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Recreational windsurfing-related acute injuries: a narrative review. Part 1: injury epidemiology and a proposal for standardized injury definitions

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Objective: *The purpose of this review was to identify the epidemiology of, and develop standardized injury definitions for, acute injuries among recreational windsurfers*.

Methods: *A literature search was conducted from the PubMed and Google Scholar databases through February 28, 2023, using relevant keywords with Boolean operators, such as "windsurfing" AND "epidemiology" AND "risk factors." Only peer-reviewed, relevant windsurfing-related injury articles were included*.

Results: *A wide range of acute injuries, from minor, moderate, severe, to catastrophic, were reported. Injury*

Blessures aiguës liées à la pratique récréative de la planche à voile: une étude narrative. Partie 1: épidémiologie des blessures et proposition de définitions normalisées des blessures

Objectif: *Le but de cette étude était d'identifier l'épidémiologie des blessures aiguës chez les véliplanchistes amateurs et d'élaborer des définitions normalisées de ces blessures*.

Méthodologie: *Une recherche documentaire a été effectuée dans les bases de données PubMed et Google Scholar jusqu'au 28 février 2023, en utilisant des mots clés pertinents avec des opérateurs booléens, tels que "windsurfing" AND "epidemiology" AND "risk factors" (planche à voile ET épidémiologie ET facteurs de risque). Seuls les articles pertinents sur les blessures liées à la planche à voile, examinés par des pairs, ont été retenus*.

Résultats: *Un large éventail de blessures aiguës, allant de mineures à catastrophiques, a été rapporté*.

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rates, frequency of anatomical distributions, existing and potential risk factors, the proposed standardization definitions of behaviour types, skill levels, general windsurfing-related injuries, and injury severity classifications and levels for windsurfing epidemiology were identified and tabled.

Conclusions: *There is inconsistency in the epidemiological methods and definitions of windsurfing research. The injury rates remain difficult to compare among the identified studies. Future in-depth windsurfing-related injury studies should focus on prospective designs using standardized injury definitions.*

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KEY WORDS: acute injuries, causes, chiropractic, demographics, epidemiology, injury definitions, injury patterns, mechanisms, risk factors, sports behaviour, sports nutrition, windsurfing

Les taux de blessures, la fréquence des répartitions anatomiques, les facteurs de risque existants et potentiels, les définitions de normalisation proposées pour les types de comportement, les niveaux de compétence, les blessures générales liées à la planche à voile, ainsi que les classifications et les niveaux de gravité des blessures pour l'épidémiologie de la planche à voile ont été déterminés et présentés.

Conclusions: *Les méthodes et définitions épidémiologiques de la recherche sur la planche à voile manquent de cohérence. Les taux de blessures restent difficiles à comparer entre les études retenues. Les futures études approfondies sur les blessures liées à la planche à voile devraient se pencher sur des modèles prospectifs utilisant des définitions de blessures standardisées.*

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MOTS CLÉS : blessures aiguës, causes, chiropratique, démographie, épidémiologie, définitions de blessures, modèles de blessures, mécanismes, facteurs de risque, comportement sportif, nutrition sportive, planche à voile.

Introduction

Injuries are unavoidable for both recreational and elite-level competitive windsurfers.[1] Three types of windsurfing-related injuries have been identified: a wide range of *acute* injuries[2-4] from minor, moderate, and severe to catastrophic injuries, such as spinal and spinal cord injuries,[5,6] and drowning death;[2,6,7] *overuse* injuries,[3,4] such as low back pain,[3,8] and entrapment of the posterior interosseus nerve;[9] and *overexposure* or prolonged-exposure injuries, such as sunburn,[4,10] life-threatening hypothermia,[2,4,6,7] and external auditory exostosis[11].

Little is known about sports chiropractic involvement in windsurfing-related injury research. One chiropractic retrospective survey questionnaire study provided data on physical characteristics and acute and overuse injuries, including low back pain, in nine elite women windsurfers.[3] Another chiropractic retrospective survey questionnaire study of low back pain and harness use in windsurfing provided data on prevalence and found that 152 of 400 high-wind windsurfers showed a 93.3% prevalence of low back pain among the windsurfers versus 75.7% among the control group.[8]

Injury epidemiology can be regarded as a "cornerstone" for the evidence-based practice of sports medicine. Sports injury epidemiological data has helped to identify causes of injuries and has been used to reduce injury rates evidently by developing and implementing prevention strategies such as the prohibition of "spearing" in football[12] and strict judging and heavy penalties for uncontrolled blows in karate[13]. Until recently, relatively little research using standardized epidemiological methods has been addressed. To encourage consistency in the definitions and methods used, and to enable data across studies to be compared, 11 international sport-specific or setting-specific consensus papers on standardized injury epidemiology have been published.[14]

There is limited data on the epidemiology of windsurfing-related acute injuries. To date, the demographic characteristics and injury characteristics, such as injury rates, risk factors, patterns, causes, and mechanisms of recrea-

tional windsurfing-related acute injuries, are largely unclear. Standardized injury definitions for windsurfing-related injuries are needed. The severe and catastrophic windsurfing-related acute injuries highlight the need for injury prevention studies. To provide clinicians with a practical overview of injury epidemiology and preventive strategies, the narrative review of "recreational windsurfing-related acute injuries" is organized into two parts:

Part 1: injury epidemiology and a proposal for standardized injury definitions.
Part 2: injury prevention and a proposal for a set of potential prevention strategies with a holistic approach.

The purpose of this review was to identify the epidemiology of, and develop standardized injury definitions for, acute injuries among recreational windsurfers. The research question, "What are the existing injury characteristics regarding windsurfing-related injuries, definitions, demographic characteristics, injury severities, injury rates, factors, patterns, causes, and mechanisms for recreational windsurfing-related acute injuries?", was developed.

Methods

A literature search was conducted from inception up to February 28, 2023, for recreational windsurfing-related acute injuries. The PubMed and Google Scholar electronic databases were searched. In addition, manual searching of reference lists was used to identify additional articles with Google Scholar.

Search strategy

To provide the most articles pertaining to the research question, the search method was broken down into the following categories using the Boolean operator and relevant keywords: "injury epidemiology" AND "windsurfing" OR "boardsailing," "demographic characteristics "AND "windsurfing" OR "boardsailing," "acute injury" AND "windsurfing" OR "boardsailing," "injury definition" AND "windsurfing" OR "boardsailing," "injury severity" AND "windsurfing" OR "boardsailing," "injury rates" AND "windsurfing" OR "boardsailing," "risk factors" AND "windsurfing" OR "boardsailing," "injury pattern" AND "windsurfing" OR "boardsailing," "injury causes" AND "windsurfing" OR "boardsailing," "injury mechanism" AND "windsurfing" OR "boardsailing," and "behavior" AND "windsurfing."

Inclusion and exclusion criteria

For the inclusion criteria for relevant articles, data were collected on at least one outcome related to demographic characteristics, injury types, anatomical locations, injury severities, injury rates, risk factors, injury patterns, and mechanisms of recreational windsurfing-related acute injuries. Only peer-reviewed English-language articles on windsurfing-related acute injuries were included. Articles were excluded if their contents were duplicated, ambiguous, or unavailable in English. Boat sailing, stand-up paddle-sailing, or kite-sailing were excluded.

Article selection

A PRISMA-type flow chart was used to provide information through the different phases of the study selection process of *identification*, *screening*, *eligibility*, and *inclusion* of citations into the final review. Articles were identified through a preliminary search. Duplications were removed. Articles were initially screened by title and abstract for eligibility. Full-text materials were then assessed for eligibility and finally included in the full-text review. Article screening, selection, and reviewing were done by the author exclusively.

Data extraction

The titles, authors, year of publications, objectives, study designs, number of participants, settings, locations, demographic characteristics, injury characteristics, including risk factor classification (intrinsic/extrinsic), and acute windsurfing-related injuries were extracted. All data were reviewed for relevance.

Results

The preliminary search identified 297 articles. 47 articles were included in the final review from 87 publications assessed for eligibility (Figure 1). Regarding the study designs, only retrospective study data (hospital record reviews and questionnaires) and prospective study data (telephone interviews and questionnaires) were identified. Regarding injury epidemiology, injury rates for recreational windsurfers of different skill levels in different countries were summarized in Table 1; the frequency

of anatomical distributions of windsurfing-related acute injuries of recreational and professional skill levels was summarized in Table 2; and the existing and potential injury risk factors of windsurfing-related acute injuries were summarized in Table 3. There was inconsistency in the injury epidemiological definitions of windsurfing research. To encourage consistency in the definitions for standardized epidemiological research, the proposed standardization definitions of behaviour types, skill levels, and general windsurfing-related injury were summarized in Table 4, and injury severity classifications and levels for windsurfing epidemiology were summarized in Table 5, respectively.

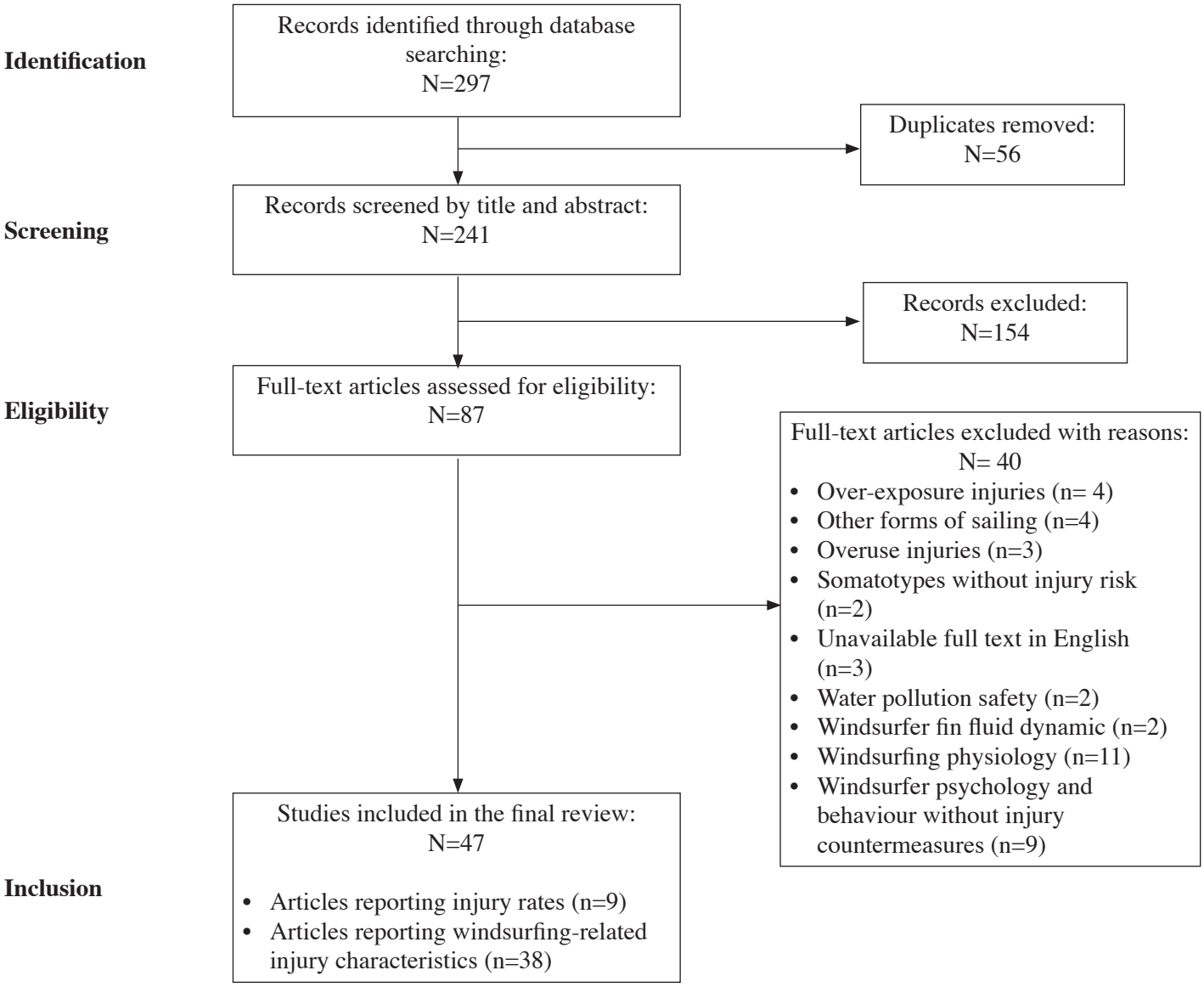

Figure 1.
Summary of a PRISMA-type flow chart of information through the different phases of the article selection process.

Table 1.
Summary of injury rates for recreational windsurfers of different countries

Study	Study design and duration of collection (if available)	Total number (n) of participants (including gender)	Country, skill level, and number (n) of participants	Injury rates (Expressed as number of injuries/1000 hours exposure, and/or number of injuries/ athlete/year) (Recreational windsurfers, if available)
McCormick, Davis 1988 [10]	Retrospective study (A review of medical hospital records for the period 1976-1986, and survey questionnaire-interview)	n=73 (51 men, 22 women)	Windsurfers from United States: • *Novice:* all men n=16 (31%), all women n=10 (45%); • *Intermediate:* all men n=29 (57%), all women n=11 (50%); • *Expert:* all men n=6 (12%), all women n=1 (5%); and • *"Hurricane man"* (40 knots): n=6 (60%)	• Overall: 0.22/1000 hours windsurfing. (*Recreational windsurfers*)
Mettler, Biener 1991 [36]	Retrospective study (A review of medical record)	n =189	Windsurfers from Swiss Windsurfing Federation: • National-level windsurfers.	• Overall: 0.02/athlete/year.
Salvi-et al. 1997 [26]	A retrospective study between June to October 1993 evaluating acute and overuse injuries of muscle and bone.	n=123 (118 men, 5 women)	Windsurfers from Italy (*national/international*): • Competitive slalom, course racing, & wave n=76; • Competitive slalom & wave, n-35; and • Competitive slalom & course racing, n=22.	• Overall: 0.22/1000 hours activity, 0.003/athlete/year. • Acute injuries: 0.128/1000 hour activity, 0.0019/athlete/ year.
Nathanson, Reinert 1999 [7]	A retrospective study of an internet survey specific questionnaire between February 1997 and May 1997 and an identical paper survey distributed to windsurfers at beaches in the US and Dominican Republic between April 1994 and April 1997.	n=294 (90% men including 2 expert professionals)	Windsurfers from 24 countries, majority (67%) were from United States: • *Beginner:* n=21 (7%); • *Intermediate*: n=176 (60%); and • *Expert*: n=95 (32.3%).	• Overall:1/1000 hours sailing. Predominantly *recreational* windsurfers n=292 (99.3%).
Lim et al. 2003 [37]	A retrospective & prospective telephone interview study with structured questionnaires over 1 year.	n=64	Windsurfers from Britain: • Competitive amateur shortboard including wavesailing and slalom (*national*).	Overall: 2.6/1000 hours • During training: 2.3/1000 hours • During competition: 3.7/1000 hours
Dyson et al. 2006 [1]	A retrospective study of a paper survey specific questionnaire distributed to windsurfers at the event site and collected by hand in the 1999/2000 seasons	n=107 (88 men, 19 women)	Windsurfers from United Kingdom: *Recreational* group: n=28; • *Competitive raceboard* group *(national/ international):* n=36; and • *Competitive wave/slalom* group *(national/ international):* n=43.	• Overall: 1.5/person/year; • *Recreational group*: 1.2/ person/year • *Raceboard group*: 1.0/person/ year; • *Wave/slalom group*: 2.0/ person/year.
Kucera, Psalman 2015 [38]	Retrospective study (Questionnaire)	n =104	Windsurfers from Czech Republic: • *Recreational group A:* n=35, funboard including slalom & wave with free style acrobatic/aerial maneuvers; • *Raceboard group B (national):* n=45; and • *Raceboard group C (professional):* n= 24.	• *Recreational group:* 2.63/athlete/year. • *Raceboard (national)* group: 1.04/athlete/year. • *Raceboard (professional) group*: 0.63/athleteyear.
van Bergen et al. 2016 [27]	A retrospective study of hospital medical record review from September 2009 through September 2011 and a postal questionnaire. Hospital record: windsurfing group n= 25 (21 men, 4 women).	n=18 completed questionnaire	Windsurfers from Netherlands: • Beginner: n=1; • Intermediate: n=0; • Advanced: n=9; and • Expert: n=8.	• Overall: 5.2/1000 hours windsurfing. (*Recreational windsurfers*)
Minghelli et al. 2019 [39]	Retrospective study (Questionnaire)	n =58	Windsurfers (*World Championships*) from Portugal: • *Competitive raceboard*: n=27; and • *Competitive Windsurfing Formula*: n=31.	• Overall: 3.91 injuries/1000 hours windsurfing training.

Table 2.

Summary of the frequency of anatomical distributions of windsurfing-related acute injuries

1. Frequency of body regions

Study	Study design	Total number (n) of participants and skill levels	Frequency of body regions (%) in decreasing order (Number of acute injuries)
Nathanson, Reinert. 1999 [7]	Retrospective study (a paper- & internet-based survey) Paper-based survey collected between April 1997 & April 1994 and an internet-based survey between February 1997 & May 1997.	n= 294 windsurfers: • 292 recreationalists • 2 professionals	n=339 acute injuries • Lower extremity (44.6%) • Upper extremity (18.5%) • Head & neck (17.8%) • Trunk (16%)
Gosheger et al. 2001 [54]	Retrospective study (Survey questionnaire)	n=49 windsurfers: • 49 professionals (10 women, 31 men)	n=260 acute injuries • Lower extremity 59% • Head (17%) • Trunk (15%) • Upper extremity (9%)
Hopkins, Hooker. 2002 [15]	Retrospective study (Emergency department database review between April 1, 1995, & September 30, 1998)	n=220 windsurfers	n=222 acute injuries • Lower extremity (48%) • Head/neck (25%) • Trunk (9%) • Upper extremity (8%)
Kucera, Psalman. 2015 [38]	Retrospective study	n=104 windsurfers: • 35 recreationalists • 45 nationals • 24 professionals	*Recreational level* (funboarding, wave, & slalom) n=92 acute injuries • Lower extremity (42%) • Head & neck (23%) • Upper extremity (20%) • Trunk (15%) *National level* (race-boarding) n=37 acute injuries • Upper extremity (52%) • Lower extremity (26%) • Head & neck (13%) • Trunk (9%) *Professional level* (race-boarding) n=15 acute injuries • Upper extremity (53%) • Lower extremity (27%) • Head & neck (13%) • Trunk (7%)
Van Bergenet al. 2016 [27]	Retrospective study (Review of hospital records between 2009 through September 2011)	n=25 windsurfers	Number of injuries per 1000 h Affected body site (number & % of patient) • Lower extremity 10 (40%) • Head & cervical spine 9 (36%) • Upper extremity 6 (24%) • Trunk & thoracolumbar spine 0 (0%)

2. Frequency of body parts

Study	Study design	Total number (n) of participants and skill levels	Frequency of body parts (%) in decreasing order (Number of acute injuries)
Ullis, Anno. 1984 [25]	Retrospective study (Survey questionnaire) Data collected at 3 events in 1982.	n=57 windsurfers: (14 female, 43 male) • 30.2% recreationalists • 69.8% professionals	*Female windsurfers (n=14)* Skin 100%, Shins 100%, feet 100%, back 71.4%, forearms 71.4%, shoulder 64.3%, head 57.1%, neck 57.1 %, fingers 50%, chest 42.5%, thighs 35.7%, elbows 28.6%, wrist 21.4%, ears 21.4%, eye 14.3%, mouth, throat, and teeth 14.3%, knee 7.1%, ankle 14.3%, abdomen 7.1%, genitalia 7.1% *Male windsurfers (n=43)* Skin 100%, feet 95.3%, back 79.1%, shins 77.6%, forearms 60.5%, head 55.8 %, neck 51.2%, fingers 48.8%, shoulder 39.5%, knee 39.5%, ankle 34.9%, ears 34.9%, chest 39.5%, genitalia 29.5%, eyes 27.9%, elbows 27.9%, thighs 23.3%, wrist 16.3%, mouth, throat, and teeth 19.3%, nose 9.3%, abdomen 2.3%, heart 2.3%
Nathanson, Reinert. 1999 [7]	Retrospective study (paper- & internet-based survey) Paper-based survey collected between April 1997 & April 1994 and an internet-based survey collected between February 1997 & May 1997.	n= 294 windsurfers: • 292 recreationalists • 2 professionals	n=339 acute injuries Foot 17.7%, knee 9.4%, chest wall 8.9%, ankle 8.6%, head 7.4%, leg 7.4%, shoulder 7.1%, back 6.8%, neck 4.7%, hand 4.4%, face 3.5%, wrist 3.5%, arm 3.2%, other 2.9%, toe 1.5%, eye 0.9%, nose 0.9%, teeth 0.9%. elbow 0.3%

Table 3.
Summary of the existing and proposed potential injury risk factors for windsurfing-related acute injuries

Intrinsic risk factors	Extrinsic risk factors
Demographic characteristics: • Age (older) [15,16,18] • Gender [15,17] • Body size (height and weight) [3,19] and composition (body mass index) * • Somatotypes: endomorph (fatness), mesomorph (muscularity), and ectomorph (linearity) * *Physiological characteristics: ** • Physical fatigue • Physical fitness • Aerobic fitness • Muscle strength, imbalance, tightness, and fatigue • Joint mobility (ligament laxity, flexibility, hypermobility, and hypomobility) • Neuromuscular proprioception control (slow reaction time) • Balance (static and dynamic) *Biomechanical factors: ** • Spinal mobility and core stability • Sacroiliac joint dysfunction • Pelvic girdle insufficiency (ligament laxity) • Internal rotation of the hip • Genu valgus and varum • External rotation of the tibia • Leg length discrepancy • Foot (pronation), pes planus, and pes cavus *Nutritional conditions:* • Fluid consumption (insufficient and incorrect hydration) [50] • Food consumption (insufficient nutrition) [20] *Behaviour factors:* • Adventurous risk-taking behaviour [4,44] (expectations, motivations, and pressures) • Alcohol consumption [4] (prior training or competition) • Drug abuse [4] (prior training or competition) *Medical conditions:* • Previous injuries and inadequate rehabilitation • Epilepsy [10] • Cardiovascular diseases [10] • Diabetes * • Asthma *	*Equipment conditions:* • Equipment (poorly maintained, worn, and damaged) [47] • Sizes (board, sail, [4,23,24] and fin) • Design safety (fin hazards) [7,26] *Environmental conditions:* • Unknown venue [4] • Strong wind forces (overpowering) [4,24,48] and direction (offshore winds [29]) • High waves [4,24,28] • Current [48] (rip current) • Weather [4,24] (sunny,[62] heavy rainfall, lightning, poor visibility fog or mist, cold or hot temperature, and high humidity) • Sea animals (sharks, needlefish, and jellyfish) [2,10,29] *Discipline types:* • Wave (jumping maneuvers) [1,23,25] • Slalom [1,26] • Course racing [1,26] • Freestyle (acrobatic or aerial maneuvers) [18,38] *Training parameters: ** • Training load and fatigue (schedule congestion or overtraining) • Training exposure times • Training techniques (incorrect) • Incorrect physical preparations • Training recovery (short and insufficient) *Competition parameters: ** • Competition load and fatigue (over-competition) • Competition exposure times • Skill levels [38] • Levels of competition • Competition demands (a large number in the year) • Competition recovery (short and insufficient)

Adopted from [1-4,7,10,15-18,20,23-26,28,29,38, 44,47,48,50,62], and modified from [42] with potential risk factors. (*)

Table 4.
Proposal for standardization of definitions of windsurfing-specific behaviour types and skill levels and general windsurfing-related (or other sports-related) injuries

Behaviour types (windsurfing-specific)	A. Behaviour types and definitions of recreational windsurfers [22] • *Occasional recreational windsurfers* are defined as beginner-level athletes who prefer *middle (4-7 m/s) wind speeds* over *strong (8 m/s and over) wind speeds* and prefer only summer conditions with high crowding. • *Social recreational windsurfers* are defined as intermediate-level athletes who prefer middle wind speeds over strong winds and summer and spring conditions with higher crowding. • *Competitive recreational windsurfers* are defined as experienced *non-professional* competitive athletes who prefer strong wind in the summer over spring conditions with high crowding. • *Pleasure recreational windsurfers* are defined as experienced, aggressive athletes who prefer strong wind speeds in the summer over spring conditions with high crowding.
Skill levels (windsufing-specific)	B. Skill levels and definitions of recreational windsurfers [1,10] • *Beginner level* is defined as an inexperienced novice windsurfer with learning and training skills equivalent to a basic windsurfing course. • *Intermediate level* is defined as an experienced windsurfer with learning and training skills equivalent to an intermediate windsurfing course. • *Advanced level* is defined as an elite experienced windsurfer with learning and training skills equivalent to an advanced windsurfing course (such as advanced slalom skills, advanced aerial and freestyle maneuvers, or advanced wave jumping and sailing maneuvers). • *Expert level* is defined as an extremely experienced windsurfer with skills above advanced level and capable of sailing in *gale-force winds* with 40 knots 10 and *high waves*.
General windsurfing-related (or other sports-related) injury definitions	C. General windsurfing-related (or other sports-related) injury definitions (modified from [59]) • *Acute windsurfing (sports) injury* is defined as the damage to body site(s) of sudden onset sustained by an athlete that resulted during windsurfing (sports) training or competition, irrespective of the need for medical attention or time loss from or incapacity to windsurfing (sports) activities. • *Injury severity* is defined as the inability to train or complete windsurfing (sports) normally, with several days having elapsed from the date of the injury to the date of the athlete's return to full training and competition. The absence from windsurfing (sports) can range from more than 1 day, more than 6 weeks, to a permanent disability. • *A sports-related medical attention or intervention injury* is defined as an injury that results in an athlete receiving "medical attention (intervention)" by qualified healthcare practitioners. • *A sports-related time-loss injury* is defined as an injury that results in an athlete being unable to take part in windsurfing (sports) training or competition. • *A sports-related recurrent injury* is defined as an injury of the same type and at the same site as an index windsurfing (sports) injury that occurs after an athlete's return to full participation from the index injury. Also, a recurrent injury may not necessarily need to be identical in severity to be considered recurrent. • *Early recurrence* is defined as a sports-related recurrent injury occurring within 2 months after an athlete's return to full participation. • *Late recurrence* is defined as a sports-related recurrent injury occurring 2-12 months after an athlete's return to full participation. • *Delayed recurrence* is defined as a sports-related recurrent injury occurring more than 12 months after an athlete's return to full participation.

Adopted and modified from [1,10,22,59]

Table 5.
Proposal for standardization of definitions of injury severity classifications and levels for windsurfing (or other sports)

Injury severity classifications and Levels (1-4)	**Definitions of athletic injury severity for windsurfing (or other sports)**	**Medical attentions (interventions)**	**Consequences of acute athletic injuries for windsurfing (or other sports)**
Minor Level (1)	• A *minor injury* is defined as an *injury from windsurfing (or other sports) resulting in the inability to train or complete sports normally*. • An athletic injury is temporary and self-limited but requires first-aid management.	• Management by qualified sports first aiders is needed. • Medical attention by qualified primary healthcare providers and athletic trainers is not required.	• *No time loss* or • May result in an inability to train or compete in windsurfing (or other sports) normally.
Moderate Level (2)	• A *moderate injury* is defined as an *injury from windsurfing (or other sports) resulting in absence for more than 1 day*. • An athletic injury is temporary and curable, and it is reversible in most instances.	• Medical attention by qualified primary healthcare providers may be required. • Neuromusculoskeletal sports rehabilitation may be required. • An emergency department visit may be required. • Hospitalization is not required.	• *Time loss* • Absence from windsurfing (or other sports) for *not more than 6 months* • Not life-threatening
Severe Level (3)	• A *severe injury* is defined as an *injury from windsurfing (or other sports) resulting in absence for 6 weeks to more than 6 months*. • An athletic injury is irreversible and may cause long-term disability.	• Medical attention by qualified healthcare specialists is required. • Neuromusculoskeletal sports rehabilitation is required. • A tertiary hospital and hospitalization are required.	• *Time loss* • Absence from windsurfing (or other sports) for *more than 6 months* • Not life-threatening
Catastrophic Level (4)	• A *catastrophic injury* is defined as an *injury from windsurfing (or other sports) resulting in permanent disability, a life-threatening condition, or death*. • An athletic injury may be associated with critical accidents, such as near-drowning, drowning, spinal injuries, spinal cord injuries, and loss of limbs.	• Intensive care with advanced life support is required. • If the injured athlete survived, tertiary hospital multidisciplinary medical and other interventions, such as neurological, physical, mental, and respiratory rehabilitation, are required.	• *Permanent time loss* • Loss of limb(s) or • Permanent disability or • Life-threatening or • death

Adopted and modified from [27, 60,61]

Demographic characteristics and windsurfing-related injuries – Age and gender

Windsurfing is a sport for young to middle-aged people, predominantly men.[15] The average age of windsurfing injuries was 35 years old, ranging from 12 to 68 years of age;[15] and 10% were older than 50 years of age[16]. The ratio of male to female injuries is 9:1.[7,15] Men windsurfers are injured more frequently during competition than training (79.5%, $p<0.05$, vs 22.2%);[17] and women windsurfers are injured more frequently during training than competition (77.8%, $p<0.05$, vs 20.5%)[17,18]. Women windsurfers are more likely to suffer serious injuries during training sessions.[17] Freestyle involves a greater risk of leg injuries for women.[18] The knee is the most injured area, both for men and women, followed by the leg.[17]

Anthropometric characteristics

Data about the anthropometric characteristics of windsurfing-related injuries is sparse. In one retrospective survey study of 41 elite windsurfers, the heights of 36 male (age range: 15-44 years) and five female (age range: 15-39 years) elite windsurfers ranged from 1.65-1.90 m and 1.55-1.70 m, respectively, and their weights ranged from 55-94 kg and 50-64 kg, respectively.[19] The study also indicates that elite windsurfers suffer predominantly minor acute injuries, which are mainly abrasions and lacerations to the lower limbs. Another retrospective study of the physical characteristics and injuries of nine elite women world champions (age range: 23-34 years) found that no serious acute injuries in the organized windsurfing competition were reported, and only one case of an acute minor lower leg contusion injury by sailboard during freestyle was found. Their height ranged from 1.62-1.78 m (mean =1.69 m) and their weight ranged from 56-64 kg (mean = 60 kg). In another study of anthropometry among 91 windsurfers of different disciplines, the wave or freestyle group (n = 46) demonstrated lower percentages of body fat (21%), circumferences, skinfolds, body mass index (23.9 kg/m^2), and fat mass index (5.1 kg/m^2) compared with the slalom or formula group (n = 45) (body fat 25.2%, body mass index 26.1 kg/m^2, and fat mass index 6.6).[20] A very recent anthropometric study of 21 young elite windsurfers (age range = 12-18 years) found that the high-level performance elite windsurfers had a greater percentage of arm muscle mass and leg muscle mass compared to low-level performance windsurfers.[21]

Behavioural types

A conjoint analysis was used to examine windsurfing preferences. Three attributes— wind velocity, season, and crowding— were considered.[22] Four behavioural types of recreational windsurfers were identified: occasional, social, competitive, and pleasure windsurfers. The definitions of four behavioural types are summarized in Table 4A. Regarding wind speed preferences, occasional and social windsurfers prefer middle wind speeds, and competitive and pleasure windsurfers prefer strong wind speeds.[22] However, the frequency of windsurfing-related injuries among different behavioural types of windsurfers is unknown.

Skill levels

Four skill levels of recreational windsurfers were found: *beginner* (7%,[7] 31% men, and 45% women10), *intermediate* (60%,[7] 57% men, and 50% women10), *advanced* [1], and *expert* (33%,[7] 12% men, and 5% women10). Inexperienced beginners and intermediate athletes,[2] especially women,[10] appear to have an increased injury risk in recreational windsurfing. The definitions of the four skill levels of recreational windsurfers are summarized in Table 4B.

Acute windsurfing-related injuries

A wide range of acute windsurfing-related injuries, from minor to moderate to severe to catastrophic, were reported. Most windsurfing-related injuries occur when doing jumps in wave conditions.[23] The frequency of anatomical distributions of windsurfing-related acute injuries is summarized in Table 2. Most recreational windsurfers sustained minor injuries, such as abrasions, lacerations, contusions, strains, and sprains;[1,3,7,10] and 43% of new injuries were muscle and tendon strains[1]. According to a retrospective study of hospital records from the emergency department,[15] the frequency of 222 cases of windsurfing-related injuries was as follows: laceration (36%), contusion (21%), fracture (14%), sprain (7%), dislocation (4%), and strain (3%). Recreational windsurfers sustained serious acute injuries[7] when they practiced in overpowering winds and wave conditions[4,24] or simply did not follow safety rules and procedures[4].

Spinal injuries and pelvic injuries

Studies showed that recreational windsurfers sustained fewer acute back (6.8%) and neck (4.7%) injuries,[7]

whereas professionals sustained more acute back (women 71.4% and men 79.1%) and neck (women 57% and men 51%) injuries[25] (Table 2). Acute moderate neck strain, upper back strain, and lower back injuries,[1,25] as well as serious pelvic injuries and non-catastrophic and catastrophic spinal injuries, caused by windsurfing-related accidents, have been documented[2,5-7,25-28]. Head and cervical spine injuries make up 36% of all injuries.[27] Reported serious spinal and pelvic injuries are the cervical (C) spine injuries,[1,7,27] such as a cervical sprain;[26] lateral wedging of thoracic (T8/9) disc;[5] lumbar spine injuries;[6] intervertebral disc herniations;[2,7,25] and pelvic injuries with sacral fractures and pubic symphysis diastasis[28]. Reported catastrophic spine and spinal cord injuries include thoracic spine injuries with pain and transient thoracic spinal cord injuries, cervical spine (C2) fracture, and tetraplegia.[5,6]

Extra-spinal injuries

Studies showed that recreational windsurfers sustained more lower extremity (44.6%) and fewer upper extremity acute injuries (18.5%),[7] whereas professionals sustained more upper extremity (53%), and fewer lower extremity (27%) acute injuries (Table 2). Reported acutely serious and catastrophic extra-spinal windsurfing-related injuries include shark bites,[2,29] axillary artery tear,[30] head injuries,[7,27] concussions,[1,6,25] eye injuries,[7] hearing injuries with tympanic membrane rupture,[1,6,7,15] teeth injuries,[7] nasal fractures,[7] pectoris major muscle rupture,[31] rib fractures with pneumothorax,[2,4] shoulder fractures and dislocations,[4,6,32] arm, elbow, wrist, and hand injuries with fractures[2,7,25] or finger dislocations,[1] knee injuries with anterior cruciate ligament and medial collateral ligament sprains or meniscus tears,[7,33,34] leg, ankle, and foot injuries[7] with Lisfranc fracture-dislocations,[35] drownings, and near-drownings or drowning deaths[2,6,7].

Injury rates

Windsurfing injury rates for different skill levels of recreational windsurfers among national [1,10,26,27,36-39] and international[7] athletes are summarized in Table 1. The existing incidence rate of windsurfing-related acute injuries varied in the definition of injury, study design, methods of data collection, and observational period. The injury rates of these non-standardized epidemiology studies for recreational windsurfers[1,7,10,26,27,37-39] remain difficult to compare among studies due to heterogeneity.

Injury risk factors

Intrinsic and extrinsic risk factors

According to Meeuwisse's model,[40] the risk factors are traditionally classified as intrinsic and extrinsic.

- *Intrinsic risk factors* are defined as individual, biological, and psychosocial characteristics that predispose an athlete to injury.[41]
- *Extrinsic risk factors* are defined as external factors that can cause an athletic injury and are closely related to the type of athletic activity performed.[41]

Windsurfing-related injury risk factors

Based on a systematic review of soccer players' risk factors[42] and the extracted data from this review, existing and potential windsurfing risk factors are summarized in Table 3. Intrinsic risk factors and strategies for injury prevention have been highlighted.[41] However, a multifactorial approach should be used to account for all the intrinsic and extrinsic risk factors as well as injury mechanisms.[43] Windsurfing-related accidents may result from modifiable high-risk, reckless behaviours,[4,44] when certain basic rules, such as the rules of the water or procedures, are violated[4]. Surprisingly, alcohol consumption was found in 22% (4 out of 18) of windsurfers three hours before sailing.[4] *Non-modifiable medical risk factors*, such as epilepsy attacks,[45] and heart attacks[10,46] have been identified.

Environmental risk factors

Extrinsic environmental risk factors, such as Beaufort wind force and rough weather conditions,[4] should be checked for windsurfing suitability before sailing. The Beaufort scale number ranges from 0 (calm) to 12 (hurricane), with wind speeds ranging from under 1 knot to over 63 knots.[47] Underestimation of weather conditions[24] or unawareness of rough weather conditions[4] may increase the risks of accidental injuries.

Equipment-related risk factors

The equipment used in windsurfing has the potential to cause or contribute to *equipment-related injuries*. A retrospective study of 189 windsurfers found that one-third of all injuries were due to board contact events, and 19% were due to falls on the mast.[36] Another retrospective

study found that direct injury from windsurfing equipment resulted in 64.5% of all 339 acute injuries: 17.2% from the boom, 16.7% from the foot straps, 12.7% from the mast, 8.7% from the board, and 8.1% from the fin.[7] Most accidents happen because of an overpowering situation,[4,24,48] i.e., the sail is too big for the wind force[48]. The overpowering situation should be prevented by choosing the right board and sail size.[24]

Sports nutrition risk considerations

Study evidence has revealed that glycogen is the predominant energy fuel during windsurfing pumping.[49] However, a previous dietary quality study found that the overall negative energy balance was due to crucial glycogen depletion between different windsurfing disciplines.[20] Also, a recent study of the assessment of nutrition status in amateur windsurfers found that daily fluid consumption was insufficient.[50] It is important to be aware that the combination of exercise and high environmental heat stress can produce dehydration,[51] and dehydration can hamper performance, including through cognitive impairment and increased injuries[52].

Injury patterns

Clinicians should have a basic knowledge of injury patterns and the hazards of windsurfing to promote prevention strategies and educate their patients.[53] Identifying injury patterns in windsurfing may help clinicians know what to expect[7] and what prevention strategies to consider[54]. Injury patterns appear similar in both recreational1,[7] and competitive[1,54] windsurfing. Windsurfing-specific equipment-related mechanism-based injury patterns have been reported. For example, a *head-to-equipment collision injury*[7] is mainly caused by a collision with the mast or boom due to high-speed falls;[4] the head injuries can range from minor head injuries to severe brain concussions with loss of consciousness[4]. The *boom-hanging and fall-shoulder injury*[7] is caused by a fall while hanging on the boom to maintain a pull on the sail, leading to an anterior shoulder dislocation[4,7]. Falls may also cause a *foot-fixation injury* (foot strap injury) due to the fixation of the feet in the foot straps.[34]

Causes

In windsurfing, there are several causes of unpredictable traumatic forces in the reported acute injuries, such as the overpowering forces of sudden, unexpectedly strong winds,[5] and high waves,[28] and the pulling, rotating, and collision forces of high-speed and low-speed falls from poorly performed jumping and aerial maneuvers. A retrospective study of 327 windsurfers with an overall 630 accidents found that most accidents happen at Beaufort scales 5-6 (fresh breeze to strong breeze with 17–27 knots[47]) after two hours of exercise.[24] A previous study found that one-third of all acute injuries were caused by board contact, one-fifth happened on the shore, and 19% were attributed to falls on the mast.[48] Collision force with equipment in recreational windsurfers[1,7] when overpowered by wind and waves is the most common reported cause of injury occurrence[1,49,55] and serious injuries,[24] such as spinal injuries[25,56] and spinal cord injuries[24].

Injury mechanisms

The most documented windsurfing injury mechanisms are maneuvering, board impacting, and traction or twisting the fixed foot.[23,44] The identified maneuvers most likely to result in injury are jumping, high-speed falls, catapult falls, and launching[7] or acrobatic maneuvers[55]. Recreational athletes injure themselves due to uncontrolled catapult falls. A previous study found that catapult crashes resulting from jumping maneuvers were the most common type of windsurfing-related accident.[1] In wave-related accidents, neck hyperextension may be the most common mechanism of cervical spine injuries.[57] Low-speed falls[7] may cause knee, leg, ankle, and foot injuries ascribed to the feet's fixation in the foot-straps,[7,34] while high-speed falls[7] in wave-riding may cause head, shoulder, and upper extremity injuries consistent with the mechanism of catapulting[24] mainly caused by the impact of landing on the mast or the boom,[7] or the mechanism of falling while maintaining a pull on the sail with the athlete's arms hanging onto the boom and causing shoulder dislocation[27].

Proposal for standardization of definitions for windsurfing-related injuries

Uniform definitions are important and necessary to enhance the comparability of research data.[58] There is a need to collect and report injury data using standardized windsurfing-related injury definitions to enable data across future studies to be compared. The *general windsurfing-related injury definitions* (Table 4C), including *injury severity*, were modified from the consensus statement on

injury definitions and data collection procedures in studies of soccer injuries.[59]

Injury severity classifications and levels for windsurfing
The reported injury's *four severity classifications* (Table 5) ranged from mild (17%) to medium (33%), severe (44%), and catastrophic (6%).[27] The severity of sports injuries can be described based on six criteria: the nature of the injury, the duration and nature of the treatment, sporting time lost, working time lost, permanent damage, and cost.[58] According to recent safety and risk assessment research,[60] the four *levels of injury severity* (Table 5) are determined by the type of "medical intervention" (such as first aid, a visit to the accident and emergency department, and hospitalization) required for the injury scenario. According to the RAPLEX guidelines,[61] the four *levels of injury severity* are:

- *Level 1*: An injury or consequence that, after basic treatment such as first aid, does not hamper functioning or cause excessive pain; usually the consequences are completely reversible.
- *Level 2*: An injury or consequence for which a visit to emergency may be necessary, but in general, hospitalization is not required. Functioning may be affected for a limited period, not more than about 6 months, and recovery is complete.
- *Level 3*: An injury or consequence that normally requires transportation of the athlete to a tertiary hospital and hospitalization and will affect functioning for more than 6 months or lead to a permanent loss of function.
- *Level 4*: An injury or consequence that is or could be fatal, including brain death; a consequence that affects reproduction or offspring; severe loss of limbs and/or function, leading to more than approximately 10% of disability.

Based on and modified from the RAPLEX guidelines,[61] injury severity levels,[27] and injury definitions,[60] standardized definitions of injury severity classifications, and levels of acute windsurfing-related injuries are proposed (Table 5).

Discussion

It is difficult to compare the injury rates in Table 1. These data [1,7,10,26,27,36-39] have been calculated from non-standardized study designs using different ways of collecting data, sample sizes, injury definitions, disciplines, and skill levels. It is possible that participants underestimated the amount of time they practiced windsurfing during the time of these studies,[27] and thus these data are subject to reporting bias, recall bias,[7] and collecting bias. When similar study designs using a review of hospital medical records and a questionnaire are compared, the injury rate shows remarkable increases, from 0.22/1000 h in the McCormick and Davis 1988 study[10] to 5.2/1000 h in the van Bergen *et al*. 2016 study[27]. This could be attributed to technological development, lighter and more sophisticated materials, and risk-taking behaviour.

In frequency studies [7,15,25,27,38,54] of body regions and body parts of windsurfing-related acute injuries (Table 2), no information was available regarding windsurfing disciplines such as speed, slalom, freestyle, and wave sailing. Future studies should consider including data on skill levels and sporting disciplines.

Windsurfing is not without injury risk, whether the individual windsurfer is an elite athlete or involved only in recreational participation. Windsurfing injury risk is a complex and multifactorial phenomenon. The identification of injury risk factors represents an important step before the implementation of prevention strategies.[58] Multiple intrinsic and extrinsic risk factors have been identified (Table 3). Intrinsic risk factors are those within the athlete's body. For example, risk factors may pertain to age, gender, anthropometrics, previous injuries, and physical, functional, psychological, and medical conditions. Extrinsic risk factors are those external to the athlete's body, such as windsurfing exposure, training conditions, sports discipline specialization, sports equipment-related conditions, and environmental conditions. For example, participation in windsurfing often entails the unavoidable extrinsic hazard risk of exposure to high levels of solar radiation.[62] Hot, humid weather should be recognized as carrying the potential threat of hyperthermia and dehydration and, therefore, serious injury to windsurfers. Cold weather requires alertness to the possibility of hypothermia. Also. the use of hired windsurfing equipment may be a potential extrinsic risk

factor. It is not clear whether it is the equipment per se, its maintenance, or the athletes who use rental equipment that make rental equipment a risk factor. Nevertheless, *equipment-related risks,* such as the wetsuits, personal floating device, rig (mast, sail, and boom), universal joint, and board, should be checked regularly for worn and damaged parts before sailing. Windsurfers, therefore, should be knowledgeable about choosing the appropriate board and sail size according to their physical conditions and abilities.[4] Both modifiable and non-modifiable intrinsic and extrinsic risk factors for recreational windsurfers should be addressed. *Modifiable* risk factors refer to those that have the potential to be altered by appropriate prevention strategies. Different types of behaviour relate to injury risk factors and mechanisms in other sports.[63] The association between drowning and ethanol consumption before windsurfing has been documented.[10] As such, modifiable intrinsic *risk-taking behaviours* should be addressed. Of the four different behavioural types of recreational windsurfers; occasional and social windsurfers prefer middle wind (4-7 m/s), whereas competitive and pleasure windsurfers prefer strong wind (8 m/s and over).[22] The injury epidemiology of these four behavioural types of recreational windsurfers is unknown. The negative impact of inadequate nutrition and hydration may cause fatigue and exercise-associated hyperthermia in windsurfers. Also, modifiable *previous injuries* with inadequate rehabilitation should be managed with exercise interventions. Nonmodifiable intrinsic risk factors such as epilepsy attacks[45] and heart attacks[10,46] may cause potential submersion injuries or death during windsurfing and should be screened and disqualified.

Since windsurfing is a high-speed, exhilarating sport, it is not without the physical risk[15] of acute windsurfing-related injuries. Several identified injury patterns in recreational windsurfing differ substantially in their injury causes and mechanisms. According to a retrospective study, direct injuries from windsurfing equipment resulted in 64.5% of all 339 acute injuries: 17.2% from the boom, 16.7% from the foot straps, 12.7% from the mast, 8.7% from the board, and 8.1% from the fin.[7] Understanding mechanisms is a key component of preventing injuries in windsurfing.[47] Identifying the most frequent windsurfing-related injury mechanisms will lead to recommendations for protective gear.[7]

Strengths and limitations

According to my knowledge, this is the first review summarizing the injury epidemiological characteristics, such as a summary of the frequency of anatomical distributions of windsurfing-related injuries and a summary of multiple existing and potential risk factors among recreational windsurfers. The proposed standardization definitions of general windsurfing-related injuries and injury severity classifications and levels can be adapted to other sports. However, this study has several limitations. Other electronic databases were not searched; relevant and important data could be missed. There is a single author and article selection bias; information extraction was also done subjectively. The limited data on standardized injury epidemiology, such as evidence-based risk and predictor variables of windsurfing-related injuries, does not permit an empirically based list of suggestions for injury prevention.

Conclusions

There is inconsistency in the epidemiological methods and definitions of windsurfing research. The injury rates remain difficult to compare among studies. The findings in this review provide sports medicine researchers, including sports chiropractors, with a practical overview for further studies on the epidemiology of windsurfing-related acute injuries. Future studies should examine the significance and modifiability of both the existing and potential intrinsic and extrinsic risk factors for windsurfing injury epidemiology. The proposed standardization of definitions of general windsurfing-related injury terminologies and injury severity classifications and levels for windsurfing can be adapted to other sports for injury epidemiology. Understanding windsurfing-related injury rates, risk factors, patterns, causes, and mechanisms allows future studies to investigate and develop potential risk mitigation and/or prevention strategies. Future in-depth recreational windsurfing-related injury studies should focus on prospective designs using standardized injury epidemiological methods and definitions.

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