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Epidemiology of elite sprint kayak injuries: A 3-year prospective study

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ABSTRACT

Objectives: To analyse the characteristics of injuries sustained by elite sprint kayak athletes, to investigate relationships between initial and subsequent injuries, and to examine injury differences between male and female athletes.
Design: Descriptive epidemiology study.
Methods: Data from 63 athletes (37 male, 26 female) of the Australian national sprint kayak squad were prospectively collected over three continuous years (September 2014-August 2017). All medical attention injuries were recorded irrespective of time-loss and modality of training. Descriptive analyses were performed, and frequency comparisons across genders assessed with chi squared tests.
Results: Forty-nine athletes (78%) sustained 146 injuries (median = 2, interquartile range = 1–4, range = 0–12). Most injuries were to the upper limb (48%), with the shoulder being the most common body site injured (27%). Thirty-one athletes (49%) sustained at least one subsequent injury, equating to 97 subsequent injuries. The majority (68%) of subsequent injuries occurred at a different site and nature to previous injuries. Male athletes were more likely to sustain an injury than remain injury free compared to female athletes ($Chi^2_{(1)} = 6.75$, $p = 0.009$), but there was no difference between males and females who thereafter sustained a subsequent injury ($Chi^2_{(1)} = 0.84$, $p = 0.359$).
Conclusions: Injury occurrence is common in sprint kayak, with many athletes experiencing more than one injury. Small variations in injury characteristics exist between male and female athletes in sprint kayak. This study identifies upper limb and trunk, and joint and muscle injuries as the most prevalent sprint kayak injuries, providing a focus for the development of future injury prevention strategies.

Practical implications

- This paper provides the first descriptive injury profile specific for sprint kayak athletes, extending beyond a singular competition period.
- Sprint kayak athletes are susceptible to injuries, with the shoulder being the most frequent body site injured in both male and female athletes.
- The majority of subsequent injuries in sprint kayak occur at a different site and are of a different nature to previous injuries.
- Male and female sprint kayak athletes sustain different injury types, which needs to be considered in the development of future injury prevention strategies.

1. Introduction

Sprint kayak has been an Olympic sport since the 1936 Berlin Olympic Games.[1] Athletes, equipped with a double edged paddle, seated within a kayak boat, race from a stationary start over a straight flatwater course to a finish line.[2,3] At the elite level, events are currently contested over 200 m, 500 m and 1000 m, with the boats containing either one (K1), two (K2) or four (K4) athletes.[4,5] Nine separate sprint kayak events were contested by male and female athletes at the 2016 Rio de Janeiro Olympic Games.

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Senior Australian elite sprint kayak athletes typically train approximately 10 times per week on-water and 3–4 times per week in the gym. Within the 10 sessions, the number of individual boat sessions (K1) compared to team boat sessions (K2/K4) varies across the year. Depending on the time of the season, athletes will also cross train on a surf-ski, cycle or run. Up to and including the Rio Olympic Games, only men contested the 1000 m events and only women the 500 m events (both men and women competed over 200 m). This presents substantial gender differences with regards to total training load, in terms of intensity and volume. During a volume phase in the Australian national sprint kayak program, the male 1000 m athletes often complete 150–160 km of paddling per week while the female 500 m athletes complete approximately 100–110 km per week. (Nicola Bullock, PhD, written communication, April 23, 2018)

Despite a long history of competition (sprint kayak was first included in the summer Olympic Games more than 80 years ago), there is limited published literature detailing the characteristics of injuries and injured athletes at any participation level. To date, no prospective injury studies have reported the injury characteristics in sprint kayak beyond the short competition surveillance period of the summer Olympic Games.[6,7] Athlete sex has been suggested to influence the risk and type of injury sustained in other paddling sports,[8,9] but has not been examined in sprint kayak athletes. Understanding sex specific injury types and their mechanisms are vital components for the targeting and development of successful injury prevention programs.[10,11]

Injuries have been reported for other forms of kayaking, such as endurance[8,12] and whitewater,[13,14] and these studies have highlighted high frequencies of shoulder overuse injuries. However, the large magnitude of high velocity trunk and upper limb rotational forces performed in the sprint kayak stroke, whilst maintaining balance on an unstable base over flatwater, differentiates it from the other kayak disciplines. While kayaking is classified predominately as an upper body sport, it has been shown that lower limb action significantly contributes to the sprint kayak stroke; approximately 20% to the stroke force which translates to approximately 15% of the kayak speed.[15] The unique paddling stroke, combined with a high racing intensity, potentially impacts the risk and types of injury that occur in these athletes.[16,17]

The initial stages of injury prevention require high quality injury surveillance to identify and establish the injury characteristics, aetiology and mechanisms within a specified athlete group.[18,19] In turn, this information can be used to inform primary, secondary and tertiary injury prevention strategies.[20] Tertiary prevention strategies aim to reduce complications of an injury following clinical diagnosis, which includes mitigating the risk of future injury occurrence.[20,21] Given the majority of subsequent injuries an athlete sustains are of a different type to earlier ones,[22,24,25] it is imperative that the relationships between different injury types are understood to support the appropriate prescription of secondary and tertiary prevention measures.[27] This information is currently not available in sprint kayak.

Therefore, the aims of this study were: (1) to describe the characteristics of injuries sustained by elite sprint kayak athletes in terms of the number, type and severity; (2) to investigate the relationships between the most common initial injuries and an athlete's subsequent injuries, in terms of type, timing and severity; and (3) to compare injury occurrence between male and female athletes.

2. Methods

All sixty-three Australian sprint kayak athletes (37 male, 26 female) of the Australian national senior, under-23 and under-18 teams were prospectively followed over three consecutive seasons (Season 1: September 2014-August 2015; Season 2: September 2015-August 2016; Season 3: September 2016-August 2017). The number of athletes within the program varied slightly over the three seasons, (37 in 2015, 35 in 2016 and 34 in 2017). In Season 3, three athletes (two female and one male) withdrew from the squad, and one female athlete was added as a replacement to the squad mid-way through the season. Of the 63 athletes, 22 (35%) were included for all three seasons, 28 (44%) were included for two seasons and 13 (21%) were included for only one season. The study captured the two seasons leading into the major competition for elite senior sprint kayak athletes: Olympic qualification in Season 1 and the Rio de Janeiro Olympic Games (August 7th–20th 2016) in Season 2; while Season 3 captured the year following this major competition. All injuries sustained during the entire three seasons, inclusive of pre-season training, in-season training, competition and off-season periods were included. Ethical approval for the study was obtained from the Human Research Ethics Committee of the Australian Institute of Sport (Approval Number 20160401).

All injury data were entered into a centralised database (Athlete Management System (AMS), Fusion Sport Pty Ltd., Brisbane, Australia) by the squads' physiotherapists or medical doctors. Each injury was assigned a four character Orchard Sports Injury Classification System 10 (OSICS-10.1)[28] injury diagnosis code, with the description of the injury diagnosis, side of injury occurrence, mechanism of injury, date of injury, date of return to training, and date of full injury resolution also recorded. All data were de-identified (linked by a unique athlete ID) and injuries were time ordered according to the date of injury for each injured athlete.[29] Information about the injury mechanism and the activity at the time of injury was only intermittently available as these data were non-compulsory fields in the injury record form.

An injury was defined as any recordable incident sustained that resulted in loss or abnormality of bodily structure or functioning, diagnosed by the squad's physiotherapist or medical doctor (Supplement 1). All injuries were recorded whether or not there was time-loss from training or competition. This injury definition is consistent with the clinical examination definition described by Timpka et al.[30] Subsequent injuries were further classified into one of eight data-driven categories of the subsequent injury categorisation model (SIC-2.0) (Supplement 1).[35]

Injuries were analysed according to their temporal injury sequence number allocated at the time of injury occurrence for each athlete. Put simply, the first injury sustained for each athlete was assigned injury number 1, the second injury was assigned injury number 2, and so forth. Injury numbers were grouped in tertiles for the subsequent injury analysis due to the relatively small number of injuries sustained in later parts of the surveillance period. Therefore, injuries were grouped as first injuries sustained, n = 49; second and third injuries sustained, n = 52; fourth plus injuries sustained (up to a maximum of 12), n = 45.

Data were extracted from the AMS and imported into Stata (Stata/IC 14.2, StataCorp., USA). Descriptive analysis of injuries are presented as n, % and SIC-2.0 data categories. Binomial tests were used to determine if there was a difference in the proportion of male and female athletes under surveillance for either one, two, or three of the seasons. The significance of any differences between the proportions of specified injury variables in male and female athletes were calculated using chi squared approximations with the significance level set at 0.05.

3. Results

There were 146 new injuries sustained by 49 (78%) athletes (33 males, median age = 24, with an interquartile range (IQR) = 21–29; 16 females, median age 23 and IQR = 20–26), over the 36 month

Table 1
Injury distribution across the 3 sprint kayak seasons[a].

	2015			2016			2017			All 3 seasons[b]		
	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total
Total athletes, n	21	16	37	21	14	35	19	16	35	37	26	63
Total injured athletes, n	21	12	33	19	9	28	18	9	27	33	16	49
Number of athletes with:												
0 injuries	0	4	4	2	5	7	1	7	8	4	10	14
1 injury	9	5	14	13	5	18	16	7	23	13	5	18
2 injuries	7	4	11	4	4	8	1	1	2	6	4	10
3-4 injuries	4	1	5	2	0	2	0	1	1	8	3	11
5-6 injuries	1	2	3	–	–	–	1	0	1	4	2	6
7-8 injuries	–	–	–	–	–	–	–	–	–	0	1	2
9-10 injuries	–	–	–	–	–	–	–	–	–	0	0	0
11-12 injuries	–	–	–	–	–	–	–	–	–	1	1	2
Total injuries sustained	42	27	69	28	13	41	23	13	36	93	53	146
Time loss injuries	22	13	33	11	6	17	10	3	13	41	22	63
1-7[c]	6	6	12	5	2	7	6	1	7	17	9	26
8-28[c]	7	3	10	4	1	5	3	2	5	14	6	20
>28[c]	7	4	11	2	3	5	1	0	1	10	7	17
Non-time loss injuries	20	14	36	17	7	24	13	10	23	52	31	83

n = number of athletes.

[a] Injuries are only reported under 2015, 2016 or 2017 if they were sustained during that season; that is if an athlete sustains 6 injuries in the 2015 season they are considered under the "Number of athletes with 5–6 injuries" row.

[b] The accumulated total of injuries throughout the 3 seasons of surveillance; inclusive of all 63 athletes who were under surveillance for at least 1 season; if an athlete who was involved for 3 seasons sustained 12 injuries throughout this period they are considered under the "Number of athletes with 11–12 injuries" row.

[c] Injury severity category according to the number of days of time loss for each time loss injury.

surveillance period (Table 1). Thirty-one of the 63 athletes (49%) were injured at least twice over the 3-year period, equating to a total of 97 subsequent injuries. The median number of injuries was 2, IQR = 1–4, and range = 0–12. There was no difference observed in the proportion of male and female athletes who were under surveillance for either all three seasons (12 males, 10 females, p = 0.832), two seasons (17 males, 11 females, p = 0.345), or only one season (7 males, 6 females, p = 1.000). The 33 male athletes sustained 93 injuries (median = 2, IQR = 1–4, range = 1–12), and the 16 female athletes sustained 53 injuries (median = 2, IQR = 1–4.5, range = 1–11). The male athletes were more likely to be injured at least once during the entire surveillance period than the female athletes ($Chi^2_{(1)} = 6.75$, p = 0.009). Once injured, there was no difference in the proportion of males and females who thereafter sustained a subsequent injury ($Chi^2_{(1)} = 0.84$, p = 0.359).

The distribution of injuries varied across the three seasons (Table 1). The majority of the injuries occurred in the 2015 season for both female (51%) and male (45%) athletes. A tendency for reduced reporting of injuries was observed over the surveillance period for both male and female athletes. Sixty-three of the injuries sustained (43%) resulted in a period of time-loss from the athlete's training or competition program. There was no difference between the male (44%) and female (42%) athletes in terms of the distribution of time-loss injuries over the three year period ($Chi^2_{(1)} = 0.09$, p = 0.762). The proportion of time-loss injuries reduced over the 3-year period with a relative higher proportion of non-time loss injuries being recorded in season 2017.

Most injuries were to the upper limb (n = 70, 48%) or the trunk (n = 50, 34%). Female athletes had a higher proportion of upper limb injuries (53%) compared to male athletes (45%), although this was not a statistically significant difference ($Chi^2_{(1)} = 0.80$, p = 0.372) (Table 2). The shoulder was the most common site of injury for both males and females (males: n = 25, 27%; females: n = 14, 26%). Thoracic and lumbar injuries (n = 14, 15%) were the second most common injury site in males, while the elbow was second (n = 8, 15%) in females.

Differing injury distributions for males and females were identified when the site of injury was analysed over the three temporal groupings of injuries sustained (injury 1; injuries 2–3; injuries 4+). In male athletes, shoulder injuries were the most common injury regardless of their occurrence order, but were less common from the fourth injury onwards, where thoracic spine and lumbar spine injuries occurred more frequently (Fig. 1a.). Shoulder injuries were the most common in female athletes as the first, second or third injury, however following the occurrence of a fourth injury onwards, both elbow and wrist/hand injuries became the most common.

Joint sprains (n = 35, 24%), muscle injuries (n = 32, 22%) and tendon injuries (n = 20, 14%) were the most frequently diagnosed nature of injuries over the surveillance period for all athletes. Muscle injuries were the most common injury nature in female athletes (26%) compared to male athletes (19%) ($Chi^2_{(1)} = 0.98$, p = 0.321). In males, joint sprain injuries were the most common (29%), at almost double the frequency that was recorded in the female athletes (15%) ($Chi^2_{(1)} = 3.60$, p = 0.058) (Table 2).

In female athletes, the most common nature of the initial injury was diagnosed as impingement/synovitis. However, the nature of injuries were not as common in subsequent injuries (i.e. second injury sustained or thereafter) (Fig. 1b.). Muscle injuries were the most common subsequent injury. For male athletes, joint sprains were the most common nature of injury across the sequence of injury occurrences (i.e. both initial and subsequent injuries were joint sprains). Reporting of injury with a non-specific nature was also more common for subsequent rather than initial injuries.

The median duration of an injury over the 3-year period was 25 days (IQR = 53, range 1–405). The majority of injuries sustained by both male (46%) and female (47%) athletes were of a duration greater than 28 days (Supplement 2). For injuries that resulted in time-loss, the median number of days lost from training was 14 days (IQR = 29, range 1–174). One-third of time-loss injuries in females (33%) and more than a quarter (26%) of time-loss injuries in males resulted in more than 28 days lost from training or competition.

More than two-thirds of the subsequent injuries sustained (68%) were classified as Category VIII subsequent injuries (injury sustained at a different anatomical site and of a different nature). Subsequent injuries sustained at the same site but of a different nature (Category VI) were the second most common (15%), followed by 11% of subsequent injuries sustained at a different site but of the same nature (Category VII). Only 2% of the injuries were

Table 2
Distribution of all injuries sustained across the 2015–2017 Australian sprint kayak seasons by body region, body site, injury nature and days injured[a].

	Male			Female			Total		
	n	%	days[b] (IQR)	n	%	days[b] (IQR)	n	%	days[b] (IQR)
Region injured									
Upper limb	42	45	33 (66)	28	53	29 (115)	70	48	31 (68)
Trunk	37	40	22 (47)	13	25	33 (26)	50	34	24 (47)
Lower limb	7	8	14 (42)	7	13	23 (135)	14	10	17 (41)
Head/neck	7	8	34 (44)	5	9	3 (21)	12	8	19 (43)
Site injured									
Shoulder	25	27	36 (65)	14	26	23 (37)	39	27	31 (66)
Thoracic	14	15	15 (19)	5	9	15 (23)	19	13	15 (29)
Lumbar	14	15	35 (56)	3	6	33 (43)	17	12	34 (48)
Pelvis/hip	8	9	22 (30)	6	11	22 (39)	14	10	22 (33)
Other[c]	8	9	19 (46)	6	11	33 (126)	14	10	23 (40)
Elbow	5	5	17 (27)	8	15	28 (154)	13	9	25 (39)
Neck	7	8	34 (44)	5	9	3 (21)	12	8	18.5 (43)
Wrist/hand	8	9	79 (107)	4	8	69 (194)	12	8	79 (127)
Forearm	4	4	19 (21)	2	4	85 (91)	6	4	31 (34)
Injury nature									
Joint sprains	27	29	25 (64)	8	15	26 (119)	35	24	25 (64)
Muscle injury	18	19	20 (43)	14	26	19 (35)	32	22	20 (46)
Tendon injury	12	13	23 (52)	8	15	127 (216)	20	14	29 116)
Impingement/synovitis	11	12	29 (111)	8	15	38 (121)	19	13	29 (116)
Non-specific	12	13	33 (45)	3	6	23 (33)	15	10	28 (43)
Other[d]	6	7	25 (47)	3	6	8 (31)	9	6	8 (41)
Haematoma	4	4	24 (24)	3	6	31 (21)	7	5	26 (18)
Cartilage injury	2	2	34 (0)	3	6	86 (263)	5	3	34 (52)
Nerve injury	1	1	15 (0)	3	6	20 (64)	4	3	18 (32)
Injury type[e]									
Thoracic facet joint	10	11	15 (55)	5	9	15 (23)	15	10	15 (53)
Shoulder tendon	9	10	23 (36)	1	2	14 (0)	10	7	19 (36)
Shoulder impingement	4	4	81 (116)	5	9	51 (115)	9	6	51 (115)
Shoulder joint	4	4	44 (66)	2	4	189 (378)	6	4	87 (98)
Shoulder muscle	2	2	44 (79)	4	8	11 (18)	6	4	11 (24)
Elbow tendon	0	0	–	5	9	130 (191)	5	3	130 (191)
Lumbar facet joint	4	4	32 (196)	1	2	24 (0)	5	3	29 (11)
Lumbar muscle	4	4	66 (75)	1	2	67 (0)	5	3	67 (17)
Neck muscle	1	1	16 (0)	4	8	2 (12)	5	3	3 (16)
Other[f]	55	59	23 (39)	25	47	31 (62)	80	55	26 (40)
Total	93	100	25 (49)	53	100	25 (66)	146	100	25 (53)

n = number of injuries.
[a] Total of 49 injured athletes (33 males and 16 females) over the 3-year surveillance period.
[b] The median number of days spent injured irrespective of time-loss; IQR = interquartile range.
[c] Other is inclusive of each of the following injury sites that were allocated a small count during the surveillance period: foot, ankle, knee, thigh and chest.
[d] Other is inclusive of each of the following injury natures that were only allocated one count during the surveillance period: chronic instability, laceration, stress fracture, whiplash and arthritis.
[e] Injury type represents the injuries with a total count greater than four according to the first two letters of the allocated OSICS-10.1 diagnosis code.
[f] Other is inclusive of all other injury types with total counts less than five.

categorised as recurrent, i.e. the same site, same nature and same structure that followed recovery (Category II), and none of these injuries were recorded prior to the injury being determined as recovered by the squad's medical staff (Category III).

4. Discussion

This study presents the first descriptive injury profile in sprint kayak over a 3-year surveillance period. Sprint kayak athletes are susceptible to injury and sustaining more than one injury is common, with almost half of all athletes injured at least twice. Most injuries were sustained in the upper limb, with the shoulder being the most frequently injured body site in both male and female athletes. Time-loss from training and competition was common following injury, with more than one quarter of the time-loss injuries resulting in the more than 28 days of time-loss from training or competition. The findings of this paper provide a basis for further exploration into the aetiology and mechanisms of injury in sprint kayak, to help guide the development of future targeted injury prevention strategies.

Although it is difficult to accurately compare risk of injury between sexes given the absence of training and competition exposure, there appears to be differences in the characteristics of injuries. Female athletes were more likely to remain injury free compared to male athletes; however, once an initial injury had been sustained there was no difference in the risk of then sustaining a subsequent injury. Our study provides justification that sex-specific injury differences need to be considered in the following discussion, and in future investigations.

Injuries to the upper limb, in particular to the shoulder, were the most common site of injury for both male and female athletes. The large physical demand transmitted through the upper limb to execute the sprint kayak stroke efficiently likely explains the higher proportion of injuries observed at these sites.[15] Furthermore, the repetitious nature of performing the paddling stroke over flatwater has been proposed as a causal factor for sustaining overuse shoulder injuries.[31]

A reduction in the reported number of injuries was observed over time. The large majority of the injuries were reported in the first season of the surveillance period in both male (45%) and female (51%) athletes. It cannot be ascertained why more injuries were reported in this season compared to the 2016 and 2017 seasons due to the absence of exposure data across the seasons. Future surveillance, with the inclusion of training and competition exposure data,

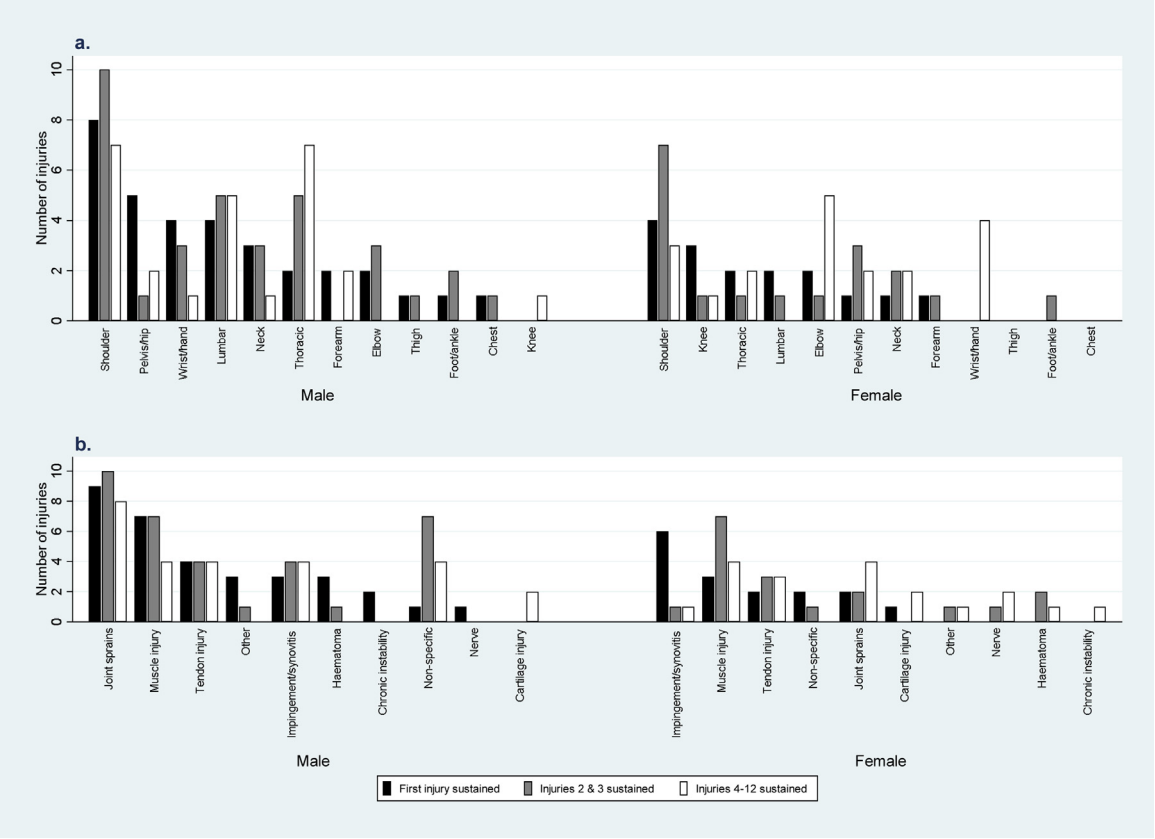

Fig. 1. Frequency of injuries over the grouped sequential injury occurrence (injury 1, injuries 2–3, and injuries 4–12) for the athletes who sustained at least one injury (total injured athletes n = 49; male, n = 33; female, n = 16), according to: (a) body site injured; (b) injury nature.

is needed to confirm if seasonal injury disparity is typical across the four-year Olympiad cycle for sprint kayak.

When the injuries were analysed by body site for each sex according to their temporal sequence, interesting patterns were observed. Both lumbar and thoracic injuries tended to increase in frequency following a sequence of any type of previous injuries in male athletes. In the female athletes, a tendency for a higher occurrence of elbow and hand/wrist injuries could be observed following the occurrence of previous injuries. The sprint kayak stroke requires the efficient functioning of adjacent regions for optimal force generation.[16,32] An injury at an adjacent site along the kinetic chain could predispose one of these regions to subsequent injury, particularly following the development of post-injury asymmetries, which have previously been associated with injury in sprint kayak.[33]

A high proportion of subsequent injuries occurred at a different site and were of a different nature to the initial injury. However, this proportion (68%) was lower than previously reported in other studies using SIC-2.0. In elite rugby sevens[34,35] and elite water polo,[36] between 79% and 81% of subsequent injuries have been categorised as SIC-2.0 category VIII (different site and different nature) subsequent injuries. The variation in this SIC-2.0 category proportion could potentially be explained by differences between the sports. While further analyses with larger injury numbers would be required to guide tertiary prevention strategies, such findings can still be considered in the development of future injury prevention programs as there appears to be patterns in the body sites susceptible to injury following previous injury.

Due to the small number of athletes within the squad, sub-group analyses according to different team and event classifications were not performed. While a strength of the study was to include all of the injuries sustained by the sprint kayak athletes, it must be acknowledged that a number of these injuries could have been sustained in other modalities of training such as gym sessions and in activities outside of structured sprint kayak training such as swimming or surf ski paddling.

The injuries were grouped together by temporal occurrence due to the limited number of athletes who sustained a high number of multiple subsequent injuries. The subsequent injury findings may have been skewed due to the smaller number of athletes who sustained a large number of subsequent injuries (four or more injuries). Only 22 of the 63 (35%) athletes were in the Australian squad under surveillance for all three seasons, which may have caused the injuries sustained by these athletes to bias the injury distribution for the overall squad. While the number of non-injured athletes per season was recorded, these data were unable to be linked to the injury dataset due to the de-identified nature of the injury data. This prevented identifying which of the individual athletes remained uninjured in each season and therefore prevented the time at risk from being accounted for within the analysis. Given that a time at risk analysis was unable to be performed, care should be taken when interpreting the findings comparing male and female athletes. It is also acknowledged that some athletes may have been injured prior to this surveillance period, which prevents the relationships between previous injuries and injuries sustained during the surveillance period to be examined. This remains a limitation in the application of all existing subsequent injury frameworks.[23]

Continuing injury surveillance over multiple seasons including consistent reporting of injury mechanisms, will enhance the understanding of injury and allow for more robust analyses to be conducted. There also needs to be a focus on capturing exposure data. Accurate recording of athlete exposure time in training and competition should be prioritised in future work to allow for comparison of injury trends between different seasons and sub-groups

to allow for participation injury risk to be measured for injured and non-injured athletes. Furthermore, capture of athlete training and competition workload should be incorporated into future surveillance to enable the relationship between injury and athlete workload relationship to be examined as it has been in many other sports.[37,38] Recording the mechanism of injury will also strengthen the injury causation conclusions that can be ascertained surrounding the relationships between different subsequent injury types and risk for future injury, which can then further inform the development of future injury prevention strategies.

5. Conclusion

Injury occurrence is common in sprint kayak, with many athletes experiencing more than one injury. Upper limb injuries, more specifically injuries to the shoulder, were the most common injuries in both male and female athletes. Small variations in injury characteristics exist between male and female athletes in sprint kayak. This study has identified the types of injuries that kayak sprint athletes sustain, which directs future investigation into the mechanisms of these key injury types to guide the development of future injury prevention strategies.

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Appendix A. Supplementary data

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