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# Knowledge, attitudes, and behavior toward concussion in adult cyclists

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**ABSTRACT**

**Objective:** To determine knowledge, attitudes, and behavior toward concussion in cyclists and to identify predictors of concussion knowledge.

**Methods:** Cycling organizations sent members a web link to online information about the study and a questionnaire. Anyone aged >16 years, living in New Zealand and engaged in a cycling activity was invited to participate. The 36-item questionnaire included sociodemographics, knowledge about concussion, helmet use, and personal concussion history. Data were collected between 15/05/19 and 30/06/19. A multiple linear regression model identified factors associated with levels of concussion knowledge.

**Results:** The questionnaire was completed by 672 participants aged between 16 and 82 years ($\bar{x}$ = 48.6 years). Knowledge of concussion was high. However, knowledge that helmets are not able to prevent concussion was low and time to return to sport after injury was variable. Knowledge did not always translate to seeking of medical attention or replacement of helmet behavior. Younger age and having sustained at least one prior concussion were associated with higher levels of concussion knowledge $F(df = 3) = 8.81$, $p < .001$.

**Conclusions:** Knowledge and attitudes toward concussion were positive. However, knowledge gaps and discrepancies between attitudes and behavior were identified. Consistent, clear messages are needed around return to sport timeframes.

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## Introduction

Concussion is a mild traumatic brain injury (mTBI) caused by a direct or indirect force transmitted to the brain, resulting in neurological symptoms which may affect the individual cognitively, somatically, and emotionally (1). Individuals with concussion may experience headaches, dizziness, neck pain, confusion, drowsiness, nausea and vomiting, balance and visual problems, reduced concentration, memory loss, emotional and mood changes, fatigue, and sleep disturbances (2). Whilst some people recover naturally within a few days to weeks, nearly half of those affected can have ongoing symptoms for months or years (3,4). In New Zealand (NZ), patients can present to a range of primary (General Practitioner, Physiotherapist, School Nurse) or secondary care (accident and medical clinics, hospitals) services following a concussion. Following an assessment of clinical presentation, patients may receive a computed tomography (CT) scan if there is a high risk of complications and are provided with acute recovery advice. If patients do not recover within 10 days then they can be referred to specialist concussion clinics for interdisciplinary rehabilitation (5).

Participation in sport exposes the individual to an increased risk of sustaining a concussion, with some experiencing repeated injury (6,7). One study revealed that 21% of all TBIs were sustained during sport-related activities (7). Rugby, cycling and equestrian activities were identified as the sports with the highest risk of injury (7).

A New Zealand survey of engagement in sports and recreational activities revealed that cycling is a popular sport, with up to 29% of people reporting engaging in a cycling activity whether for competition, transport, or recreation in the past week (8). Cycling activities are diverse including road or track racing, BMX, mountain biking, commuting, and triathlon. Cycling activities carry the inherent risk of falling or colliding with stationery or moving objects and therefore a risk of sustaining a concussion (9,10). Concussions account for 8–9% of all injuries from cycling events (11).

Mandatory cycle helmet legislation is now in place in many countries across the world, particularly for commuting on public roads. Helmets have been found to reduce the effects of serious head injury (12) through protecting against skull fractures, head lacerations, and penetrating injuries. However, most helmets offer no protection against the rotational and shearing forces that so often cause intracranial injury associated with concussion (13).

As many cycling events such as road racing have no sidelines, no timeouts or substitutes, current assessments for concussion are less feasible to apply to cycling sports (14). The time taken to assess for concussion using standard tools such as the Sports Concussion Assessment Tool 5 (SCAT-5) (15) could penalize the riders position in the race. However, with the potential for compromised decision making, delayed reaction times and impaired balance and coordination continuation following a suspected concussion and risk of

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delayed recovery puts the rider and others in the race at risk. Secondary impacts to the brain before the brain has recovered can lead to significant impairment or even death (16). Consequently, there is a need to explore how best to recognize and manage concussion within cycling activities (14).

To prevent risk of concussion, there is a need to improve concussion knowledge, attitudes, and behavior in cyclists, coaches, and event staff and to identify barriers to effective concussion management. By identifying levels of knowledge and attitudes toward concussion; health promotion initiatives can then be targeted to address current gaps. Current evidence on concussion has predominantly focused on contact sports (e.g., rugby, football, ice hockey) or high school athletes (17–19). This study aims to determine the knowledge, attitudes, and behaviors toward concussion in cyclists, coaches, and managers to ascertain where there may be knowledge gaps.

## Methods

Ethical approval for the study was received from the Auckland University of Technology Ethics Committee (Reference: 19/103).

### The survey method and questionnaire

A cross-sectional anonymous questionnaire was used to assess knowledge and attitudes toward concussion. The online questionnaire (administered via SurveyMonkey) was based on a previous study conducted on concussion awareness in high school rugby players (17) and adapted for relevance to cycling activities and latest research evidence on concussion (e.g., including questions on helmet use). There were 36 questions in total, which comprised of a mixture of a combination of multiple choice, likert scale, and open field questions. The questionnaire included sociodemographic questions about the participant and participation in cycling activities, knowledge about concussion, attitudes, and behavior with regard to helmet use, return to sport following concussion, seeking of medical treatment, in addition to details about personal concussion history. The questionnaire took approximately 15 minutes to complete.

### Participants and recruitment

A weblink to the participant information sheet and online questionnaire was sent to members by 23 cycling clubs across New Zealand, nine cycling businesses, and Cycling NZ, Triathlon NZ, NZ Cyclocross and BMX via their databases, newsletters, and social media platforms between 15th May 2019 and 30th June 2019. It was not possible to calculate a response rate, as the number of participants who saw the advert, but chose not to respond, was unknown.

Anyone aged 16 years and over living in NZ and actively involved in cycling as a participant, coach, manager was eligible to participate. On completion of the survey participants were invited to enter a prize draw for products donated by cycling businesses. In order to maintain the anonymity of the questionnaire, if they wished to be entered, participants clicked on a link to a new questionnaire to provide their contact details. winners selected by a computerized randomized number generator. All contact details were then deleted.

### Data analysis

Data were extracted into Statistical Package for the Social Sciences (IBM SPSS, version 25). Descriptive analyses of participant characteristics and responses to the questionnaire items are presented with means and (±) standard deviations (SD) or frequencies and percentages as appropriate. Levels of concussion awareness were categorized as >80% very high, 60–80% high, 40–60% moderate, 20–40 low, and <40% very low. Responses to concussion knowledge items were classified as correct (1) or incorrect (0) and summed to yield a total knowledge score (range 0–32), with higher scores indicating higher knowledge. Stepwise forward selection was used to develop the regression model for levels of concussion knowledge including age, gender, prior concussion history (a dichotomous variable stating whether the participant had sustained at least one concussion or not) and whether they cycled competitively or not. Variables were retained in each model if the $p$-value was ≤0.05. Responses to the four open field questions "what would you do if you were to experience a concussion in the future"; "what might stop you from seeking medical attention after a concussion; "what might prevent you from replacing a helmet after a fall" and "are they any other comments you would like to make" were coded and collated into key categories using conventional content analysis (20).

## Results

### Participants

A total of 704 participants responded to the initial survey invitation. Of these 15 (2.1%) were excluded as they did not meet the eligibility criteria (11 did not live in NZ and four were under 16 years of age). A further 17 (2.4%) were excluded as no questionnaire data related to concussion were completed. The final sample included data from 672 participants. Missing data appeared to be systematic and were not imputed. For example, there were missing data for the question regarding the number of concussions experienced, after participants had already indicated that they had experienced at least one concussion in their lifetime in the previous question. Open text field comments reflected uncertainty of how many they had experienced. For example, one participant stated "many minor ones while playing rugby, one major concussion while motorbiking." Consequently, these missing data were determined to reflect uncertainty of concussion history and were not imputed. As shown in Table 1 participants were predominantly male Europeans, engaged in road cycling or mountain biking. Participants ranged in age between 16 and 82 years, with a mean age of 48.6 ± 11.4 years. Participants had been cycling for an average of 18.4 ± 12.9 years and cycled for an average of 7.6 ± 4.5 hours per week.

Table 1. Characteristics of the 672 study participants.

| | Frequency (%) |
|---|---|
| **Gender** | 428 (63.7) |
| Male | 240 (35.7) |
| Female | 4 (<1) |
| Missing | |
| **Ethnicity** | 610 (90.8) |
| European | 60 (8.9) |
| Non-European | 2 (<1) |
| Missing | |
| **Cycling activities engage in (tick as many as apply)** | 562 (83.6) |
| Road racing | 386 (57.4) |
| Mountain biking | 264 (39.3) |
| Commuting | 62 (9.2) |
| Coaching/Managing | 54 (8.0) |
| Track racing | 48 (7.1) |
| Cyclocross | 5 (<1) |
| BMX | 58 (8.6) |
| Other (e.g. guiding, touring, gravel, indoor, triathlon, bike polo, adventure, indoor or Brevet) | |
| **Highest level of competition in cycling?** | 259 (38.5) |
| National level | 130 (19.3) |
| Regional level | 164 (24.4) |
| Local level | 119 (17.7) |
| Not competitive/Missing | |
| **Information about concussion received from (tick as many as apply)**: | 419 (62.4) |
| Friends or family | 387 (57.6) |
| Doctor/physiotherapists or other health professionals | 357 (53.1) |
| TV or social media | 290 (43.2) |
| Other cyclists | 210 (31.2) |
| National accident compensation provider | 140 (20.8) |
| School/work | 56 (8.3) |
| Coach/manager | 45 (6.7) |
| Cycling organization | |
| **Personal concussion history** | 219 (32.6) |
| None | 184 (27.4) |
| One | 109 (16.2) |
| Two | 104 (15.5) |
| Three or more | 56 (8.3) |
| Don't know/Missing | |

### *Concussion frequency*

Over half (397, 59.4%) of participants had experienced at least one concussion (either medically or self-diagnosed), with the total numbers of lifetime concussions sustained ranging between 1 and 20 concussions, with a mean of 2.2 ± 1.9. For those cyclists who had experienced one or more concussions, 216 (54.1%) had always sought medical treatment following a concussion, 112 (28.1%) sometimes sought medical treatment and 71 (17.8%) had never sought medical treatment for a concussion. Key categories identified in response to the open field question as to what they would do if they experienced a concussion in the future included seek medical attention, rest and stop riding and depends on symptoms.

### *Knowledge of concussion*

As shown in Table 2 general knowledge of concussion was very high, with the majority of participants understanding that a concussion is a form of brain injury, there are potential cumulative effects of reinjury, and that you don't need to directly hit your head or lose consciousness to have a concussion. There was very high knowledge of symptoms of concussion such as amnesia, confusion, loss of consciousness, headache, dizziness, poor balance, vacant look, blurred vision, and nausea. Knowledge was high for light sensitivity, fatigue and being slow to get up, moderate for insomnia and seizure, and low for tonic posturing.

### *Seeking medical treatment and return to sport*

Attitudes did not always translate to behavior. Whilst 654 (97.3%) agreed or strongly agreed that a person should seek medical treatment after injury, only 236 (35.1%) had always done so in the past. Potential barriers to seeking health-care treatment were identified from the open text field question with key categories identified as; location/accessibility, ability to drive, not knowing if their injury was severe enough/not wanting to waste professionals time, cost, belief services were unable to do anything or concerns about lack of knowledge and recognition by doctors, not realizing that they had experienced a concussion, being a health professional themselves and seeing no need for further advice, perceived consequences for work or not being able to ride and pride/embarrassment. In contrast, there was general agreement between knowledge of the timeframe people should wait before return to cycling (e.g., 380, 56.5% would wait until symptoms had resolved) and how long people reported that they actually would wait if they were injured (e.g., 377,

**Table 2.** Knowledge, attitudes, and behavior toward concussion.

| Knowledge Items | Frequency (%) |
|---|---|
| **Have you ever heard of the term concussion?** | 666 (99.1) |
| Yes | 4 (0.6) |
| No | 2 (0.3) |
| Not sure/missing | |
| **Please indicate the following you would consider to be a sign or symptom of concussion (tick all that apply)** | 641 (95.4) |
| Amnesia (not remembering what happened before or after the accident) | 620 (92.3) |
| Confusion | 611 (90.9) |
| Loss of consciousness (being knocked out) | 597 (88.8) |
| Headache | 590 (87.8) |
| Dizziness | 579 (86.2) |
| Poor balance (unsteady on feet) | 578 (86.0) |
| Vacant look (expression that shows that someone does not seem to be looking or thinking about anything) | 567 (84.4) |
| Blurred vision | 556 (82.7) |
| Nausea (feeling sick/need to vomit) | 511 (76.0) |
| Sensitivity to light | 511 (76.0) |
| Fatigue (feeling extremely tired) | 473 (70.4) |
| Person is slow to get up | 367 (54.6) |
| Insomnia (trouble sleeping) | 313 (46.6) |
| Seizure (uncontrollable jerking movements of the arms and legs or unresponsive and staring into space) | 266 (39.6) |
| Bleeding form the ear | 235 (35.0) |
| Weakness in movements | 155 (23.1) |
| Numbness or tingling in arms | 137 (20.4) |
| Black eye | 85 (12.6) |
| Tonic posturing (arms become fixed and stiff) | 52 (7.7) |
| Difficulty swallowing | 30 (4.5) |
| Fever | 11 (1.6) |
| Skin rash | |
| **A concussion only occurs if you lose consciousness?** | 8 (1.2) |
| True | 662 (98.5) |
| False | 2 (<1) |
| Missing | |
| **Concussion is a form of traumatic brain injury?** | 657 (97.8) |
| True | 15 (2.2) |
| False | |
| **Symptoms of concussion can occur several hours or days later?** | 665 (99.0) |
| True | 7 (1.0) |
| False | |
| **You need to directly hit your head to experience a concussion?** | 154 (22.9) |
| True | 517 (76.9) |
| False | 1 (<1) |
| Missing | |
| **If you already have one concussion the effects of further concussions are greater?** | 636 (94.6) |
| True | 34 (5.1) |
| False | 2 (<1) |
| Missing | |
| **If someone gets concussed how long should they wait before cycling again?** | 2 (<1) |
| Straight away | 67 (10.0) |
| 1–2 weeks | 57 (8.4) |
| 3–4 weeks | 31 (4.6) |
| More than 4 weeks | 380 (56.5) |
| When symptoms have resolved (gone away) | 135 (20.1) |
| Don't know/missing | |
| **Returning to cycling too soon after a concussion can increase symptoms and delay recovery?** | 596 (88.7) |
| True | 75 (11.2) |
| False | 1 (<1) |
| Missing | |
| **If someone has suffered a concussion who is the best person to decide if they should cycle again?** | 565 (84.1) |
| Doctor | 66 (9.8) |
| The person themselves | 6 (<1) |
| Parents/colleagues/friends | 3 (<1) |
| Coach/manager | 32 (4.8) |
| Other (e.g. physiotherapist, concussion specialist, sports physician, occupational therapist, combination of doctor, themselves and/or coach/manager) | |
| **What does wearing a cycling helmet prevent? Tick as many as apply)** | 634 (94.3) |
| Absorbs impact from a fall | 618 (92.0) |
| Reduces the risk of skull fracture | 586 (87.2) |
| Reduces the risk of concussion | 471 (70.1) |
| Reduces risk of cuts/lacerations and bruises | 149 (22.2) |
| Reduces the risk of neck injury | 2 (<1) |
| Don't know | |
| **Attitude and Behavior items** | |

(*Continued*)

Table 2. (Continued).

| Knowledge Items | Frequency (%) |
|---|---|
| **To what extent do you agree with the following statement? It is important to seek medical attention as soon as possible after a concussion (e.g. see a doctor or go to an emergency clinic)** | 515 (76.6) |
| Strongly agree | 139 (20.7) |
| Agree | 6 (<1) |
| Not sure | 12 (1.8) |
| Disagree | 0 (0) |
| Strongly Disagree | |
| **How long would you wait before returning to cycling?** | 27 (4.0) |
| Straight away | 122 (18.2) |
| 1–2 weeks | 59 (8.8) |
| 3–4 weeks | 30 (4.5) |
| More than 4 weeks | 377 (56.1) |
| When symptoms have resolved (gone away) | 57 (8.5) |
| Don't know/missing | |
| **Do you always wear a helmet whatever the cycling activity?** | 659 (98.1) |
| Yes | 10 (1.5) |
| No | 3 (<1) |
| Missing | |
| **You should not use the same helmet again after a fall when there was a hit to the head and a new one should be purchased.** | 424 (63.1) |
| Strongly agree | 180 (26.8) |
| Agree | 32 (4.8) |
| Not sure | 20 (3.0) |
| Disagree | 10 (1.5) |
| Strongly Disagree | 6 (<1) |
| Missing | |
| **Have you ever continued to use the same helmet after a hit to the head?** | 207 (36.8) |
| Yes | 460 (68.5) |
| No | 5 (<1) |
| Missing | |
| **Would you like to know more about concussion?** | 448 (66.7) |
| Yes | 214 (31.8 |
| No | 10 (1.5) |
| Don't know/missing | |

56.1% said they would return after symptoms had resolved).

### *Helmet use*

Most participants reported wearing a helmet whenever they went cycling. There was very high knowledge that helmets can help to absorb the impact of a fall and reduce risk of skull fracture. However, only 86 (12.8%) of people were aware that helmets were not able to prevent concussion. A discrepancy was that whilst 604 participants (89.9%) agreed or strongly agreed that a helmet should be replaced after a fall, 207 participants (36.8%) reported that they had continued to ride in a helmet after an accident. In the open comments field, there were many comments where participants mentioned cracking or damaging their helmets but felt no perceived risk of concussion. For example: one participant said, "I have crashed multiple times during commuting and trail riding and smashed three helmets and broken two pairs of glasses but have never injured my head." Reasons for not replacing a helmet after damage included cost, focus should be on prevention of crashes, helmets are perceived to be over-rated, seen others riding in damaged helmet, few people wear helmets correctly, lack of perceived need to replace if no obvious damage, lack of knowledge of best type of helmet for each activity, peers do not wear helmets in training. Only 135 (20.1%) had been taught how to fall to reduce the risk of injury.

### *Total concussion knowledge scores*

Total concussion knowledge scores ranged between 17 and 31, with an average score of 25.2 (SD 2.6). The final regression model is shown in Table 3. Younger age and prior concussion history were significantly associated with higher levels of concussion knowledge $F(df = 3) = 8.8$, $p < .001$. Key categories identified from the open question where participants were asked if they had any further comments to make at the end of the survey included; concussion is underestimated and misunderstood; poor attitudes toward concussion in sport and need for a cycling specific policy regarding concussion.

## Discussion

This study aimed to determine knowledge, attitudes, and behavior toward concussion in adults engaged in cycling activities in NZ. The study found high to very high levels of concussion knowledge, although knowledge of the function of helmets was

Table 3. Variables associated with levels of concussion knowledge.

| Parameter | Estimate | *T* | *P* value | CIs | $R^2$ |
|---|---|---|---|---|---|
| Constant | - | 46.35 | <0.01 | 24.51 to 26.68 | |
| Age | −0.090 | −2.30 | 0.02 | −0.030 to −0.002 | |
| Gender | 0.131 | 3.37 | <0.01 | 0.297 to 1.128 | |
| Concussion history | −0.096 | −2.52 | 0.01 | −0.717 to −0.089 | |
| | | | | Overall model | 0.39 |

Variables were retained in the model at the $p < 0.05$ level

very low. There appeared to be discrepancies between knowledge and attitudes, and behavior toward health care seeking and replacing a helmet after a hit to the head highlighting the complexities around decision making. Public health initiatives need to focus on clearer, consistent messaging across sports to clarify recommendations around return to play to reduce confusion. There is also a need for cycling-specific messaging for sport-specific issues such as helmet use from cycling organizations.

### Symptoms of concussion

Knowledge of signs of concussion including confusion, dizziness, headache, and loss of consciousness were higher than found in previous studies in rugby players and equestrian athletes (17,21). Although other symptoms such as seizure, tonic posturing, and poor sleep were less well known. It is unclear if this reflects an improvement in concussion knowledge over time due to concussion awareness initiatives and increased media attention over the last 5 years, or differences in knowledge across different sports. Direct comparisons of knowledge symptoms between studies are difficult due to differences in the wording and types of symptoms included.

There was a false-positive rate on symptoms unrelated to concussion, such as skin rash and fever, suggesting a lack of knowledge specificity. Some confusion between the symptoms of concussion and more severe brain or neurological injury (such as bleeding from the ear and numbness or tingling in the arms) was also evident as found in previous studies (22,23). Understanding the differences between concussion and indicators of more severe brain injury are important due to pathways of care (e.g., calling an ambulance or directing the person to their general practitioner). In NZ, there are only specific concussion awareness guidelines available for mountain biking (24). These guidelines highlight specific 'high risk' symptoms, that could indicate more severe injury, and require immediate hospital attention (such as seizure, repeated vomiting, and disorientation lasting >30 minutes) and symptoms indicating a less severe injury requiring support from general practitioners or accident and emergency clinics (e.g., headache, poor sleep or fatigue, and confusion) (24). These symptom distinctions may be useful to include in concussion education programmes more broadly and determining awareness of these different care pathways in sports populations (25).

### Seeking medical treatment

The identification of discrepancies between knowledge and attitudes and behaviors such as health care seeking reflects findings from other sports such as motorsports. For example, one study using qualitative interviews revealed discrepancies between drivers and medical personnel regarding concussion (26). In contrast, there appears to be a clearer link between concussion knowledge and behaviors such as concussion reporting (17).

Delayed early management of concussion has been shown to be associated with increased psychological symptoms and longer recovery times (27). Therefore, awareness and knowledge of injury to enable early identification and treatment is key to early treatment (28). Additionally, given the difficulties in assessing concussion during cycle events and lack of medical professionals during training/commuting, there is an increased need for cyclists to feel confident in seeking medical treatment. The wide range of barriers to seeking medical treatment identified in this study, despite high knowledge of the need to seek medical assistance after concussion, is a concern and needs to be urgently addressed. Reducing barriers to seeking of medical treatment may help to reduce the identified discrepancy between knowledge and attitudes and people's behavior.

### Return to cycling after concussion

There was considerable variability in knowledge of when to return to sport/riding following a concussion. This may reflect inconsistent messages across different sports and age groups. For example, rugby specifies a stand-minimum down period of 21 days for people 19 years and 23 days for those under 19 years of age, whereas other sports such as equestrian activities require clearance from a medical doctor with no specified timeframe. Mountain biking guidelines recommend no return to sport on the same day with a gradual return to sport, increasing activity every 24 hours if no symptom exacerbation (24). Many participants specified that not all their prior concussions were sustained during cycling, indeed many previous injuries were reported as being sustained in other sports and activities of daily living. Therefore, broader public health initiatives for concussion both within and outside of the sports context may provide a more consistent simple message about the correct action to take if a concussion is suspected.

### Sources of information on concussion

Most participants reported learning about concussion from friends, family, and health professionals in response to previous injury. Indeed, prior concussion history was significantly associated with higher levels of concussion knowledge. A more proactive approach to concussion awareness is needed by cycling organizations so that people know how to minimize the risk of injury and learn about sport-specific issues relating to concussion such as helmet use. Further, only one in five participants had received training in how to fall to reduce injury. Currently, there is no requirement for mandatory concussion education training or recording of concussion incidents for sports such as cycling in NZ and many countries internationally. Cycling-specific coaching/training programmes and cycling skills training in addition to broader public health concussion messaging may help reduce both concussion and other external injuries may help to both prevent injury as well as improve concussion management within the sport of cycling. Indeed, preparation and education are recommended to be the first steps to reduce potential long-term consequences of concussion (29). Several concussion

education initiatives exist and could be drawn upon to assist in increasing knowledge and improving attitudes toward concussion (30,31).

### Helmet use

Reporting of helmet use whilst riding was very high. However, of concern was that 87% incorrectly believed a helmet could prevent concussion. This was higher than in a previous study of rugby union players (18). This finding was supported by free text responses not linking damage to helmets with perceived injury and suggests that knowledge of how a concussion is sustained (e.g., brain moving around within the skull) may be lacking and should be considered in public health campaigns.

New helmet technology, such as the Multi-Directional Impact Protection System has a slipcover inside the helmet allowing sliding between the head and helmet on impact and the WAVECEL utilizing the Angular Impact Mitigation system has an inner lining to absorb accelerations during impact. Both systems show promising results in reducing rotational head acceleration and thereby reducing concussion, however, more research is needed as to the effectiveness of these devices in real life concussive events for cyclists (32,33). More information on how to choose the best helmet and what different types of helmet protect against concussion are needed so that cyclists can make informed choices.

### Total concussion knowledge scores

Our findings that younger age was association with improved concussion knowledge contrasts with a previous study across multiple sports showing a link between older age and improved concussion knowledge (34). This may reflect differences between the sport codes. However, the influence of prior injury on concussion knowledge was consistent across both studies. Females had higher levels of concussion knowledge than males. The reasons for this difference remain unclear but mirror findings from other sports such as equestrian activities (35). Further exploration of the role of these factors on concussion knowledge in different sports may be beneficial to help identify the audiences who may benefit most from being targeted with further education.

### Strengths and limitations of the study

A strength of the study was that there was representation from a wide diversity of cycling sports including both recreational and competitive riders as well as coaches and event staff. However, the generalizability of the findings may be affected as we were not able to capture responses from cyclists not linked to cycling organizations or clubs or those engaged in cycling solely for the purpose of commuting. It was also not possible to estimate the questionnaire response rate and generalizability of the survey to the wider cycling population remains unclear. Despite these limitations this study has identified key gaps in knowledge and factors influencing behavior for cyclists who are at high risk of concussion to inform concussion education programmes.

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## Authors contributions

All authors contributed to the study design. MR, AT, and SM drafted the initial version of the manuscript and performed the statistical analysis. All authors were involved in the interpretation of the data. All authors critically revised the paper and read and approved the final manuscript.

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