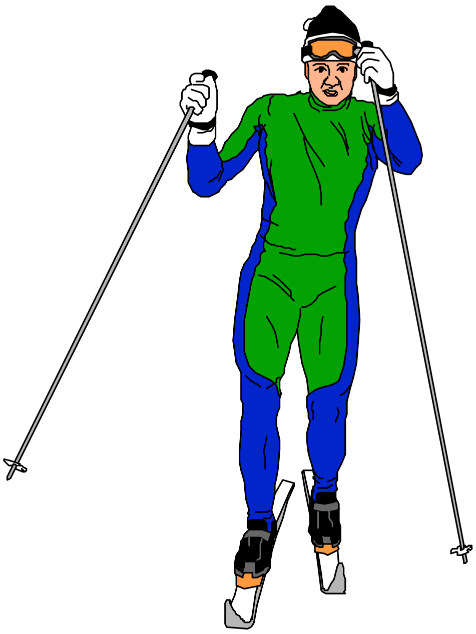
MONASH UNIVERSITY

ACCIDENT RESEARCH CENTRE

A REVIEW OF INJURY COUNTERMEASURES AND THEIR EFFECTIVENESS FOR CROSS-COUNTRY SKIING



by

Helen L Kelsall

Caroline F Finch

REPORT NO. 100

SEPTEMBER 1996

MONASH UNIVERSITY ACCIDENT RESEARCH CENTRE

REPORT DOCUMENTATION PAGE

Report No.	Date	ISBN	Pages
100	September 1996	0 7326 0680 2	59

Title and sub-title:

A review of injury countermeasures and their effectiveness for cross-country skiing

Author(s)

Kelsall HL
Finch CF

Type of Report and Period Covered:

Critical Review, 1990-1996

Sponsoring Organisation(s):

Sport and Recreation Victoria

Abstract:

Cross-country skiing is a popular alpine sport. It can be one of the most physically demanding of all sports, involving most of the body's muscles, and requiring a sustained cardiovascular and respiratory output. It is also ideal as a recreational sport, and can be enjoyed by individuals of all ages. Cross-country skiing includes ski-touring, defined trail skiing using the diagonal stride or skating techniques, and cross-country/downhill skiing. Cross-country skiers have been estimated to account for approximately 20% of all participants in alpine sports. The most common type of cross-country skiing injuries are sprains/twists, fractures and bruises. The most frequently injured body regions are the knee, arm/hand and the ankle. Risk factors for injury, include poor condition of ski tracks; unsuitable or inferior equipment; poor balance, inadequate mastery of the cross-country skiing technique and overuse. The aim of this report is to present a critical review of the extent to which the effectiveness of cross-country skiing injury countermeasures has been evaluated and to make recommendations for further research, development and implementation. Countermeasures specifically reviewed in this report include: ski pole handle design, ski bindings and equipment, skiing technique, pre-season conditioning, ski lessons, clothing, adequate nutrition and reduced alcohol intake, standards for skiing equipment, environmental factors, ski patrollers, first aid, rescue equipment and general resort safety. Little is known about cross-country skiers, their characteristics, aetiology and injury patterns, equipment related factors and the relationship between injury patterns and causal factors such as skiing ability, equipment, snow conditions and terrain. Some cross-country injuries are similar to those among alpine skiers. This suggests that countermeasures that have been effective in preventing alpine injuries, such as improvements in equipment design, may also prevent cross-country injuries. More attention needs to be directed towards preventing cross-country injuries, including data collection and epidemiology studies of injury patterns, studies of the mechanisms of injury and the safety of equipment.

Key Words:

cross-country skiing, injury prevention, countermeasures, evaluation

Monash University Accident Research Centre,
Wellington Road, Clayton, Victoria, 3168 Australia.
Telephone: +61 3 9905 4371
Fax: +61 3 9905 4363

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGMENTS

This study was funded by Sport and Recreation Victoria.

Dr Helen Kelsall worked on this project as a Public Health Trainee on placement at the Monash University Accident Research Centre. The Public Health Training Scheme is funded by the Public Health Branch, Department of Human Services, Victoria.

Dr Caroline Finch was funded by a Public Health Research and Development Committee (PHRDC) Research Fellowship.

Prof Peter Vulcan and Dr Joan Ozanne-Smith (Monash University Accident Research Centre) and Mr Rob Barrow (Victorian Cross-country Chairman, Snow Sports Victoria) are thanked for their valuable comments on the draft report.

Mr Hamish Derricks (Snow Sports Victoria) is also thanked for his general support for this research project.

EXECUTIVE SUMMARY

INTRODUCTION

Cross-country (or nordic) skiing is a popular sport in which there is a broad range of standards and ages of skiers. Cross-country skiing can be one of the most demanding of all sports, involving most of the body's muscles, and requiring a sustained cardiovascular and respiratory output. It is also ideal as a recreational sport, and can be enjoyed by individuals of all ages.

Cross-country skiing includes ski-touring (usually skiing away from defined resort areas), defined trail (or track) skiing using the diagonal stride or skating techniques, and cross-country/downhill skiing (combined with ski touring or sometimes on the regular ski runs). Equipment has been designed to suit the particular requirements of each type. As a sport, cross-country skiing has developed considerably since the 1980s with improvements in technology and design of equipment and clothing. There has been considerably less research on the epidemiology of cross-country skiing injuries or on evaluation of countermeasures to reduce injuries than there has been in alpine skiing.

Cross-country skiers have been estimated to account for approximately 20% of all participants in alpine sports. In a 1985 Australian study, the cross-country skiing injury rate was 0.49 injuries per 1000 skier days, while the alpine injury rate was 3.54 per 1000 skier days. Whilst the incidence of skiing injuries is lower in cross-country than alpine skiing, there is evidence to suggest that the severity of injuries may be comparable. The most common type of cross-country skiing injuries are sprains/twists (43%), fractures (25%) and bruises (18%). The most common body locations are the knee (26%), arm/hand (13%), and the ankle (12%). Risk factors for injury, especially amongst recreational skiers, include poor condition of ski tracks (deep tracks, ruts, iciness, sharp bends etc) and the downhill segment of terrain; unsuitable or inferior equipment (slippery glass fibre skis, wrong type of wax, boot not matched to the skiing style, etc); poor balance and inadequate mastery of the cross-country skiing technique.

The aim of this report is to present a critical review of the extent to which the effectiveness of injury countermeasures for cross-country skiing have been evaluated, consider the results of such evaluation and the level of supporting evidence, and make recommendations for further action in injury prevention research and practice. Measures to prevent or control injury, ie injury countermeasures can be targeted toward primary (pre-event), secondary (event) and tertiary (post-event) prevention in the chain of injury events. Primary countermeasures for cross-country skiing include pre-season conditioning and fitness programs and adequate warm ups, skiing technique, equipment factors (skis, boots, bindings, ski poles, eye wear, clothing, helmets), adherence by skiers to the skiers' safety and courtesy codes, ski patrollers, adequate nutrition and fluid intake, environmental factors (condition and design of ski trails), skier education programs, skiing instruction and expertise of instructors, adequate supervision of children, and use of safety equipment. Secondary countermeasures include protective equipment (helmets, eye wear), skiers conduct code and speed control, general sports equipment (ski pole handle design, standard of bindings, ski boots), condition of ski trails and environmental factors. Tertiary countermeasures include location of injured skiers, availability of first aid equipment; ski patrol assessment, treatment and transport; access to medical care; and adequate treatment and rehabilitation of injuries before resumption of skiing.

The following sections describe the major countermeasures reviewed and give the recommendations for further research, development and implementation.

SKI POLE HANDLE DESIGN

Injuries to the thumb are the most common upper extremity injury in skiing. The injuries can occur in all directions of fall, although a forward fall is more commonly reported. Retention of the ski pole in the hand during a fall is the major cause of this type of injury. Ski poles (or stocks) are carried by both cross-country and alpine skiers. Ski poles used by cross-country skiers are longer and have narrowed handles, compared to alpine ski poles. Skiers use them to push themselves along on the flat or uphill and as part of the skiing turn. The research on ski pole handle design has been done in relation to alpine skiing. Although the identified and reviewed studies relate to alpine ski pole handle design, there are significant implications for injury prevention in cross-country skiing and further attention to cross-country ski pole handle design is warranted.

Recommendations for further research, development and implementation

- Further research into the design of ski pole handles and ski straps is needed.
- Further research into the design of ski gloves.
- Controlled evaluations of both ski pole handles and ski glove designs in the field are required.
- An assessment of correct falling techniques and consideration of what is taught by ski schools in relation to this should be made.
- There should be continued support for a high standard of ski patrol services to provide a rapid response and safe transport of injured skiers.
- Specific advice, or training, for doctors in and around ski field areas, about the examination, management and rehabilitation of thumb and shoulder injuries needs to be developed and promoted.

SKI BINDINGS AND EQUIPMENT

Ski bindings and boot design are particularly relevant to lower limb injuries. The heel position is not fixed, and bindings are not designed to release. Convertible or cable bindings or heel plates that stabilise or fix the heel during turning and skiing downhill can provide better control, but may increase the risk of injury, with the ski acting as a lever about which the knee twists. Releasable cross-country bindings are reputably being developed, but as in alpine skiing, safe design and reliable performance criteria need to be met if they are to assist in injury reduction. The choice of ski boot depends on the cross-country skiing activity for which they will be used, eg touring, racing or skating, but should be flexible at the forefoot and allow free motion at the ankle.

Recommendations for further research, development and implementation

- Further research into the mechanisms of lower extremity injuries is needed.
- Detailed studies of the potential role of releasable cross-country bindings are warranted before they are widely promoted.
- Monitoring of injury trends as new equipment becomes available.
- Education of cross-country skiers about the most appropriate equipment for their type of cross-country skiing.

SKIING TECHNIQUE

During the mid-1980's the skating technique largely replaced the traditional diagonal striding as a racing technique and revolutionised the sport. The upper body plays a more propulsive role in cross-country skiing than alpine skiing, and more so in the skating that diagonal striding technique. Overuse injuries can consequently be a problem.

Recommendations for research, development and implementation

- Monitor overuse injury trends, particularly in competitive skiers.
- Encourage adequate preparation and warm-up before skiing.
- Include consideration of the potential for overuse injuries and their prevention in training programs.

PRE-SEASON CONDITIONING

Cross-country skiing is a physically demanding sport. Skiing requires muscle endurance, strength, flexibility and cardiopulmonary fitness. Whilst highly trained athletes (racers) and experienced skiers still have injuries, the recreational skier with low skills and inadequate physical preparation may be at greater risk.

Recommendations for research, development and implementation

- Additional research into the effectiveness of conditioning programs on the prevention of skiing injuries is required.
- A more rigorous evaluation of the impact and health outcomes of the Australian Physiotherapy Association's "Get Fit to Ski with Physiotherapy" program should be undertaken.
- Specific conditioning programs for cross-country skiers should be investigated.

SKI LESSONS

Ski lessons are available at most Australian resorts. A number of epidemiological studies of injuries among alpine skiers have considered the association of ability, and sometimes a history of having taken ski lessons, with injury rates. Similar studies have not been done with respect to cross-country skiing, but the results are reported here because similar principles apply to cross-country skiing. The role of skiing instruction in preventing injuries is controversial, and it is considered that skiing lessons must be coupled with experience to have positive effect. The reviewed literature suggests that beginners and less experienced skiers have a higher risk of injury than advanced or intermediate skiers. The effect of ski lessons on the injury rates of intermediate or advanced skiers is less obvious. Ski lessons have other advantages including orientating skiers to the use of lifts, social contact and fun, the resort and it's layout, suitable slopes for their ability and other safety measures. The effectiveness of ski lessons as a countermeasure, however, has not been evaluated in a formal, controlled way, especially for cross-country skiers.

Recommendations for research, development and implementation

- There should be standardisation of epidemiological data collection and reporting systems for categories of skiing ability and history of ski lessons in future studies.

- Controlled studies to evaluate the effectiveness of ski lessons for injury prevention should be undertaken.
- A review of the content of ski lessons with respect to skiing safety should be undertaken.

CLOTHING

Clothing serves several purposes in alpine conditions, including protection from a variety of weather conditions such as snow, sleet or rain, high winds, poor visibility, brilliantly sunny days and strong reflective glare. Clothing that is inadequate in providing warmth and wind factor protection can leave the skier at risk of hypothermia and frostbite. Consideration of clothing design and injury is an area that warrants particular attention to consumer acceptance.

Recommendations for research, development and implementation

- Continue to improve the materials for skiing garments and eyewear.
- Consider manufacturing clothing with higher coefficients of friction.
- Continue to reinforce the essential and protective aspects of clothing to skiers.
- Continue to encourage the use of protective sun screen.
- Consider a specific review of children's clothing and eyewear.

ADEQUATE NUTRITION AND REDUCED ALCOHOL INTAKE

Injuries are more likely to occur at certain times of the day, such as late morning and late afternoon, and fatigue at such times may contribute to the risk of injury. Adequate rest, nutrition and energy replenishment are also likely requirements for both enhanced performance and injury prevention.

Recommendations for research, development and implementation

- Reinforce the importance of good nutrition and adequate carbohydrate replenishment during skiing.
- Conduct preliminary studies on the alcohol consumption patterns of Australian skiers, and cross-country skiers more specifically, to determine the extent to which it is a factor in injuries.
- Undertake controlled studies on the relationship between alcohol consumption and injury occurrence.

STANDARDS FOR SKIING EQUIPMENT

No standards relating specifically to cross-country skiing equipment were identified through this review.

Recommendations for further standards development

- A review of Australia's policy regarding skiing equipment and requirements in relation to equipment standards should be undertaken.
- A review of Australia's policy regarding training and standards for ski shop personnel, ski binding fitting and adjustment in retail and hire outlets needs to be performed.
- Based on the results of these two reviews, Australian policies may need to be reviewed.

ENVIRONMENTAL FACTORS

Cross-country skiers often ski away from resort areas, alpine ski slopes and established trails. However, an increasing number of skiers are seen to be telemarking down ski runs. Environmental factors are important in both alpine and cross-country skiing. Ski patrols report that they use injury data collected throughout the season to monitor injury rates and take targeted remedial action if particular patterns are appearing. The effectiveness of various methods of hazard identification and mitigation have not been formally evaluated. Standardisation of policies and methods for hazard identification and mitigation and injury severity scores assist in comparisons of techniques and resort areas, and the monitoring of the effectiveness of interventions.

Recommendations for further research, development and implementation

- Standardisation of policies and methods for hazard identification and mitigation
- Consider a pilot test and validation of the calculation of injury severity scores and corrected injury severity scores to aid in ongoing assessment of slopes.
- More formal evaluation of the effectiveness of hazard identification and mitigation in injury reduction is needed.
- Continued support for the ski patrol role in the identification and removal of hazards.
- Attention to cross-country skiing injuries in data collections and identification of those that occur on resort ski runs.

SKI PATROLLERS, FIRST AID, RESCUE EQUIPMENT AND RESORT SAFETY

The organisation of emergencies services, selection and maintenance of equipment, administration of first aid treatment, transport and the use of trained personnel have been identified as important aspects of a service to administer first aid to skiers. Ongoing injury surveillance (especially by ski patrollers) can identify slopes or trails where a number of injuries have occurred and assist in focusing hazard identification and mitigation and injury prevention. Action may involve advice to resort management, a speed control program, promotion of safety helmets, trail or ski run closure, signage or obstacle markers or avalanche danger control. Ongoing surveillance can also assist in evaluating the effectiveness of interventions.

Recommendations for further research, development and implementation

- Standardise data collection by ski patrollers and all Australian ski resorts and include information on weather and snow conditions and terrain.
- Review the incident/injury report forms used by ski patrollers to maximise the use of information for injury research and monitoring, with particular attention to cross-country skiing injuries.
- Consider methods for the collection of injury severity data and the potential for standardisation of this.
- Standardise the age groups used for statistical comparisons in the analysis and reporting of injury data.
- Further develop injury surveillance programs for a range of snow sports.
- The standardisation of data collection across all Australian resorts would provide an improved data base for research, statistical comparisons, surveillance, the monitoring of injury trends and evaluation of the effectiveness of interventions or injury control programs.

- Continue to support the Ski Patrol Association.
- Make available at least one Global Positioning System unit at all ski resorts.
- Investigate making alerting devices, eg mobile phones or transmitters, available to skiers to alert ski patrols and to identify location if lost or injured.
- Continue to promote safe driving in the mountains.

CONCLUSIONS

The technology and techniques of cross-country skiing have developed at a rapid pace over the last 10 years, but cross-country injuries have not been subjected to the same degree of research and countermeasure development as alpine skiing injuries. Studies on cross-country skiing injuries are complicated by the lack of a large injury data base, little information about the population at risk and smaller numbers of skiers and injury cases for comparative purposes and trend analysis.

Cross-country skiing injuries, the bio-mechanical and equipment related factors and epidemiological data, have not been as well studied as alpine skiing. Little is known about cross-country skiers, their characteristics, aetiology and injury patterns, equipment related factors and the relationship between injury patterns as determined by epidemiological studies and causal factors such as skiing ability, equipment snow conditions and terrain. Some cross-country injuries are similar to those among alpine skiers. This suggests that countermeasures that have been effective in preventing alpine injuries, such as improvements in equipment design, may also prevent cross-country injuries. More attention needs to be directed towards cross-country skiing from a safety point of view, from data collection and epidemiology studies of injury patterns to the bio-mechanics of injury and the safety of equipment.

1. INTRODUCTION

Alpine sports, including cross-country skiing, are growing in popularity in Victoria, Australia. The official season is from the Queen's Birthday weekend in June through to late September. Although participation in skiing in Australia has been estimated at 10-12% of the population, the true level of "real" skiers is likely to be closer to 5%, with an annual growth rate of 1.5%. In comparison, about 8% of the population of the United States or Canada ski (Fetterplace, 1995), and a greater proportion of Scandinavians.

Essentially there are two broad categories of skiing: alpine (or downhill) skiing and nordic (or cross-country) skiing. In reference articles, and in Australia generally, the terms downhill and cross-country skiing are more commonly used, respectively, and these will be used in this document. Cross-country skiing includes ski-touring (usually away from defined resort areas), defined trail (or track) skiing using the diagonal stride or skating techniques, and cross-country/downhill skiing (sometimes on the regular ski runs). Snowboarding is another alpine sport that is popular with younger people and developing rapidly.

Resort surveys have estimated the breakdown of alpine sports participants to be alpine skiers (75%), cross-country skiers (20%) and snowboarders (5%) (Fetterplace, 1995). Within each of these sports there is a broad range of standards and ages of participants. The term "recreational skier" will be used to define a person who is skiing in a non-professional capacity.

Commercial development of skiing has progressed since the mid-1950s, and skiing is an established sport enjoyed by over a million Australians every year (Sherry and Fenelon, 1991). Skiing is a sport that requires specific equipment. The technological aspects of this equipment and the associated injury patterns have changed over time. Skiing is also a physically demanding sport that requires strength, flexibility, endurance, good anticipation and reflexes. Persons with various types of neuromuscular, orthopaedic or sensory disability can also participate and compete in alpine sports.

Snow sports are undertaken in conditions and an environment that change throughout the day and from one day to the next. Whilst this is part of the attraction of the sport and the experience of being in the mountains, skiers may not be adequately prepared for these changes. The skier, ski equipment and the environment all play a role both in the occurrence of injuries and their prevention.

There is considerable scope for injury prevention in terms of the equipment used by skiers and their ability, fitness, attitude and behaviour on the slopes. A considerable amount has been published on the epidemiology and biomechanics of skiing injuries with informed or expert conclusions on the contribution of equipment or skier behaviour. There is however a noticeable lack of formal, controlled evaluations of the effectiveness of injury prevention countermeasures in skiing. Consistent epidemiological surveillance of skiing injuries on a state and national basis is another important aspect of an injury prevention program.

2. AIMS

The overall aim of this report is to critically review both formal literature and informal sources that describe injury prevention measures, or countermeasures, for cross-country skiing. In doing so, it provides an evaluation of the extent to which these countermeasures have been demonstrated to be effective.

Unlike other reports of cross-country skiing, this report does not focus mainly on the epidemiology of skiing injuries. Rather, this report presents a detailed examination of the range of countermeasures promoted to prevent such injuries. However, a brief overview of the epidemiology of skiing injuries, particularly from an Australian perspective, is given to set the scene for the subsequent discussion of countermeasures.

In this report, the countermeasures discussed are widely promoted to prevent cross-country skiing injuries. Detailed reviews of the countermeasures to prevent alpine skiing and snowboarding injuries can be found elsewhere (Kelsall and Finch, 1996a; Kelsall and Finch, 1996b). Some of the more general countermeasures relate to injury prevention in all three alpine sports.

3. METHODOLOGY

The sources of information used to compile this report were:

- Medline CD-ROM for published medical literature (over the past 10-15 years)
- Sport discus CD-ROM search for published sports literature (over the past 10 years)
- injury conference proceedings scans
- information presented at the 1995 Alpine Safety Conference in Melbourne, November 1995
- discussions with key Australian researchers and sporting organisations
- correspondence with relevant state and national sporting organisations
- correspondence with relevant researchers registered by the National Sports Injury Research Centre
- a posting to the Injury List on the Internet
- Standards Australia
- world-wide standards index on CD-ROM 1995/96 issue. US Database: key words of helmet, sport, recreation
- information prepared by the Victorian Skiing Association
- NEXUS database scan on the keyword skiing
- scanning of other Internet and world wide web sites.

This review is based on English-language material only. It is acknowledged, however, that some of the European skiing injury information is published in foreign languages and that these articles may have some relevance to this report. Foreign-language articles with English abstracts have been included in this review where appropriate.

The literature gathered for this review was critically assessed to determine the extent to which the various countermeasures had been fully evaluated and demonstrated to be effective in preventing injuries. A gradation scale for the strength of the evidence presented in the identified literature was developed. This is shown in Figure 1.

Figure 1: Grading scale for assessing the extent to which countermeasures have been fully evaluated

STRENGTH OF THE SCIENTIFIC EVIDENCE	TYPE OF SCIENTIFIC EVIDENCE
least ↑	anecdotal or informed/expert opinion
	laboratory-based/equipment testing
	data-based evidence (uncontrolled)
↓ **most**	controlled evaluations

This scale reflects a public health approach to injury prevention that considers demonstration of the effectiveness of a countermeasure's performance in the field to be the highest level of 'proof'. This is particularly important for sports injury countermeasures where any change to the nature of the sport is an important factor to be considered. In general, changes to factors such as how the game is played, the behaviour of the participants and the level of enjoyment can only be measured during "in-the-field" evaluations.

At the "least" evidence end of the scale are anecdotal reports of injuries and their prevention and comments based on informed or expert opinion. This category would include, for example, statements like "I treated 5 cases of concussion during last year's ski season and all would have been prevented if they were wearing a helmet at the time" or "none of the children I treated last year had had their bindings properly adjusted before skiing".

Laboratory-based evidence is a very important source of information about sports injury countermeasures. In this category, we include reports that have explored equipment design and testing, development of standard testing procedures and biomechanical research, including that performed on animals, cadavers and simulated body tissue such as crash-test dummies. Such information provides detail about the extent to which countermeasures such as protective equipment and properly designed skiing equipment (eg bindings) perform under certain stress and/or impact conditions. This research is generally performed under laboratory conditions which are often controlled. However, such conditions are often not a good representation of actual field or playing conditions.

Data-based evidence can take a number of forms. Case-series studies or routine surveillance systems document the incidence of new injury cases over periods of time. Patterns in this data can be examined over time to draw conclusions about the value that countermeasures may have on injury rates. Cross-sectional epidemiological studies provide some information about injury prevalence at a given point of time but are unable to assess the influence of countermeasures on injury rates. Quasi-experimental studies are not controlled evaluations but do enable a comparison of pre-intervention with post-intervention data to examine the effects of some countermeasures.

Controlled evaluations provide the most definitive evidence for the effectiveness of countermeasures. In such studies, the units of interest (ie skiers, resorts, types of equipment, etc) are randomly assigned to test and control groups. Case-control studies and longitudinal (cohort) studies are common forms of controlled studies. However, a randomised controlled trial is considered to provide the best evidence.

Another important aspect of countermeasure implementation is the extent to which they are accepted or adopted by the users for whom they were intended. Countermeasures must be acceptable to those they were designed to protect. Community consultation and awareness programs must therefore be considered in any implementation process. It is also important to assess barriers towards use of injury countermeasures and an examination of attitudes, knowledge and behaviours is crucial to this. Studies looking at these factors are generally conducted after implementation of a countermeasure and can highlight the need for behavioural or educational change at either the individual or organisational level. Because of the importance of this sort of research, the literature describing these studies is also included in this review.

Another measure of the success of countermeasures is a demonstration of their benefit/cost ratios. This information is often needed by regulatory bodies and those involved in policy or rule making to inform their decisions about countermeasures. Unfortunately, studies of the economic benefits of sports injury countermeasures are rare, to date. Where they have been found, they have been included in this review.

4. WHAT IS CROSS-COUNTRY SKIING?

Rock carvings depicting a skier that were discovered in Rødøy, North Norway in 1933 have been dated to be 4000 years old. Since then, cross-country skiing has been used as a means of transport in winter, in hunting and military operations (Ekstrom, 1987). Cross-country skiing has increased in popularity. As a sport, cross-country skiing has developed considerably since the 1980s. Improvements in technology and design of equipment and clothing can meet specific requirements of different aspects of the sport.

Cross-country skiing can be one of the most demanding of all sports, involving most of the body's muscles. It also requires a sustained elevated level of cardiovascular and respiratory output. It is ideal as a recreational sport, and can be enjoyed by individuals of all ages. The standard can vary from "ski-walkers" to elite athletes. About 10 to 20% of cross-country skiers may be classed as active skiers, the remainder as "ski walkers" (Gillette, 1980).

In general, cross-country (or nordic) skiers ski on more gentle gradients and at slower speeds than alpine skiers. The slopes may be groomed with tracks cut, or ungroomed. Cross-country skiers tend to be older. Cross-country skiing is however a more physiologically demanding sport, and skiers may become fatigued earlier. Elite cross-country skiers have the highest oxygen uptake of all sports (Karlsson, 1984).

Techniques in cross-country skiing involve the traditional diagonal striding, a marathon skate technique, variations of V-skating with or without double poling, or other combinations of the skating or poling techniques (Renstrom and Johnson, 1989). Top level skiers can reach speeds of up to 6 metres/second in diagonal striding, 8 to 9 metres/second in skating and 60 to 80 km/hour on downhill slopes. To increase their stride length, skiers must increase endurance as well as the forces generated by their muscles. The repetitive nature of the technique can render them susceptible to overuse injuries (Renstrom and Johnson, 1989).

There have been major technological advances in cross-country ski equipment from solid wooden skis and ski poles to synthetic equipment incorporating carbon and Kevlar fibres. The length, width, camber and weight of skis and poles has also changed. This equipment is now lighter, faster and more responsive. With improvements in mechanical racing track setting procedures and waxes, speed and performance in racers have improved dramatically. These advances have generally taken place over the last 17 years (Street, 1992; Renstrom and Johnson, 1989; Ekstrom, 1987). Quality control in the manufacturing of cross-country skis requires compliance with the standard norms of International Organization for Standardization (ISO) ISO 7140 7797 (International Organization for Standardization, 1982a; International Organization for Standardization, 1982b).

There are various ways skiers can participate in, and enjoy, cross-country skiing and the equipment has been designed to suit the particular requirements of the various aspects of the sport. Cross-country skiing includes ski-touring (usually skiing away from defined resort areas), defined trail (or track) skiing using the diagonal stride or skating techniques, and cross-country/downhill skiing (combined with ski touring or sometimes on the regular ski runs).

The technology and techniques of cross-country skiing have developed at a rapid pace over the last 10 years (Ekstrom, 1987). However, cross-country injuries have not been subjected to the same degree of analysis as those associated with downhill skiing (Shealy and Miller, 1991). Downhill skiing is generally more organised, taking place in defined resorts. This makes it relatively easier to gather injury and participation data. Studies on cross-country skiing injuries are complicated by the lack of a large injury and participation data base and little information about the population at risk and smaller numbers of skiers and injury cases. One must therefore be careful in drawing conclusions, but cross-country skiing may not be as benign as people tend to think (Shealy and Miller, 1991). Such comments on the difficulties of data collection and analysis in relation to cross-country skiing have been made in relation to Europe and the United States, but would be equally applicable, to Australia.

5. AN OVERVIEW OF THE EPIDEMIOLOGY OF CROSS-COUNTRY SKIING INJURIES

Australian resorts and conditions are often different from those of Europe or the United States (where most of the research has been done), and this can also make international comparisons of injury rates difficult. Equipment used in skiing in Australia is similar, however, and the countermeasures are comparable.

Ski patrol data collection and statistics are the main source of both alpine and cross-country skiing injury data in Victoria and Australia. In Victoria, if a patroller is called to respond to an incident, the call is noted in a log book, and the patroller responds and tries to find the person. The call is referred to as a "dispatch" or a "call-out". If the person is not found or has moved on, the call is referred to as a "stand-down". If the incident or injury is minor and treated on the slope, no "Ski Patrol Accident Report" form is completed. If the person needs further medical intervention, at the patroller's discretion, they are transported to the Medical Centre. A Ski Patrol Accident Report form is then completed and this forms the basis of data collection. The patrollers' diagnosis recorded on this form is not corroborated with a final diagnosis.

On the basis of Ski Patrol records at Victorian resorts in 1994, skiing injury rates were estimated to be between 1.5 and 3.9 injuries per 1000 visitor days (Parfitt, 1995). In 1988, the rate was 2.4 injuries per 1000 visitor days or 1.9 per 1000 skier days (Fetterplace, 1995). Comparison of these rates, indicates a decline in skiing injuries over time in Australia. For example, the injury rate in Perisher Valley dropped from 10.90 per 1000 skier days in 1962 to 3.22 in 1988. This was a statistically significant annual decline of 2.8% per annum for the whole period (Sherry and Fenelon, 1991). The injury rates in Australia are similar to those reported internationally which vary from 0.8 to 9.1 per 1000 skier days with a "benchmark" mean of 3.65 per 1000 skier days (Lamont, 1991).

There are a number of difficulties in accurately comparing trends over time and between resorts and between countries. These include differences in the original populations from whom data was collected (eg ski patrol clients, patients at injury clinics, special surveys, etc) and in the denominator definitions (*skier days* or *skier visits*). The mix of injuries has altered more than the actual rate of injury over time. Injuries have shifted away from the lower limb towards the upper limb, shoulder and head. With respect to knee trauma, however, there has been an increase in ligamentous damage (Lamont, 1991; Johnson et al, 1989).

According to ski patrol records, approximately 400-500 people are transported to the Medical Centre at Mt Hotham resort each year. A further 100-200 minor incidents or injuries are treated on the slope. The 1995 "Summary-Resort Accident Statistics" are presented as the *number of call-outs/1000 visitor days*, the types of injuries, the numbers of cases requiring ambulance transport off the mountain and the number of fatalities. In the 1995 Victorian season there was an average of 2.8 callouts/1000 visitor days for all resorts(Alpine Safety Conference, 1995).

A 32-year study of skiing related deaths in the Snowy Mountains reported an overall incidence of 0.87 deaths per million skier days. This rate was broken down into 0.24 for trauma-related, 0.45 cardiac-related and 0.18 hypothermia-related deaths per million skier days (Sherry and Clout, 1988).

Estimates of the rate of injuries in cross-country skiing are 0.72 per 1000 skier days (Boyle et al, 1985) and constitute 15-20% of all ski injuries in areas where cross-country and alpine skiing are practiced (Boyle et al, 1985; Heuman et al, 1984). Studies in the mid 1970s estimated the injury rate to be from as low as 0.2 per 1000 skier days up to 1.5 to 2.0 per 1000 skier days (Renstrom and Johnson, 1989).

Cross-country injuries tend to occur at particular times of the day, with peaks occurring at about 1 and 3 pm and most injuries occur in the afternoon (Westlin, 1976).

Comparison of different types of skiing injuries can be difficult. Reasons for this are variations in specificity of the diagnostic categories presented in different studies, variations in the sample population from whom the data was obtained (hospital, injury clinic or prevalence survey) and the different conditions encountered in the country in which the study was undertaken.

Downhill skiing is characterised by its degree of organisation, taking place in managed resort areas with ski lifts and ski patrols and medical facilities. Cross-country skiing is less formally organised, although maintained and marked trails are provided in some mountain areas. This presents problems in establishing accurate injury rates in cross-country skiing, which can take place wherever snow is available (Renstrom and Johnson, 1989). Other difficulties relate to lack of data on the population at risk, relatively small numbers in some studies, and under-reporting of minor injuries or overuse injuries (Renstrom and Johnson, 1989).

Boyle et al (1985) conducted a prospective study over 2 seasons of the incidence of cross-country skiing injuries at ski touring centres in northern Vermont, USA. Skiers on the trails or in lodges were selected as controls in the second season. The numbers were fairly small with 21 injured skiers and a total of 24 injuries in 14,000 skier days in the first season (with 26 controls); and 22 injured skiers with 25 injuries and 45,000 skier days in the second season (with 59 controls). Of the 49 injuries sustained by 43 skiers, upper extremity injuries accounted for 41%, lower extremity 49% and face, head and trunk 10% of injures. Slightly more than half the injured and control skiers were male, and beginners and intermediate skiers formed 81% of the touring centre population.

The estimated injury rates were 1.5 and 0.48 injuries per 1000 skier days for 2 consecutive seasons. The combined injury rate was thus 0.72 per 1000 skier days. The higher rate in the first season was attributed to an unusual season with light snow conditions and lower attendances. As in alpine skiing, level of skill can influence the injury rate. However, this study found no significant differences between the self-assessed skiing ability of the injured and control groups. Of the control groups, 79% had some previous downhill skiing experience compared to 33% of the injured group. The control group had an average of 4.3 years of previous cross-country experience compared to 3.5 years for the injured population. The analysis of ski lessons for both groups was not detailed to make valid conclusions about their effect on injury rates.

Over 80% of both injured and control skiers used touring equipment, and the remainder used racing equipment. The use of rented of borrowed equipment was 13% in the control skiers and 23% in injured skiers. All skiers use either a standard serrated heel plate or a ridged heel plated with a grooved boot heel. The proportion of skiers using serrated heel plate was 89% in controls and 67% in injured skiers. The ridged heel plate was used in 11% of controls and 33% of injured skiers. Eighty percent of the control population and 50% of the injured population used “Nordic-norm” bindings. Touring or racing norm 50 mm bindings were used by 12% of the control and 27% of the injured populations. The 38 mm norm bindings were used by 8% of the control and 18% of the injured skiers.

Based on self reporting, most incidents resulted from falls that followed loss of ability to maintain proper balance, such as loss of edge control or catching a ski tip. Most injuries resulted from impact with the snow surface (21 injuries) or impact with objects (10 injuries).

The equipment is least suited for the downhill phase of cross-country skiing. Injured skiers reported that their injuries occurred when skiing on downhill terrain (88.4%), on flat terrain (4.7%) or mild uphill terrain (2.3%). All but 2 skiers (4.7%) were injured on prepared trails. Twenty-seven (62.8%) were injured on tracked trails and 14 (32.5%) were injured on untracked but prepared trails. Recording of the data on snow conditions at the time of injury was reported to be of questionable validity by the researchers (Boyle et al, 1985).

Based on a retrospective analysis of downhill and cross-country injuries through the Consumer Product Safety Commission National Electronic Injury Surveillance System data files and a survey of skiing population demographics, the age and gender distribution of the populations were similar as was the nature of injury. In the analysis of injury severity rating there was no significant difference between the two sports (Shealy and Miller, 1991). The table below presents their findings.

Table 1: Comparison of injuries in alpine and cross-country skiing

Diagnosis	Skiing style: alpine %	Skiing style: cross-country %	Body part	Skiing style: alpine %	Skiing style: cross-country %	Skiing style: ratio (of alpine to cross-country)
Strain/sprain	42.7	42.9	Head/face/neck	9.5	5.9	1.6
Abrasion/bruise	23.4	17.7	Shoulder	7.7	10.1	0.8
Fracture	21.7	25.2	Hand/wrist/ arm/elbow	7.5	13.4	0.6
Laceration	5.0	7.6	Finger/thumb	17.0	10.9	1.6
Dislocation	2.6	5.0	Torso	7.8	10.1	0.8
Concussion/ head injury	2.6	1.7	Upper leg	1.7	0.8	2.1
All others	2.1	0.0	Knee	26.5	26.1	1.0
			Lower leg	11.2	4.2	2.7
			Ankle	9.0	11.8	0.8
			Foot/toe	2.1	6.7	0.3

Source of table: (Shealy and Miller, 1991)

In another study of cross-country skiing injuries in Vermont, upper extremity injuries accounted for 40.8%, lower extremity 48.9% and head, face and trunk 10.2%. Most injuries occurred in beginners or intermediate skiers and on downhill terrain. The injury rate was 0.72 per 1000 skier days (Boyle et al, 1985).

A retrospective study compared 88 cross-country skiing injuries treated at the Perisher Ski Injury Clinic in NSW in 1984 and 1985 with data on alpine skiing injuries compiled from medical records of the same clinic (Sherry and Asquith, 1987). The size of the population at risk was obtained from gate counts on the main access road of the number of persons who intended to ski cross-country for one full day in the National Park. The denominator population was calculated to be 180118 cross-country skier days.

The 1985 nordic (cross-country) skiing injury rate was 0.49 per 1000 skier days and the alpine injury rate was 3.54 per 1000 skier days (Sherry and Asquith, 1987).

The average age of injured cross-country skiers was 31 years and that of injured alpine skiers was 22 years (Sherry and Asquith, 1987). A significant difference with respect to age and gender between populations of injured cross-country and alpine skiers was also reported in a United States data base study. The injured cross-country skiing population tended to be older and more likely to be female than the injured alpine population (Shealy and Miller, 1991; Shealy, 1985).

Cross-country skiers in the Australian study (Sherry and Asquith, 1987) sustained significantly more injuries to the ankle and upper limb than alpine skiers (Table 2). A rating scale from Grade 1, equal to minor injuries (eg mild knee sprain) to Grade 5; equal to death or loss of limb was used to assess the severity of the injury. Grade 1, 2 and 3 injuries were treated at the resort and Grade 4 and 5 required evacuation to hospital. Nordic skiers incurred significantly more Grade 2 and 4 injuries than did alpine skiers, but alpine skiers had more Grade 3 injuries (Sherry and Asquith, 1987).

Table 2: Comparison of alpine and cross-country skiing injuries in Australia

Type of injury	Alpine skiing %	Nordic skiing %	Body region	Alpine skiing %	Nordic skiing %
n	1545	88	n	1538	88
Sprain/twist	41	45	Head/face	16	9
Bruise	14	16	Shoulder	9	9
Fracture	15	19	Arm	9	18
Laceration	20	11	Thumb	7	8
Dislocation	6	5	Trunk/spine	7	5
Concussion	3	3	Leg	17	11
			Knee	31	25
			Ankle	4	15

Source: Sherry and Asquith, 1987

The incidence of skiing injuries is lower in cross-country than alpine skiing, but cross-country skiers experienced a greater proportion of more severe Grade 4 injuries. Approximately 50% of the injuries occurred in the lower extremity in both alpine and cross-country skiing. A greater proportion of upper extremity injuries (including the shoulder) occurred in cross-country skiing (35%) when compared to alpine skiing (24.5%) (Sherry and Asquith, 1987).

A Norwegian study calculated injury rates based on the number of injuries in skiers using different equipment and a denominator population of the lift transports. These rates were used to determine the relative percentages of injuries as alpine skiers (85%), telemark skiers (12.5%) and snowboarders (2.5%) (Ekeland, 1995). As most cross-country skiers do not use lifts, this may have underestimated the percentage of cross-country skiers amongst all injured skiers.

Although an English article on ski trauma did not cite its data source, approximate injury rates for the different types of skiing were estimated to be downhill 3-5, snowboarding 1-4, cross-country 0.2 and ski jumping 4-9 per 1000 skier days (Crisp, 1995).

6. AN OVERVIEW OF INJURY COUNTERMEASURES FOR CROSS-COUNTRY SKIING

Injury countermeasures are measures that can "counter", prevent or reduce the risk of injury. A number of researchers have described how countermeasures should be targeted at the different links in the chain of events leading to injury (Haddon, 1972; Ozanne-Smith and Vulcan, 1992; Watt and Finch, 1996). Such injury countermeasures can be equated with primary (pre-event), secondary (event) and tertiary (post-event) prevention in the chain of events in an injury.

Primary countermeasures act before an event or incident that could potentially lead to injury to prevent the injury from occurring in the first place. Table 3 lists some of the major primary (pre-event) countermeasures for cross-country skiing.

Table 3: Primary (or pre-event) measures to prevent or control cross-country skiing injuries

• Pre-season conditioning and fitness programs • Adequate warm ups • Skiing technique • Equipment factors (eg, skis, boots, bindings, ski poles, eyewear, clothing, helmets) • Adherence by skiers to the skiers' safety and courtesy codes • Ski patrollers • Environmental factors (eg. condition and design of ski trails) • Skier education programs • Skiing instruction and expertise of instructors • Limiting alcohol intake • Adequate supervision of children • Use of safety equipment.

Secondary countermeasures act during the event of incident to prevent the injury occurring or to reduce the severity of the injury. Table 4 summarises the secondary countermeasures for cross-country skiing injuries.

Table 4: Secondary (or event) measures to prevent or control cross-country skiing injuries

• Condition of ski slopes and environmental factors • General sports equipment (ski pole handle design, standard of bindings, ski boots) • Weather conditions • Skiers' conduct code and speed control • Protective equipment (helmets, eyewear)

The third level of countermeasures act after the chain of events/incident leading to injury and help to minimise the consequences of injury. These tertiary countermeasures are summarised in Table 5.

There is a multitude of factors that contribute to the risk of injury in skiing. Generally, more than one factor is involved in each injury.

Table 5: Tertiary (or post-event) measures to prevent or control cross-country skiing injuries

• Availability of first aid equipment • Ski patrol assessment, treatment and transport • Prompt access to medical care • Alerting systems • Retrieval of injured skiers • Rest, Ice, Compression, Elevation, Referral of injuries • Adequate treatment and rehabilitation of injuries before resumption of skiing

Skiing requires muscle endurance, strength, flexibility and cardio-pulmonary fitness. The average recreational skier may ski for a limited period of time each year, without adequate preparation and with resultant fatigue. Conditions in Victorian and Australian alpine resorts are variable, and often unpredictable and difficult with characteristically icy conditions in mornings and late afternoons, and mid-afternoon "soup" or "slush". On other occasions, conditions can be absolutely wonderful. Collisions, particularly high speed ones, with other objects such as trees, equipment or other skiers, have been implicated in the most serious injuries. Protective clothing and eyewear (ski goggles or sunglasses) are essential for all of these conditions.

The forces transmitted through the lower limb to the boot/binding/ski system, and vice versa, in turning or responding reflexively to loss of balance can be large. Fixation of the heel with the extended leverage of skis, the movements involved in skiing and falling and the difficulty of bindings to adequately perform retention or release as required, leave the skier at risk of lower limb injuries. Historically, ski boots were lower and more flexible with fractures and sprains around the ankle. With higher, stiffer boots injuries have moved up the leg with an increase in the rates of twisting knee injuries and serious ligamentous damage in particular. Binding release systems have improved, but not yet able to meet the demands of skiing, and also need to be correctly adjusted.

The most common upper limb injury is to the thumb, and in this category to the ulnar collateral ligament of the metacarpophalangeal joint (UCLMPJ) of the thumb. Unfortunately, this injury is likely to be significantly under reported in general injury statistics. However, ski pole handle design has been implicated as a major factor.

In the forthcoming sections of this report, the literature assessing the effectiveness of the various countermeasures for the prevention of skiing injuries listed above will be reviewed. For each countermeasure, the rationale for its use as a safety measure is presented together with a critical review of the extent to which it has been fully evaluated. The various studies are summarised in more detail in tabular form in the Appendices.

The epidemiology of injuries in cross-country skiing and injury prevention countermeasures have not been as well studied as for alpine skiing. The general features of cross-country skiing equipment and countermeasures will be described and, where relevant, contrasted with that of alpine skiing.

Risk factors for injury, especially in recreational skiers, include poor condition of ski tracks (deep tracks, ruts, iciness, sharp bends etc), unsuitable or inferior equipment (slippery glass fibre skis, wrong type of wax, ski bindings which are not released when the skier falls), poor balance and inadequate mastery of the cross-country skiing technique (Kannus et al, 1988).

The equipment used in the variations of cross-country skiing is also quite different from that used in alpine skiing. Features of cross-country ski equipment that are relevant to performance include the ski width and length, stiffness of the mid-camber of the ski for sufficient grip during the kick phase (which relates in part to skier's level of technique and body weight), the type of skiing to be done, the patterning or waxing of the bases, metal edges, ski bindings and boots (MacGregor et al, 1985).

Laboratory equipment has also been developed to assess cross-country skiers and the bio-mechanics and ergonomics involved in the sport. Co-operation between skiers, coaches, sports scientists and corporations could result in even greater developments and performance, and formation of a database on equipment could provide athletes and coaches with bench-marks for evaluation of new equipment (Street, 1992).

Cross-country ski bindings fix the forward tip of the boot while leaving the heel free to elevate from the ski. Pin bindings are the most commonly used being 50 or 75 mm wide (Bauman and Walkhoff, 1993). Some bindings are pin-less spring bindings which allow flexion within the binding instead of forcing the lip of the boot or the forefoot to bend when the heel lifts from the ski (Renstrom and Johnson, 1989). Cable or convertible bindings are also available for ski touring which allow fixation of the heel for a more conventional downhill turning technique.

As is the case in alpine skiing, a common mechanism of injury to the lower extremity is an external rotation abduction moment applied by an entrapped ski to the leg. The potential for torsion in a forward fall is less than in alpine skiing because the heel is not fixed (Renstrom and Johnson, 1989).

The binding release mechanism is not designed to release during a fall. One study (Ekstrom, 1987) of forces at play in the cross-country ski and binding system compared different ski and binding constructions. These are rather loosely related to the release settings of alpine bindings and the potential for injury. A release binding is recommended for skiers of beginner and intermediate standard (Ekstrom, 1987). This may well be reasonable but the reasoning or justification is not fully articulated.

Releasable cross-country bindings are reputably being developed, but as in alpine skiing, safe design and reliable performance criteria need to be met if they are to assist in injury reduction. A fractured ankle or tibia as the result of poor bindings or a severe fall, can have severe implications for skiers touring in the wilderness far from the immediate assistance of the ski patrol (MacGregor et al, 1985).

Although the heel position is generally not fixed to the ski as it is in alpine skiing, heel stabilisation during turning can provide better control. This can be achieved through certain types of heel design in the binding system that assist the heel in remaining in contact with the ski. Such designs include serrated heel plates, a rigid heel plate with a grooved boot or a peg and a locator type of heel plate. There may, however, be an increased risk of injury if the skier's weight cannot be removed from the ski during a twisting fall. As in downhill skiing, the ski acts as a lever about which the knee twists (Renstrom and Johnson, 1989). Biomechanical testing suggests that heel plates may be implicated in injury, but the results are inconclusive (Boyle et al, 1985).

The choice of ski boot depends on the activity for which they will be used, eg touring, racing or skating. The toe design needs to be compatible with the binding used. For traditional diagonal stride, the boot should be flexible at the forefoot and allow free motion at the ankle. For skating technique, however, a very rigid sole is needed on the boot. A boot which is flexible at the forefront is therefore not desirable (Barrow, 1996). Boots should fit well so blisters don't form.

Top grain leather boots are durable, water-proof and air permeable but Goretex and synthetic materials have also been used. Overboots can help protect in cold or slushy conditions. Racing boots have a plastic sole to ensure torsional stability (Renstrom and Johnson, 1989).

The upper body plays a more propulsive role in cross-country skiing than alpine, and more so in the skating than in the diagonal striding technique. Ski poles also vary in length, strength and weight and in diagonal striding top skiers can gain up to 30% of their forward thrust from poling and the strap is used to gain more power. The grip is usually with the wrist up and through the strap so that the hand grasps both the strap and the pole handle as in one of the methods described for downhill skiing. Cross-country skiers can also sustain thumb injuries in falls to the outstretched hand, and shoulder dislocation can result from entrapment of the ski basket on a tree branch (Renstrom and Johnson, 1989).

Over a period in 1985 to 1987 skating largely replaced the traditional diagonal striding as racing technique and revolutionised the sport. As discussed in Section 7.3, cross-country skiing technique has been the subject of research that relates particularly to the possibility of overuse injuries resulting from the use of different techniques.

Specific injuries (orthopaedic and non-orthopaedic problems), their management and rehabilitation are described by Renstrom and Johnson (1989).

Waxing of skis, snow conditions and tracks are important for enjoyable and safe cross-country skiing. A good grip for the kick involved in diagonal striding is assisted by steps or patterns on the bases of the skis, or by application of wax to the bases that is suitable to the snow conditions. In the kick, glide and pole phases of diagonal striding, if the ski backslips the thrust may be violent and can cause muscular or tendon problems especially in the groin or thigh area. This is not a problem with the skating technique (Renstrom and Johnson, 1989). The risk of slipping is greatest in icy conditions, whereas gliding in heavy snow is more tiring and can result in muscle fatigue.

Narrow downhill trails and trails with sharp corners can be hazardous. Skiers following closely behind a fallen skier may have no choice but to fall themselves. This is particularly important along trails where experienced and inexperienced skiers mix. Terrain adjacent to trails should be clear of branches or brush, especially at the eye and face level (Renstrom and Johnson, 1989).

Clothing should be warm, but should minimise perspiration. As in alpine skiing, layering is a key concept. The inner layer is important, and an inner layer of polypropylene or another porous material can transmit moisture away from the skin. Outer layers should insulate but also transmit moisture away from the skin. The stretch materials often worn by racers do not insulate well. The head and hands should be covered (Renstrom and Johnson, 1989).

Cross-country skis do not always have metal edges as do alpine skis. Cross-country skiers wear lower cut ski boots, made of materials that are less supportive of the ankle, and ski bindings are not releasable during a fall. The arms play a more active role in propulsion in cross-country skiing. These characteristics of the sport and its participants may explain some of the injury patterns in the comparison of cross-country and alpine skiing.

Cross-country skiers are more prone than alpine skiers to injuries relating to the arm, shoulder, twisting of ankles or knees, and even dislocation of knees. Factors that may contribute to injury risk in cross-country skiing are that skiers have not been taught how to fall, their personal technique, skiing off groomed slopes and poor track conditions. Equipment failure rarely contributes, in comparison to downhill skiing, where equipment failure is common.

There are, however, very adventurous cross-country skiers using cross-country/downhill or telemark equipment who ski difficult steep slopes within the resort or out of the resort in isolated areas. One of the great joys of cross-country skiing is the freedom to ski and experience the mountains away from the resorts, and the Victorian High Plains areas provide a magnificent opportunity for this. Skiers need to be adequately prepared to ski in such conditions, and delays in obtaining medical attention leave injured skiers vulnerable to complications.

There is high energy expenditure in sustained activity within this cross-country skiing, and the requirements for replacement of this energy and liquid replenishment for competing athletes have been described (Renstrom and Johnson, 1989). Although this is dependant in part on the level of activity within the sport, adequate energy and liquid replenishment is relevant to recreational skiers as well.

Cross-country skiing injuries, the bio-mechanical and equipment related factors and epidemiological data, have not been as well studied as alpine skiing. Relatively, little is known about cross-country skiers, their characteristics, aetiology and injury patterns, equipment related factors and the relationship between injury patterns as determined by epidemiological studies and causal factors such as skiing ability, equipment snow conditions and terrain.

Some of the types of injury in cross-country skiing are similar to those in alpine skiing that have been reduced by improvements in equipment. More attention needs to be directed towards cross-country skiing from a safety point of view, from data collection and epidemiology studies of injury patterns to the bio-mechanics of injury and equipment and the safety of equipment.

There is a growing interest in skiing downhill terrain that demands better edge control and support. A trend to more ability to lock the heel in turning manoeuvres, such as through heel plates or cable bindings, may increase the risk of injury in weighted falls. The numbers in one prospective study were too small to reach definitive conclusions about heel plates (Boyle et al, 1985) and the risk of lower limb injury, but the trends are ominous. More rigid locators such as peg-and-locator heel plates or alpine-type convertible mountain bindings produce even more rigid constraints of the heel during downhill turning and potential for injury exists in weighted falls (Boyle et al, 1985).

Problems in the available epidemiological evaluations of cross-country injuries include:

- possible differences between resort cross-country skiers and those who ski in more remote areas
- differences in equipment, techniques, abilities, experience and patterns of injury in cross-country skiers participating in the different types of cross-country skiing
- cross-country skiers are difficult to access as a population
- injury numbers are relatively small and make statistical comparisons difficult
- many years of study is required to evaluate trends, especially when equipment is rapidly evolving.

7. DETAILED REVIEW OF CROSS-COUNTRY SKIING INJURY COUNTERMEASURES

This chapter provides a detailed review of each cross-country injury countermeasure. Each section begins with a description of the rationale for the countermeasure, including a brief description of the biomechanics of the particular injuries being prevented. A summary of the studies evaluating each countermeasure is presented and details of the studies can be found in the appendices. Finally, suggestions for further countermeasure research, development and implementation are given.

7.1 SKI POLE HANDLE AND SKI GLOVE DESIGN

7.1.1 Background

Injuries to the thumb are the most common upper extremity injury in skiing. Upper extremity injuries account for about 17-25% of all alpine skiing injuries (Carr et al, 1981; Fairclough and Mintowt-Czyz, 1986). In one study of upper extremity alpine skiing injuries, 40% involved the thumb, and of these 80-85% included injuries to the ulnar collateral ligament of the metacarpophalangeal joint (UCLMCJ) of the thumb (Carr et al, 1981). In other surveys, 60-71% of thumb alpine skiing injuries involved an injury to the UCLMCPJ (Fairclough and Mintowt-Czyz, 1986). The injuries can occur in all directions of fall, although a forward fall is more commonly reported (Carr et al, 1981).

Upper extremity and thumb injuries also account for a significant proportion of cross-country skiing injuries (Shealy and Miller, 1991), with shoulder injuries accounting for 10.1%, hand/wrist/arm/elbow injuries for 13.4% and finger/thumb for 10.9% of all injuries (see Table 1). Sherry and Asquith (1987) found that thumb injuries accounted for 8% of all cross-country injuries (Table 2).

Thumb injuries are rarely disabling at first and injured skiers often do not seek medical attention. This means that there may be considerable under reporting of these injuries in the formal statistics. A survey of skiers found that 23% had injured their thumb at least once, and only 27% of these had reported the injury (Carr et al, 1981). Optimal hand function for most daily living and sporting activities requires stability of the thumb and for this the UCL MCP joint prevents radial deviation. These injuries can carry a risk of disabling chronic injury if not treated adequately and some require surgery (Fricker and Hintermann, 1995).

The trauma mechanism for this type of injury is forced abduction and extension of the thumb. It is generally reasoned that retention of the ski pole in the hand during a fall is relevant to injury (Carr et al, 1981; Fairclough and Mintowt-Czyz, 1986; Ekeland and Nordsletten, 1994; Fricker and Hintermann, 1995). Rotation of the metacarpophalangeal (MCP) joint when the tip of the skier's thumb comes in contact with the snow has been proposed as a contributory factor (Lamont, 1989). There is a lack of similar injuries in other sports that involve falls onto the outstretched hand (Fairclough and Mintowt-Czyz, 1986). Such injuries sometimes occur in sports where there is direct ball to thumb contact (Fricker and Hintermann, 1995). Another suggestion is that the thumb is forced into an abduction/hyperextension position and in this position is jammed into the snow and this leads to the injury (Fairclough and Mintowt-Czyz, 1986).

Countermeasures relevant to this type of injury include the design of the ski pole handle, the way the skier grips the pole, training skiers to discard poles during a fall (Morrissey et al, 1987; Fricker and Hintermann, 1995), a specially designed ski glove that assists release (Fairclough and Mintowt-Czyz, 1986), learning to fall correctly using shoulder-trunk rolling in a way that does not expose the shoulder, neck or head to injury (Morrissey et al, 1987) and strengthening the thumb musculature through pre-season ball squeeze exercises to prevent forced abduction and extension (Morrissey et al, 1987).

Ski poles (or stocks) are carried by both cross-country and downhill skiers, but not snowboarders. Ski poles used by cross-country skiers are longer and have narrowed handles, compared to alpine ski poles. Skiers use them to push themselves along on the flat or uphill and as part of the skiing turn. The research on ski pole handle design has been done in relation to alpine skiing. It is none the less relevant to cross-country skiing upper limb injuries and their prevention and for that reason some of this research is presented in this report.

There are generally three types of handles:

(a) an ordinary handle with the strap connected to the upper part of the handle

(b) a handle with a broad plate on top under which the strap is attached

(c) a handle without a strap and a front bow (often referred to as new grip, pistol or sabre).

A variety of ski poles have been designed, and different methods of holding them advocated, to ensure that the released ski pole will release from the hand during a fall. However, the impact of these measures is not reflected in a reduction in injury rates according to some researchers. This is the rationale behind their design of a webbed ski glove to prevent an UCLMCJ injury (Fairclough and Mintowt-Czyz, 1986).

Another significant upper limb injury is that of shoulder dislocations. Such injuries accounted for 3.7% of injuries in a 1982 study, and bone fracture or nerve injury can be involved. Reduction of the injury site is done as soon as possible, often at the ski resort medical centre. Subsequent immobilisation and rehabilitation are an important part of the management. Limitation of range of movement, recurrent dislocation, neurological sequelae and pain or discomfort under stress can be disabling sequelae (Binet et al, 1985).

Shoulder dislocation was the focus of a retrospective study (Binet et al, 1985) based on 1338 dislocations seen by 11 ski resort consulting rooms in France in the early 1980s. This injury occurred most commonly in adult males (79%) and most commonly on days when the snow was frozen and hard. Eighty-eight percent of dislocations were reduced in the doctor's rooms by simple manipulation without the use of general anaesthesia. Several recommendations in terms of reduction of shoulder injuries were made, and are presented in the following section.

7.1.2 Evidence for the effectiveness of ski pole handle or glove design

As stated previously, the evidence for the effectiveness of ski pole handle of ski glove design comes from studies of alpine skiers. Nevertheless, there are some obvious parallels with cross-country skiers, particularly when a similar mechanism is responsible for the injury.

Thumb injuries, and in particular injuries to the UCLMPJ, are common in skiing and may be chronically disabling if inadequately managed. There is likely to be under reporting of these injuries by skiers and thus an underestimation of the problem in formal injury statistics. The available research for alpine ski pole design consists of: epidemiological studies of injury patterns, exploration of the association between handle design or the method of holding the ski pole strap with injury rates, an ergonomic evaluation of the mechanism of injury and the contribution of ski pole handle design to this and one prospective study of the influence on injury rates of providing alpine skiers with ski poles with a new "sabre" design of handle and a ski glove design.

A study in which a randomly selected group of 160 alpine skiers was sent ski poles with a new type of bowed grip (Hauser, 1989) found a decreased number of thumb injuries in this group (3%) compared to a control group of skiers (4%). Although the percentage is less, no test of statistical significance was reported in relation to this difference. This makes conclusions about the effectiveness of the special bowed ski pole grip in reducing injuries is less definitive.

If discarding of the pole were important, it would be expected that the position of the strap in relation to the hand would have made a difference. However this did not seem to be the case. It was noted, however, that World Cup racers retained ski poles in their hand throughout a fall (although whether they actually wore straps was not stated). It may be a natural reflex to retain one's grip and the strap may not influence this. It was not considered justified to use a handle design that prevents opening of the hand in a fall, as this may lead to more serious injuries. Only small numbers and percentage of skiers in both the sample and control groups used the new "sabre" handle design. It may therefore be premature to discount the potential value of this design.

A survey of base lodge skiers (Carr et al, 1981) was unclear about a number of factors including the denominator population and the relation to percentages cited and the study's use of controls. Of the 408 skiers interviewed, 329 skiers (81%) had straps on their poles. The proportions of skiers receiving thumb injuries using the various grip techniques were: outside straps (5%); straight through (21%); up, through and down (25%); "new grips" (pistol, sabre and pullout grips) (27%). Firm conclusions would be difficult to draw from this study given its design, particularly the lack of controls, and reporting of results.

The feasibility of altering a reflex action in the difficult positions skiers often find themselves in during a fall has not been examined further. A handle designed to retain the pole firmly in the hand, without the reflex opening of the hand or abduction of the thumb, may in turn put the skier at risk of other more serious hand injuries.

No type of ski pole in general use today eliminates the risk for injury. Innovations in ski pole handle design have not been associated with a decreasing trend in thumb injury rates (Fairclough and Mintowt-Czyz, 1986).

A ski glove designed to eject the ski pole on falling is an interesting concept. To be effective it would have to be worn without the skier's hand through straps on the pole. The appearance (as schematically illustrated in the article) may deter consumers, but this could possibly be refined. Formal testing of the glove was not reported (Fairclough and Mintowt-Czyz, 1986).

There has been no formal evaluation of the proposed ski glove, falling technique, or pre-season exercises for strengthening thumb musculature.

Appropriate examination and management of thumb injuries are important, not only to prevent further damage during the examination but also to detect injuries that require more extensive treatment or specialist referral. Delayed healing or chronic disability can result from inadequate management, and is painful and disabling with loss of hand function and contains the risk of post traumatic arthritis. Taping of the thumb may be helpful for preventing further injury in some sports (eg those involving ball handling). However, it cannot effectively prevent forced radial deviation, a feature of many skiing injuries (Fricker and Hintermann, 1995).

In relation to prevention of shoulder injuries, French researchers considered that certain preventive measures were relevant at different stages. In the pre-event stage, such countermeasures include: good physical condition of the skier, instruction on how to fall to be given in ski lessons, a realistic appraisal of skiers' abilities so they do not ski on slopes that are too difficult and good slope preparation. After the event, coordinated and rapid action by rescue services to facilitate reduction of dislocations as soon as possible and correct immobilisation for the transport by ski patrollers reduces the tension within the patient. It also enables an easier reduction of the injury. Immobilisation that is more likely to be tolerated by patients, and early and effective rehabilitation, are important and necessary and will hopefully reduce the occurrence of sequelae (Binet et al, 1985).

On the basis of these studies relating alpine ski pole handle design and injury, the weight of evidence suggesting that any particular handle design or method of holding the strap would have a major influence on the likelihood of injury was not strong. Similarly, there is not strong evidence for a significant contribution to injury prevention if all skiers were to use a certain design of ski pole handle or hold their ski poles in a particular way. It is likely that this would also apply to cross-country skiers. There were, however, methodological problems with some of the alpine skiing studies and the results were not always clearly presented.

Innovation in design or biomechanical testing and evaluation in relation to this countermeasure does not appear to have been developed as much or received as much attention as other countermeasures such as the functional unit of the ski/binding/brake/boot system. This suggests that there is still scope for further developments and improvements.

Newer types of handle design may have the potential to be associated with fewer thumb injuries. However, their evaluation in controlled trials or their usage by skiers in the epidemiological trials has not been sufficient to provide clear evidence of their potential for injury prevention.

The ski glove designed to eject the ski pole from the skier's hand during a fall, was an innovative and lateral approach to the problem of thumb injuries, but with no evaluation. The ergonomic study was more optimistic about the potential for reduction of injury. It gave practical suggestions for discontinuation of the use of ski straps altogether (for all but competitive skiers) and improvements in handle design.

Although each of the studies reviewed here relate to alpine ski pole handle design, there are significant implications for injury prevention in cross-country skiing and further attention to cross-country ski pole handle design is warranted. Further details of the reviewed studies is given in another report (Kelsall and Finch, 1996a). Four studies provided evaluations of ski pole handle design and one described ski glove design. Of the studies evaluating ski pole handle design, all provided data-based evidence and two provided a detailed examination of equipment design. None of these studies provided a controlled evaluation of these countermeasures.

7.1.3 Recommendations for further research, development and implementation

- Further research into the design of ski pole handles and ski straps is needed.
- Further research into the design of ski gloves.

- Controlled evaluations of both ski pole handles and ski glove designs in the field are required.
- An assessment of correct falling techniques and consideration of what is taught by ski schools in relation to this should be made.
- There should be continued support for a high standard of ski patrol services to provide a rapid response and safe transport of injured skiers.
- Specific advice, or training, for doctors in and around ski field areas, about the examination, management and rehabilitation of thumb and shoulder injuries needs to be developed and promoted.

7.2 SKI BINDINGS AND SKIS

The equipment used in the variations of cross-country skiing is also quite different to that used in alpine skiing. Features of cross-country ski equipment that is relevant to performance include the ski width and length, stiffness of the mid-camber of the ski for sufficient grip during the kick phase (which relates in part to skier's level of technique and body weight), the type of skiing to be done, the patterning or waxing of the bases, metal edges, ski bindings and boots (MacGregor et al, 1985).

Laboratory equipment has been developed to assess cross-country skiers and the bio-mechanics and ergonomics involved in the sport. Co-operation between skiers, coaches, sports scientists and corporations could result in even greater developments and performance, and formation of a database on equipment could provide athletes and coaches with bench-marks for evaluation of new equipment (Street, 1992).

In alpine skiing, knee injuries are the most common site of injury, accounting for between 20 and 32% of all injuries (Johnson et al, 1979; Shealy and Miller, 1991; Coolahan et al, 1994). In a study in the 1970s in the US, lower extremity injuries accounted for 58% of all skiing injuries, and 80% were classified as lower extremity equipment-related injuries (Gillette, 1980). With the changes in alpine boot design toward higher and more rigid boots since the mid-1970s, ankle injuries have become less frequent. However, knee injuries have become more common and are now the most common site of injury overall. Inadequate release of ski bindings has been implicated in lower limb injuries. The severity of lower limb injuries varies from ligament strains to ligament ruptures and bone fractures (Johnson et al, 1979; McConkey, 1986; Feagin et al, 1987; Sterett and Krisoff, 1994; Aune et al, 1995; Speer et al, 1995).

In cross-country skiing the heel is mobile and the toe piece of the binding does not release during a fall. This allows more movement in the lower limb. Knee injuries are also common in cross-country skiing but ankle and foot/toe injuries are relatively more frequent (see Tables 1 and 2). Although, heel position is generally not fixed to the ski as it is in alpine skiing, heel stabilisation during turning can provide better control. This can be achieved through certain types of heel design in the binding system that assist the heel in remaining in contact with the ski. Such designs include serrated heel plates, a rigid heel plate with a grooved boot or a peg and a locator type of heel plate. There may, however, be an increased risk of injury if the skier's weight cannot be removed from the ski during a twisting fall. As in downhill skiing, the ski acts as a lever about which the knee twists (Renstrom and Johnson, 1989). Biomechanical testing suggests that heel plates may be implicated in injury, but the results are inconclusive (Boyle et al, 1985).

Cross-country skiers using lifts are required to use a safety strap to attach the ski to their boot. Before the development and introduction of ski-stoppers in alpine skiing, lacerations and other "egg-beater" injuries were associated with falling skiers tumbling down the slopes with their skis attached. Such lacerations may also occur with cross-country skies using straps, although cross-country skis do not always have the sharp metal edges of alpine skis and the bindings do not release.

As is the case in alpine skiing, a common mechanism of injury to the lower extremity is an external rotation abduction moment applied by an entrapped ski to the leg. The potential for torsion in a forward fall is less than in alpine skiing because the heel is not fixed (Renstrom and Johnson, 1989).

The binding release mechanism is not designed to release during a fall. One study (Ekstrom, 1987) of forces at play in the cross-country ski and binding system compared different ski and binding constructions. These are rather loosely related to the release settings of alpine bindings and the potential for injury. A release binding is recommended for skiers of beginner and intermediate standard (Ekstrom, 1987). This may well be reasonable but the reasoning or justification is not fully articulated.

Appendix 1 provides details of two biomechanical studies that have looked at cross-country skiing equipment. Further details of the studies based on alpine skiers can be found in another report (Kelsall and Finch, 1996a);

7.2.1 Recommendations for further research, development and implementation

- Further research into the mechanisms of lower extremity injuries is needed.
- Detailed studies of the potential role of releasable cross-country bindings are warranted before they are widely promoted.
- Monitoring of injury trends as new equipment becomes available.
- Education of cross-country skiers about the most appropriate equipment for their particular type of cross-country skiing.

7.3 SKIING TECHNIQUE

During the mid-1980s, skating largely replaced the traditional diagonal striding as a racing technique and revolutionised the sport. The skating technique has a number of variations in the combinations of poling and skating steps. The change from diagonal striding to skating as a technique did not seem to bring about significant changes in the number and type of acute injuries over this period, and a reduction (sometimes significant) in the number of overuse injuries requiring medical attention was noted especially those affecting the back, neck-shoulder region and the upper limbs (Kannus et al, 1988). With respect to overuse symptoms, other researchers have reported that young competitive skiers changing over in style from diagonal stride to skating technique have experienced fewer back and knee pains and less muscle tension in lower limbs, but an increase in complaints related to the buttocks, hip, lower leg, arch of the foot, and forefoot (Mahlamaki et al, 1985).

A Finnish study (Kannus et al, 1988) looked at overuse injuries in cross-country skiers who were training regularly. It did so over a time when there was a dramatic increase in the number of skiers and racers using the skating technique, and compared over a 2 year transitional period the number and type of overuse injuries sustained by the skiers as a population to see if there was any pattern of change. This study was not able to determine the exact ratio between the skating or diagonal striding techniques used by the skiers and thus technique was not related back to injuries at an individual level. The researchers in this study acknowledge that more strictly controlled studies concerning the skiing style that was used are needed to confirm or refute their findings.

In this Finnish study the change from diagonal striding to skating as a technique did not seem to bring about significant changes in the number and type of acute injuries over this period. A reduction (sometimes significant) in the number of overuse injuries requiring medical attention was noted especially those affecting the back, neck-shoulder region and the upper limbs. The researchers (Kannus et al, 1988) made no comment on possible countermeasures to reduce overuse injuries. The repetitive nature of the technique and long training hours of competitive skiers contribute to the risk of overuse injuries. Other contributing factors include training errors, faulty technique and inadequate equipment (Renstrom and Johnson, 1989).

With respect to overuse symptoms, other researchers have reported that young competitive skiers changing over in style from diagonal stride to skating technique have experienced fewer back and knee pains and less muscle tension in lower limbs, but an increase in complaints related to the buttocks, hip, lower leg, arch of the foot, and forefoot (Mahlamaki et al, 1985). The studies had limitations however, and definitive conclusions cannot be made.

Theoretically, potential countermeasures could include adequate physical conditioning and warm-up, balanced training to avoid repetition, improved instruction and technique and adequate equipment. However, studies of these have not been identified, and there were no evaluation studies.

The reason for the technique of double-poling stride combined with skating being dangerous for beginners is not stated, or related to the findings presented in the rest of the article (Ekstrom, 1987).

Appendix 2 provides more detail about the study by Kannus et al (1988) which examined the relationship between injury trends and changes in cross-country skiing style.

7.3.1 Recommendations for research, development and implementation

- Monitor overuse injury trends, particularly in competitive skiers.
- Encourage adequate preparation and warm-up before skiing.
- Include consideration of the potential for overuse injuries and their prevention in training programs.

7.4 PRE-SEASON CONDITIONING

Skiing is a physically demanding sport. The average recreational skier in Australia may ski for a limited period each year, whether it is for a week or two, occasional weekends or day trips. Skiers like to make the most of their time on the slopes once there, but are not going to ski well if fatigued. Skiing all day, every day, without physical preparation can put skiers at risk of injury. The muscle and joint soreness and fatigue at the end of a day's skiing can reduce a skier's enjoyment of the sport.

Skiing requires muscle endurance, strength, flexibility and cardiopulmonary fitness. Whilst highly trained athletes (racers) and experienced skiers still have injuries, the recreational skier with low skills and inadequate physical preparation may be at greater risk.

The Australian Physiotherapy Association's "Get Fit to Ski" program aims to improve four major areas of fitness for skiing: strength, flexibility, endurance, and postural awareness or proprioception. Classes run for 1 hour, twice per week from late May to July. Participants are encouraged to supplement this with swimming, running or bike riding 2 or 3 times per week. The program coordinators acknowledge that timing can present a problem if the ski season starts late.

An evaluation of the APA "Get Fit to Ski" program sought the responses of skiers to a questionnaire. The results indicated positive perceived benefits from participants with 96% indicating their intention to attend classes in the following season. Unfortunately, with respect to injury prevention, there was no baseline for comparison and no control group. Nevertheless 75% of the survey respondents completed the season without injury. If the remaining 25% of skiers sustained an injury, this percentage is high. This is not, however, clear from the report (Australian Physiotherapy Association, 1989).

Similar difficulties in interpretation were encountered in an analysis of behavioural risk factors for skiing, which commented on the lack of identified protective effect of pre-season ski gymnastics preparation (Bouter and Knipschild, 1991). In this study it was not explicitly stated whether other factors such as age or existing general level of fitness were controlled for in the calculation of risk.

The requirements of a musculoskeletal conditioning program to prepare for skiing was described. This was based on a comprehensive literature review and informed opinion of the anaerobic and aerobic energy demands, biomechanics and physiology of human movement and injury, muscles used and type of contraction for both alpine and cross-country skiing (Morrissey, 1987). Separate alpine and cross-country programs for improved performance were suggested that involved training at least 2 days/week during the off-season, and 3 days/week during ski season, or ideally a strengthening or endurance program on alternate days for 6 days/week.

Whether recreational skiers are likely to commit themselves to such a rigorous and sustained program is questionable. The authors acknowledge that research and evaluation is needed to determine the effectiveness of conditioning programs for preventing musculoskeletal injuries. They were not aware of any studies that had addressed this (Morrissey, 1987).

Approaches to the study of the effectiveness of preseason conditioning in the reduction of skiing injury face methodological difficulties, particularly with respect to retrospective self-assessment/reporting and validity. It is also possible that the general recreational skiing population may not accept the requirements of a rigorous training program that may have a more substantial and measurable impact on the reduction of injury rates. Expert and informed opinion is in favour of pre-season conditioning, and such conditioning should not be discouraged, but the effectiveness in preventing injury has not been formally evaluated.

7.4.1 Recommendations for research, development and implementation

- Additional research into the effectiveness of conditioning programs on the prevention of skiing injuries is required.
- A more rigorous evaluation of the impact and health outcomes of the Australian Physiotherapy Association’s "Get Fit to Ski with Physiotherapy" program should be undertaken.
- Specific conditioning programs for cross-country skiers should be investigated.

7.5 SKI LESSONS

Ski lessons are available at most Australian resorts. Ski lessons can be undertaken in a variety of alpine sports (downhill, cross-country skiing and snowboarding) and at all levels. They are taught by instructors accredited by the relevant professional body. One of these bodies is the Australian Professional Ski Instructors Association (APSI) which is responsible for the training and qualifying of alpine and snowboard instructors. Some of these instructors are also qualified to instruct in cross-country skiing.

Ski school lessons (from a trained professional) are recommended in the "Snow Safe" safety booklet (Victorian Ski Association, 1995) on the basis that:

- statistics indicate that more experienced skiers have less accidents, and the best way to gain that experience is to take lessons
- training progresses from the level the skier has already attained
- general enjoyment of the sport is often related to the ability to handle different conditions and terrains and lessons assist in broadening a skiers' capabilities
- lessons provide fun and social contact
- skiers can inform instructors of what aspects of skiing they would like to improve
- instructors can direct participants to the most suitable ski runs after the lesson.

A number of epidemiological studies of injuries among alpine skiers have considered the association of ability, and sometimes a history of having taken ski lessons, with injury rates. These studies are summarised below. Similar studies have not been done with respect to cross-country skiing, but the results are reported here because similar principles apply to cross-country skiing. Difficulties in interpreting the results, and weighing up the evidence, lie in the self-reporting of ability, the lack of consistency (or definition thereof) in reported categories as to ability and the history of ski lessons.

A study in the 1970s found an injury ratio of up to 5:1 of beginners to expert skiers (Spademan, 1978). A prospective study (Johnson et al, 1993) of injuries in Vermont between 1972 and 1990 found the ratio of injured:control skiers in the beginner/novice category was about 4:1. The injured:control ratio for the advanced/expert category was 1:2.

Similarly, skiers with less skill or experience were found to have a higher incidence of injuries than more experienced skiers or a control population (Garrick and Requa, 1979). A New Zealand study also found beginners, and those who had skied fewer than 3 days that season and had not had lessons to have higher injury rates. Australian studies of injury in children report that more children than adults are beginners and level of ability is considered as a risk factor (Giddings et al, 1993).

The role of skiing instruction in preventing injuries is controversial, and it is considered that skiing lessons must be coupled with experience to have positive effect. Ski instructors should also put more emphasis on proper functioning of equipment and teaching proper falling techniques (Ekeland and Nordsletten, 1994).

The weight of evidence is that beginners and less experienced skiers have a higher risk of injury than advanced or intermediate skiers. The effect of ski lessons on the injury rates of intermediate or advanced skiers is less obvious. An assumption is often made that ski lessons assist in reducing the risk of injury, and do so by increasing a skier's ability more quickly than if the skier did not take lessons. This is likely to be the case. For this, and other reasons, ski lessons are to be recommended. Ski lessons have other advantages including orientating skiers to the use of lifts, social contact and fun, the resort and it's layout, suitable slopes for their ability and other safety measures.

The effectiveness of ski lessons as a countermeasure, however, has not been evaluated in a formal, controlled way, especially for cross-country skiers.

The content of ski lessons (eg how much is taught with respect to safety measures, falling techniques or recommendations made by instructors regarding binding adjustment) has not been the subject of consideration or evaluation in studies on associations between injuries and risk factors.

7.5.1 Recommendations for research, development and implementation

- There should be standardisation of epidemiological data collection and reporting systems for categories of skiing ability and history of ski lessons in future studies.
- Controlled studies to evaluate the effectiveness of ski lessons for injury prevention should be undertaken.
- A review of the content of ski lessons with respect to skiing safety should be undertaken.

7.6 CLOTHING, INCLUDING EYEWEAR AND SKIN PROTECTION

Clothing serves several purposes in alpine conditions, including protection from a variety of weather conditions such as snow, sleet or rain, high winds, poor visibility, brilliantly sunny days and strong reflective glare. Clothing that is inadequate in providing warmth and wind factor protection can leave the skier at risk of hypothermia and frostbite. Most body heat is lost through the head and trunk, but the fingers, toes and ears are particularly prone to frostbite (Fitzpatrick, 1995).

Skin and eye protection from direct or reflected sunlight are essential even on cloudy days. Physical exertion in skiing can be intense. Skiers can be uncomfortable if they become too hot and sweat, particularly as they will cool down rapidly upon stopping or resting. Conditions in alpine areas can change very rapidly and clothing needs to be suitable for a variety of conditions (Fitzpatrick, 1995).

Epidemiological studies confirm eye injuries represent a small (or rare) percentage of skiing injuries. Reports on eyewear in relation to them are usually non-specific, but are generally minor and infrequent (approx 18 per year in the USA) (Piziali, 1989). Injuries as a result of broken lens glass are extremely rare and almost non-existent since the passage of eyewear standards. Frames are more frequently mentioned in eye injury reports than lenses (Piziali, 1989).

The general principle of skiing clothing is to dress in layers that trap air between them, thereby acting as insulation. Clothing can be divided into 2 layers: the inner insulating layer and the outer windproof and water proof layer (Victorian Ski Association, 1995). The number of insulating layers should be selected according to weather conditions and activity levels so the skier remains comfortable (Victorian Ski Association, 1995).

It has been suggested that the layer of clothing next to the skin is the most important, and should include warm underwear. Wool is good but can become irritating, and cotton absorbs sweat and becomes damp too easily. The newer fibres and style of thermal underwear are designed to allow moisture to move away from the skin. The second layer can be wool or "fibre pile" materials. Skivvies or jumpers that cover the neck if required in cold weather should also be considered by skiers. The outer layer should be both water and wind proof. To achieve this, garments made of materials such as Gore-tex or Entrant are best (Fitzpatrick, 1995).

Hats, warm socks and gloves are also very important items of clothing as ears, feet and fingers are particularly prone to frostbite.

Hundreds of dollars can be spent on ski clothing, but it is not necessary. For those skiers without their own, protective outer clothing can be hired through most hire outlets (Victorian Ski Association, 1995).

Glare from the snow and levels of UV light can be considerable, even on overcast days. Eyewear is essential to protect the eyes from damage and "snow blindness" that can occur. Ski goggles are generally equipped with lenses that are tinted. The type of lens may be more suitable to conditions of bright sunlight or low visibility and fog. Some goggles have lenses that are suitable, or adapt, to both extremes of visibility, but may be more expensive. Sunglasses are suitable only for fair weather conditions, and it is recommended that skiers always carry goggles as a precautionary measure. If skiers are dependent on spectacles they should carry a spare pair (Victorian Ski Association, 1995).

In the review of literature, no references were identified that considered children's eyewear. Given the generally low standard of equipment such as skis, boots and bindings that researches have found to be used by children, clothing and eyewear as a countermeasure for this age group may need more detailed consideration.

Consideration of clothing design and injury is an area that warrants particular attention to consumer acceptance.

7.6.1 Recommendations for research, development and implementation

- Continue to improve the materials for skiing garments and eyewear.
- Consider manufacturing clothing with higher coefficients of friction.
- Continue to reinforce the essential and protective aspects of clothing to skiers.
- Continue to encourage the use of protective sun screen.
- Consider a specific review of children's clothing and eyewear.

7.7 ADEQUATE NUTRITION AND REDUCED ALCOHOL INTAKE

Injuries are more likely to occur at certain times of the day, such as late morning and late afternoon, and fatigue at such times may contribute to the risk of injury (Sterett and Krisoff, 1994). Adequate rest, nutrition and energy replenishment are also likely requirements for both enhanced performance and injury prevention.

The use of alcohol may potentiate hypothermia in a cold environment. Alcohol-induced unconsciousness or stupor in the mountain environment may increase the serious risk.

Consumption of alcohol during a skiing day or in excess amounts the night before, may interfere with concentration, coordination and reflexes and increase the risk of injury.

A study of alcohol consumption by alpine skiers during breaks found that, of injured skiers 79% never consumed alcohol, 18% sometimes and 3% did so every day. This can be compared to uninjured skiers amongst whom 67% never consumed alcohol, 28% sometimes and 6% every day. With respect to daily average alcohol consumption for injured skiers, 61% consumed 0,1 or 2 glasses and 15% consumed 5 or more glasses per day. Amongst non-injured skiers, 53% consumed 0,1 or 2 glasses and 23% consumed 5 or more glasses (Bouter and Knipschild, 1991). These percentages seem quite high, especially considering that they may be under-reported as the study population consisted of Dutch skiers who were claiming through their insurance company.

The authors (Bouter and Knipschild, 1991) cited studies in German, which reinforced their argument that perceptible blood or breath alcohol levels are, in fact, rare in injured or uninjured skiers. Moreover, alcohol consumption is neither a major risk factor in skiing nor is it a preventive factor.

A potentially low measurable prevalence of a risk factor such as alcohol consumption in a population makes the study of alcohol involvement in skiing injuries difficult.

Effective injury prevention will not be achieved if skier education is handled in a loose, non-specific way. The result may be ineffective (Bouter and Knipschild, 1991), but it may also be unfair to make skiers feel guilty about even a moderate intake of alcohol if this is prematurely decreed as being a risk factor for injury.

The weight of evidence suggests that the level of alcohol consumption in the hours immediately before skiing is not clear, nor is the effect that alcohol consumption may have on the risk of injury. The prevalence of measurable blood alcohol amongst skiers may be lower than expected. This has not been studied in Australian resorts. No studies have been done on this in relation to cross-country skiing.

There are potential biases and methodological difficulties in the estimation of this in studies. There are also practical difficulties in the measurement of blood alcohol concentration with a breath analyser in very cold conditions. The evidence suggests that adequate carbohydrate (and nutritional) intake and replenishment during and after skiing is important and to be recommended. The dangers associated with hypothermia in a mountain environment and the evidence of the effect of blood alcohol levels on coordination, concentration and reflexes in other research are well recognised. Given this, it would seem prudent to caution skiers to consider their alcohol intake and the potential effect it may have on skiing performance, and not to drink alcohol during skiing breaks.

There have been no specific studies of the relationship of alcohol intake to cross-country skiing injuries.

7.7.1 Recommendations for research, development and implementation

- Reinforce the importance of good nutrition and adequate carbohydrate replenishment during skiing.

- Conduct preliminary studies on the alcohol consumption patterns of Australian skiers, and cross-country skiers more specifically, to determine the extent to which it is a factor in injuries.
- Undertake controlled studies on the relationship between alcohol consumption and injury occurrence.

7.8 STANDARDS FOR SKIING EQUIPMENT

Standards Australia has emphasised the need for relevant and technically competent Australian standards. Standards Australia has a policy of adopting an international standard wherever an appropriate one is available. In developing new standards, a genuine need and community or interest group support needs to be demonstrated (Standards Australia, 1995).

In the historical development of skiing standards, in 1972 the ASTM became involved with the formation of Subcommittee F08.14 on Skiing within Committee F-8 on Sports Equipment and Facilities. It progressed to full committee status in 1982 as Committee F-27 on Snow Skiing (Roberts, 1992). This reference (Roberts, 1992) presents a brief overview of each of the snow skiing standards that has been developed to date and comments on how the standard is expected to enhance skiing safety. The authors discuss concerns of the committee, and issues in relation to research and future standards development (Roberts, 1992), including:

- additional standard on specifications for ski binding testing devices
- skiing helmets
- ski poles
- testing of ski/boot binding systems by ski shops and skiing rental operations.

Standards that were referred to included:

- Test Devices for the Adjustment of the Functional Unit Ski/Binding/Brake/Boot; DIN 32 921 German Industrial Standard, Beuth-Verlag GmbH, Berlin, 1982 (Nagel and Mosch, 1987)
- Assessment, combination, mounting and setting of the functional unit ski/binding/brake/boot; DIN 32923 German Industrial Standard, Beuth-Verlag GmbH, Berlin, 1984 (Nagel and Mosch, 1987)

A search was conducted by Standards Australia on the World-wide Standards Index on CD-ROM (1995/96 issue) for the US Database. The keywords of helmet, sport, or recreation were used. Nothing was located on standards that specifically referred to skiing, skiing helmets or bobsled helmets.

A similar search on the International European Database located relevant standards that included:

- DIN 33952. Protective sports helmets: ski helmets; safety requirements, testing. Publication date 1988.
- DIN 5333. Ski goggles: safety requirements and testing. Publication date 1986.

No standards relating specifically to cross-country skiing equipment were identified through this review.

7.8.1 Recommendations for further standards development

- A review of Australia's policy regarding skiing equipment and requirements in relation to equipment standards should be undertaken.
- A review of Australia's policy regarding training and standards for ski shop personnel, ski binding fitting and adjustment in retail and hire outlets needs to be performed.
- Based on the results of these two reviews, Australian policies may need to be reviewed.

7.9 ENVIRONMENTAL FACTORS

Many of the potential hazards of skiing will never be completely removed from the sport, and to do so may detract from the aesthetic beauty of the skiing in the mountains or the appeal of skiing as a vigorous adventurous sport (Penniman, 1993). Some potential hazards such as ski lift towers are an unavoidable component of the resort structure, and trees provide shelter, protection against erosion, natural beauty and reference points in poor visibility. It is generally accepted by skiers and the ski industry that it is the skier's responsibility to ski in a responsible manner, to visually assess the slope and snow conditions below them, and decide whether or not he or she has the skills necessary to successfully negotiate the slope. However, potentially hazardous slope conditions may not be visible simply by looking down the slope from above (Penniman, 1993).

Cross-country skiers often ski away from resort areas and alpine ski slopes and established trails. However, an increasing number of skiers are seen to be telemarking down ski runs. Environmental factors are important in both alpine and cross-country skiing.

A review of the practice of using visual markings and signs to give warning and direction to skiers for potentially hazardous conditions has described a number of important factors including (Penniman, 1993):

- the role of the professional patroller in any successful program for hazard marking, and the removal of signage once it is no longer required
- the importance of communication between different departments on the mountain
- methodology of hazard marking (the types of hazards, methods of hazard marking, the hazards that require warnings and those that require barriers)
- typical hazard marking materials
- typical formats for warnings and for barriers
- typical signs
- padding of obstacles
- methods of traffic control (signs, wing fences, mazes, speed patrollers).

This review (Penniman, 1993) also emphasises that while a custom and practice for identifying and mitigating common hazards at US ski areas has developed, no uniform safety standards have been written or officially adopted. The unwritten policy or practice in each ski area may vary, and may not be clearly understood by the skiing public or even by the professional ski patroller.

Injury in skiing areas have been the subject of litigation, with plaintiffs claiming that their injuries were a direct result of failure to remove or warn against a common hazard (Penniman, 1993).

A consistent policy of hazard mitigation is important, for both skiers and the ski industry, in any program to reduce skiing injuries.

Measures taken by professional ski patrollers or resort management in Victoria include:

- grading of ski slopes according to degree of difficulty with standardised signage: ‘easiest’ denoted by a green circle, ‘more difficult’ by a blue square, ‘most difficult’ by a
- slope signs such as ‘slow down’, ‘trails merge’, or ‘hidden obstacles’
- trail design to avoid intersections and congestion
- trail design to separate advanced and beginner skiers
- summer grooming and maintenance of ski slopes
- winter slope grooming
- removal of obstacles, where possible, or alerting skiers to their existence through signage and barriers on slopes
- visible, updated information on slope and weather conditions.
- visible, updated information on slope and weather conditions.

Ski patrols report that they use injury data collected throughout the season to monitor injury rates and take targeted remedial action if particular patterns are appearing. The effectiveness of various methods of hazard identification and mitigation have not been formally evaluated. Standardisation of policies and methods for hazard identification and mitigation and injury severity scores assist in comparisons of techniques and resort areas, and the monitoring of the effectiveness of interventions.

7.9.1 Recommendations for further research, development and implementation

- Standardisation of policies and methods for hazard identification and mitigation
- Consider a pilot test and validation of the calculation of injury severity scores and corrected injury severity scores to aid in ongoing assessment of slopes.
- More formal evaluation of the effectiveness of hazard identification and mitigation in injury reduction is needed.
- Continued support for the ski patrol role in the identification and removal of hazards.
- Attention to cross-country skiing injuries in data collections and identification of those that occur on resort ski runs.

7.10 SKI PATROLLERS, FIRST AID ON THE SKI SLOPES AND RESCUE EQUIPMENT, RESORT SAFETY

The organisation of emergencies services, selection and maintenance of equipment, administration of first aid treatment, transport and the use of trained personnel have been identified as important aspects of a service to administer first aid to skiers (Allan, 1976).

Under the Alpine Resorts Act of 1983 the Alpine Resorts Commission has the overall responsibility for resort safety, even though lift companies lease resorts and the ski slopes. If the Act changes, the emphasis of responsibility could also change.

Legislation, and the Ski Safety Act of Colorado, was a topic of presentation and discussion at the 1995 Alpine Safety Conference. Part of the discussion revolved around acknowledgment of the dangers and risks inherent in snow sports and the rights of persons engaged in such sports in relation to recovery from a ski area operator for injuries resulting from inherent dangers and risks.

In the Canadian province of Quebec, the Quebec Sport Safety Board (QSSB) was created in 1979 by an act of the National Assembly of the province of Quebec. It is responsible for "supervising the personal safety and integrity in the practice of sports" and is unique in Canada (Regnier and Goulet, 1995). The events leading to it's creation, mandate, legislative and regulatory powers, and some particular interventions are described in this article (Regnier and Goulet, 1995). The QSSB is empowered to (Regnier and Goulet, 1995):

- gather, analyse and disseminate information on sports safety
- conduct, or cause others to conduct research on sports safety
- educate the public on safety in relation to the practice of sports
- prepare safety training methods for those who work in the sports field
- give technical assistance to sports federations or unaffiliated sports bodies in preparing safety regulations
- assist any person requesting advice on means to ensure sports safety.

With respect to alpine sports in particular, the owners of ski resorts are responsible for resort safety and enforcing regulations applicable to resort safety (Goulet, 1996). Standardisation has been a key concept, which resort owners have the responsibility for implementing and enforcing. This includes standardisation of signs indicating and reflecting the degree of difficulty of the slope; standards for first aid personnel (eg minimum education); standards for first aid equipment; slope grooming equipment regulations (including movement of such equipment on the slopes); a code of conduct for alpine skiers and snowboarders, including a speed control policy, that must be enforced by resort management (Goulet, 1996).

The Ski Patrol plays a valuable role in Australia alpine sports safety with both professional and trained volunteer patrollers. Victoria has ski patrollers located at 7 resorts: Mt Hotham, Mt Buller, Falls Creek, Mt Buffalo, Lake Mountain, Mt BawBaw and Mt St Gwinear.

Ski patrollers perform a multitude of functions that relate to all stages of injury prevention, including:

- ski patrols on the slopes throughout the day
- ski patrols on marked cross-country ski trails associated with ski resorts

- on-slope skier education
- education of junior and school groups
- speed control programs
- response to reports of skier difficulties or injuries
- provision of first aid on the slopes
- transport of injured skiers medical or ambulance services
- search and rescue for lost skiers
- collection of data on the "Ski Patrol Accident Report" form
- data entry and analysis
- ongoing injury surveillance throughout the season
- hazard identification and mitigation throughout the season
- advice to resort management
- review and comparison with other resorts at the end of the season
- training and education of applicants and existing members in skiing and mountain rescue techniques, first aid knowledge and qualifications.

Patrollers may also be called to assist skiers who are in difficulty, even though they may not be actually injured. This is also registered as a call-out in their report forms.

A speed control policy aims to make skiing safer for all skiers. Action as a result of a speed control program may be progressive depending on the circumstances. Action can involve speaking to the skier regarding the risks or confiscation of the skier's lift ticket for a 2-3 hour period or permanently. Skiers are generally responsive to the less severe measures (Pelly, 1995). Such measures are less likely to be relevant to cross-country skiers who do not generally ski at high speeds.

Ongoing injury surveillance can identify slopes or trails where a number of injuries have occurred and assist in focusing hazard identification and mitigation and injury prevention. Action may involve advice to resort management, a speed control program, promotion of safety helmets, trail or ski run closure, signage or obstacle markers or avalanche danger control. Ongoing surveillance can also assist in evaluating the effectiveness of interventions.

Data collection is an important component of any injury control program. Ski patrollers have collected data as part of their routine work for years. However, data is not collected in the same format at all Victorian resorts, nor is it consistent with that of NSW resorts. The variability of skiing conditions throughout the season, and from one season to the next, also makes comparisons difficult. The standardisation of data collection across all Australian resorts would provide an improved data base for research, statistical comparisons, surveillance, the monitoring of injury trends and evaluation of the effectiveness of interventions or injury control programs.

In search and rescue operations, the successful use of the Global Positioning System (GPS) was presented at the 1995 Alpine Safety Conference. This is particularly important for cross-country skiing, since many skiers do not use established resort trails.

The traditional navigation aids of map and compass have limited capabilities under white-out or blizzard conditions especially in non-resort or remote areas. A GPS enables search and rescue teams to plot their position on to a topographical map out in the field and relay their position to base. Other advantages of use of the GPS are that it saves time and expense in a search and rescue operation, reduces the likelihood of severe exposure injuries to lost skiers, increases the personal safety of the rescuers, allows more rapid progress in adverse conditions and increases user confidence on the ground, and it is a useful navigation and location aid in field emergencies.

In presenting the advantages of such a system, it was noted that attention also needs to be paid to the operational aspects including planning, training of those who will use the GPS, and purchase of equipment. The estimated cost of a GPS unit is approximately $1,200. It was proposed at the Alpine Safety Conference that all ski resorts should have at least one GPS unit.

Access to the mountain is another aspect of resort safety. Driving in the mountains can be hazardous. There is a legal obligation for those entering mountain areas to carry and fit wheel chains as directed. Driver skill and care are important. The quality of wheel chains was also considered important, and the performance of diamond pattern chains in terms of safety was a topic of presentation at the 1995 Alpine Safety Conference.

7.10.1 Recommendations for further research, development and implementation

- Standardise data collection by ski patrollers and all Australian ski resorts and include information on weather and snow conditions and terrain.
- Review the incident/injury report forms used by ski patrollers to maximise the use of information for injury research and monitoring, with particular attention to cross-country skiing injuries.
- Consider methods for the collection of injury severity data and the potential for standardisation of this.
- Standardise the age groups used for statistical comparisons in the analysis and reporting of injury data.
- Further develop injury surveillance programs for a range of snow sports.
- The standardisation of data collection across all Australian resorts would provide an improved data base for research, statistical comparisons, surveillance, the monitoring of injury trends and evaluation of the effectiveness of interventions or injury control programs.
- Continue to support the Ski Patrol Association.
- Make available at least one GPS unit at all ski resorts.
- Investigate making alerting devices, eg mobile phones or transmitters, available to skiers to alert ski patrols and to identify location if lost or injured.
- Continue to promote safe driving in the mountains.

8. SUMMARY AND CONCLUSIONS

Skiing is a popular sport in which there is a broad range of standards and ages of skiers, including skiers with various types of disabilities. Cross-country (nordic) skiing can be one of the most demanding of all sports, involving most of the body's muscles, and requiring a sustained cardiovascular and respiratory output. It is also ideal as a recreational sport, and can be enjoyed by individuals of all ages. According to the Alpine Resorts Commission, participation in skiing has been estimated at 10-12% of the population but the true level of "real" skiers is likely to be closer to 5%, with an annual growth rate of 1.5%. Cross-country skiers have been estimated to account for approximately 20% of participants in alpine sports.

Cross-country skiing includes ski-touring (usually skiing away from defined resort areas), defined trail (or track) skiing using the diagonal stride or skating techniques, and cross-country/downhill skiing (combined with ski touring or sometimes on the regular ski runs). Equipment has been designed to suit the particular requirements of each type.

As a sport, cross-country skiing has developed considerably since the 1980s with improvements in technology and design of equipment and clothing. There has been considerably less research on the epidemiology of cross-country skiing injuries or on evaluation of countermeasures to reduce injuries than there has in alpine skiing.

The main source of skiing injury data in Victoria and Australia are the Ski Patrol data collection and statistics. Data collection through this source underestimate the injury rate. Cross-country skiing is less formally organised and may take place wherever snow is available and away from managed resort areas with medical facilities and ski patrols. There are other difficulties in the study of cross-country skiing injuries that include lack of data on the populations at risk, relatively small numbers in some studies, and under-reporting of minor injuries or overuse injuries.

In cross-country skiing, the boots are of a lower cut and are more flexible than those of alpine skiing. The bindings fix the forward tip of the boots while leaving the heel free to elevate from the ski and the binding release mechanism is not designed to release during a fall, and equipment failure is less likely to contribute in the same way as it does in alpine skiing. The skis are narrower and ski poles are longer. Cross-country skiers ski on a variety of slopes, but generally with a more gentle gradient and with slower speeds.

The cross-country injury rate from an overseas study was 0.72 per 1000 skier days. In a 1985 Australian study, the cross-country injury rate was 0.49 injuries per 1000 skier days, while the alpine injury rate was 3.54 per 1000 skier days. Whilst the incidence of skiing injuries is lower in cross-country than alpine skiing, there is evidence to suggest that the severity of injuries may be comparable.

The most common type of cross-country skiing injuries are sprains/twists, bruises, fractures and lacerations. The most common body locations are knee, ankle, leg and arm/hand. There are differences in the proportions of various injuries sustained in alpine and cross-country skiing that are explained in part by the different nature and usual terrains of the sports, and the equipment used. As in alpine skiing, a common mechanism of injury to the lower extremity is an external rotation abduction moment applied by an entrapped ski to the leg, although the potential for torsion in a forward fall is less because the heel is not fixed. Knee injuries are commonly reported in cross-country skiing, but ankle injuries are relatively more frequent.

The objective of this review was to determine the extent to which injury countermeasures in the sport of cross-country skiing have been evaluated, consider the results of such evaluation and the level of supporting evidence, and make recommendations for further action in injury prevention research and practice.

The sources of information used to compile this critical review were Medline, Sport Discus, conference/proceedings scan and NEXUS, discussions with local researchers and sporting organisations, Internet injury list postings, Standards Australia and CD-ROM world-wide standards index 1995/96 issue, presentations at the 1995 Alpine Safety Conference in Melbourne, and the Victorian Snowsafe booklet and video (1995) as well as consultation with experts in the field such as the Ski Patrol Association and key stakeholders. The literature review was restricted to articles in the English language available in Australian libraries, but where possible has focused on controlled trials.

Equipment and skiing style vary in different aspects of cross-country skiing, although the basic groups of countermeasures are the same. Risk factors for injury, especially amongst recreational skiers, include poor condition of ski tracks (deep tracks, ruts, iciness, sharp bends etc) and the downhill segment of terrain; unsuitable or inferior equipment (slippery glass fibre skis, wrong type of wax); poor balance and inadequate mastery of the cross-country skiing technique.

Measures to prevent or control injury, ie injury countermeasures can be targeted toward primary (pre-event), secondary (event) and tertiary (post-event) prevention in the chain of injury events. Primary countermeasures for cross-country skiing include pre-season conditioning and fitness programs and adequate warm ups, skiing technique, equipment factors (skis, boots, bindings, ski poles, eye wear, clothing, helmets), adherence by skiers to the skiers' safety and courtesy codes, ski patrollers, adequate nutrition and fluid intake, environmental factors (condition and design of ski trails), skier education programs, skiing instruction and expertise of instructors, adequate supervision of children, and use of safety equipment.

Secondary countermeasures include protective equipment (helmets, eye wear), skiers conduct code and speed control, general sports equipment (ski pole handle design, standard of bindings, ski boots), condition of ski trails and environmental factors.

Tertiary countermeasures include location of injured skiers, availability of first aid equipment; ski patrol assessment, treatment and transport; access to medical care; and adequate treatment and rehabilitation of injuries before resumption of skiing.

Ski bindings and boot design are particularly relevant to lower limb injuries. The heel position is not fixed, and bindings are not designed to release. Convertible or cable bindings or heel plates that stabilise or fix the heel during turning and skiing downhill can provide better control, but may increase the risk of injury, with the ski acting as a lever about which the knee twists. Releasable cross-country bindings are reputably being developed, but as in alpine skiing, safe design and reliable performance criteria need to be met if they are to assist in injury reduction.

The choice of ski boot depends on the cross-country skiing activity for which they will be used, eg touring, racing or skating, but should be flexible at the forefoot and allow free motion at the ankle. They should fit well so blisters don't form, but be durable and as waterproof as possible, and provide thermal protection. Overboots or gaiters can help protect in wet or slushy conditions or in deep snow.

The upper body plays a more propulsive role in cross-country skiing than alpine, and more so in the skating that diagonal striding technique. Thumb injuries and the association with ski pole handle design are a problem in cross-country skiing as in alpine skiing, and the overuse injuries are of concern.

Over a period during the mid-1980's skating largely replaced the traditional diagonal striding as racing technique and revolutionised the sport. In a Finnish study the change from diagonal striding to skating as a technique did not seem to bring about significant changes in the number and type of acute injuries over this period. A reduction (sometimes significant) in the number of overuse injuries requiring medical attention was noted especially those affecting the back, neck-shoulder region and the upper limbs. With respect to overuse symptoms, other researchers have reported that young competitive skiers changing over in style from diagonal stride to skating technique have experienced fewer back and knee pains and less muscle tension in lower limbs, but an increase in complaints related to the buttocks, hip, lower leg, arch of the foot, and forefoot. The studies had limitations however, and definitive conclusions cannot be made.

The repetitive nature of the technique and long training hours of competitive skiers contribute to the risk of overuse injuries, as do training errors, faulty technique and inadequate equipment, but the researchers in this field made no comment on possible countermeasures to reduce overuse injuries. Theoretically, potential countermeasures could include adequate physical conditioning and warm-up, balanced training to avoid repetition, improved instruction and technique and adequate equipment. However, there were no evaluation studies identified.

Waxing of skis, tread pattern on non-waxing skis, snow conditions and tracks are important for minimising injuries associated with skiers slipping or falling. Environmental countermeasures include trail design, clearance of hazards on and adjacent to trails, and trail marking.

Clothing should be warm and protective, but should minimise perspiration, and layering is a key concept. Adequate eye wear and sun screen are essential countermeasures.

One of the great joys of cross-country skiing is the freedom to ski and experience the mountains away from the resorts, and the Victorian High Plains areas provide a magnificent opportunity for this. There are very adventurous cross-country skiers who ski difficult steep slopes within the resort or out of the resort in isolated areas. Skiers need to be adequately prepared to ski in such conditions, and delays in reaching medical attention leave injured skiers vulnerable to complications.

There is high energy expenditure in sustained activity in cross-country skiing, and adequate energy and liquid replenishment is relevant to both recreational and competitive skiers.

The technology and techniques of cross-country skiing have developed at a rapid pace over the last 10 years, but cross-country injuries have not been subjected to the same degree of analysis as alpine skiing injuries. Alpine skiing is generally more organised, taking place in defined resorts, and gathering data is relatively easier. Studies on cross-country skiing injuries are also complicated by the lack of a large injury data base, little information about the population at risk and smaller numbers of skiers and injury cases for comparative purposes and trend analysis. One must therefore be careful in drawing conclusions, but cross-country skiing may not be as benign as people tend to think.

Cross-country skiing injuries, the bio-mechanical and equipment related factors and epidemiological data, have not been as well studied as alpine skiing. Little is known about cross-country skiers, their characteristics, aetiology and injury patterns, equipment related factors and the relationship between injury patterns as determined by epidemiological studies and causal factors such as skiing ability, equipment snow conditions and terrain.

Some of the types of injury in cross-country skiing are similar to those in alpine skiing that have been reduced by improvements in equipment. More attention needs to be directed towards cross-country skiing from a safety point of view, from data collection and epidemiology studies of injury patterns to the bio-mechanics of injury and the safety of equipment.

Recommendations for further countermeasure development and research include:

- Standardise data collection by ski patrols and resorts and include information on categories of cross-country skiers, terrain, weather and snow conditions.
- Ongoing attention to trail design and maintenance.
- Ongoing skier education around alpine safety and choosing appropriate equipment.
- The importance of pre-skiing fitness for preventing injuries.
- Increased attention to cross-country skiing injuries in the routine data collection by the Ski Patrol.
- Further epidemiological research into cross-country skiing injuries and monitoring of injury trends.
- More research and attention to the evaluation of cross-country skiing equipment and injury countermeasures.
- More research into the mechanisms of cross-country skiing injuries.
- Investigate the development of electronic alerting and locating devices.

9. REFERENCES

Allan JB. First aid on the ski slopes. Ortho Clincs North America 1976; 7 (1):251-253.

Alpine Safety Conference, Melbourne, Victoria. November 1995.

Aune AK, Schaff P, Nordsletten L. Contraction of knee flexors and extensors in skiing related to the backward fall mechanism of injury to the anterior cruciate ligament. Scand J Med Sci Sports (Copenhagan) 1995; 5:165-169.

Australian Physiotherapy Association. "Get Fit to Ski with Physiotherapy" program-a preventative initiative. 1989. Document supplied by The Australian Physiotherapy Association in Victoria, October, 1995.

Barrow R. Chairman, Cross-country Skiing Committee, Snow Sports Victoria. Personal communication. 1996.

Bauman C, Walkhoff K. A ski boot manufacturer's study regarding the possible reduction of alpine related skiing knee injuries. Paper presented at the 10th International World Congress on Ski Trauma and Skiing Safety, Zell am See, Austria, May 17-21, 1993 cited in Ekeland and Nordsletten (1994).

Bergstrøm KA, Askild O, Jørgensen NA, Ekeland A. Organisation of skiing safety in a new alpine area: injury severity score used to compare and classify the difficulty of the slopes. In: Johnson RJ, Mote CD, Zelcer J, eds. Skiing trauma and safety: 9th international symposium, ASTM STP 1182. Philadelphia: American Society for Testing and Materials, 1993:229-235.

Binet MH, Berrehail M, Montillet B, Terrenoir F, Tissier B. Shoulder dislocations resulting from ski injuries. In: Johnson RJ, Mote CD, eds. Skiing trauma and safety: fifth international symposium, ASTM STP 860. Philadelphia: American Society for Testing and Materials, 1985:395-407.

Bouter LM, Knipschild PG. Behavioural risk factors for skiing injury: problem analysis as a basis for effective health education. In: Johnson RJ, Mote CD, eds. Skiing trauma and safety: eighth international symposium, ASTM STP 1104. Philadelphia: American Society for Testing and Materials, 1991:257-64.

Boyle JJ, Johnson RJ, Pope MH, Pierce JC, Brady MM. Cross-country skiing injuries. In: Johnson RJ, Mote CD, eds. Skiing trauma and safety: fifth international symposium, ASTM STP 860. Philadelphia: American Society for Testing Materials, 1985:411-22.

Carr D, Johnson RJ, Pope MH. Upper extremity injuries in skiing. Am J Sports Med 1981; 9 (6):378-83.

Coolahan L, Jones JE, Fung SC, Lyle D. Winter sports injuries. In: NSW Public Health Bulletin 1994; 5 (8):88-90.

Crisp T. Ski trauma: prevention and treatment. Practitioner 1995; 239:88-94.

Ekeland A, Nordsletten L. Equipment related injuries in skiing. Sports Med 1994; 17 (5):283-7.

Ekeland A. The knees are in danger in skiing. Scand J Med Sci Sports (Copenhagan) 1995; 5:61-3.

Ekström H. The force interplay between the foot, binding, and ski in cross-country skiing. In: Mote CD, Johnson RJ, eds. Skiing trauma and safety: sixth international symposium, ASTM STP 938. Philadelphia: American Society for Testing and Materials, 1987:100-9.

Fairclough JA, Mintowt-Czyz WJ. Skier's thumb-a method of prevention. Injury 1986; 17:203-4.

Feagin JA, Lambert KL, Cunningham RR, Anderson LM, Riegel J, King PH, VanGenderen L. Consideration of the anterior cruciate ligament in skiing. Clinical Orthopaedics and Related Research; 1987; 216:13-8.

Fetterplace D. Alpine Resorts Commission, Box Hill, Victoria. Personal communication, November 1995.

Fitzpatrick J. Fashion or function-what to wear in the cold. Sport Health 1995; 13 (2):20-1.

Fricker R, Hintermann B. Skier's thumb: treatment, prevention and recommendations. Sports Med 1995; 19 (1):73-79.

Garrick JG, Requa RK. Injury patterns in children and adolescent skiers. Am J Sports Med 1979; 7 (4):245-8.

Giddings PH, McCallum IG, Duff PA. Children's skiing injuries in Victoria, Australia. In: Johnson RJ, Mote CD, Zelcer J, eds. Skiing trauma and safety: 9th international symposium, ASTM STP 1182. Philadelphia: American Society for Testing and Materials, 1993:50-4.

Gillette N. Nordic 1981-2nd Annual Trade Publication, Vol 2. Nordic Skiing Inc., West Brattleboro, VT, 1980:8-11 cited in (94).

Goulet C. Research Officer with the Québec Sports Safety Board, Québec, Canada. Personal communication, Melbourne, March 1996.

Haddon W. A logical framework for categorizing highway safety phenomena and activity. J Trauma 12 1972; 12: 197-207.

Hauser W. Experimental prospective skiing injury study. In: Johnson RJ, Mote CD, Binet M-H, eds. Skiing trauma and safety: seventh international symposium, ATSM STP 1022. Philadelphia: American Society for Testing and Materials, 1989:18-24.

International Organization for Standardization (ISO). Cross-country skis - dynamic performance - laboratory method. ISO 7140 1982a. Cited in Ekstrom (1987).

International Organization for Standardization (ISO). Cross-country skis -determination of breaking load-test method with quasistatic loading. ISO 7797 1982b. Cited in Ekstrom (1987).

International Organization for Standardization (ISO). Cross-country skis-determination of breaking load-test method with quasistatic loading, ISO 7797, 1982 cited in Ekstrom (1987).

Johnson RJ, Ettinger CF, Shealy JE. Skier injury trends - 1972-1990. In: Johnson RJ, Mote CD, Zelcer J, eds. Skiing trauma and safety: 9th international symposium, ASTM STP 1182. Philadelphia: American Society for Testing and Materials, 1993:11-22.

Johnson RJ, Ettlinger CF, Shealy JE. Skier injury trends. In: Johnson RJ, Mote CD, Binet M-H, eds. Skiing trauma and safety: seventh international symposium, ASTM STP 1022. Philadelphia: American Society For Testing and Materials, 1989:25-31.

Johnson RJ, Pope MH, Weisman G, White BF. Knee injury in skiing. A multifaceted approach. Am J Sports Med 1979; 7 (6):321-7.

Kannus P, Niittymäki S, Järvinen M. Cross-country skiing injuries: has the change of skiing style affected the frequency and types of skiing injuries treated at an outpatient sports clinic? Scand J Sports Sci 1988; 10 (1):17-21.

Karlsson J. Profiles of cross-country and alpine skiers. Clinics Sports Med 1984; 3 (1):245-71.

Kelsall H, Finch C. A review of countermeasures snowboarding injuries. Monash University Accident Research Centre. Report No 94. August 1996. 1996a.

Kelsall H, Finch C. A review of injury countermeasures and their effectiveness for alpine skiing. Monash University Accident Research Centre. Report No 99. September 1996. 1996a.

Lamont MK. Ski injury statistics-what changes? In: Johnson RJ, Mote CD, eds. Skiing trauma and safety: eighth international symposium, ASTM STP 1104. Philadelphia: American Society For Testing and Materials, 1991:158-63.

Lamont MK. Skier's thumb: continuing biomechanical analysis. In: Johnson RJ, Mote CD, Binet M-H, eds. Skiing trauma and safety: seventh international symposium, ASTM STP 1022. Philadelphia: American Society for Testing and Materials, 1989:311-5.

MacGregor D, Hull ML, Dorius LK. A microcomputer controlled snow ski binding system-1. Instrumentation and field evaluation. J Biomechanics 1985; 18 (4):255-265.

Mahlamäki S, Michelsson JE, Pekkarinen H. Musculoskeletal symptoms caused by skating style skiing. Finn Sports Exerc Med 1985; 4:110-113 cited in Kannus et al (1988).

McConkey JP. Anterior cruciate ligament rupture in skiing. A new mechanism of injury. Am J Sports Med 1986; 14 (2):160-164.

Morrissey MC, Seto JL, Brewster CE, Kerlan RC. Conditioning for skiing and ski injury prevention. JOSPT 1987; 8 (9):428-437.

Nagel A, Mosch S. Test devices for ski bindings sold in sports shops: state of the art and future development. In: Mote CD, Johnson RJ, eds. Skiing trauma and safety: sixth international symposium, ASTM STP 938. Philadelphia: American Society for Testing, 1987:217-224.

Ozanne-Smith J, Vulcan P. Injury control. In: McNeil J, King R, Jennings G, et al, editors. A textbook of preventive medicine. Edward Arnold, Melbourne. 1990

Parfitt I. 1994 Alpine Safety Conference. Summary-resort accident statistics. Personal communication, Melbourne, October 1995.

Pelly T. Mt Hotham Ski Patrol Director. Personal communication, October 1995.

Penniman D. The custom and practice for identification and mitigation of common hazards at US ski areas-an opportunity for standards. In: Johnson RJ, Mote CD, Zelcer J, eds. Skiing trauma and safety: 9th international symposium, ASTM STP 1182. Philadelphia: American Society for Testing and Materials, 1993:215-228.

Piziali RL. Eyewear-related eye injuries in snow skiing. In: Johnson RJ, Mote CD, Binet M-H, eds. Skiing trauma and safety: seventh international symposium, ASTM STP 1022. Philadelphia: American Society For Testing and Materials, 1989:126-131.

Régnier G, Goulet C. The Québec Sports Safety Board: a governmental agency dedicated to the prevention of sports and recreational injuries. Injury Prevention 1995; 1:141-145.

Renstrom P, Johnson RJ. Cross-country skiing injuries and biomechanics. Sports Med 1989; 8 (6):346-370.

Roberts CC. Skiing injuries are going downhill. An update on ASTM Committee F-27 on Snow Skiing. ASTM Standardization News, June 1992.

Shealy JE, Miller DA. A relative analysis of downhill and cross-country ski injuries. In: Mote CD, Johnson RJ, eds. Skiing trauma and safety: sixth international symposium, ASTM STP 1104. Philadelphia: American Society for Testing Materials, 1991:133-143.

Shealy JE. A comparison of downhill and cross-country skiing injuries. Cross-country skiing injuries. In: Johnson RJ, Mote CD, eds. Skiing trauma and safety: fifth international symposium, ASTM STP 860. Philadelphia: American Society for Testing and Materials, 1985:423-432.

Sherry E, Asquith J. Nordic (cross-country) skiing injuries in Australia. Med J Aust 1987; 146:245-246.

Sherry E, Clout L. Deaths associated with skiing in Australia: a 32 year study of cases from the Snowy Mountain. Med J Aust 1988; 149:615-618.

Sherry E, Fenelon L. Trends in skiing injury type and rates in Australia. A review of 22 261 injuries over 27 years in the Snowy Mountains. Med J Aust 1991; 155:513-515.

Smith M, Matheson GO, Meeuwisse WH. Injuries in cross-country skiing. A critical appraisal of the literature. Sport Med 1996, 21 (3):239-250.

Spademan R. Lower extremity injuries as related to the use of ski safety bindings. JAMA 1978; 203:103-8 cited in Sterett and Krisoff (1994).

Speer KP, Warren RF, Wickiewicz TL, Horowitz L, Henderson L. Observations on the injury mechanism of anterior cruciate ligament tears in skiers. Am J Sports Med 1995; 23 (1):77-81.

Standards Australia. Australian Standards 1995. Catalogue of Australian standards and other publications. Standards Association of Australia publication, Strathfield, NSW.

Sterett WI, Krisoff WB. Femur fractures in alpine skiing: classification and mechanisms of injury in 85 cases. J Ortho Trauma 1994; 8 (4):310-314.

Street GM. Technological advances in cross-country ski equipment. Med Sci Sports Exerc 1992; 24 (9):1048-1054.

Victorian Ski Association. Snowsafe: a comprehensive safety booklet for visitors to Victoria's alpine areas. 6th ed. Victoria 1995. Victorian Ski Association Inc, Victoria, Australia.

Watt GM, Finch CF. Preventing equestrian injuries. Locking the stable door. Sports Med 1996; 22(3):187-197.

Westlin NE. Factors contributing to the production of skiing injuries. Orthop Clin North Am 1976; 443:1-45 cited in Karlsson (1984).

APPENDIX 1 Summary of the studies evaluating cross-country skiing equipment

Anecdotal/Informed opinion	Biomechanical and laboratory testing and equipment design	Article reference
Modern equipment contributes to the injury risk in cross-country skiing. All development of skiing safety equipment must place the biomechanical performance of humans at the centre. The relatively new style of double-poling stride combined with skating steps is much used by elite skiers today. It is reputedly dangerous for beginner and intermediate skiers.	The breaking strength of skis in bending (4 different types of construction) and ski-boot binding combinations in torsion (3 types: Nordic norm 75 mm, 50 mm and 38 mm racing norm) was compared to biomechanical fracture strength data of the knee and tibia, and the recommended value for alpine release bindings	Ekström (1987)
Results: Fracture moment of the ski and of the binding or sole of the boot varied between the different skis and binding constructions. The strength in torsion and bending of the man-ski-equipment-system in cross-country ski equipment is 2 to 5 times higher for bindings and skis, when compared with the recommended release value for alpine release findings.		
If more rigid, better supporting boots become more popular, the difference in release capabilities of the heel locators may become evident. In weighted falls, heel locators can become rigid transmitters of potentially injurious loads to the lower extremity.	Testing of boot binding combinations, 2 of which used a standard serrated heel plate and one using a ridged heel plate with a grooved boot heel. Medial or lateral deviation under downward pressure was recorded. The loads perceived by a simulated tibia under lateral deviation of the heel were recorded.	Boyle et. al. (1985)
Results: In situations simulating partial weight bearing (132 N) all 3 bindings tested remained coupled when laterally or medially directed forces at the boot heel were applied up to 226 N, but release occurred with higher loads.. With a greater downward load applied at the boot heel (539 N) all systems remained coupled until medial or lateral loads applied at the heel exceeded 245 N. These tests were unable to demonstrate differences in the release capabilities of the standard serrated heel plate and the ridged heel plate. The releases that were observed occurred because of deformation of the boot sole and inability of the boot upper to constrain the heel.		

Anecdotal/Informed opinion	Biomechanical and laboratory testing and equipment design	Article reference
Friction, or reduction of friction, is important in a number of aspects of ski equipment. Ski safety is dependent on the friction between the boot and the upper ski surface. Minimising the friction between the ski and the snow increases the speed of downhill skiing. The speed of cross-country skiing depends on an interaction between static friction when the ski is stationary relative to the snow and dynamic friction when the ski is gliding over the snow. The cross-country skier has to propel along level ground and uphill, and maximise speed downhill.	Methods of modifying the coefficients of friction and the influence of temperature on them are considered. Coefficient of friction between boot and ski with various boot shoe materials, conditions of the ski surface, temperature and wet and dry conditions was measured.	Outwater (1970)
Results: Reduction of friction between the ski boot and the ski is important in binding release. Teflon was the only satisfactory material for an antifriction pad on the ski beneath the surface of the ski boot. Use of a lubricant such as silicone grease would be impractical for skiers. With respect to friction between the skis and the snow, no material had the consistently low frictional resistance that teflon did under all conditions, and is the best ski surface from a frictional point of view. Unfortunately, teflon has too low a static coefficient to be useful. All waxes tested for static coefficients were adequate at temperatures below minus 7 degrees Celsius, but 2 were optimal regarding dynamic coefficients; at lower temperatures one of these was superior in this.		

APPENDIX 2 Summary of a study examining the role of cross-country skiing technique

Anecdotal/Informed opinion	Data-based evidence	Article reference
No reports on acute injury have been published. Risk factors for injury, especially in recreational skiers, include poor condition of ski tracks, unsuitable or inferior equipment, poor balance and inadequate mastery of the technique.	A prospective 2 year study of first time visits of competitive and enthusiastic recreational cross-country skiers, all in active training, presenting to a Finnish Sports Medicine Research Station (clinic). The aim was to determine whether the recent general changeover from diagonal stride to skating had affected the number and types of skiing injuries (acute and overuse). The epidemiology of injury in 4 successive 6 month periods was compared.	Kannus et. al. (1988)
Results: Approximately half of the acute injuries occurred in the knee joint, and the majority were ligamentous injuries. The knee was the most frequent site of overuse injuries in approximately 30% of patients (included non specific synovitis, meniscus degeneration, and extensor tendonitis). The lower back was the second most common site for overuse injuries, with length difference between the lower limbs and chronic lumbosacral pain the most common diagnoses. There was a significant reduction in the number of overuse complaints of the upper back, neck, shoulder region and upper limbs over the study period (diagnoses included non specific pain of the thoracic spine, supraspinatus tendonitis and lateral epicondylitis). The most common sites of injury, other than the knee, were the shin, ankle and calcaneal tendon. No changes in acute injuries were noted over the 2 year period, but there was a reduction of about 50% in total number of overuse injuries. Skating may be less stressful on the skiers back. Once overuse complaints in a transition phase were overcome (eg neck-shoulder pains) less overuse injuries occurred in the upper body. There was no increase in overuse injuries, and no change in the number and type of overuse injuries of the knee.		