-average win/loss record than those who had daily contact in practices.

Touch Football

EQUIPMENT

In a 1970 RCT, Kraus et al. studied the effect of helmet use on the incidence of head injury in an intramural touch-football league (Kraus, Anderson, & Mueller, 1970). They concluded that while the overall rate of injury did not change, there was a noticeable reduction in the risk of head injury and a significant reduction in the incidence of head concussions ($p = 0.048$). The study quality was 0/5.

GAME OFFICIALS

In 1971, Kraus et al. conducted a RCT on the impact of well-trained and experienced officials on reducing the number of injuries in college intramural touch football (Kraus, Anderson, Mueller, 1971). Officials with higher and lower levels of experience were randomly selected to officiate the intramural touch football games. Based on the reported frequency of injuries, highly trained and experienced officials did not reduce injury rates in touch football.

PLAYING SURFACE

Stevenson and Anderson's 1971 RCT examined the incidence of injury in 834 college intramural touch football players using natural grass and artificial turf (Tartan Turf). The authors indicated that the major complaints against artificial surfaces were its abrasive qualities, heat factors involved with the surface and hardness compared to natural turf. Their research found that athletes playing on the artificial turf suffered significantly more minor injuries, primarily abrasion injuries. There were no differences in the number of severe injuries between natural and artificial turf. The authors recommended the use of knee and elbow pads in an effort to reduce the number of abrasion injuries encountered while playing on artificial turf.

Discussion

Football is a very popular sport among spectators and athletes in North America. Consequently, there has been considerable research on interventions to reduce or prevent injury in competitive football. Very little of this research has focused on children. Future research should first investigate the incidence and severity of injury in child football players, and secondly, test interventions to reduce injury incidence among this population.

Within the populations that have been studied, there is still much doubt or controversy regarding which interventions are most effective at reducing injury rates and severity. Shoe and cleat design has changed radically in the last thirty years. Athletes can now choose between dozens of models. Additionally, artificial playing surfaces have been introduced which changes the shoe-to-surface interface and possibly the mechanism of injury. Which cleat is best probably depends on the player's position, strength, speed, agility and playing surface. While no concrete recommendations on cleat design can be made based on the results of this literature review, most of the studies indicate that cleats with lower surface friction reduce injury rates. Future research needs to investigate the impact of modern shoe design on lower extremity injury while playing on natural and artificial surfaces. Differences in injury incidence and shoe type should be further examined in athletes playing at different positions and level of competition, to determine if differences in injury patterns exist among these groups.

It is also difficult to make recommendations on prophylactic bracing. The use of prophylactic bracing as a means of injury prevention is still a very contentious issue within the sports medicine and football communities. While numerous studies have demonstrated decreased injury rates and severity in athletes wearing a brace, many studies have found the opposite effect. Since many different types of braces have been tested on various populations of athletes, it is difficult to compare the results of the studies. To adequately determine if preventative braces do have a positive impact on injury rates, there are a multitude of controllable variables that need to be recognized and addressed in future research projects. Many of the studies in this review that found a benefit from using braces were conducted on high school athletes. Perhaps the physical demands of high school football are significantly different enough from college and professional to make the braces effective at one level of play but not another. This issue should be addressed in future research. Additionally, some studies controlled for factors such as: prior injury; position of play; height, weight, strength, and age of the player; artificial versus natural playing surfaces; and the skill level and ability of the players. However, many did not use these controls, and none attempted to control for all these factors. The definition and diagnosis of injury varied between studies. Some athletes were examined by orthopedic surgeons while other studies relied on self-reporting. The effectiveness of different brands of braces also needs to be considered before conclusive results can be reached about the benefit of preventive braces.

In addition to the controllable variables that many investigators have addressed, Schriner identified other uncontrollable variables that must be considered when evaluating prophylactic bracing. The size and aggressiveness of the players wearing the brace, the team's win/loss record, field conditions, emotions, psychology of the situation and the pure element of chance are all important factors in the occurrence of athletic injuries (Schriner, 1987). Most athletic injuries are the result of multiple intrinsic and extrinsic factors. To truly assess an intervention's ability to reduce injury, future studies must control for confounding variables. Well-designed and analyzed research that addresses the controllable and uncontrollable factors is essential to decisively determine the benefit or detriment of prophylactic bracing in competitive football.

Future research should test modern brace designs across all levels of competition to determine their effectiveness in different populations. Further, confounding factors such as position, playing surface, age, experience, foot wear, physical abilities, emotional state and history of injury should all be controlled to allow a true comparison of different braces in high school, college and professional athletes.

As with cleats and braces, it is difficult to make recommendations on football helmets and equipment. Many of the studies extend over a thirty-year period and the quality of equipment has changed in that time. What is clear from the studies is that equipment must be properly fitted and in good condition for the athlete to obtain a reasonable amount of protection. As football equipment continues to evolve, further research and testing of new designs is imperative to determine if the new gear is providing protection to the athletes and to make recommendations to improve future generations of protective equipment.

Artificial turf designs have also changed considerably since their inception in the 1960s. While early studies found a definite increase in injury rates on artificial surfaces, the differences are less distinct on modern surfaces. Additionally, shoe design will affect the amount of traction and foot fixation on both natural and artificial turf. It does seem clear that there is an increased incidence of minor abrasion injury while playing on artificial surfaces. Athletes competing on artificial turf should wear protective knee and elbow pads to reduce these minor injuries. Controlled research is required to test the relationship between contemporary turf surfaces and cleat design to understand the impact of different playing surfaces on serious injury. There has not been a well-controlled study of injury rate on different playing surfaces in nearly a decade. Undoubtedly, turf designs have continued to improve in this time. Additionally, no studies have adequately investigated the relationship between shoe design and playing surfaces. Before any definitive conclusions can be drawn regarding the current relationship between injury and playing surface, a comprehensive and controlled study accounting for player position, shoe type, playing surface, weather, etc. is required.

A considerable amount of research has investigated the environmental factors associated with football injury. Playing surface, cleat design, and equipment have all been studied quite extensively. However, the research has not consistently demonstrated what role equipment has in the prevention or instigation of football injuries. Further, there are many additional etiologic factors that are associated with the occurrence of football injury that have yet to be adequately studied. In an attempt to reduce injury, several educational programs have been developed to physically and mentally prepare athletes for competitive football. Many of these programs have been evaluated to determine their impact on injury rates.

While the effect of some environmental interventions on injury incidence is unclear, several educational interventions have demonstrated distinct reductions in injury. Pre-season and off-season training have a significant effect on reducing injury and should be adopted. The type of exercise specified during the pre-season should also be evaluated further. Rapidly increasing the duration, intensity or frequency of exercise puts athletes at an increased risk of injury. Implementing cross-training activities into the pre-season training, such as swimming, cycling or water running, could reduce the incidence of pre-season injury without negatively affecting athletic performance. While almost all teams participate in pre-game warm-up and stretching, one study has clearly indicated reduced injuries in athletes completing a post-halftime warm-up. Finally, one study indicated reduced injuries in football players that participated in progressive relaxation techniques. Further research on stress management in athletes is required to determine the relationship between stress and injury and the best methods of reducing stress to prevent injuries. While the relationship between pre-season training and reduced injury has been established, further research should investigate the best programs for each player position at different levels of play. Undoubtedly, the physical demands of each position and level of play are different, hence investigation is required to determine appropriate training programs for different populations of athletes.

Football rules and regulation have changed drastically since the first game between Princeton and Rutgers in 1869 (Mueller et al., 1987). Football helmets were not introduced until 1896 and "strategy played little part in the outcome of the game. Brute force, physical conditioning and endurance were the determining factors" (Mueller et al., 1987). As a result, there were a significant number of injuries and deaths resulting from football. Not until "President Roosevelt demanded that the sport be saved by removing every objectionable feature" were rules to decrease the roughness finally implemented (Mueller & Blyth, 1987). Since then, many rules and regulations have been implemented to reduce the risk of injury in the sport of football. Some of the changes had an immediate impact on injury rates while others still require further research.

Numerous regulations have been implemented in football in an effort to eliminate unnecessary roughness and reduce injury. Some of the rules changes, such as eliminating spearing and butt blocking, had an obvious and immediate impact on injury rate. Some of the other regulations still require further investigation. While most coaches and officials involved in football would probably agree the number and expertise of the referees has an impact on injury rate, there is no quantifiable research to support this hypothesis. Most states and provinces now require some level of certification and experience before someone is allowed to coach football. An early study (Blyth & Mueller, 1974a) identified a relationship between coaching experience and injury rates but no current study has determined the benefit of coaching certification programs or continuing education at preventing injury. Rule changes within competitive football have definitely had significant effects on reducing injury rates. Rules that eliminate unnecessary roughness in the sport will continue to have a positive effect on injury rates.

Football is an intense physical sport and it may never be possible to eliminate injury from the sport. However with proper equipment, education and regulations, the injury incidence can undoubtedly be reduced. Ongoing research is required to determine which contemporary equipment designs best reduce injury. Educational strategies including pre-season training, warm-up and fluid replacement have all had a significant benefits in reducing injuries however further research is required to continue improving these programs. Finally, while having better trained coaches and officials seems an intuitive method of reducing injuries, there is little or no controlled research to support these hypotheses. Future research into injury prevention strategies should produce better equipment, coaches, athletes and officials, all of which will make the game a more exciting spectator event while increasing the safety of the athletes.

Recommendations

Research

ENVIRONMENTAL

- Evaluate the amount of surface friction and foot fixation in modern cleat designs;
- Determine which cleat design provides the best combination of surface friction and foot fixation and enhances athletic performance while reducing injury rates;
- Determine what differences in shoe-surface interface exists between artificial and natural turf and its impact on injury incidence;
- Test contemporary artificial turf designs to determine if injury rates differ between artificial and natural turf;
- Test the effectiveness of modern prophylactic braces in a randomized and controlled subject population;
- Employ similar study designs for different brands of braces to compare the effectiveness the brands;
- Employ similar study designs in high school and college populations to ascertain if the physical demands are significantly different at various levels of play and to determine if prophylactic braces should be recommended for high school students;
- Evaluate modern football equipment to determine which models are most effective at reducing injury and provide recommendations for future designs.

EDUCATIONAL

- Investigate the benefit of cross-training activities at reducing pre-season injury and maintaining or even improving fitness levels;
- Determine the most appropriate pre-season training regime for different levels of play and player positions;
- Research the effect of proprioceptive training programs at preventing specific types of injuries such as ACL ruptures;
- Evaluate pre- and mid-game warm-up protocols to determine the appropriate activity, intensity and duration to reduce the incidence of injury;
- Determine the relationship between stress and football injuries and develop appropriate measures to reduce the incidence of injury.

REGULATORY

- Evaluate the effect of more and/or better-trained officials at reducing the number of football injuries;
- Determine the effect of better-educated or experienced coaches at reducing injury;
- Examine the incidence of football injury in children to determine if similar injuries are occurring and at the same rates as older athletes;
- Develop appropriate training and competition guidelines for children based on age, size and/or physical/skeletal maturity of the athletes;

- Determine the appropriate amount of contact for children and the safest method to introduce and teach the physical skills of football;
- Investigate the effect of regulation changes on injury rate.

Practice

- All players should have equipment that is the safest available. Helmets must meet National Operating Committee on Standards for Athletic Equipment (NOCSAE) and/or CSA safety requirements. All equipment must be properly maintained and fitted for each individual athlete. The equipment must also be appropriate for the athlete's playing position;
- Playing surfaces must be well-maintained and athletes should wear shoes appropriate to the playing surface;
- Until future research provides conclusive evidence for or against prophylactic braces, they should be available for athletes requiring them. Care must be taken to ensure that the braces meet quality standards and are upgraded when needed;
- Pre-season and off-season training is essential for injury prevention in competitive football. Pre-season training should gradually increase in intensity, duration and frequency to prevent overuse injuries. Pre-season training must emphasize all the components of fitness required in football including: aerobic and anaerobic endurance. Muscular strength, especially in the neck and upper back; and overall flexibility. Cross-training should be incorporated into pre-season training to reduce the risk of developing overuse injuries;
- Athletes should complete a warm-up consisting of light aerobic exercise and stretching prior to a game or practice, and should also perform a warm-up following the halftime break to reduce the possibility of sprain or strain injuries;
- Further regulations that reduce the roughness of football and prevent athletes from using the helmet as a weapon should be introduced. Current regulations need to be enforced by game officials;
- Certification and continuing education should be essential for all coaches and officials to inform them of new injury prevention information.

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Table 1: Football Study Characteristics

First Author	Study Design	Quality Rating	Year of Publication	Country	Study Time Period	Funding
Kaufman	RCT	Moderate (3/5)	1984	USA	1982 college football season	Not reported
Kraus (1970)	RCT	Poor (0/5)	1970	USA	1968	Injury Control Program -US Public Health Service, National Intramural Association
Kraus (1971)	RCT	Poor (2/5)	1971	USA	1969 touch football season	Injury Control Program, US Public Health Service, Univ of Minnesota, National Intramural Association
Quillian	RCT	Poor (1/5)	1987	USA	1984-1985	Not reported
Sitler	RCT	Poor (2/5)	1990	USA	1986-1987	US Army Medical Research & Development Command
Stevenson	RCT	Poor (1/5)	1971	USA	1971	Not reported
Cameron	Non-Equivalent Control Group	Poor (6/14)	1973	USA	1969 football season	Not reported
Grace	Non-Equivalent Control Group	Good (13/14)	1988	USA	Not reported	Not funded
Adkison	Prospective Cohort	Poor (7.5/17)	1974	USA	1971	Not reported
Albright	Prospective Cohort	Moderate (9/17)	1994	USA	1985-1987	Big Ten Conference, NCAA
Andrish	Prospective Cohort	Poor (8/17)	1977	USA	1974	Not reported
Blyth	Prospective Cohort	Poor (4/17)	1974	USA	1969, 1971, 1972	Not reported
Blyth	Prospective Cohort	Poor (4.5/17)	1974	USA	1969-1972	Not reported
Bramwell	Prospective Cohort	Poor (8.5/17)	1972	USA	1970 season	Not reported
Brixler	Prospective Cohort	Poor (5/17)	1992	USA	Not reported	Dept of Health & Human Services, Bureau of Health Professions, Public Health Service
Brodersen	Prospective Cohort	Poor (7/17)	1993	USA	1979-1987	Not reported
Deppen	Prospective Cohort	Moderate (12/17)	1994	USA	Not reported	Not reported
Gorse	Prospective Cohort	Moderate (8.5/17)	1997	USA	1991-1995	Not reported
Hewson	Prospective Cohort	Moderate (11.5/17)	1986	USA	1977-1985	Not reported
Lambson	Prospective Cohort	Moderate (11.5/17)	1996	USA	1989-1991	Panhandle Sports Medicine Institute, Sports Therapy & Rehabilitation

Table 1: Football Study Characteristics (*continued*)

First Author	Study Design	Quality Rating	Year of Publication	Country	Study Time Period	Funding
Larson	Prospective Cohort	Poor (6/17)	1974	USA	1963	Not reported
Mueller	Prospective Cohort	Poor (6/17)	1974	USA	1969-1972	Public Health Service Grant-Environment Control Administration, NCAA and University of N. Carolina
Powell	Prospective Cohort	Moderate (10.5/17)	1987	USA	1980-1985	Not reported
Robey	Prospective Cohort	Poor (5/17)	1972	USA	1968-1970	US Public Health Service; NCAA
Rowe	Prospective Cohort	Poor (5.5/17)	1969	USA	Not reported	Not reported
Schriner	Prospective Cohort	Moderate (9/17)	1987	USA	1984-1985	Not funded
Tietz	Prospective Cohort	Poor (6.5/17)	1987	USA	1984-1985	NCAA
Zemper (1994)	Prospective Cohort	Moderate (9.5/17)	1994	USA	1986-1990	International Institute for Sport and Human Performance, University of Oregon, Exercise Research Associates and Mitcoff & Jacks
Zemper (1990)	Prospective Cohort	Poor (6/17)	1990	USA	1986-1987	International Institute for Sport & Human Performance, College of Human Development & Performance, University of Oregon
Hansen	Retrospective Cohort	Poor (5.5/17)	1985	USA	1980-1984	Not reported
Powell	Retrospective Cohort	Moderate (10.5/17)	1992	USA	1980-1989	NFL Injury Surveillance System, NFL Professional Athletic Trainers Society
Rovere	Retrospective Cohort	Moderate (8/14)	1988	USA	1980-1986	Not reported
Shaw	Retrospective Cohort	Poor (3/17)	1987	USA	1983-1986	Not reported
Fine	Time Series	Moderate (8/14)	1991	USA	1975-1987	Not reported
Mueller (1987)	Time Series	Moderate (7/14)	1987	USA	1945-1984	American Football Coaches Assoc., CAA National Federation State High School Association, U. of N. Carolina
Mueller (1986)	Time Series	Poor (6/14)	1986	USA	1931-1985	NCAA, American Football Coaches Association
Torg	Time Series	Moderate (8/14)	1987	USA	1971-1984	Not reported
Cahill	Type II Pre-Post Test	Moderate (7/14)	1984	USA	1969-1980	Not reported

Table 1. Football Study Characteristics (*continued*)

First Author	Study Design	Quality Rating	Year of Publication	Country	Study Time Period	Funding
Cahill	Type II Pre-Post Test	Moderate (10/14)	1978	USA	1969-1976	Great Plains Sports Medicine Foundation
Davis	Type II Pre-Post Test	Poor (5/14)	1991	USA	Not reported	Southwest Missouri State University faculty grants program
Heiser	Type II Pre-Post Test	Moderate (8/14)	1984	USA	1973-1982	Not reported
Jackson	Type II Pre-Post Test	Moderate (12/14)	1991	Canada	1977-1988	Not reported
Keene	Type II Pre-Post Test	Moderate (8/14)	1980	USA	1960-1973 (1975-77 data gathered but not presented)	Not reported
Rovere	Type II Pre-Post Test	Moderate (8/14)	1987	USA	1981-1985	Not reported
Torg (1971)	Type II Pre-Post Test	Moderate (9/14)	1971	USA	1968-1970	Not reported
Torg (1973)	Type II Pre-Post Test	Moderate (10/14)	1973	USA	1968-1971	Not reported
Torg (1979)	Type II Pre-Post Test	Poor (5/14)	1979	USA	1971-1977	Robert Maxwell Memorial Football Club

Table 2: Football Study Design

First Author	Study aim	Study Setting	Study Participants/ Targets	Participant Selection/ Recruitment
Kaufman	Test the effects of a Mandibular Orthopedic Repositioning Appliance (MORA) on performance, injury (number, type and severity), physical fitness and satisfaction with the mouthpiece.	College/University Intramural	Sport/Recreation Participant	The 60 players most likely to make the C.W. Post college football team.
Kraus (1970)	Determine whether a head injury control device (helmet) could significantly reduce the incidence of head injuries in college intramural touch football games.	College/University Intramural	Sport/Recreation Participant	From 1968 touch football league, University of Minnesota; players were required to wear helmets.
Kraus (1971)	Test whether or not well-trained and experienced officials could significantly reduce the incidence of injuries in college intramural touch football games.	College/University Intramural	Sport/Recreation Participant	All those participating in intramural touch football in the 1969 season – randomly assigned.
Quillian	Assess the effectiveness of preventive knee braces in high school football players to reduce knee injuries.	High school	Sport/Recreation Participant	All players from one high school in Florida.
Sitler	Determine the efficacy of a prophylactic knee brace to reduce the frequency and severity of acute knee injuries in football.	College/University Intramural	Sport/Recreation Participant	AU Players in the 8 man intramural tackle football program at West Point; recruitment by voluntary consent.
Stevenson	Compare injury rates in touch football played on synthetic Tartan turf and natural grass.	College/University Intramurals	Sport/Recreation Participant	Random selection from 140 teams in intramural association Michigan; questionnaires; voluntary participation.
Cameron	Compare high school football players wearing swivel shoes with those wearing conventional shoes for knee and ankle injuries, as well as for agility.	High school	Sport/Recreation Participant	Not reported
Grace	Determine the effect of prophylactic knee braces on injuries of the knee and lower extremity in high school football players.	High school	Sport/Recreation Participant	High school varsity and Junior varsity football players from Albuquerque and Santa Fe.
Adkison	Study the effect on injury rates of both synthetic and natural playing surfaces.	High school	Sport/Recreation Participant	Players from 73 high schools in the Seattle and Spokane, Washington and Portland, Oregon areas.
Albright	Assess the effectiveness of prophylactic knee braces in NCAA Division I college football players.	College/University Varsity	Sport/Recreation Participant	All Big Ten team members eligible, if no prior knee injury; voluntary participation.

Table 2: Football Study Design (*continued*)

First Author	Study aim	Study Setting	Study Participants/ Targets	Participant Selection/ Recruitment
Andrish	Test the efficacy of the "neck strap" to prevent flexion cervical sprains in football.	College/ University Varsity	Sport/Recreation Participant	135 varsity, junior varsity and freshman football players from the US naval academy
Blyth	Investigate the training and experience of coaches and the relationship to injury.	High school	Sport/Recreation Participant	From North Carolina High School Football League
Blyth	Assess the association of injury rates by brand of protective equipment, (for helmets, shoulder pads) or by type of equipment (cleats vs. soccer shoes.	High school	Sport/Recreation Participant	All injured football players in 43 North Carolina high schools.
Bramwell	Compare the injury rates between natural and artificial turf.	High school	Sport/Recreation Participant	High school football teams in the greater Seattle area; recruitment done by questionnaire.
Brixler	Assess whether completing a warm up and stretching routine during half time reduces the incidence of 3rd quarter injuries in high school football players.	High school	Sport/Recreation Participant	Based on previous interactions between investigators and team coaches/trainers.
Brodersen	Assess the efficacy of double upright hinged knee brace in reducing the number and severity of knee injuries in football players.	College/ University varsity	Sport/Recreation Participant	All members of the Iowa State University football teams, 1979-1987
Deppen	Investigate the injury rate of high school football players who utilized preventive knee braces vs. those who did not by comparing the number of contact exposures with the number and type of injuries sustained by the players.	Not reported	Sport/Recreation Participant (males, 16-18 years)	High school football players from 8 teams
Gorse	Compare the occurrence of pre-season football conditioning injuries in traditional and crossover training programs over 5 pre-season training camps.	College/ University Varsity	Sport/Recreation Participant	Members of Carnegie Mellon varsity football teams 1991-1995
Hewson	Evaluate the effectiveness of the Anderson Knee Stabler in preventing knee injuries.	College/ University Varsity	Sport/Recreation Participant	University of Arizona players from 1977-1985.
Lambson	Evaluate torsional resistance of modern football cleat designs and the incidence of surgically documented all tears in high school football players wearing different cleat types.	High school	Sport/Recreation Participant	High school football players from varsity, junior varsity, sophomore and freshman teams from Texas Panhandle high schools
Larson	Compare the incidence of prepatellar and olecranon bursitis on both grass and artificial turf fields.	College/ University Intramurals	Sport/Recreation Participant	All 8 teams in the Pacific-8 football conference
Mueller	Present information in four areas: (1) the injury rate associated with different brand name football helmets and shoulder pads; (2) reduction of knee and ankle injuries by improving playing surfaces and changing cleat type; (3) reduction of injuries by a limited contact program; and (4) the incidence of re-injury to participants.	High school	Sport/Recreation Participant	43 North Carolina high school football teams

Table 2: Football Study Design (*continued*)

First Author	Study aim	Study Setting	Study Participants/ Targets	Participant Selection/ Recruitment
Powell	Examine injury risk patterns for NFL games as they associated with playing surfaces.	Professional teams	Sport/Recreation Participant	All NFL teams 1980-1985
Robey	Assess the concussion injury rates for helmets with different mounting systems, and different categories of conditions and fit in high school football players.	High school	Sport/Recreation Participant	Not reported
Rowe	Determine the effect of different types of cleats on knee and ankle injury incidence in high school football.	High school	Sport/Recreation Participant	Football teams from all 80 high schools in 11 leagues in New York
Schriner	Determine the effectiveness of knee braces in preventing knee injuries in non-injured high school football players.	High school	Sport/Recreation Participant	Football players from 25 high schools in Genesse County, Michigan
Tietz	Compare incidence and severity of knee injuries in college football players wearing knee braces with those not wearing braces.	College/University Varsity	Sport/Recreation Participant	All NCAA Division I schools – self selection
Zemper (1994)	Assess the rate of cerebral concussion injury with different models of football helmets, and to assess the effect of concussion history on concussion rates.	College/University Varsity	Sport/Recreation Participant	Random National sample of NCAA and NAIA football teams from the Athletic Injury Monitoring System Database
Zemper (1990)	Assess the efficacy of prophylactic knee braces in reducing the incidence and/or severity of knee injuries in football players.	College/University varsity	Sport/Recreation Participant	All intercollegiate football players from 32 teams from NCAA and NAIA in 1986 and all from 27 teams in NCAA and NAIA in 1987.
Hansen	Assess knee injuries in USC football players between those wearing the Anderson Knee Stabler brace and those not using it.	College/University Varsity	Sport/Recreation Participant	USC varsity football teams – all members 1980-1984
Powell	Assess football knee injury rates for natural grass and Astroturf surfaces and the risk factors of game position and type of play.	Professional team	Sport/Recreation Participant	Part of NFL Injury Surveillance System – all NFL players were selected
Rovere	Retrospectively assess the effectiveness of taping compared to wearing a laced stabilizer in preventing ankle injuries and reinjury.	College/University Varsity	Sport/Recreation Participant	All football players at Wake Forest University
Shaw	Assess whether use of McDavid Knee Guard is associated with the incidence of knee injuries in football players at one Texas high school.	High school	Sport/Recreation Participant	Football players from one Texas high school—varsity and junior varsity
Fine	Examine trends in cervical spine injuries before and after the NCAA banned "spearing" with football helmets (head first tackling and blocking).	All organized football	Sport/Recreation Participant	Related cervical spine injuries reported to the National Football Head & Neck Injury Registry; interview with athlete, parent, school officials

Table 2: Football Study Design (*continued*)

First Author	Study aim	Study Setting	Study Participants/ Targets	Participant Selection/ Recruitment
Mueller (1987)	Assess trends in head and cervical spine fatalities in football with respect to rule changes (spearing) and national helmet standards.	All levels of sport	Sport/Recreation Participant	All head and cervical spine fatalities directly due to organized football. Personal contact and questionnaires sent to all organized football programs.
Mueller (1986)	Assess the impact of rule changes (helmet tackling and approved standards for helmets) on fatalities and permanent cervical cord injuries in football players.	All organized football	Sport/Recreation Participant	All reported fatalities and cervical cord injuries directly due to organized football
Torg	Describe how the rule change banning spearing in 1976 resulted in a significant reduction of cervical spine injuries associated with quadriplegia	All levels of sport	Sport/Recreation Participant	All players in organized football 1974-1984; recruitment not reported
Cahill	Assess whether the reduction in knee injuries associated with supervised pre-season conditioning is maintained after conditioning is less supervised.	High school	Sport/Recreation Participant	Varsity high school football players in Midstate Eight conference; participation was voluntary
Cahill	Compare the effect of pre-season conditioning and no pre-season conditioning on knee injuries of high school football players.	High school	Sport/Recreation Participant	All varsity football players in the midstate nine conference in Peoria, Illinois; participation was voluntary
Davis	Assess whether progressive relaxation and sports-related imagery during team workouts would lead to reduced number of injuries.	College/University Varsity	Sport/Recreation Participant	Varsity football players from Texas Christian University
Heiser	Compare the effect of isokinetic testing and rehabilitation of muscle imbalances, using the Cybex II isokinetic dynamometer, on prevention of hamstring strains and recurrence of injury versus non-use.	College/University Varsity	Sport/Recreation Participant	University of Nebraska football team (1973-1982)
Jackson	Assess the incidence and severity of knee injuries in a professional football team with regards to risk factors (i.e., games, practice, experience, position) and the role of prophylactic knee bracing over a 12 year period.	Professional Team	Sport/Recreation Participant	All players from Toronto Argonauts in 1977-1988; retrospective study using records
Keene	Compare college football injuries occurring on grass with those occurring on tartan turf at the University of Wisconsin.	College/University Varsity	Sport/Recreation Participant	All University of Wisconsin varsity football players, 1960-73; sent questionnaires; voluntary reply to survey
Rovere	Compare knee injury rates when college football players in one team wore braces for 2 seasons with a previous 2 year period when no braces were worn.	College/University Varsity	Sport/Recreation Participant	All players on the Wake Forest University College Football Team; recruitment was required by coaching staff

Table 2: Football Study Design (*continued*)

First Author	Study aim	Study Setting	Study Participants/ Targets	Participant Selection/ Recruitment
Torg (1971)	Present head and neck injuries sustained as a result from football from 1971 through and including the 1977 season presented in 4 groups: (1) 1971 – 1975, (2) 1975, (3) 1976, and (4) 1977. To present nonstatistical comparison of injury data for two five-year periods: 1959-63 and 97-75.	All organized football	Sport/Recreation Participant	National Registry of Football Head & Neck Injuries – whole population
Torg (1973)	Assess whether changing from conventional cleated football shoes to soccer-type shoes has an affect on knee and ankle injuries.	High school	Sport/Recreation Participant	All teams in the Philadelphia Public High School League, and 16 of 18 teams in the Philadelphia Catholic League.
Torg (1979)	Assess whether changing from conventional cleated football shoes to soccer-type shoes has an effect on knee and ankle injuries.	High school	Sport/Recreation Participant	All teams in the Philadelphia Public High School League, and 16 of 18 teams in the Philadelphia Catholic League.

Table 3: Football Study Intervention

First Author	Intervention Type	Details of Intervention	Frequency Duration	Primary Outcome measure	Outcome Collection Method
Kaufman	Environmental	Personal protective equipment worn by participant: players were randomly assigned to either wear the MORA or a conventional mouthpiece.	Unclear	Mean number and severity of injury number of different types of injury Mean physical fitness scores Satisfaction with mouthpiece	School records
Kraus (1970)	Environmental	Personal protective equipment worn by participant: the experimental group was required to wear helmets.	Unclear	Injury rate	Other medical records (Medical Association Injury Report Form - Health Services), other (Officials-I-M touch football score card)
Kraus (1971)	Regulatory	Policy: Using experienced, trained officials (Random assignment of experimental [good quality, trained] officials and control [lower quality, untrained] officials to approximately 750 touch football games with an evaluation of concomitant injury experience resulting from these games).	Ongoing: season	Injury rate, serious injury rate Injury rate by location of injury Injury rate by type of injury	Other medical records (Accidental injury report form, university health service, game scorecard), self report-questionnaire
Quillia	Environmental	Personal protective equipment worn by participant: use of the Anderson Knee Stabler on both knees vs. non-use.	Unclear	Incidence of knee injury	School records
Sitler	Environmental	Personal protective equipment worn by participant: DonJoy Orthopaedics Protector Knee Guard assigned at random to approximately half of the subjects.	Unclear	Frequency of knee injury Structural injury frequencies Structural injury severity	Unclear
Stevenson	Environmental	Teams were randomly assigned to play games either on Tartan turf or natural grass.	Unclear	Injury incidence overall Injury incidence by severity	

Table 3: Football Study Intervention (*continued*)

First Author	Intervention Type	Details of Intervention	Frequency Duration	Primary Outcome measure	Outcome Collection Method
Cameron	Environmental	Personal protective equipment worn by participant: wearing newly developed swivel shoes vs. wearing conventional shoes (including cleated, heel plate and soccer shoes).	Unclear	Percentage of players with knee injuries Percentage of players with ankle injuries Agility test	Doctor diagnosis (attending physician), Other (investigating team)
Grace	Environmental	Personal protective equipment worn by participant: single-hinged or double-hinged knee braces vs. no braces.	Unclear	Knee injury rates Ankle/foot injury rates	Doctor records (school physicians and orthopaedic surgeons), school records
Adkison	Environmental	Synthetic or natural playing surfaces (i.e., grass astroturf A, B, C and tartan turf), wet or dry.	Unclear	Injury rate Severity	Self report questionnaire
Albright	Environmental	Personal protective equipment worn by participant: wearing prophylactic knee braces vs. not wearing.	Unclear	Injury rate/100 knee exposures (incidence of MCL injury, expressed as injury rate per 100 knee exposures)	School records
Andrish	Environmental	Use of a semi-elastic "neck strap" attached from the shoulder pads to the helmet vs. non-use.	Unclear	Incidence of neck injury Type of neck injury	Doctor diagnosis (team physician), school records, self report: face-to-face interview
Blyth	Educational Regulatory	Policy—training and experience of head coaches (Head coach and age, education, playing experience, coaching experience, assistant coaches, contact work, administering liquids, limited contract).	Unclear	Injury rate	Unclear
Blyth	Environmental	Different brands of football helmets and shoulder pads used; use of soccer shoes vs. regular cleats.	Unclear	Concussion rate Shoulder girdle injury rate Knee/ankle injury rate	Self reports: face-to-face interview and telephone interview
Bramwell	Environmental	Approach involved the physical environment--synthetic astroturf vs. natural grass and wet vs. dry conditions.	Unclear	Injury rate Injury severity	School records
Brixler	Educational	During half time, 1.5 min warm-up (running in place and jumping jacks) followed by 1.5 minutes of stretching (trunk twist, hamstring stretch, groin stretch, quad stretch).	Unclear	Mean 3^{rd} quarter injuries per game Mean overall injuries per game Injury rate by type	School records

Table 3: Football Study Intervention (*continued*)

First Author	Intervention Type	Details of Intervention	Frequency Duration	Primary Outcome measure	Outcome Collection Method
Brodersen	Environmental	Use of a double upright (medial and collateral) hinged knee brace with thigh and calf cuffs	Unclear	Injury rates Injury severity (time-loss) Injury severity (Ligament damage)	School records
Deppen	Environmental	Personal protective equipment worn by participant: knee braces.	Unclear	Injury rate Injury type	Unclear
Gorse	Educational	Turf group (1991-92) did a combination of running, sprinting, and weight training, while the turf and swim group (1993-1995) used the cross over effect of swimming and running/sprinting on alternate days (along with weight training).	Ongoing: pre-season, 2 weeks	Prevalence of injury, by type of conditioning Prevalence of injury by class Prevalence of injury, by location of injury	Unclear
Hewson	Environmental	Personal protective equipment worn by participant: Anderson Knee Stabler.	Unclear	Type of injury/severity Rate of injury	Doctor diagnosis (orthopaedic surgeons), other medical records (athletic treatment center daily goal), school records, surveillance system
Lambson	Environmental	Protective equipment worn by participant—Compared four styles of football shoes: (1) edge, longer irregular cleats, (2) flat, similar style to soccer cleats, (3) screw-in cleats, and (4) pivot disk.	Unclear	Rate of all injury Torsional resistance of cleats	Doctor diagnosis (arthroscopic evaluation by physician), school records
Larson	Environmental	Grass fields vs. synthetic turf	Unclear	Incidence of prepatellar and Olecranon bursitis	School records
Mueller	Educational Environmental	Limited vs. full contact Different types of football helmets, shoulder pads, and cleat types Field maintenance	Ongoing	Incidence of concussion Incidence of shoulder injury Incidence of knee and ankle injury Incidence of injury following limited contact	Self report: face-to-face interview

Table 3: Football Study Intervention (*continued*)

First Author	Intervention Type	Details of Intervention	Frequency Duration	Primary Outcome measure	Outcome Collection Method
Powell	Environmental	Comparing different playing surfaces (grass, AstroTurf, Tartan Turf, or Super Turf)	Unclear	Injury incidence by severity of injury Injuries by severity of location	Surveillance system Sport association, or team records
Robey	Environmental	Personal protective equipment worn by participant: helmet mounting system - suspension vs. combined-padded suspension vs. padded; fit - poor, too large, too small, suspension up, thin jaw pads; and condition - good, poor.	Unclear	Concussion injury rates	Unclear
Rowe	Environmental	Use of high shoe with conventional heel cleats (HC) vs. high shoe with disk heel Conventional sole cleats (HD) vs. Low shoe with conventional heel cleat (LC) vs. Low shoe with disk heel, conventional sole cleat (LD) vs. Soccer or rubber cleats (SE)	Unclear	Incidence of knee/ankle injury Severity of knee/ankle injury	
Schriner	Environmental	Use of braces vs. no braces (3 different braces used: Anderson, McDavid, and Don Joy)	Unclear	Percentage of injuries, lateral forces, 1984 Percentage of injuries, lateral forces, 1985	Doctor diagnosis (player's physician) school records
Tietz	Environmental	Personal protective equipment worn by participant: use of preventive knee braces in NCAA Division I football players vs. non-use.	Unclear	Rate of injury 1984, 1985 Severity of injury 1984, 1985	School records
Zemper (1994)	Environmental	Protective equipment worn by participant: use of 10 different models of football helmets.	Unclear	Concussion rate by model of helmet	Surveillance system, school records
Zemper (1990)	Environmental	Use of prophylactic knee brace vs. non-use	Unclear	Incidence of knee injury Severity of knee injury Type of knee injury	Surveillance system, school records
Hansen	Environmental	Use of Anderson Knee Stabler vs. non use	Unclear	Injury rate overall	School records

Table 3: Football Study Intervention (*continued*)

First Author	Intervention Type	Details of Intervention	Frequency Duration	Primary Outcome measure	Outcome Collection Method
Powell	Environmental	Approach involved the physical environment: Type of surfaces (natural grass vs. Astroturf), with analyses controlled for game, position and type of play.		Overall knee sprain rates Knee sprain rates, by MCL vs. ACL sprain Injury rates controlling for position and type of play	Surveillance system, sport association or team records
Rovere	Environmental	Personal protective equipment worn by participant: ankle taping vs. laced stabilizer. After a period where all players had taped ankles, players chose either ankle taping or a laced ankle stabilizer.	Unclear	Injury rate per 1000 exposures Re-injury rate	Doctor diagnosis (team physician), school records
Shaw	Environmental	Voluntary use of the McDavid Knee Guard on both knees	Unclear	Number of knee injuries Number of days lost	School records
Fine	Regulatory	Rule eliminating spearing	Unclear	Annual incidence of serious cervical spine injuries Annual incidence of permanent cervical spine quadriplegia	Hospital records, Surveillance system, school records, self report, questionnaire
Mueller (1987)	Regulatory	1976 rule that banned spearing and helmet standards set in 1978-1980	Unclear	Head fatalities by decade Cervical spine fatalities by decade	School records, sport association or team records, self report-questionnaire, self report-telephone interview
Mueller (1986)	Regulatory	NCAA rule change in 1976 prohibiting spearing with helmets The helmet standard took effect in 1978 at the college level and 1980 at the high school level.	Unclear	Head fatalities by decade Cervical spine fatalities by decade	School records, self report-questionnaire, self report-telephone interview, other
Torg	Regulatory	Rule that banned "head-first" tackling in 1976	Unclear	Head and neck injury and death rates	Doctor diagnosis (responsible physician), school records, other

Table 3: Football Study Intervention (*continued*)

First Author	Intervention Type	Details of Intervention	Frequency Duration	Primary Outcome measure	Outcome Collection Method
Cahill	Educational	This is a follow-up of a 4 season supervised pre-season conditioning program. For the next 4 years, the conditioning program remained in effect, but with less supervision by members of the sports medicine staff.	3 times a week for 5-6 weeks	Knee injury rates/1000 players Number of operations/1000 players	Hospital records, other medical records (medical society), doctor diagnosis (author), sport association or team records
Cahill	Educational	Pre-season conditioning program containing cardiovascular stressing, acclimatization to heat, weight training, flexibility drills and agility exercises	3 times a week for 5-6 weeks	Injury incidence Injury severity	Hospital records, other medical records (Peoria Medical Society), doctor diagnosis, sport association or team records
Davis	Educational	Stress management program: for swimmers,10 mins. of progressive relaxation followed by 5 mins. of guided imagery after afternoon practices, conducted by researcher; for football players, after mid-practice water break, 10 minutes of progressive relaxation and sports-related imagery.	Ongoing: pre-season and season	Number of injuries — swimmers Number of injuries — football players	School records
Heiser	Educational	1973-77 - prophylactic pre-season conditioning program consisting of self-designed stretching and staff-designed, year long running and weight lifting programs. 1978-82 - prophylactic conditioning program consisting of staff-designed running, stretching, and weight lifting programs, plus use of the Cybex II isokinetic dynamometer to test and rehabilitate muscle imbalances.	Ongoing	Incidence of hamstring strain	School records
Jackson	Environmental	Use of prophylactic knee brace on both knees vs. non-use	Unclear	Incidence of major knee injuries Effect of risk factors on incidence Effect of braces on injury incidence severity	Doctor diagnosis (team physician), sport association or team records

Table 3: Football Study Intervention (*continued*)

First Author	Intervention Type	Details of Intervention	Frequency Duration	Primary Outcome measure	Outcome Collection Method
Keene	Environmental	University of Wisconsin football field: Natural grass (1960-68) vs. Tartan Turf (1967-73)	Unclear	Number of injuries by type of injury Major injuries	Doctor diagnosis, self report-questionnaire
Rovere	Environmental	Personal protective equipment worn by participant: Anderson Knee Stabler brace (used by all players on the team during practices and games 1983-1985). From 1981-1982, no players wore knee braces.	Unclear	Incidence of knee injuries/100 players Types of injuries	Doctor diagnosis (author orthopaedic surgeon or resident in orthopaedic surgery), school records
Torg (1971)	Regulatory	Rule changes modifying the use of the head in playing techniques: No striking with the top of the helmet, no spearing, and no deliberate use of the helmet to ram an opponent.	Unclear	Head & neck injury registry data	Surveillance system
Torg (1973)	Environmental	Personal protective equipment worn by participant: In both leagues, players had been wearing conventional football cleats. The rules were then changed, requiring players to wear soccer-type shoes.	Unclear	Public league knee injuries Catholic league knee injuries	Doctor diagnosis (orthopaedic surgeon)
Torg (1979)	Environmental	In both leagues, players had been wearing conventional football cleats. The rules were then changed requiring players to wear soccer-type shoes.	Unclear	Public league knee injury rate Catholic league knee injury rate Catholic league ankle injury rate	Doctor diagnosis (orthopaedic surgeon)

Table 4: Football Study Results

First Author	Intervention Group	Results per group	*p-value*	Conclusion
Kaufman	**Group 1** MORA (n=21) **Group 2** Conventional (*n* = 19)	Mean severity score=5.44 Mean injuries=1.43 Mean severity score=4.70 Mean injuries=1.79	$p < 0.05$	Players with MORA had significantly fewer severe injuries than those with the conventional mouthpiece. There is no significant difference between the groups on the number of injuries.
Kraus (1970)	**Group 1** Helmet (*n* = 222) **Group 2** No helmet (*n* = 488)	Rate of concussion/100 games=0.9% Rate of concussion/100 games=3.5%.	$p = 0.048$	The risk of head concussion was about 3 1/2 times greater for nonhelmeted than for helmeted exposures.
Kraus (1971)	**Group 1** High quality officials **Group 2** Lower quality officials	73 injuries / 391 games 59 injuries / 342 games	$p = 0.02$	There was no significant difference in overall injury rates (18.7% experimental vs. 19.3% control). There was also no significant difference in serious injury rates (8.4% experimental vs. 7.3 % control, $p = 0.36$).
Quillian	**Group 1** Braced (659 hours) **Group 2** Non-braced (1996 hours)	1 knee injury per 659 contact hours 0 MCL injuries 13 knee injuries per 1996 contact hours 6 MCL injuries	$p < 0.01$	Players wearing knee braces sustained fewer and less significant injuries than players who did not wear knee braces.
Sitler	**Group 1** Braced *n* = 16/691 Braced *n* = 12/691 **Group 2** Not braced *n* = 37/905 Not braced *n* = 25/905	Knee injury rate/1000 exposures: Braced = 1.50, Non-braced = 3.40.	$p = 0.005$	There is a significant reduction in the frequency of knee injuries with use of prophylactic knee braces, both in the total number of subjects injured and total number of MCL injuries. However, this reduction of injury frequency was dependent on player position.
Stevenson	**Group 1** Tartan turf **Group 2** Grass	68 injuries, corresponding to 15.9 / 100 players 38 injuries, corresponding to 9.5 / 100 players	$p < 0.05$	It was found that significantly more injuries occur on Tartan turf than on natural grass. However, there were no significant differences in the number of major injuries on Tartan turf vs. grass. A number of minor injuries reported were abrasions.

Table 4: Football Study Results (*continued*)

First Author	Intervention Group	Results per group	*p-value*	Conclusion
Cameron	**Group 1** Swivel shoes Swivel shoes **Group 2** Cleated shoes Cleated shoes **Group 3** Heel plate shoes Heel plate shoes **Group 4** Soccer shoes Soccer shoes	n = 10 injuries / 466 players n = 14 injuries / 466 players n = 162 injuries / 2055 players n = 194 injuries / 2055 players n = 3 injuries / 52 players n = 4 injuries / 52 players n = 14 injuries / 266 players n = 15 injuries / 266 players		Percentage of players with knee injuries: Swivel shoes = 2.14% Cleated = 7.88% Heel plate = 5.77% Soccer = 5.29%. No sig. test reported. Swivel shoes had the lowest incidence of knee injury. Total number with outcome = 189 knee injuries.
Grace	**Group 1** Single-hinged brace Knee brace, 2nd season **Group 2** No brace No braces, 2nd season	37 injuries/247 players 11 injuries/ 250 players	$p < 0.001$	Results show that athletes with single-hinged braces had a knee injury 3.7x more often than those without braces. Increase in number of knee injuries in braced group were seen especially for mild to moderate injuries. There was also a great increase in ankle and foot injuries in braced athletes.
Adkison	**Group 1** Grass (424) **Group 2** Astroturf (183) **Group 3** Tartan turf (53)	218 injuries; injury rate = 0.51 injuries / game 116 injuries; injury rate = 0.63 injuries / game 15 injuries; injury rate = 0.28 injuries / game	$p < 0.05$ Stat sig. – $p < 0.05$ and $p < 0.01$ (Tartan vs. astro)	Astro turf fields had significantly higher injury rates than did grass or tartan turf. Grass had an intermediate injury rate and tartan turf had the lowest injury rate.
Albright	Braced players vs. non-braced players	MCL injury rate for braced players is 0.065 vs. 0.077 for unbraced players. During a game, MCL injury rate for braced players is 0.312 vs. 0.214 in unbraced players. During practice, it is 0.045 vs. 0.034, n.s.	Not reported	MCL injury rate for braced players is 0.065 vs. 0.077 for unbraced players. Non significant.
Andrish	**Group 1** Neck strap (93) **Group 2** No strap (42)	10.8% of strapped athletes suffered a neck injury. 26.2% of non-strapped athletes received neck injuries.	Not reported	The following trend was apparent: previous neck injury increases the likelihood of another injury (5 times more than one who has never had a neck sprain). The effectiveness of the neck strap has been suggested.

Table 4: Football Study Results (*continued*)

First Author	Intervention Group	Results per group	*p-value*	Conclusion
Bixler	**Group 1** With intervention (*n* = 28 3rd q) **Group 2** Without intervention (*n* = 24 3rd q)	Mean number of injuries in 3rd per game: Intervention = 0.3, control = 0.8, not significant. These mean scores do not seem correct.	$p < 0.05$	Intervention teams sustained significantly fewer 3rd quarter sprains and strains per game. This suggests an association between post half-time warm-up and stretching and injuries sustained in the 3rd quarter.
Blyth	The following data were collected as determinants of effectiveness of the coach (in injury prevention): age, playing experience, coaching experience, and education.	Data showed that coaches' age, college playing experience, coaching experience and advanced degrees have important relationship to injury in the team. Injury rates are higher in teams whose coach is younger than 30 years, only have high school playing experience, etc. Coaches over 45, with high school and college playing experience, etc., tend to have teams with lower injury rates.	Not reported	Coaches with a specific type of background and training are associated with a low injury rate. Important considerations of the coach's background are age, college playing experience, coaching experience and advanced degrees.
Blyth	Data was collected from players' description of injuries. The following equipment was studied: helmets, shoulder pads, types of cleats and field surface.	Results summarized in conclusion.	$p < 0.05$	The injury rate was lower for players wearing helmets in poor conditions than new helmets. This study also showed that properly fitted shoulder pads do not protect the players (as shown in past studies). It was also found that players wearing new pads had a higher injury rate than those wearing used pads (an explanation that football players who wear new pads are also the ones who are exposed to more contact in practice in games). There is a higher incidence of injury to players wearing soccer shoes than those wearing regular football cleats. However, conditions of the playing fields are influential since it was found that rate of knee and ankle injuries was reduced when soccer shoes were worn on well-maintained fields.
Bramwell	**Group 1** Synthetic turf (*n* = 80) **Group 2** Natural grass (*n* = 148)	Injury rates=0.73 Injury rates=0.52	$p < 0.01$	Injury rates on grass fields is much less than on synthetic fields. Injury rates for dry artificial turf is much higher than all other surfaces and conditions. Total number with outcome = 132 injuries.
Brodersen	**Group 1** Knee brace **Group 2** No brace	Frequency of knee injury: 132 / 503 Frequency of knee injury: n = 121 / 273	$p < 0.001$	26% of braced group suffered injury vs. 44% of non-braced group – significant difference at $p < 0.001$.

Table 4: Football Study Results (*continued*)

First Author	Intervention Group	Results per group	*p-value*	Conclusion
Deppen	**Group 1** Braced (n = 21640 exposures) Braced (n = 21640 exposures) **Group 2** Non-braced (19484 exposures) Non-braced (19484 exposures)	23 knee injuries 26 knee injuries	$p < 0.05$	No difference in injury rates occurred for those who did and did not wear braces. In addition, there was no statistically significant difference between contact and non-contact mechanisms of injury between the braced and non-braced groups.
Gorse	**Group 1** Turf (71/205) **Group 2** Turf and Swim (42/314)	35% developed a conditioning injury vs. 13% of the turf and swim group developed a conditioning injury	$p < 0.0001$	There are significantly fewer pre-season conditioning injuries in the turf and swim group than in the turf group. Running and swimming may decrease the number of overuse injuries associated with repetitive running on artificial turf.
Hewson	**Group 1** Braced (n = 28191) **Group 2** No brace (n = 29293)	48 injuries 54 injuries	Not reported	Total number of knee injuries for both groups are very similar. Total MCL injuries show no statistical difference: 33 for braced, 41 for non-braced. 15 tertiary MCL injuries occurred in the non-braced group, while 8 occurred in the braced group. Prophylactic knee bracing does not improve knee injury prevention.

Table 4: Football Study Results (*continued*)

First Author	Intervention Group	Results per group	*p-value*	Conclusion
Lambson	**Group 1** (*n* = 2231 players) Edge, longer irregular cleats at peripheral margin with smaller pointed cleats interiorly **Group 2** (*n* = 832 players) Flat cleats (soccer-type shoe) **Group 3** (*n* = 46 players) Screw-in (7) cleats **Group 4** (*n* = 10 players) 4) Pivot disk	ACL injuries: Edge group=0.017 Non-edge group (combination of three remaining shoe designs since they did not show significantly torsional resistance on turf or grass) = 0.0005.	$p = 0.0062$	The edge cleat group had a much higher ACL injury rate (0.017%) than the other three shoe types combined (0.005%). The edge shoe design also produced significantly higher torsional resistance than the other shoe types on artificial turf and natural grass.
Larson	**Group 1** Grass (prepatellar) **Group 2** Synthetic (prepatellar) **Group 3** Grass (olecranon) **Group 4** Synthetic (olecranon)	28 cases of prepatellar bursitis occurred; 5 (17.9%) cases on grass, and 23 (82.1%) cases on synthetic turf. Olecranon bursitis occurred 15 times; 2 (12.5%) cases on grass, and 14 (87.5%) on synthetic turf.	Not reported	There is an apparent increase in the incidence of prepatellar and olecranon bursitis among football players since the installation of an artificial turf.

Table 4: Football Study Results (*continued*)

First Author	Intervention Group	Results per group	*p-value*	Conclusion
Mueller	Head injuries by make of helmet Injury rates by shoulder pad type Knee and ankle injuries by cleat-type Knee and ankle injuries by field type	Highest number of injuries with Riddell TK2 (75 injuries out of 6251 players) Highest number of injuries with Rawlings CP (62 injuries out of 5742) Highest number of injuries with short cleat type (618 out of 6751) Highest number of injuries with regular, unsurfaced fields	$p < 0.05$	This study has led to evidence that: (1) there are specific brand names of football equipment that are associated with significantly higher injury rates; (2) knee and ankle injuries are reduced when players wear soccer type shoes and when fields are properly maintained; (3) a limited-contact program during practice will reduce injuries; and (4) full recovery is important to prevent re-injury upon return to play.
Powell	**Group 1** Grass (total 1520 team games) **Group 2** Astro Turf (1450) **Group 3** Tartan Turf (146) **Group 4** Super Turf (190)	6 year average of incidence of injury per team game All reported cases = 1.78, sig. cases = 0.83, major cases = 0.38 All reported cases = 1.94, sig. cases = 0.95, major cases = 0.49 All reported cases = 2.36, sig. cases = 1.06, major cases = 0.52 All reported cases = 1.88, sig. cases = 1.06, major cases 0.46	Not reported	Over the six seasons of NFL, the incidence of injury per game was higher for Astroturf than grass. Tartan Turf no longer exists and there are fewer than 20 games a year played on Super Turf.
Robey	**Group 1**—Suspension helmets Good condition Poor condition **Group 2**—Combined-padded suspension helmets Good condition Poor condition **Group 3**—Padded helmets Good condition Poor condition	Not reported	Not reported	There is no difference in injury rate for suspension helmets by fit or condition as long as the suspension is adjusted correctly. Combined suspension/padded helmets have higher injury rates if there is improper suspension or if the helmet is too small.

Table 4: Football Study Results (*continued*)

First Author	Intervention Group	Results per group	*p-value*	Conclusion
Rowe	**Group 1** HC – high shoe with conventional heel cleats (349) **Group 2** HD – high shoe with disk heel (190) **Group 3** LC - low shoe with conventional heel cleats (278) **Group 4** LD - low shoe with disk heel	Incidence of knee and ankle injuries in terms of percentage of participants: Knee: 7.2 Ankle 4.6 Knee: 7.4 Ankle 5.8 Knee 10.4 Ankle 8.3 Knee 6.6 Ankle 5.8		The LC group had the highest injury rates and percentage. The LD group had the lowest indicating that it is the safest shoe-cleat equipment combination.
Schriner	**Group 1** Braced: 236 players **Group 2** Non-Braced: 314 athletes	1984: 0 injuries from lateral forces 2 injuries from medial-posterior forces and hyperextension 1985: 6 lateral forces 2 medial-posterior forces and hyperextension 1984: 45 lateral forces 12 medial-posterior forces and hyperextension 1985: 25 lateral forces 3 medial-posterior forces and hyperextension		The difference in percentage of players injured from lateral forces was statistically significant, $p < 0.01$. The percentage of injuries in the medial posterior forces was not significant.
Tietz	**Group 1**—Braced **Group 2**--No brace	252 injuries/2297 players 258 injuries/4010 players	$p < 0.001$	Injury rate for 1984=11.0% brace, 6.0% no brace. In 1985, 9.4% brace, 6.4% no brace. Overall, players who wore knee braces had significantly more injuries than players who did not wear braces. There was no difference in the severity of the injuries in the two groups.
Zemper (1994)	Ten helmet models were studied with a total of 8,312 used and 618,596 player exposures.	From the total of 245 concussions observed (out of 244.99 concussions expected), two models, the Bike Air Power and Bike Pro Air showed the highest number of concussions with 115 and 81 respectively.	$p < 0.05$	The chi square test was significant, indicating significantly different concussion rates. An analysis of residuals shows Bike Air Power and Pro Air to be associated with a greater concussion rate.

Table 4: Football Study Results (*continued*)

First Author	Intervention Group	Results per group	*p-value*	Conclusion
Zemper (1990)	**Group 1** Braced (1744) **Group 2** Unbraced (4485)	185 observed total knee injuries (145.9 expected) 336 observed total knee injuries (375.1 expected)	$p < 0.05$	Players wearing prophylactic knee braces experienced a significantly greater incidence of knee injuries than those who did not wear braces. There was no significant difference in incidence of MCL injuries between braced and non-braced players.
Hansen	**Group 1** No brace (329 players) **Group 2** Brace (148 players)	35 injuries 7 injuries	Not reported	There was an 11% rate of injury for those without braces vs. 5% injury for those with braces; no statistical testing done. 1.4% of those with brace required surgery to repair collateral ligament injury, vs. 5.2% of those without brace.
Powell	**Group 1** grass—504/2572 grass—342/2572 **Group 2** Astroturf--577/2604 Astroturf--395/2604	Injury rates per team game: 0.20 knee sprains, 0.13 MCL sprains, 0.02 ACL 0.22 knee sprains, 0.15 MCL sprains, 0.02 ACL	$p = 0.04$	There is a statistically significant difference between the higher Astro Turf injury rates for knee sprains. When knee injuries are separated into ACL and MCL sprains, only the ACL sprains show a statistically significantly higher injury rate for Astro Turf.
Rovere	**Group 1** Taped ; 233 players Taped **Group 2** Stabilizer; 127 players Stabilizer	190 injuries/233 players 23 reinjury 34 injuries/127 players 1 reinjury	$p = 0.003$	The results show that players wearing stabilizers had half of the risk of injury of the players wearing tapes. This result was statistically significant. The rates of injury differed by position.
Shaw	**Group 1** Braced-McDavid Knee Guard (MKG) **Group 2** Not Braced	1983 – 19 knee injuries, no braced players at this point. 1984 – 17 knee injuries, no breakdown by braced vs. not braced 1985 – 9 injuries, 6 braced vs. 3 not braced. 1986 – 6 injuries, no breakdown	Not reported	There are fewer injuries to athletes wearing the MKG than those not wearing the knee guard. In addition, there are fewer days lost to injury (i.e., 1984 statistics showed 5 days lost to MKG wearers vs. 90 days lost to non-wearers).

Table 4: Football Study Results (*continued*)

First Author	Intervention Group	Results per group	*p-value*	Conclusion
Fine	Data was collected from the National Football Head and Neck Injury Registry and included injury that: 1) required hospitalization for more than 72 hours 2) required surgical intervention 3) involved a fracture resulted in paralysis or death	Summarized in conclusion	Not reported	Cervical spine injuries declined from ~100 per year in 1975-76 to ~55 per year from 1978- 87. The 1976 NCAA rule banning spearing has resulted in dramatic decrease of fractures, subluxations, and dislocations of the cervical spine. No summary stat reported for significance test.
Mueller (1987)	**Group 1** 1945-54 1945-54 **Group 2** 1955-64 1955-64 **Group 3** 1965-1974 1965-74 **Group 4** 1975-84 1975-84	 87 head fatalities 32 cervical spine fatalities 115 head fatalities 23 cervical spine fatalities 37 other fatalities 162 head fatalities 42 cervical spine fatalities 19 other fatalities 69 head fatalities 14 cervical spine fatalities 9 other fatalities	Not reported	The decade with the highest incidence of head and cervical spine fatalities was 1965-74, while a dramatic reduction was seen from 1975-84. This was largely due to the 1976 rule that prohibits initial contact with the helmet or facemask when tackling or blocking.

Table 4: Football Study Results (*continued*)

First Author	Intervention Group	Results per group	*p-value*	Conclusion
Mueller (1986)	**Group 1** 1945 – 54 1945 – 54 **Group 2** 1955 – 64 1955 – 64 **Group 3** 1965 – 74 1965 – 74 **Group 4** 1975 – 84 1975 – 84	 87 head fatalities by decade 32 cervical spine fatalities 115 head fatalities by decade 23 cervical spine fatalities 162 head fatalities by decade 42 cervical spine fatalities 69 head fatalities by decade 14 cervical spine fatalities	$p < 0.05$	The decade with the highest incidence of head and cervical spine fatalities was 1965-74, while a dramatic reduction was seen from 1975-84. This was largely due to the 1976 rule that prohibits initial contact with the helmet or face mask when tackling or blocking.
Torg	Not reported	Not reported	Not reported	There was an increasing incidence of intracranial hemorrhage due to advent of widespread CAT scans rather than increasing number. Craniocerebral death is constant over time. There was a dramatic decrease in number of cervical spine injuries.
Cahill	**Group 1** No conditioning (68) No conditioning (15.2) **Group 2** Supervised conditioning (41) Supervised conditioning (5.9) **Group 3** Less supervised conditioning (39) Less supervised conditioning (2.3)	 Injury rate = 68 (per 1000 athletes) Injury rate = 40 Injury rate = 40	Not reported	There was a decrease in injury rate for the supervised conditioning groups, as well as fewer days lost. The pre-season conditioning program was also effective in reducing the number of early season knee injuries.

Table 4: Football Study Results (*continued*)

First Author	Intervention Group	Results per group	*p-value*	Conclusion
Cahill	**Group 1** No conditioning 1969-72 (1254) No conditioning (19) **Group 2** Conditioning 1973-76 (1227) Conditioning (7)		$p < 0.01$	Injury incidence: pre-season conditioning decreases early season knee injuries, decreases the total number of knee injuries throughout the season, and decreases the severity of those injuries that occur.
Davis	**Group 1** Pre-intervention (21) Pre-intervention **Group 2** Post-intervention (25) Intervention-year 1 **Group 3** 2) Intervention year 2		Not reported	Both competition and injury data support the effectiveness of the sport psychology program. After winning only 16% of 113 previous games, the TCU team had their best season in 20 years with a record of 8 wins and 4 losses. Prior to stress management, there were 18 severe injuries while during two years of intervention, the rate dropped to 12 and 13 respectively.
Heiser	**Group 1** 1973 – 77 (n = 534) **Group 2** 1978 – 82 (n = 564)	Suffered 4 hamstring strains at 7.7%. 13/41 suffered recurrences (31.7%)/ Suffered only 6 hamstring strains (1.1%). No recurrences occurred (P < 0.1).	$p = 0.005$	The group that received supervised winter running programs and staff-designed stretching, running, and weight-lifting programs combined with treatment of injuries with isokinetic rehabilitation showed fewer hamstring injuries and no recurrences.
Jackson-	Risk factors for knee injuries were identified as: Practices, games, and playing surfaces Experience Position use of knee braces	--A player is 87 times more likely to be injured in a game than in a practice and the risk of injury on grass is 1.49 times that on synthetic turf. --Less experienced players have relative risk of 5.8 to injuries than more experienced players. --Overall, offense had slightly higher risk than defense. --Knee braces have been shown to significantly lower injury risks.	$p < 0.001$	2 sample tests were taken for binomial proportions. For overall knee injuries, no difference was seen in 2 time periods – a mean of 17.3 knee injuries/ year. For major knee injuries, the percentage dropped from 31.7% (77-83) to 14.7% (84-88), highly significant $p < 0.001$.

Table 4: Football Study Results (*continued*)

First Author	Intervention Group	Results per group	*p-value*	Conclusion
Keene	Players who completed the survey were categorized as: Competed on grass only (1969) Practiced on grass surface but competed on Tartan (1967-68) Competed on Tartan only (1969-73)	number of injuries for scrape: grass = 50, tartan = 142, $p < 0.001$ number of injuries for sprain: grass = 86, tartan = 56 , $p < 0.001$ number of injuries for torn ligament: grass = 30, tartan = 19 , $p < 0.05$ number of injuries for swollen joint: grass = 38, tartan = 36 , not significant. number of injuries for broken bone: grass = 25, tartan = 18 , not significant number of injuries for swollen joint: grass = 13, tartan = 6 , $p < 0.05$		The number of injuries on each playing field were not significantly different, but the type and severity of injuries were significantly different. More serious sprains and torn ligaments occurred more often on grass than on Tartan Turf. More scrapes (minor injuries) occurred on Tartan Turf than on grass.
Rovere	**Group 1**: Not braced **Group 2**: Braced	24 injuries/368 players 29 injuries/374 players	Not reported	The number of injuries/100 players of ACL knee injuries for no brace was 4.0, vs. 4.8 with brace. For MCL grade 1, the figures were 6.1 vs. 7.5, respectively. Therefore, there was a greater overall injury rate and MCL injury rate during the brace period.
Torg (1971)	**Group 1** 1971-75 seasons **Group 2** 1975 season **Group 3** 1976 season **Group 4** 1977 season	72 head and neck injuries 58 Craniocerebral deaths 259 cervical spine and spinal cord injuries 99 permanent quadriplegias 21 head and neck injuries 13 Craniocerebral deaths 92 cervical spine and spinal cord injuries 27 permanent quadriplegias 20 head and neck injuries 15 Craniocerebral deaths 115 cervical spine and spinal cord injuries 35 permanent quadriplegias 10 head and neck injuries 6 Craniocerebral deaths 84 cervical spine and spinal cord injuries 19 permanent quadriplegias	Not reported	The apparent decrease in serious head injuries has been attributed to the protective capabilities of the helmet/face mask unit. However, the number of cervical spine injuries has been shown to increase. This may be due to the fact that the helmet has been used as a battering ram, putting the cervical spine at risk of injury.

Table 4: Football Study Results (*continued*)

First Author	Intervention Group	Results per group	*p-value*	Conclusion
Torg (1973)	**Group 1** 1968 conventional (*n* = 51/594) 1969 conventional (*n* = 93/904) **Group 2** 1969 soccer (*n* = 24/594) 1970 soccer (*n* = 38/704) **Group 3** 1970 soccer (*n* = 30/594) 1971 soccer (*n* = 35/704) **Group 4** (1) 1971 soccer (*n* = 29/594)	For year 1968 – injury rate = 0.33, number of class III & IV injuries = 31, number of surgical knees = 242. For 1969 – injury rate = 0.14, number of class III & IV injuries = 7, number of surgical knees = 4 For 1970, -- injury rate = 0.17, number of class III & IV injuries = 9, number of surgical knees = 7. For 1971 -- injury rate = 0.17, number of class III & IV injuries = 8, number of surgical knees = 2.	Not reported	Results of the study have shown a significant reduction in both the incidence and severity of knee injuries after players began wearing the soccer-type shoe.
Torg (1979)	**Group 1** 1968 conventional 1969 conventional **Group 2** 1969 soccer 1970 soccer **Group 3** (1) 1970 soccer	 n = 51 / 594 n = 93 / 705 n = 24 / 594 n = 38 / 705 n = 30 / 704		Results of the study have shown a significant reduction in both the incidence and severity of knee injuries after players began wearing the soccer-type shoe. The use of conventional football cleats was strongly discouraged and it was recommended that only shoes meeting the following criteria should be used: Synthetic molded sole; Minimum of 14 cleats per shoe; Minimum cleat tip diameter of ½ inch; Maximum cleat length of 3/8 inch.

IX. REVIEW OF ICE HOCKEY INJURY PREVENTION STRATEGIES

Canada is the birthplace of ice hockey. From the backyard rink to the National Hockey League, players and fans have made ice hockey one of Canada's most popular sports. In the Canadian Hockey Association, organized sport begins with children as young as six and extends to the many 'old timers' who still participate. Although traditionally a male-dominated sport, hockey has had more interest from females in recent years, and will likely see an upsurge in enrollment with women's hockey now recognized as an Olympic sport.

A fast-paced game, the players of each team risk contact with a hockey stick or the puck, the surrounding boards, goal posts or ice surface on which they play, or other players. In many leagues, contact with other players is often deliberate and frequent and thus, many describe the game as violent. Regardless of the style of play, injuries are not unusual and are often serious.

An analysis of 1997 CHIRPP (Canadian Hospitals Injury Reporting and Prevention Program) data for Eastern Ontario and British Columbia found that hockey injuries ranked third, after basketball and soccer, in emergency room visits related to sport and recreational activities. In a proxy measure for injury severity, hockey ranked fourth for frequency of hospitalization. Hockey-related injury accounted for 8% of children and youth presenting at emergency rooms that were subsequently admitted. When examining hockey-related injuries, the pediatric emergency room physician attends most often to males between 10 and 14 years-of-age. Little literature, however, has focused on this group.

In an international review of English literature published in 1996, Montelpare et al (Soma et al., 1996) reported that it is difficult to ascertain valid and reliable indices of hockey injury regardless of player age. Limiting factors are the recorder's lack of compliance and use of standardized reporting, as well as the existence of different rules and regulations between different levels of the sport. Over the last few decades, the sport has also seen changes in the use of protective equipment and style of play making it a challenge to generalize across the sport. In addition, the definition of injury is often inconsistent in studies reviewed. Daly and colleagues (1990) echoed these points, adding that player age, size and skill level may also influence injury potential and make comparison between studies more challenging.

In an attempt to offer a summary for injury incidence, Montelpare et al. report that rates are dependent upon the sample and the league from which data were collected, but that in general injury rates from hockey are low relative to the number of participants. It must be kept in mind, however that minor injury may not be reported and that legislation on the use of protective equipment and the enforcement of rule changes may have reduced incidence in more recent years. Injury rates in the studies reviewed ranged from 1.4 injuries/1000 athlete exposures during an elite team's practices to 119 injuries/1000 athlete exposures for university athletes during game play. In the articles reviewed, contusions and sprains were the top injury types, with lacerations also frequently reported. Although many epidemiological studies report the head and face as the body part most often injured, Montelpare et al. reported that the studies in their review reported injuries to the knee, followed by the shoulder, hands and ankles as most frequent.

In a review of literature completed between 1969 and 1989, Daly (1990) reported that the most common injuries to the upper extremity tend to be shoulder dislocations and fractures of the hand. In the lower extremities, strains of the hip adductor, tears of knee ligaments, and contusions of the thigh are frequently seen injuries. Many of these injuries are attributed to contact with other players, specifically body checking, as well as the skating stride. The hockey stick is mentioned as the primary mechanism of "game-keepers" thumb (detachment of the ligaments of the thumb), one of the more common upper extremity injuries and caused by falling with a stick in hand. According to Montelpare, the studies suggested that the hockey stick was the most frequently reported mechanism of injury.

Although at one time injuries to the eye were quite common, there has been a dramatic decrease in the number reported in more recent years. In a review of eye injury, Jones (1989) explains the changes in the sport influenced by Pashby's publications such as the widespread use of head and eye protection. Reynen and Clancy (1994) also recognize the significant contribution of Pashby in their investigation of cervical spine injury in the sport. The incidence of these injuries rose with the use of head and eye protection. The authors consider that the style of play used by a helmeted player may increase the likelihood of cervical injury.

The type of play is often implicated as a factor in injury incidence. Roy et al. (1989) reported that injuries occurred four times as often in a contact league when compared to a non-contact league. In addition, all of the studies found that injuries occurred more often during games than practices. It was noted however, that the type of play often associated with injury is not always present in practice sessions.

Results

A search of computerized databases identified fifty-eight potentially relevant articles. Twenty-two were Canadian and nine were written in a language other than English: seven French (four Canadian), one Dutch and one Swedish. Eight additional potentially relevant English language articles were identified through hand searching, four of which were Canadian.

Of the total of 65 identified, eight articles met relevance criteria and are included for review. One of the eight was identified through hand searching. Over 70% of the non-relevant articles were excluded because of the lack of a control group. All relevant articles were published in English; 5 were Canadian and three were from the US. The earliest piece, published in 1970 by Kraus et al., aimed to determine how mandatory use of a vinyl helmet might affect head injury incidence. In 1979, Downs assessed the value of facial protection by comparing teams with and without mandatory protection rules. In 1977, 1979 and 1985, Tom Pashby and colleagues focused on eye injury and the factors that would improve its significant presence in the sport. More recent work in 1996 and 1997 by Watson, investigated the influence of introducing penalties for checking from behind and ice surface size on injury outcome. Roberts (1996) assessed implementation of fair play rules on the rate, type and severity of injury in ice hockey.

Except for Watson's (1997) work on ice-surface size, authors evaluated the effectiveness of a regulatory approach to injury reduction and all targeted participants playing organized competitive hockey as opposed to parents, coaches or officials. Five of the articles were type II pre-post designs, whereby the same league of players was monitored for injury in subsequent seasons with and without an intervention were compared. One was a prospective cohort and the other was a nonequivalent control group design. Four of the studies were determined to be of poor quality while four were moderate quality. The average quality score for the pre-post designs was 6.4/14. The cohort scored 11/17 and the nonequivalent study had a score of 9/14.

Six of the eight studies involved regular season play, one involved tournament players and one involved players participating in an intramural season. Although only specifically reported by Roberts et al. (1996), participants in all studies are assumed to have been exclusively male. Three of the studies specifically studied college and university-aged players; the remaining four included all players under twenty.

Study outcomes amongst the eight articles reviewed were similar. All authors assessed injury incidence; Pashby, however, also specifically focused on injury severity and the US studies focused on neurotrauma. Watson also documented penalties in both his 1996 and 1997 investigations.

Environmental Interventions

EQUIPMENT

Prior to 1979, the American Amateur Hockey Association had introduced mandatory facial protection for its players. Organizers of intercollegiate hockey at Michigan State University, however, had not adopted this rule. Although not specifically evaluating the effectiveness of a rule mandating the use of facial protection, Down et al. (1979) evaluated the effectiveness of facial protection by comparing injury rates in players from a team in each of the organizations. The non-protected group had a higher percentage (52%) of injury than the protected group (21%). Michigan State players had 1 injury per 8.4 playing hours where the Amateur team players had 1 injury per 38.04 hours. The authors do not define the classification of injury, nor is the reader aware of how the data was collected. Authors explain that the differences in injury rates between the two groups could not be attributed to differing levels of roughness in play. In support of their argument, it is reported that except for puck injuries, there was no significant differences found between the groups with respect to the injury mechanism such as the stick, puck, skate and player contact injuries.

Although helmet use is now mandatory in all organized ice hockey, one early study investigating the effect of helmet use in hockey met relevance criteria. In the 1968 season, non-helmeted players in an intramural league were assessed for injuries and compared to the next season of players who all wore a soft and flexible vinyl foam helmet. The injury data source was the University Health Service's injury reporting form, and data on the number of games and participants were obtained from the University's "Ice Hockey Score Card". There was no detail on how this information was collected or what constituted an "injury". There was a statistically significant difference between the two seasons with respect the number of injury-free games. During the control period, there were 31 games where an injury occurred out of the 192 played. This injury rate of 16.1% is much higher than the 8.8% of the intervention period (21/238). The significant difference remained when investigating specifically those games where a head injury occurred.

PLAYING SURFACE

Prompted by suspicions from the medical community, Watson and colleagues (1997) conducted a cohort investigation of the Ontario Hockey League (OHL) and found that there was a highly significant association between ice surface size and game injury rate. As the size of the ice surface increased; the rate of injury decreased. This, however, was not the case when neurotrauma injury was specifically examined. There was also no association between ice size and the number of penalties regardless of whether they were aggressive or non-aggressive. Injuries are often closely linked with illegal behavior such as checking from behind, as indicated in Watson's previous work (1997) included in this review. Injury data was procured for all sixteen teams through injury forms completed by each team's trainers/therapist, as well as from reports kept by the International Hockey Centre of Excellence. Penalty information was taken from OHL official game sheets. It is assumed that increased player size and speed will increase player-to-player and player-to-equipment contact, and that these events would be reduced in an arena greater in size than the "standard" 200 x 85 ft.

Regulatory Interventions

Roberts et al. (1996) introduced "fair play" rules in some of the 31 games played by 16 teams participating in a Junior level tournament. Under these rules, teams were assigned additional points for playing without excessive penalties and players with more than five penalties in one game were given a game suspension. In a "regular" rules game, points were only awarded for a simple win, loss or tie regardless of penalty calls. After tracking injuries reported to the athletic trainer and reviewing penalties from score sheets, it was determined that the rate of notable injuries (concussion and facial laceration of moderate level of severity and above) during regular rule games was nearly five times that of the rate during fair play games. The average number of penalties per game was 13 and 7.1 respectively.

The effect of a change in rules on injury outcome was also seen after the Ontario University Athletic Association (OCUAA) disallowed checking from behind (CFB). The safety rule introduced in the 1989-1990 season allowed referee discretion to assess either a minor or major penalty for checking from behind except where an injury resulted, in which an automatic major penalty and game expulsion was required. Watson and colleagues (1996) investigated the effect of this new rule on injuries reported to an athletic therapist or physician as a result of a game incident by comparing the three seasons prior to and three seasons after the rule induction. An examination of injuries and penalty records for three teams that had complete information for the six years under investigation found a significant increase in CFB minor penalties, and a decrease in head/neck and back injury after rule induction. CFB minor penalties increased from a rate of 0.07 penalties/game to 0.29/game. The head and neck injury rate decreased from 6.16/1000 player games to 4.49 and back injury rate from 4.98 to 4.49. There was an increase in the rate of shoulder injuries, however, from 16.11/1000 player games to 19.38. Interestingly, there was no significant association between the new rule and penalties assigned for either body contact or stick-related infractions.

Another area of focus has been player's protective equipment. Both hockey helmets and facial protectors are now mandatory in Canadian Hockey Federation and the International Ice Hockey Federation. Three articles by Tom Pashby included in this review follow the adoption of facial protection as well as the rule against high-sticking (raising the stick above the shoulder), a frequent contributor to eye injury.

Over the years, as the Canadian Hockey Association established standards for facial protection and helmet use, Pashby collected data on eye injures among Canadian amateur hockey players from members of the Canadian Ophthalmological Society (COS). Between 1972 and 1975, Pashby and co-workers found that fifteen percent of the player sample were rendered legally blind as a result of an on ice incident (Pashby et al., 1975). This report led to the requirement of mandatory use of a helmet with a facemask in the 1976-77 season. In addition, the hockey stick and puck were reported as the top two causes of eye injury. Consequently, high-sticking regulations were strictly enforced within the sport.

A follow-up study was done two years after the original work (Pashby, 1977) to determine if face protectors and the new high-sticking rules were having an effect on eye injuries in the sport. Injuries reported to the COS in the year leading up to and following the rule change were compared. Eye injuries declined from 253 to 90 and the proportion that resulted in blindness decreased from one in seven to one in eight. Pashby noted that there appeared to have been a shift in injuries from younger to older players. In the 1977-78 season there were 51 eye injuries reported to the COS and in the 1978-79 season, there were 42 reported incidents (Pashby 1979). Thus, eye injury incidence continued to decline after the implementation of the new rules and the facemask's increasing popularity in upper level sport. The only exception noted was that the rate of a specific type of injury, the "ruptured globe" did not change. Blinding injuries were also still occurring with hockey. Pashby suggests that correct helmet fit could also be a factor in injury development.

In 1981, a rule regarding mandatory use of a face protector for all minor hockey players was introduced. Pashby reported on the effectiveness of this change, in combination with the implementation of other rule changes, by comparing data collected in the 1984-85 season to data collected previously. There were 124 players with an eye injury following the rule change, a significant decline from the incidence reported in 1974. Only 11% of those players injured were classified as legally blinded in 1984-1986, compared to 19% before high-sticking rules and mandatory facial protection were introduced. Blindness did not occur in any masked player. The average age of injured players increased from 14 years in the 1974-75 season to 24 years in the latter. Unlike minor players, older athletes are not mandated to wear facial protection.

Discussion

A multitude of players from young to old, male and increasingly female, are involved in ice hockey and the sport has considerable presence on the world stage. However, only eight articles were identified through an international literature review, many of which focus on injury prevention initiatives already adopted. In addition, the studies included for review do not specifically examine younger age groups, and many lack a measurement of exposure. In addition, sample sizes are small and less rigorous designs are used.

Using a standardized definition of injury and validated data collection methods, similar levels of hockey/styles of play need to be investigated and then compared to their counterparts in order to identify the current state of affairs. This data needs to be broken down by league—pee wee, minor, junior, etc. to guide practice for the injury community, parents and coaches. Exposure in both games and practices must be recorded to provide a reasonable estimate of injury incidence in ice hockey. In addition, there is a lack of studies meeting this review's criteria that investigate equipment currently in use such as mouth and neck guards, pads, and the hockey stick and puck.

Unfortunately, it appears that changing injury incidence in hockey goes beyond rules followed by and equipment used by players. The game of hockey is perceived as violent, accepted as violent and violence may often be encouraged. Perhaps the game of ice hockey and its injuries can be influenced by looking to modify the attitudes and practice of referees, coaches, and fans and by making the consequences of actions that cause injury more severe.

Recommendations

Research

- Obtain child specific injury data;
- Develop and use of a consistent definition of injury in future research studies;
- Studies must employ designs that use matched-control groups and include exposure measures;
- Further research is required to assess injury rates in the contemporary game of hockey which requires helmets and face masks, safety equipment and has significant rule changes;
- Investigate the effect of increased penalty severity for rule infraction;
- Determine if injury rates differ in women's hockey compared to their male counterparts;
- Examine the effect of increasing the safety of environmental targets, for example, by making rink boards impact absorbing;
- Determine the effectiveness of modern equipment including mouthguards, neck-guards, pads etc. at reducing injury severity and rate;
- Explore other measures to reduce contact injuries with objects, e.g., uniform fabric design to reduce sliding speed into boards or developing force absorbing puck materials;
- Explore strategies to change the style of play to be less aggressive;
- Establish the benefit of training and conditioning program to prevent injury;
- Investigate increased training for coaches/officials to recognize hazards and introduced injury prevention best practices as a means of increasing player safety.

Practice

- Develop an injury surveillance/reporting system that is standardized across leagues;
- Ensure adherence to current safety standards and enforcement of them;
- Strict enforcement of current safety standards and rules such as high-sticking and fighting and checking from behind;
- Develop rules of "fair play" in addition to regular rules;
- Head and facial protective equipment should be mandatory for all levels of play. Further the equipment must be properly fitted and of the highest standard;
- Safety equipment should be regularly evaluated and replaced if necessary;

- Ensure coaches are certified and qualified to teach players to be aware of injurious situations, including equipment maintenance.

Policy

- Develop new safety standards such as mandatory facial protection for all players, regardless of league;
- Make correct helmet fit mandatory (snug with straps done up).

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Table 1: Hockey Study Characteristics

First Author	Study Design	Quality Rating	Year of Publication	Country	Study Time Period	Funding
Downs	Non-Equivalent Control Group	Poor (4.5/14)	1979	USA	Post 1976 and pre-publication	Michigan State University (unclear)
Roberts	Non-Equivalent Control Group	Moderate (9/14)	1996	USA	3-day, 31 game tournament in 1994	Not reported
Watson	Prospective cohort	Moderate (11/17)	1997	Canada	1993-94 season	Not reported
Kraus	Type II Pre-post test	Moderate (7/14)	1970	USA	1968 and 1969 intramural seasons	Not reported
Pashby (1977)	Type II Pre-post test	Poor (5/14)	1977	Canada	1974-75 and 1976-77 seasons	Not reported
Pashby (1979)	Type II Pre-post test	Poor (6/14)	1979	Canada	1977-78 and 1978-79 seasons compared with 1974-75 season	Not reported
Pashby (1985)	Type II Pre-post test	Poor (6/14)	1985	Canada	1983-84 season compared with 1974-75 season	Not reported
Watson	Type II Pre-post test	Moderate (8/14)	1996	Canada	3 years before and 3 years after a 1989 rule change	Not reported

Table 2: Hockey Study Design

First Author	Study Aim	Study Setting	Study Participants/ Targets	Participant Selection/ Recruitment
Downs	Assess the relative value of mandatory facial protection.	Ice rink at Michigan State University and the rink of Greater Lansing	Participants of the Michigan State University (age and gender not specified) and the Greater Lansing Amateur Hockey Association (GLAHA) (>8 years to </=19 years)	All participants in one season (unclear)
Roberts	Determine the rate, type and severity of injuries incurred and penalties assessed during fair play and "regular" rules.	A community-organized, 3-day, 31-game tournament in Minnesota	Tournament participants (16 teams) (17-19 years and in high school, males)	Participants who provided Informed written consent from the player and their parents
Watson	Determine whether injuries decrease as ice surface size increases. To determine whether aggressive player behavior as reflected by penalties is associated with any change in injury rate.	Ice rinks across Ontario. As game location rotated, ice rinks differed in size.	Participants of the Ontario Hockey League (OHL) (16 to 20 years, gender not specified)	All league participants
Kraus	Determine the effect of introducing a new helmet on head injury in college intramural hockey.	Ice rink at the University of Minnesota	Participants in college intramurals for the 1968-69 season	All participants in the intramural program for the specified period
Pashby (1977)	Determine the efficacy of face protectors and whether new high-sticking rules have an effect on eye-injury incidence.	Ice rinks across Canada	Participants of the Canadian Amateur Hockey Association (CAHA) (up to 20 years, gender not specified)	All participants in the CAHA during the specified season
Pashby (1979)	Determine if the number of eye injuries continued to decline in the two hockey seasons following the 1976-77 season. (Author's previous investigation)	As above	As above (up to 20 years, gender not specified)	As above
Pashby (1985)	Determine the influence of face protectors on the incidence of eye injury in minor hockey players.	As above	As above (mean age 14 years for 74-75 season, 24 years for 83-84 season, gender not specified)	As above
Watson	Evaluate the impact of the 1989-90 checking from behind (CFB) rule on injury rates and on player's behavior as indicated by penalty rates.	Ice rinks across Ontario	Participants of 3 teams of the Ontario University Athletic Association (OUAA) (age and gender not specified)	All participants on the teams that had a complete injury record for the six years studied

Table 3: Hockey Study Intervention

First Author	Intervention Type	Details of Intervention	Frequency Duration	Primary Outcome Measure	Outcome Collection Method
Downs	Equipment	Full face mask or ice mask with an external mouthpiece required for all American Amateur Hockey Association (AAHA) players, not for Michigan State University (MSU) players.	All AAHA games since 1976. Study investigates one season and compares it to non-protected league players.	Injury and specifically facial injury	Unreported for AAHA league team, team physician for MSU.
Roberts	Regulation	During the qualifying round fair play rules (teams have points added to their total for staying under six penalties per game and taken away if more than 12 per game) were used, but regular rules were used in the championship round.	Tournament duration (3 days)	Injury rate—an injury needing assistance from an athletic trainer. Penalty rate	Forms completed by athletic trainer, as well as a random selection of 5 players from each team to catch unreported injuries. Collected from official score sheets
Watson	Environment	Ice surface size was divided into three groups: Standard (S) = 200 x 85 ft Larger than Standard (LTS) = >17,000 ft^2 Smaller than Standard (STS) = <17,000 ft^2	One hockey season	Injury rate and specifically neurotrauma Penalty rate	International Hockey Centre of Excellence (forms completed by team athletic trainer). Collected from official score sheets in OHL office
Kraus	Equipment	Mandatory use of a soft and flexible vinyl foam helmet in the 1969 season only.	One intramural season. (Compared to the previous non-helmeted season)	Injury incidence and specifically head injury	University Health Service injury report form

Table 3: Hockey Study Intervention (*continued*)

First Author	Intervention Type	Details of Intervention	Frequency Duration	Primary Outcome Measure	Outcome Collection Method
Pashby (1977)	Regulation	In the 1975-76 season, a mandatory penalty against high sticking was introduced (no specifics). Also: author notes that use of hexan or wire face protectors was increasing (optional use)	All games from the 1975-76 season (season 1). Study period includes one season before and the 2nd season of the new rule.	Eye injury incidence/severity	Cases reported to the Canadian Ophthalmologic Society (COS)
Pashby (1979)	Regulation	Intervention as described above.	As above. Study period includes 3rd and 4th season of the high sticking rule.	As above	As above
Pashby (1985)	Regulation	In 1981, mandatory use of a CSA (Canadian Standards Association)-approved face protector on helmets was introduced for all minor (not defined) players in the CAHA. (That is not all CAHA players).	All games from the 1981-82 season. Study period includes the 3rd season of the new rule and compares it to the 1974-75 pre-rule season.	As above	As above
Watson	Regulation	In the 1989-90 season, the checking from behind (CFB) rule was introduced. This allowed the referee to assess either a minor or major penalty whether an injury occurred or not, for a CFB anywhere on the ice. If an injury resulted, a major penalty and game expulsion was required.	All games from the 1989-90 season onward. Study period was for 3 years prior and 3 years after.	Injury rate Penalty rate	Records of the team athletic therapist Game reports from the OUAA

Table 4: Hockey Study Results

First Author	Intervention Group	Results per group	*p-value*	Conclusion
Downs	Face protection mandatory Non-mandatory group	52 injuries (11 facial--21%); 1 injury/38.04 playing hours 50 injuries (26 facial--52%);1 injury/8.4 playing hours	Not reported	Protective facial masks reduced facial injuries.
Roberts	Fair play rules (24 games) Regular rules (7 games)	17.0 injuries/1000 athlete exposures (AE), (5.7 notable); 7.1 penalties/game 64.5 injuries/1000 AE, (27.6 notable), 13 penalties/game vs. Notable injuries = an injury preventing play for that or the next day	Not reported	The ratio of regular rule injury rate to fair play rule injury rate for notable injuries was nearly 5:1. The fair-play rule concept can reduce injury rates and penalty rates.
Watson	Standard (S) Larger than Standard (LTS) Smaller than Standard (STS)	0.58 injuries/game (0.02 for neurotrauma (NT) injuries) 0.33 injuries/game (0.00 for NT) 0.76 injuries/game (0.03 for NT)	95% confidence interval	There is a highly significant association between ice surface size and injury rate for all injuries. Neurotrauma showed no significant relationship with ice size.
Kraus	Non-helmeted season Helmeted season	31 injuries (16 head injuries)/192 games played 21 injuries (9 head injuries)/238 games played	$p = 0.03$ $p = 0.02$	In the non-helmeted season, the head injury rate was 8.3/100 games and only 3.8 in the helmeted season. The game injury rate was 16.1/100 games and 8.8 respectively.
Pashby (1977)	Pre-high sticking rule Post-high sticking rule season 2	253 eye injuries (37 legally blind) 90 eye injuries (11 blind) No masked players (optional use) were blinded except for goalies.	Not reported	Eye injuries, except ruptured globes, decreased after the high sticking rule induction. The rate of blindness for eye injury decreased from 1 in 7 injured eyes to 1 in 8 between the 1974-75 and the 1976-77 seasons.

Table 4: Hockey Study Results (*continued*)

First Author	Intervention Group	Results per group	*p-value*	Conclusion
Pashby (1979)	Post-high sticking rule season 3 Post-high sticking rule season 4	51 eye injuries (8 blind) 42 eye injuries (12 blind)	Not reported	Eye injury incidence has continued to decline except for ruptured globes. Blinding injuries are still occurring; however, in season 3, only 1 of 12 blinded players was wearing an optional face protector.
Pashby (1985)	Pre-face protector rule (6 seasons prior to rule change) Post-face protector rule season 3	257 eye injuries (43 blind) 124 eye injuries (13 blind) Note: injury incidence for 74-75 season differs that what was reported in Pashby's 1977 publication.	Not reported	The incidence of eye injury has declined sharply in the 1974-75 season to the 1983-84 season. No reported injury in the latter season in players wearing a face protector (mandatory after 1981).
Watson	Pre-CFB rule Post-CFB rule	Injury—Head/neck: 6.16/1000 player games, back:4.98, shoulder: 16.11 Penalties—CFB minors 0.07 penalties/game, 3.55 body contact, 3.29 stick-related Head/neck:4.49/1000 player games, back:4.49, shoulder: 19.38 Penalties—CFB minors 0.29 penalties/game, 3.47 body contact,2.80 stick-related Injury: requiring attention from an athletic therapist or physician	$p < 0.001$ X^2=56.66	The CFB rule induction resulted in a pre-post rule decrease in two of three categories of injury and increased CFB penalty rates. There was an absence of a significant association between the CFB rule and decreases in body contact or stick-related infractions. That is, there is enhanced safety without changing player behavior.

X. REVIEW OF RUGBY INJURY PREVENTION STRATEGIES

Rugby is a fast-moving and high-intensity team sport. Although historically dominated by males the sport is gaining popularity among female athletes, particularly at the high school and collegiate levels. Studies of injury in rugby have previously reported rates of injury higher than for many other team sports (Gibbs, 1993; Gissane et al., 1997; Seward et al., 1993). The reason for this high injury rate may be related to the number of physical collisions in which players are involved during the course of the game (Gissane et al, 1997). National CHIRPP (Canadian Hospital Injury Reporting and Prevention Program) data reveals that rugby injuries occurred almost exclusively among males, and was the seventh most common sport resulting in injury in the eldest male age group (Goulet & Regnier, 1997).

An analysis of the CHIRPP database conducted in 1995 revealed that the majority of rugby-related injuries presenting in Canadian Emergency Departments were to those 15-19 years old, and 83% of all the injuries were to boys (CHIRPP Injury Reports – Rugby). The injuries were most commonly associated with tackling (32%) or with a hit (unknown or unintentional contact 20%). Slips, trips or falls accounted for 9% of the rugby injuries, collision between players 8%, and injury from a player being stepped on or kicked accounted for 8%. The nature of the injuries included abrasion/bruising/inflammation (28%), fractures (26%) and sprains and strains (25%). Concussion accounted for 4% of these injuries, and minor head injury for 3%. Close to 7% of those injured in this analysis used protective equipment.

Shoulder injuries, particularly dislocation, are very common and result from a tackle followed by a fall (Gerrard, 1998). The leg is one of the most frequently injured parts of the body, generally caused by the excessive loads being placed on the ankle or knee joints (Milburn & Barry, 1998). These injuries usually occur through unexpected contact with the playing surface or a second person. Oral/facial injuries are also common (Chalmers, 1995). Because dental tissues have almost no capacity for recovery and lost dentition can only be replaced by costly prosthesis and restorations, attention has been focused on the development of effective mouthguards which have minimal disadvantages to the user (Chalmers, 1995). Studies to test mouthguard effectiveness have suffered in the past due to poor compliance rates (Munro et al., 1995). Amongst non-users there seems to be an attitude that injuries are inevitable (Jennings, 1990).

Gum shields are now the most common form of protective device worn in body contact sports, although they are not universally accepted (Jennings, 1990). Gum shields reduce the incidence of direct and indirect injury to the teeth. Additionally they protect the lips and cheeks from laceration against the teeth, absorb forces, which might fracture the mandibular angle and reduce the incidence of brain injury. There is also a reduction of forces being transmitted to the cervical spine with a lessening of the risk of cervical cord injury (Jennings, 1990).

Results

From the search of computerized databases, thirty articles were identified to be potentially relevant for the review. Five additional articles were identified through hand searching. Of the 35 articles identified, five articles met the inclusion criteria and were included in the review. Three were conducted in the UK, one in South Africa and one in New Zealand. Of the total, one article was Canadian, thirty were written in English, four in Italian and one in French. Over 80% of the excluded articles did not evaluate the effectiveness of an injury prevention strategy.

Two of the studies were cohorts (one a historical and one prospective), two were nonequivalent control group designs and one was a pre-post test design. The study dates were 1979, 1980, 1985, 1990 and 1997. Four of the studies focused on the use of personal protective equipment, specifically mouthguards, while one study examined changes in the physical environment, specifically the movement of the playing season from fall/winter to spring/summer. All studies focused on players in organized leagues playing competitive rugby. Two focused exclusively on children and youth, two focused on adults (mean ages 25.4 years and 24.9 years) and one study did not report any age data.

The studies varied on each of the quality indexes. Quality of reporting scores ranged from 1/5 through 5/5 and total quality scores ranged from 6.5/14 – 9.5/14. In total, one study was rated as poor with the remaining four rated as moderate.

Environmental Interventions

PERSONAL PROTECTIVE EQUIPMENT

The historical cohort study (Jennings, 1990) retrospectively examined orofacial injuries and concussions sustained among rugby players at senior and mini levels. Rugby players participating in a community league (*n* = 183) were asked about their attitudes, behaviors and past injury history, and then compared in regard to whether or not they had worn mouthguards in the past. Injury morbidity was measured using a self-report questionnaire. Those players who wore mouthguards tended to report having had fewer mouth injuries as well as concussions and loss of consciousness than non-wearers, although reporting and analysis in this study were minimal.

The two nonequivalent control group studies were similar in aim. Both studies conducted pre-season dental exams among players, distributed mouth guards, and then re-examined players at the end of the season. The study conducted in the UK (Upson, 1985) did not report any age or gender data; however, subjects were recruited from community leagues (*n* = 120). In this study players were examined and then fitted with either “mouth-fitted” or “laboratory-made” mouthguards for the duration of the season. At the end of the season there was no change in the number of fractured or missing teeth in either group compared to baseline. It would be reasonable to accept that both types of mouthguards had a preventive effect against damage to the teeth. Although players reported some problems with dryness of the mouth and nausea players agreed that fitted mouthguards were far superior to the stock types of guard that they had previously worn.

The second nonequivalent control group study (de Wet et al., 1981), conducted in South Africa targeted 10 to 13 year-old boys in five different elementary schools. Boys in the intervention group (*n* = 75) received pre-season dental exams, at which time they were fitted for mouthguards. At a second dental visit, custom mouthguards were distributed and boys were given written instructions of their use and care. Boys in the control group (*n* = 75) received dental exams but not the mouthguards. Outcome data of interest included tooth and lip injuries as well as other soft tissue, and neck injuries and concussions. Mouthguard users sustained significantly fewer lip, tooth, and concussion injuries than non-users.

The type II Pre Post-Test study conducted in New Zealand examined custom-fit mouthguards acceptability and effectiveness amongst male high school players. Teams of dentists visited eight secondary schools to conduct dental exams among all rugby players, at which time players were fitted for mouth guards. One week later mouthguards were distributed and players were instructed in their use. A follow up questionnaire was completed at the end of the season asking if the boys had experienced a "serious blow to your mouth whilst playing rugby?", and "If so, were you wearing a mouthguard at the time?" Players who sustained injury to their teeth were examined and the extent of the damaged was recorded. Mouthguard wearers had significantly fewer oral fractures than non-wearers.

PLAYING SEASON

A cohort study (Gissane et al., 1997) conducted in England sought to examine whether or not the movement of the playing season from fall and winter to spring and summer would alter risk of injury to players taking part in the professional rugby league. This move meant that matches would be played in higher temperatures and on harder surfaces. During the initial European Super League Season all injuries reported for the first string team of one professional rugby league club were recorded. The injury data were compared with the first string team data from a study on the same club over four previous seasons. An injury was defined as a physical impairment received during a competitive match that prevented a player from being available for selection for the next competitive game. The risk of injury when playing summer rugby league was higher than when playing winter rugby league (relative risk = 1.67, 95% confidence interval 1.18 to 2.17). Both forwards and backs experienced an increased risk of hematomas, fractures, dislocations and joint injuries. The increased risk of injury was significantly increased for all body sites and being injured as a result of "others", which included activities such as running, and catching high balls. Only the risk of being injured when tackling or being tackled did not alter significantly between winter and summer cohorts.

Discussion

Studies in this review demonstrate that custom-fitted mouthguards are an effective mechanism of reducing oral injury in rugby. Numerous studies have shown between 90-100 percent reduction in dental injuries by wearing custom-made mouth guards (Jennings 1990).

The majority of all sport/recreation injuries that are sustained by children and adolescents are preventable. Attention to physical deficits, training methods, safety equipment, and psychological health should decrease the incidence of these injuries (American College of Sports Medicine, 1993). The prevention of injuries in rugby has been addressed by other organizations in an attempt to reduce the severity and incidence of injury in the game. For example, the Rugby Injury and Performance Project report listed multiple recommendations such as:

- Accreditation of coaches at the appropriate levels and suggested that coaching manuals and programs include information on: pre-season fitness, management of injury, and issues regarding foul play and tackling;
- All players wear mouthguards and that priority is placed on foul play and that fair play be reinforced;
- Parents of children playing junior-rugby need to be informed about the benefits of mouthguards;
- Efforts should be make to custom fit mouthguards.

It is important to remember that the growing child is in a unique phase of development which puts them at risk for developing a number of problems, including increased risk of sport-related injuries. Problems with coordination even among previously well-coordinated athletes can be extreme. (Larkins, 1991).

Athletic injuries usually have many causes, making the identification of simple risk factors challenging. Rule changes, amount of training, playing style, team tactics and player equipment all affect the incidence of injury among rugby players.

Rule Recommendations

Research

- Use of line judges on the field in addition to the referee should be investigated to determine if safer play is enforced, particularly in amateur leagues;
- Rule changes directed at preventing injuries in the scrum have been made. Studies need to determine if related injury rates have decreased;
- Rigorous study needs to determine if prophylactic taping, helmet use, shoulder pads and other common types of protective equipment are effective in reducing injuries in rugby.

Practice

- All players should wear mouthguards to prevent mouth/face injuries;
- Players should wear mouthguards during practice as well as games in order to increase comfort and familiarity;
- Accreditation of coaches at the appropriate levels and suggested that coaching manuals and programs include information on: pre-season fitness; management of injury; and issues regarding foul play and tackle;
- Priority should be placed on foul play, fair play should be reinforced;
- Parents of children playing junior-rugby need to be informed about the benefits of mouthguards;
- Efforts should be make to custom fit mouthguards.

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Table 1: Rugby Study Characteristics

First Author	Study Design	Quality Rating	Year of Publication	Country	Study Time Period	Funding
De Wet	Non-Equivalent Control Group	Moderate (7.5/14)	1981	S. Africa	1 rugby season	University
Upson	Non-Equivalent Control Group	Moderate (7/14)	1980	UK	1 rugby season (1983-84)	Health Authority
Gissanne	Prospective Cohort	Moderate (11.5/17)	1997	UK	5 rugby seasons	Not Reported
Jennings	Historical Cohort	Poor (6.5/17)	1990	UK	March-April 1990	Not Reported
Morton	Type II Pre-Post Test	Moderate (9.5/14)	1979	New Zealand	1 rugby season	Other

Table 2: Rugby Study Design

First Author	Study Aim	Study Setting	Study Participants	Participant Selection/Recruit
De Wet	Determine acceptance of a custom -made mouthguard by primary school boys; investigate problems and complaints and evaluate their effectiveness.	Elementary School	Sport Participants	Boys attending primary school with angle class 1 jaw relationships
Upson	Evaluate the efficacy of two types of mouthguards (lab made or "mouth fitted) among rugby players.	Community League	Sport Participants	Dental exams conducted at 4 rugby clubs
Gissanne	Examine whether or not the movement of the playing season from fall and winter to spring and summer would alter risk of injury to players taking part in professional rugby.	Professional Team	Sport Participants	Players selected to play for the 1st team in a given match
Jennings	Retrospectively examine orofacial injuries and concussions sustained among rugby players at senior and mini levels and their use and attitudes of gumshields.	Community League	Sport Participants	Senior players participating on 2 Saturday afternoons with 1st, 2nd and 3rd players
Morton	To examine custom fit mouthguards acceptability and effectiveness among 1st and 2nd rugby fifteens.	High school	Sport Participants	Rugby players in high schools in the area

Table 3: Rugby Study Intervention

First Author	Intervention Type	Details of Intervention	Primary Outcome Measure	Outcome Collection Method
De Wet	Personal protective equip. – participants fitted with custom Bioplast 2mm maxillary mouthguard	Case boys fitted with mouthguards and given list of use, care and told to wear guards for remains of the season, at which time they received a second oral cavity exam.	Injury incidence and amount of time mouth guard was worn	Doctor diagnosis, self report questionnaire and school records
Upson	Personal protective equip. – Mouth fitted or lab made mouthguards	Players had dental exam, were fitted with either lab-made or mouth-fitted guards, played for the season and received a second oral exam.	Injury incidence	Dental Exam and self report questionnaire
Gissanne	Environmental – playing season changed from winter to summer	Injury data compared between teams playing during fall/winter season compared to those playing the spring/summer season.	Injury incidence	Team Doctor and physio diagnosis / record keeping
Jennings	Personal protective equip. – Gumshields	Rugby players were asked about attitudes, behaviors and past injury history, then compared in regard to whether or not they had worn gum shields in the past.	Injury incidence and severity	Self report questionnaire
Morton	Personal protective equip. – custom fit and use of mouthguards.	Boys are examined and fitted with custom mouthguards and asked a number of questions regarding attitudes, beliefs, behaviors and dental history.	Injury incidence and severity	Self report questionnaire

Table 4: Rugby Study Results

First Author	Intervention Group	Results per Group	*p-value*	Conclusion
De Wet	(1) mouthguard users *n* = 75; (2) non-mouthguard users *n* = 75	1) Percentage of injuries mouthguard users sustained: 18% lip injuries; 0% tooth injuries, 0% concussions; 7% other injuries; Percentage of injuries non-mouthguard wearers sustained: 41% lip injuries; 21% tooth injuries; 12% concussions; 16% other injuries.	$p < 0.0001$	Injuries were reduced significantly when using mouthguards.
Upson	(1) lab made mouthguards *n* = 50; (2) mouth-fitted mouthguards *n* = 48	(1) no change in number of missing or fractured teeth; (2) no change in number of missing or fractured teeth		Both types of mouthguards had a preventive effect against damage to teeth
Gissanne	(1) winter n = 596.5 player hours; (2) summer *n* = 397.67 player hours	Summer rugby players had a 67% higher injury rate than winter players.	RR=1.67 CI 95% (1.18-2.17)	Summer rugby may have resulted in a shift of injury risk factors; however, other playing conditions including rule changes may have had confounding effects.
Jennings	(1) old boys with shield *n* = 60; (2) old boys with no shield *n* = 54; (3) young boys with shield *n* = 45; (4) young boys with no shield *n* = 24	(1) 20% sustained injury, 27% concussion; (2) 82% injury; 50% concussion; (3) 36% injury, 2% concussion; (4) 74% injury, 6.5 % concussion		Players wearing mouthguards sustained fewer injuries to mouth, lips, teeth, concussion and loss of consciousness compared to non-wearers.
Morton	(1) wear always *n* = 135; (2) wear not more than once *n* = 28; (3) wear occasionally *n* = 66	31 players or 14% received injury during the season; 20 were soft tissue lacerations and bruising, no fractures; 11 players not wearing mouthguards suffered a total of 13 tooth fractures. Difference of number of fractures was significant.	$p = 0.0007$	A significant difference existed between number of fractures occurring in mouthguard wearers and non-wearers.

XI. REVIEW OF SOCCER INJURY PREVENTION STRATEGIES

Soccer is the most popular sport in the world with approximately 200 million players in 186 countries registered with FIFA (the International Federation of Football Association). In Canada, interest in soccer has increased considerably over the last few decades. The Canadian Soccer Association reports the total registration in the sport for 1999 to be over 700,000 with participation increasing yearly (www.canadasoccer.com). Registration increased 13% from 1997 to 1998 and 10% from 1998 to 1999. Of registered players in Canada, 36% are female and 87% are youth under 19 years.

With the increased popularity of soccer, the number of injuries has also likely increased (Larson, Pearl, Jaffet & Rudawsky, 1996). Larson et al., in their review of soccer epidemiology literature, refer to a wide variation of reported injury rates among young soccer players. Reports range from one to 45 injuries per 1000 hours of practice or game and it is suggested that these variations are due to differences in data collection and definitions of injury. Soccer injuries are rarely fatal. However, there have been fatal incidents reported following goalpost-induced trauma with the most common mechanism being the goalpost falling on top of the child (Janda, 1995). From 1979 to 1993, there were 18 fatalities in the United States caused by falling goalposts (Janda, 1995). Collision with stationary goalposts causing head injuries has also been reported. Soccer injuries can have long-term consequences on players. Studies comparing former soccer players with those who are still active or people who have never played have found that former players appear to be at higher risk for developing osteoarthritis of the hip and knee (Larson et al., 1996).

An analysis of national 1993 CHIRPP data on 1,757 soccer injuries resulting in an emergency room visit (Health Canada, 1997) reported that more than half (55%) occurred during informal play. The most frequent injuries were superficial abrasions, bruising or inflammation (33%), followed by sprains (30%), and fractures or dislocations (29%). The lower limbs were most frequently injured (46%), with the upper limbs at 37%. Collisions were involved in 84% of the injuries.

An analysis of recent CHIRPP data from Eastern Ontario and British Columbia for 1997 (Scanlan et al, 2000) found that soccer, with 528 of the 4387 injuries reported, ranked second after basketball for emergency room visits related to sport and recreational activities. Soccer-related injury accounted for 9% of children and youth presenting at emergency rooms who were subsequently admitted to hospital. Interestingly in this data set, 83% occurred during formal play, either as either part of formal educational activities or organized competition or practice. Only 16% of the soccer injuries occurred in the context of informal activity, findings quite different from the 1933 national CHIRPP analysis. This may reflect an increase in availability of organized play.

The nature of the game involves sharp turns off a planted foot and intense ball contact (Larson et al, 1999). Ankle inversion injury is the most common ankle injury and is responsible for close to 10% of all soccer injuries. Larson et al. identified similar injury patterns between youth and adult players. Both prospective and retrospective studies indicated the lower extremity as the most frequently injured area.

Reports of head, spine and trunk injuries ranged from 10% to 25% among youth. There are several mechanisms by which a head injury can occur including heading the ball, being hit in the head by a forcefully kicked ball and head to head contact between players. Lacerations and concussions are the most common types of head trauma. Eye injuries have also been reported however, the incidence of these injuries is unclear (Larson et al., 1999).

Age is one risk factor associated with soccer injuries. The incidence of injury appears to increase with the age of the players. This is thought to be a result of increased strength, speed and aggressiveness in older players and greater force when players collide (Keller, Noyers & Buncher, 1987). According to Keller et al., younger players had a higher incidence of head, face and upper extremity injuries. These authors suggest that possible causes include more frequent falls on an outstretched arm, more frequent ball contact, lower technical expertise in heading the ball and increased ball-width to head-weight ratios. Injury risk in soccer also appears to be related to gender. The review by Larson et al. reports several studies that found higher rates of injury among female youth soccer players compared to males, or other age groups. Previous injury is also reported to be a risk factor for injury. Ekstrand and Tropp (1990) report that players with previous ankle sprains are at greater risk for future ankle injuries. Neilsen and Yde (1989) found 56% of ankle injuries occurred in players with a history of ankle sprains.

Several studies have found higher injury rates for games than for practices, and this finding was consistent at a variety of playing levels including youth soccer (Larson et al., 1999). Two Swedish studies found that traumatic injuries occurred more frequently in games and overuse injuries during practices (Ekstrand and Gillquist, 1983; Engstrom et al, 1991).

The type of playing surface also appears to play a role in injury and differences in injury patterns have been noted between artificial and natural playing surfaces. In NCAA soccer, for both men and women, the rate of injury on artificial surfaces has been found to be higher than on natural surfaces (Larson et al., 1996). Ekstrand and Nigg (1989) suggest that surface-related soccer injuries are mainly related to surface stiffness and frictional forces between the surface and the shoe.

Results

Our search of electronic databases identified 37 potentially relevant soccer-related articles. Seven additional articles were identified through hand searching, none of which were Canadian. Of the total of 44 articles identified, only five articles met the inclusion criteria. One study (Ekstrand, 1983) was an older version of the same research data published in 1984. Only Ekstrand and Gillquist's study from 1984 was included in the review. This study was identified through the hand searching procedures.

Of the four relevant studies, two were from the United States, and one each was from Sweden, and Italy. One of the studies was an RCT, two were time series and one was a nonequivalent control group design. The four studies all addressed organized, competitive play.

The four studies addressed a range of intervention strategies. Two assessed the effectiveness of training programs to reduce knee injuries. One assessed the effectiveness of a seven-part training program that encompassed both educational and environmental strategies. The final study assessed the effect of a combination of educational, environmental and regulatory strategies to reduce heat stroke during a tournament event.

The four studies varied on quality assessment. The RCT (Ekstrand & Gillquist, 1984), which tested a prophylactic training program received a 2/5 on the Jadad scale. The second training program study which used a nonequivalent control group design rated moderate (10/14) (Caraffa, Cerulli, Projetti, & Asia., 1996) and the two pre-post studies both rated moderate (8/14 for Elias, Roberts & Thorson, 1991 and 7/14 for Lehnhard, Lehnhard, Young & Butterfield, 1996).

Educational Interventions

The two studies evaluating the effectiveness of education-based strategies to reduce soccer injuries both assessed injury outcomes following training programs aimed at their reduction. The first of these studies (Caraffa et al., 1996) was conducted in Italy, using a nonequivalent control group design to assess the ability of a proprioceptive training program to reduce the incidence of anterior cruciate ligament (ACL) injury in semi-professional and amateur soccer players. A total of 40 teams participated, with half following a five-phase pre-season training program using wobble boards that continued at least three times per week during the season and half receiving no special training. All teams were followed for three seasons and the incidence of ACL injuries among teams following the program was 0.15 per team per season as compared to 1.15 per team per season among the control teams ($p < 0.001$). This study rated as moderate in the quality assessment score. The authors concluded that the program led to a 7-fold decrease in ACL injuries.

Lehnard et al. (1996) conducted a time series study in the United States over a four-year period to assess the effectiveness of a strength-training program on the incidence of injuries among players on a male college soccer team. The team was monitored for four years with a strength-training regimen incorporated into the non-season and the pre-season during the third and fourth years. In the strength-training program, upper and lower body muscles were exercised separately, twice each week. The injury rate during the years without the strength training was 15.15 injuries per 1,000 exposures as compared to 7.99 per 1,000 exposures for the two years with the strength-training. This study rated 7/14 (moderate) on the quality assessment scale. The authors acknowledge the potential confounding effect of the study design and concluded that the reduction in injuries cannot be attributed to the strength-training program with any certainty.

MULTI-COMPONENT STRATEGIES

Ekstand and Gillquist (1984) conducted a randomized controlled trial to assess the effectiveness of a seven-part program to reduce injury incidence among 17 to 36 year-old male participants in a Swedish community soccer league. Coaches selected the 15 best players from each of 12 teams, who were then assigned to one of six intervention teams (n = 90 players) or to one of six control teams (n = 90 players). The seven-part program, delivered by doctors and physiotherapists consisted of the following:

- Correction of training;
- Equipment and shin guards;

- Prophylactic ankle taping (for previous ankle sprains or instability);
- Controlled rehabilitation;
- Exclusion of players with knee instability;
- Information to coaches and players;
- Correction and supervision.

After a six-month follow-up, the intervention teams had 75% fewer injuries than the control teams (0.6 injuries per month versus 2.6 injuries per month, respectively, $p < 0.001$). Reductions in the incidence of ankle injuries, sprains, strains, operations and absences from practices and games were also reported among the intervention teams. Additional follow-up data were collected and analyzed in second phase of the study where the intervention was delivered by coaches. However, these data did not adhere to the randomized controlled study design as compared the pre- and post-intervention injury rates incidence for all teams combined. This second study phase showed a lesser degree of injury reduction (50%). Overall, this study demonstrated the effectiveness of a multi-component program; however, it is not possible to assess the relative contributions of the different program components. The study rated 2/5 on Jadad's RCT Quality Assessment Scale.

A second multi-component intervention study was conducted in the United States during a 6-day, 4000 participant youth soccer tournament (males and females aged 9-19 years) held in July (Elias et al., 1991). A time series design was used to assess the effects of emergency preventive measures to prevent heat exhaustion during the tournament. The intervention included provision of heat stroke prevention information to staff, coaches, officials and referees; as well as emergency measures with game modifications and hydration techniques. The educational strategies were implemented prior to the start of the tournament and the game modifications and hydration techniques began on the third day of the tournament. The rate of heat exhaustion per 1,000 player hours decreased after implementation of the emergency measures, from 21 cases in the first two days to 13 cases in the last four days. Unfortunately, the results were presented graphically and do not include numerical values or measures of statistical significance. This study received a poor quality rating.

Discussion

The proprioceptive training program evaluation (Caraffa et al., 1996) provides good evidence of reductions in ACL injuries among players at a senior level. However, since this is evidence from only one study, it would appear that further testing of this intervention would be helpful among younger players. The strength-training protocol (Lehnhard et al., 1996) also demonstrates potential benefit. However, as this study did not use a control group, it is difficult to attribute changes to this protocol with any certainty. It may be helpful to look at other sports where the effect of strength-training has been evaluated and assess whether it has been evaluated with younger players. Multi-component approaches to soccer injury prevention may also hold promise as indicated by the results from Ekstrand & Gillquist (1984). The ideal configuration for such a program for younger players would, however, needed to be tested. Finally, the environmental heat injury prevention study (Elias et al., 1991) showed a trend of lower heat-related injuries during a large tournament implementing a set of emergency measures. Due to the single-group nature of this study and short time period, it is not possible to draw conclusions regarding the effectiveness of these measures.

As pointed out by Larson et al. (1999), evaluation of injury prevention measures in youth soccer has been all but ignored. Of the four studies assessed in this review, only one was performed with players under age seventeen, and only one included female participants. In youth soccer, girls may be at an increased risk for injury, emphasizing the need for surveillance and greater attention to evaluation of effective injury prevention strategies in this population. The four studies reviewed do not provide conclusive findings. All four studies address different intervention approaches. This review suggests numerous gaps in knowledge about effective injury prevention strategies for young soccer players.

Recommendations

Research

- Surveillance study to assess patterns of soccer injuries among children and youth;
- Modification of training regimens for children – such as proprioceptive and strength-training strategies;
  - Replication of the proprioceptive training program, particularly with younger age groups and female players;
  - Investigate whether strength-training or other conditioning programs can be appropriately modified for children;
  - Test the effect of modified training in child and youth settings
  - Evaluation studies assessing effectiveness of modified strategies to reduce injuries;
- Design and evaluation of a multi-component strategy for injury prevention for child and youth soccer;
- Further evaluation of heat-illness prevention measures in youth soccer tournament settings;
- Assessment of the importance of other environmental factors or play conditions (such as goal post safety, playing surfaces) and how these influence injuries in children and youth.

Practice

- Ensure that environmental concerns such as heat exhaustion are addressed during soccer play in hot weather. Include tracking of injuries and prevention measures at large events;
- Develop training protocols (i.e., on-season and off-season conditioning programs, proprioceptive and strength/flexibility programs) with appropriate modifications for children.

Policy

- Develop guidelines related to the prevention of heat exhaustion for young players.

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Table 1: Soccer Study Characteristics

First Author	Study Design	Quality Rating	Year of Publication	Country	Study Time Period	Funding
Ekstand	RCT	Poor (2/5)	1984	Sweden	1980 – 1982	Industry, university and Swedish Sports Council.
Caraffa	Non-Equivalent Control Group	Moderate (10/14)	1996	Italy	3 seasons	Not reported
Elias	Time series	Moderate (8/14)	1991	USA	1988 (5 day period)	Not reported
Lehnhard	Time series	Moderate (7/14)	1996	USA	4 year period	Not reported

Table 2: Soccer Study Design

First Author	Study Aim	Study Setting	Study Participants/Targets	Participant Selection/Recruitment
Ekstand	Test a prophylactic training program.	Community soccer league	Sport/rec participants Age: 17-36 year-old males	Senior male soccer division of 12 teams: each coach selected 15 best players from each team.
Caraffa	Assess the ability of a proprioceptive training program to reduce the incidence of ACL injury in soccer players.	Community sport club PT 40 semi-professional and amateur teams	Sports/rec participants Age- not reported	40 teams contacted and asked to participate in controlled study.
Elias	Assess the effects of emergency preventive measures to prevent heat exhaustion during a youth soccer tournament.	Summer youth soccer tournament	4000 sports/rec participants exposed to preventive measures at tournament Age: 9–19 year-old males and females Coaches provided with information prior to start of the tournament.	All participants in tournament
Lehnhard	Determine whether strength-training had an effect on the incidence of injuries in a college soccer team.	College soccer team	Sports/rec participants Males Age: not reported	Not reported

Table 3: Soccer Study Interventions

First Author	Intervention Type	Details of Intervention	Frequency/Duration	Primary Outcome Measure	Outcome Measure Collection Method
Ekstand	Education/ Environmental (Personal protective equipment)	Seven part program consisting of: (1) correction of training; (2) equipment/shin guards; (3) prophylactic ankle taping (for previous ankle sprains or instability); (4) controlled rehabilitation; (5) exclusion of players with knee instability; (6) information to coaches and players; (7) correction and supervision.	Ongoing schedule not reported	(1) injury incidence (2) absence from games and practices	Doctor diagnosis Sport assoc./team records
Caraffa	Education	40 teams were divided into 2 groups (A & B). Group A received a special proprioceptive training program in addition to their standard training program while Group B trained as usual. Group A received a pre-season, 5-phase training program of increasing difficulty (using four different types of wobble boards), 20 min per day for a minimum of 30 days.	3 times per week during playing season	(1) incidence of ACL injuries	Doctor diagnosis Sport assoc./team records
Elias	Education Regulatory Environmental	Information provided to medical staff/coaches/officials/ referees regarding prevention of heat stroke. Emergency measures included game modification (shorter games, more frequent and longer breaks during play and unlimited substitution), as well as hydration techniques and a water truck spraying players.	Educational measures prior to start of 6 day tournament. Emergency measures implemented after 2 days of tournament.	(1) incidence of heat exhaustion	Doctor diagnosis
Lehnhard	Education Environmental Personal protective equipment)	Men's soccer team monitored for four years with a strength-training regimen incorporated into years three and four. Strength-training regimen included training of upper and lower body muscles using principle of exercising each set to failure. The number of sets and repetitions for each exercise varied during the year.	Training involved twice weekly training sessions during the non-season and pre-season, with no strength training during the competitive season.	(1) incidence of injuries (team injury rates)	Sport assoc./team records

Table 4: Soccer Study Results

First Author	Intervention Group	Results per group	*p-value*	Conclusion
Ekstand	Intervention group with seven part training program (n = 6 teams, 90 players) Control group-no program (6 teams, 90 players)	Injury incidence: test group 0.6 injuries per month (23 injuries) Control group = 2.6 injuries per month (93 injuries) showing a 75% reduction Subsequent follow-up with 10 of the 12 original teams, with the intervention supervised by coaches rather than doctors and physiotherapists reduced injuries by 50% (2.6 per month to 1.4 per month). This analysis was applied to the injury incidence for all teams, and did not maintain the random allocation of groups.	$p < 0.001$	After a six-month follow-up, there were 75% fewer injuries in the intervention teams. There were also lower levels of the following outcomes among the intervention teams: ankle injuries ($p < 0.05$, knee sprains $p < 0.05$, and strains $p < 0.001$, operations $p < 0.05$, and absences from practices and games $p < 0.001$). Additional follow-up that did not adhere to the randomized controlled design showed a lesser degree of injury reduction when the intervention was delivered by coaches.
Caraffa	Intervention group received proprioceptive training (n = 20 teams) Control group had no training (n = 20 teams)	Intervention group – 10 injuries (0.15 injuries/team per season) Control group – 70 injuries (1.15 injuries/team per season).	$p < 0.001$	The frequency of ACL injuries in the proprioceptive trained group showed a sevenfold reduction over the control group. This was a statistically significant difference.
Elias	Pre-emergency measures (Day 1 & 2 of tournament) Post-emergency measures (Day 3-6 of tournament)	Pre-measures: 21 cases of heat exhaustion Post-measures: 13 cases of heat exhaustion Cases of heat illness per player hour	Not reported	Rate of heat exhaustion per 1,000 player hours decreased following implementation of emergency measures, but results presented graphically. Summary numerical results not provided. No statistical analysis.
Lehnhard	Untrained injury rate (years 1 & 2) (n = 1686 exposures) Trained injury rate (years 3 & 4) (n = 1720 exposures)	Untrained injury rate: 15.15 injuries per 1,000 exposures. Trained injury rate: 7.99 injuries per 1,000 exposures.	Not reported	Team injury rates reduced Year 1 12.1 Year 2 15.9 Year 3 11.1 Year 4 8.6 No statistical analysis of the decreases in injury rates is reported.

XII. CONCLUSIONS & RECOMMENDATIONS

A systematic review of the sports and recreation literature retrieved surprisingly few well-designed and controlled studies investigating strategies to prevent injuries. An even smaller number of papers evaluated strategies to reduce injury in children and youth. Of the approximately twenty-one thousand articles identified through database and manual searching, only 740 were judged to be potentially relevant and only 117 met all the inclusion criteria.

For included studies, the majority had quality ratings of poor to moderate with only a small fraction achieving a good rating. Perhaps even more concerning are the lack of studies examining preventive strategies for the majority of sports and recreational activities examined and the fact that with the exceptions of bicycling, (all 12 studies targeted children and youth) and football (38% targeted youth), only six of the remaining 43 articles included in the synthesis specifically targeted these age groups. The lack of good evaluative studies is disappointing given the magnitude of sport and recreational related injuries among children and youth. Undoubtedly, further research is required to ascertain the scope of sport and recreation injuries in children and youth, evaluate existing prevention strategies among this age group and develop and evaluate interventions specific to the population where none exist. Future studies should also employ more rigorous study protocols. Where possible studies should apply a randomized control group design. In circumstances where randomization is not possible, studies should attempt to match subjects on factors including: age, sex, size, playing position, experience, etc. Further, a consistent definition of injury is essential to allow a comparison of results across studies, and stronger measures of exposure would further elucidate the true magnitude of the issue. Many of the studies included in this review failed to apply these basic research standards. Consequently, the validity of results is called into question and they cannot be generalized to other populations.

Despite the lack of abundant studies, the synthesis of the existing research does provide some direction for current practice. The majority of recommendations are for further research. In the absence of strong evidence to the contrary, cessation of existing practices not previously tested among children and youth cannot be recommended. Rather, the evaluation of these strategies should be given priority so that evidence is produced as to their effectiveness, and evidence-based practice recommendations for these activities can be developed. As governments in Canada continue to focus on increasing physical activity among children and youth, thought must be given to the issue of risk of injury and the relative lack of evidence of effective preventive measures and investment to improve the situation must be made.

Recommendations

Research

- Develop an injury surveillance system that allows the monitoring of injury exposure and incidence in child and youth sports and assess trends in sports when new equipment or regulations are introduced;

- Develop consistent definitions of injury for all future research so that the results of independent studies can be compared;
- Evaluate gender differences in injury rates among various sport and recreation activities;
- Evaluate contemporary artificial and natural turf surfaces to determine if injury rate, type and severity differ between the surfaces;
- Test modern shoe and cleat designs to ascertain which models offer the best balance of improved athletic performance and reduced risk of lower extremity injury;
- Evaluate the benefit of modern safety equipment (helmets, pads, mouthguards, etc.) at preventing injury or reducing injury severity;
- Further evaluate helmets and helmet fit in reducing head injury in non-contact sports such as cycling and snowboarding;
- Evaluate the effectiveness of lights and reflectors at improving driver awareness and reducing injury among cyclists and runners;
- Evaluate the impact of strength and conditioning, proprioception, and skill and coordination development programs on reducing injury in children and youth;
- Assess the effect of having better-trained and more game referees on reducing athlete injury;
- Ascertain if a coaches experience and/or training has an effect on athlete injury rate in child and youth sports;
- Determine appropriate pre-season training programs for children and youth to prevent the occurrence of injury;
- Evaluate the effect of modified rules and equipment at reducing injury in children and youth;
- Assess the effect of an increased penalty severity for rule infraction at improving fair-play and reducing sport injury in children and youth;
- Further evaluate the effectiveness of prophylactic bracing and taping at reducing sport injuries.

Practice

- In all sports, but especially contact sports, ensure that athletes have perfected basic tackling/checking skills prior to moving to more advanced leagues and introducing body contact;
- Ensure that all athletes complete a thorough warm-up and stretch routine prior to beginning practice or play, and following game intermission;
- Offer safety equipment at a discount or by donation to encourage its' use among children and youth;
- Teach young athletes to test and check their equipment prior to participation in sport and recreation activities to ensure it is functioning properly;
- Develop and run safety awareness campaigns to educate children and youth, parents, coaches and officials on proper injury prevention knowledge and techniques;
- Encourage lessons for neophytes to ensure that basic skills are mastered before children and youth are allowed to participate in unsupervised sport and recreation activities.