Sex differences in self-reported symptoms after aerobic exercise in non-injured athletes: implications for concussion management programmes

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Sex differences in self-reported symptoms after aerobic exercise in non-injured athletes: implications for concussion management programmes

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ABSTRACT

Background: After a concussion, when symptoms have decreased substantially at rest, it is recommended that athletes begin light aerobic exercise before progressing to sport specific exercise. The British Columbia Concussion Rehabilitation Programme (BC-CRP) uses a standardized cognitive and exercise test protocol designed to indicate when an athlete should progress to sport-specific exercise after a concussion.

Objective: To document the effects of exercise on symptom reporting in healthy, uninjured, male and female amateur athletes.

Design: Quasi-experimental, pretest–post-test, non-equivalent groups design.

Methods: Before the exercise protocol, 45 female and 30 male young amateur athletes completed computerized cognitive testing, symptom ratings and balance testing. The 15-minute cycle ergometry protocol, conducted at 90 revolutions/minute, was as follows: 0–2 minutes at 0 W tension, 2–5 minutes at 50 W, 5–8 minutes at 100 W, 8–11 minutes at 150 W and 11–14 minutes at 200 W tension followed by a 1-minute cooling-down period. After exercise, participants completed symptom ratings, balance testing and perceived exertion ratings. Self-reported symptoms were assessed using an abbreviated version of the Post-Concussion Scale.

Results: Significant increases in self-reported balance problems, numbness and tingling were seen for both genders after aerobic exercise. For women, emotional symptoms such as irritability, sadness, nervousness and feeling more emotional decreased significantly after aerobic exercise. Headache also decreased in the women, but no significant change was seen in the men.

Conclusions: Sex differences exist for symptom reporting after aerobic exercise. Both genders report increases in somatic symptoms, but only women report decreases in emotional symptoms. The concept of being "asymptomatic" after exercise should be reconsidered to include expected mild increases and decreases in certain symptoms.

Decisions regarding when an athlete can safely return to sport after a concussion are often made by a team athletic trainer or physician and are based on information from the athlete about their symptoms. The widely cited rule of thumb is that athletes should rest until they are asymptomatic. After this stage, a return to "light aerobic exercise" is recommended as described in the two consensus statements made at the International Concussion in Sport Conferences in Vienna[1] and Prague.[2] These guidelines recommended that an athlete satisfy three conditions before returning to play. From the perspective of a sports medicine physician, the athlete should be asymptomatic at rest and during non-contact exertion before a return to sport-specific exercise is indicated. The athlete then progresses through increasing non-contact physical exertion, until they have demonstrated asymptomatic status with heavy non-contact physical exertion and non-contact sport-specific training. The athlete can then return to full practice while being monitored for any re-emergence of symptoms.

There is a diverse emerging literature suggesting that sex differences should be considered in management programmes for concussed athletes. It is well understood that numerous physical differences that affect performance exist in male and female athletes, but very little is known about whether these physical differences influence the occurrence of or recovery from concussion in males and female athletes. There is some evidence to suggest that female athletes who participate in high school and collegiate sport have higher rates of concussion than their male counterparts.[3 4] A recent study has shown that a possible mechanism might be that males and females have different head–neck segment mass and therefore different abilities for dynamic stabilization. Dynamic joint stabilization has been defined as "the ability of the myotendon unit to absorb external loads and minimize excessive joint movement".[5] The two primary dynamic stabilizers of the head and neck are the sternocleidomastoid and upper trapezius. In a study by Tierney *et al*,[5] males exhibited 25% less angular acceleration when anticipating force application to the head, whereas females did not show these significant differences. After head acceleration, females exhibited 39% greater head–neck angular displacement, 49% less isometric neck muscle strength, and 43% less head–neck segment mass compared with males.[5] In addition, a growing list of central nervous system differences have been reported for males and females including structures such as the cerebral cortex,[6] cortical and subcortical networks for memory,[7] and the corpus striatum;[8] however, not all researchers agree that substantial differences for complex functions such as language exist.[9] Some of these recently reported differences can be seen as differences in the expression of hormones that function within limbic structures such as the bed nucleus of stria terminalis and medial amygdaloid nucleus.[10]

It is possible that physical differences between male and female athletes might be one reason why differences in injury rates and subsequent cognitive performance exist. For example, injuries to competitive female mountain bikers are caused more often by loss of control rather than mechanical failure as reported by men. In general, female mountain bikers are reported to be at greater risk of sustaining an injury than men.[11] Consistent with this, more than twice as many unhelmeted female athletes were reported to be cognitively compromised after impact compared with male athletes.[12] Gender differences for the potential of sustaining a concussion in sports such as ice hockey, soccer and lacrosse have also been reported.[4 13] In ice hockey, female players were more likely to sustain injury from contact with the boards or from their opponents. Head injury was the most common injury among women whereas thigh injury was the most common injury among men, although the rate of concussion injury was not significantly higher for women.[4 13] For elite soccer players, concussion was the second most reported injury for women (22%) but was the fourth most reported for men (8%).[3]

Female athletes may also differ in their cognitive performance before and after concussion compared with males. For example, female athletes were significantly faster and more accurate on perceptual–motor tasks and were able to generate more words for a given letter.[14] In a large study of collegiate athletes at baseline, male athletes performed better than females on a visual memory test and females outperformed males on a verbal memory test. In this study, no significant sex differences were reported for motor processing speed or reaction time.[15] In a study of 79 concussed male and female athletes, females performed significantly worse than males on visual memory scores with no differences for reaction time, motor processing speed or verbal memory.[16] In another study, pre-injury baselines did not differ by gender, ethnicity, age or history of learning disability using an internet-based neuropsychological test battery, but after concussion, female participants consistently experienced greater declines in cognitive function and reported more symptoms.[12] In another study, however, male and female athletes differed with regard to symptom reporting at baseline (ie, preseason), but these differences were not significant after injury.[17]

It is important to recognize that the gender-related pattern of cognitive response to neuropsychological testing may not exist after exercise. Declines in cognitive performance after a treadmill test of maximum oxygen uptake (VO_2 max) included verbal memory composite scores, immediate recall memory scores and delayed recall memory scores, with no differences reported for gender.[18]

Whether gender effects exist for symptom reporting before or after exercise is at this point unclear. For subconcussive impacts such as heading a soccer ball, symptoms that increased by at least 16% in both male and female respondents were: dizziness, headache, balance problems, drowsiness, irritability, feeling slowed down, feeling "in a fog"", and difficulty concentrating.[19] When symptoms are compared by gender, female athletes reported more concentration problems, fatigue, lightheadedness and vision problems.[12] In a large study of male and female collegiate athletes, females reported small but significant increases in mean symptom self-reports compared with males for headache, nausea, fatigue, sleeping more than usual, drowsiness, sensitivity to light and noise, nervousness, feeling more emotional, difficulty concentrating, visual problems and the total symptom score.[15] Retrospective evaluations of signs and symptoms of concussion such as visual sensory effects consequent to a blow to the head; the experience of head pain at least once during the week after a blow to the head; vomiting, nausea and ringing in the ears; and forgetting what to do on the field also differed by gender.[20]

Self-reported symptoms have also been reported to change before versus after physical exertion. Before activity, symptoms reported by a group of athletes (mean $\geqslant$0.25 on a 6-point scale) were: trouble sleeping, sleeping more often, drowsiness, feeling slowed down and feeling "in a fog". After a non-contact activity such as repeatedly kicking a soccer ball, symptoms reported by $\geqslant$16% of respondents were sleeping more often and drowsiness, with no gender effects reported.[19] Significant increases in self-reported fatigue after a test of maximum oxygen utilisation occur for male and female athletes.[18] However, no gender effects have been reported for studies of self-reported symptoms that follow exertion.

Less is known about base rates of symptom reporting after moderate to maximum physical activity. It is understood that once an athlete demonstrates asymptomatic status at rest, they should begin a graduated return to physical exertion before contact participation, because post-concussion difficulties might evolve, with exercise-induced changes in cerebral blood flow. The Vienna group and the Prague group have encouraged a graduated protocol,[1 2] as have other guidelines.[21] Briefly, the protocol involves an athlete successfully moving through the following exertion steps in a 24-hour period: (1) light aerobic exercise (walking, stationary biking), (2) sport-specific training (ice-skating in hockey, running in soccer; typically moderate exertion) and (3) non-contact training drills (usually heavy exertion). If the athlete's previously resolved post-concussion symptoms return at any point during the graded return to physical exertion, the athlete should return to the previous exertion level at which they were last asymptomatic.

To date, the guidelines do not recommend standardization of exercise or that the activity be supervised, and thus both allow for the possibility of harm to the athlete. After the International Symposium on Concussion in Sport that was held in Prague in November of 2004, we began developing the British Columbia Concussion Rehabilitation Programme (BC-CRP).[22 23] A need was recognized for a more precise and specific protocol that followed these internationally recognized guidelines and improved upon the transition between stages 1 to 3 (complete rest to sport-specific exercise). In addition, this programme can be used (through adaptation) as a form of active rehabilitation for athletes and civilians that are slow to recover.[24] There are no published studies that describe symptom reporting in non-concussed athletes after light aerobic exercise. Further, differences in cognitive outcome and symptom reporting in male and female athletes have only recently been explored. The aim of this study was to use the BC-CRP to describe symptom reporting for non-concussed male and female athletes before and after aerobic exercise.

METHODS

Measures

The BC-CRP (fig 1) was designed for use with athletes from any sport once they are asymptomatic at rest and before they begin stage 2 of the Prague 2004 return to play protocol that recommends "light aerobic activity".[2] The programme uses three steps of graduated difficulty separated by a minimum of 24 hours and includes documentation of symptoms and balance before and after activity, a computerized test of cognitive functioning that measures sustained attention, and a 15-minute cycle ergometry protocol. At each successive step, the protocol becomes increasingly difficult. The goal of the BC-CRP is to use an active rehabilitation philosophy to help the athlete move safely from being asymptomatic at rest, to being asymptomatic while under a relatively high cognitive and cardiovascular stress load. Therefore, the BC-CRP is consistent with the current guidelines and improves upon them by ensuring the athlete becomes increasingly active in a supervised setting with progressive and well-defined benchmarks for recovery. Its use can be advocated as part of a best-practice strategy, but may be limited by access to exercise equipment and appropriate expertise.

The BC-CRP uses a baseline, preseason recording (when possible) followed by three stages of increasing cognitive and physical activity (fig 1). Baseline recordings are recommended in order to document the athlete's functioning and symptom reporting in a non-injured state. Baseline recordings are usually obtained during training camps or in the off-season and cannot be obtained if an athlete is in the process of recovering from a concussion (ie, the athlete should ideally be at least 3 months post-concussion for a baseline evaluation). The timing of stages 1–3 depend on the athlete's recovery process. Stage 1 occurs

This program is the foundation of a concussion management program. This supervised program is designed to be used after a concussed athlete is asymptomatic at rest.

Baseline/preseason or post-concussion assessment
1. Modified balance error scoring system (M-BESS)
2. A detailed history of previous concussions and relevant medical issues
3. British Columbia major depression inventory
4. Computerized neuropsychological testing (ImPACT)
5. Baseline/preseason only: a ramped cycle ergometry protocol that starts at 0 W tension and increases by 50 W at 3-minute intervals (200 W for last 3 minutes) at 90 RPM for 15 minutes total.

* EEG and heart rate variability (HRV) are collected before and after steps 3 and 4 above at both baseline and stage 3.

Progression	Stages
When an athlete is asymptomatic for 24–48 h, assess at stage 1. If symptoms are not significantly elevated, progress to stage 2 the next day. If symptoms become elevated or athlete cannot continue, re-assess at stage 1 in 24–48 h.	Stage 1 1. Symptom reporting 2. M-BESS 3. Cognitive: Connor's Continuous Performance Test-II 4. Physical: 15-minute supervised cycle ergometry session tension set at 25 W at 90 RPM 5. Symptom reporting.
After graduating from stage 1, assess at stage 2. If symptoms are not significantly elevated, progress to stage 3 the next day. If symptoms become elevated or athlete cannot continue, re-assess at stage 2 in 48 h.	Stage 2 1. Symptom reporting 2. M-BESS 3. Cognitive: Connor's Continuous Performance Test-II 4. Physical: 15-minute supervised cycle ergometry session tension set at 75 watts at 90 RPM 5. Symptom reporting.
Assess at stage 3. If symptoms are not elevated and neuropsychological test results have returned to baseline, progress to sport specific exercise the next day. If symptoms become elevated or athlete cannot continue, re-assess at stage 3 in 48 h.	Stage 3 1. Symptom reporting 2. M-BESS 3. Cognitive: ImPACT 4. Physical: 15-minute supervised ramped cycle ergometry protocol identical to baseline * EEG and HRV before and after activity.

*Part of our clinical research protocol.

After successfully completing the BC-CRP, the athlete then proceeds to the final three steps under the supervision of a physician, coach, or trainer as recommended by the Prague consensus statement (2005): (1) sport specific exercise, (2) non-contact training drills, and (3) full contact training (after medical clearance). Once these have been completed, the athlete is cleared for game play.

Figure 1 British Columbia Concussion Rehabilitation Programme (BC-CRP).

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when an athlete has been asymptomatic at rest for 24–48 hours. If an athlete is able to complete stage 1 of the BC-CRP, they are advised to progress to stage 2 the next day. If the athlete becomes symptomatic during or after stage 1, they are advised to return to this stage at 24–48 hours. The same progression is recommended for BC-CRP stages 2 and 3. Graduation from stage 3 of the BC-CRP will allow the athlete to begin sport-specific exercise under the supervision of the coach or team athletic trainer.

The BC-CRP uses self-report symptom inventories to indicate the perceived problems an athlete experiences after a concussion. The inventories can also be used during a pre-injury baseline assessment to determine the normal level of symptom rating for an individual athlete. The self-report concussion inventory used with the BC-CRP is the Post-Concussion Scale (PCS), a component of the computerized neuropsychological testing programme, the Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT)[25 26] A 16-item subset of this scale (table 1) is used with the BC-CRP that focuses on symptoms that can fluctuate with activity (eg, sleeping more or less will not fluctuate before versus after activity). The PCS is administered twice per recording session (eg, at baseline or stages 1–3) before and after cognitive and physical activity. Symptom rating usually occurs within a minute of completion of the cycle ergometry protocol.

Supervised physical activity is a key component of the BC-CRP. During baseline and stages 1–3, athletes complete a 15-minute cycle ergometry protocol that increases in difficulty between stages. At baseline and at stage 3, the athlete completes the following protocol, all performed at 90 revolutions/minute (rpm): 0–2 minutes at 0 W tension, 2–5 minutes at 50 W tension, 5–8 minutes at 100 W tension, 8–11 minutes at 150 W tension, 11–14 minutes at 200 W tension, and a 1-minute cooling-down period at 50 W and 60 rpm.

Participants

In the present study, symptoms before and within a minute after completion of physical activity component of stage 3 of the BC-CRP were recorded using a 16-item subset of the PCS. The data collected were a part of a larger study that included the collection of electroencephalographic, cardiac and balance data. Informed consent was obtained from all participants and ethics approval for the study was obtained from the research ethics board, University of the Fraser Valley. The subjects were 45 healthy female and 30 male collegiate athletes (age range 18–24 years). The young men participated in soccer (n = 6), ice hockey (n = 5), football (n = 3) and many other sports including basketball, volleyball, swimming and mountain biking (n = 14). The young women participated in soccer (n = 20), basketball (n = 16) and other sports such as track and swimming (n = 9).

Statistical analysis

Statistical analyses were carried out using SPSS V.15 (Chicago, Illinois, USA) and included paired equal variance t-tests and Wilcoxon signed ranks tests with both $\alpha<0.05$ and medium effect sizes as criteria for significance (effect sizes of 0.2 represent "small effects", 0.5 "medium effects" and 0.8 "large effects").[27]

RESULTS

Symptoms seen to decrease significantly were in the emotional domain, such as irritability, sadness, nervousness and feeling more emotional. This occurred for women only (table 1). Symptoms that increased significantly after activity were in the somatic domain and included: balance problems and numbness or tingling. Headache, another somatic variable, decreased significantly for females only (table 1). For males, a non-parametric test indicated a significant decrease in self-reported concentration problems. It is acknowledged that a large number of paired contrasts for males and females (32 in total) were performed, increasing the likelihood of type 1 errors. A strict Bonferroni correction for family-wise alpha (ie, 0.05/32) was deemed overly conservative for this exploratory study. Conceptually, we were more comfortable with type 1 than type 2 statistical errors (ie, failing to detect a significant difference associated with the exertion protocol). Further, the

Table 1 "Post-concussion-like" symptoms from 30 male and 45 female collegiate athletes before and after activity

	Males							Females						
	Before activity		After activity					Before activity		After activity				
Symptoms	Mean	SD	Mean	SD	t Value	p Value*	Cohen d value	Mean	SD	Mean	SD	t Value	p Value*	Cohen d value
Headache	0.53	1.11	0.37	1	0.67	0.51	0.26	0.56	1.1	0.2	0.5	2	0.05	0.45
Nausea	0.13	0.51	0.27	0.98	−46.0	0.53	0.18	0.22	0.56	0.13	0.46	1	0.32	0.18
Vomiting	0	0	0	0	–	–	–	0.07	0.25	0.02	0.15	1.43	0.16	0.22
Balance problems	0.07	0.37	0.5	1.07	−51.2	0.04	0.6	0.13	0.46	0.47	0.87	−45.2	0.02	0.5
Dizziness	0.2	0.66	0.53	1.17	−74.1	0.15	0.36	0.24	0.61	0.36	0.71	−69.0	0.34	0.17
Fatigue	0.93	1.39	1.33	1.09	−61.1	0.26	0.32	1.27	1.78	1.89	1.57	−8.1	0.08	0.37
Sensitivity to light	0.2	0.55	0.07	0.25	1.16	0.26	0.33	0.2	0.5	0.09	0.36	1.3	0.2	0.26
Sensitivity to noise	0	0	0.03	0.18	−1	0.33	0.36	0.22	0.74	0.09	0.36	1.74	0.09	0.38
Irritability	0.33	0.92	0.07	0.25	1.61	0.12	0.45	0.56	1.08	0.13	0.4	2.53	0.02	0.57
Sadness	0.1	0.4	0.03	0.18	0.81	0.42	0.23	0.62	1.17	0.07	0.25	3.46	0	0.78
Nervousness	0.3	0.75	0.07	0.25	1.65	0.11	0.46	0.67	1.07	0.11	0.38	3.86	0	0.77
Feeling more emotional	0.13	0.73	0.1	0.4	0.22	0.83	0.06	0.73	1.29	0.13	0.5	3.82	0	0.67
Numbness or tingling	0	0	0.47	1.07	−83.2	0.02	0.87	0.09	0.47	0.33	0.9	−14.2	0.02	0.36
Feeling mentally foggy	0.47	1.2	0.23	0.68	0.89	0.38	0.25	0.47	1.1	0.27	0.65	1.3	0.2	0.23
Difficulty concentrating	0.57	1.07	0.17	0.46	1.99	0.06*	0.52	0.53	1.2	0.31	0.63	1.17	0.25	0.24
Visual problems	0.23	0.73	0.07	0.37	1.1	0.28	0.3	0.15	0.47	0.13	0.34	0.44	0.66	0.06
Total symptom score	4.03	4.97	4.3	5.16	−22.0	0.83	0.05	6.82	8.25	4.69	5.2	1.86	0.07	0.32

*Based on paired t-tests.
Nonparametric analyses revealed identical results, indicating a Wilcoxon signed rank test result that was significant at $p<0.05$; †this was an exception.
All symptom self-reports had a median score of 0 with the exception of fatigue (1).

probability of both men and women independently having increased dizziness and numbness by chance alone is actually greater than 1/20. Notably, the significant differences that were found had medium to large effect sizes.

As seen in table 2, most of the male athletes experienced no change in individual symptoms from before to after exercise (as illustrated in the 0 column of table 2 for males), but headaches increased in 13%, balance problems increased in 23%, fatigue increased in 53%, and numbness or tingling increased in 23%. An increase in symptoms of ⩾2 points did not occur for any male athlete for vomiting, sensitivity to light, sensitivity to noise, irritability, sadness, nervousness or difficulty concentrating.

As seen in table 2, most female athletes experienced no or limited change in individual symptoms from before and after exercise (as illustrated in the 0 and 1 columns of table 2 for females). However, changes were clearly more common in women than in men. Headaches increased in 11%, balance problems increased in 24%, fatigue increased in 51%, and numbness or tingling increased in 15.5%. Emotional symptoms tended to decrease. Irritability decreased in 24%, sadness decreased in 29%, nervousness decreased in 31% and feeling more emotional decreased in 31%. An increase of ⩾2 points in symptoms did not occur for any female athlete for vomiting, sensitivity to noise, sadness, nervousness, feeling more emotional, feeling mentally foggy or visual problems.

DISCUSSION

The effects of aerobic exercise on somatic symptom reporting were similar for male and female athletes. Mild subjective symptom increases for balance problems and numbness and tingling after aerobic activity in non-concussed male and female collegiate athletes were reported. A mild increase in numbness and tingling in the limbs is not unexpected after moderate levels of exertion, and may be related to the diversion of blood from the limbs to groups of active large muscles. The perception of numbness and tingling immediately after activity may have been heightened by the requirement of the subject to sit down immediately to complete the symptom questionnaire. The abrupt transition from cycling to walking may have resulted in the perception of mild balance problems in some athletes. This pattern of results is important for practitioners when assessing a concussed athlete with an aerobic exercise protocol.

Moderate decreases in emotional symptoms (eg, feeling more emotional) were seen after exercise in some non-concussed female athletes. Male athletes did not report increases in symptom reporting before or after exercise. Previously published studies on symptom reporting by gender after physical exertion in non-injured athletes are few, and no gender differences have been reported.[18 19] Potential mechanisms for sex differences in the emotional response to exercise may be related to learned or even biological differences in neural systems responsible for emotion.[10] There is a definite need for more research on symptom base rates in male and female athletes before and after physical exertion as well as potential physiological reasons for these differences. The results of this study suggest that for practitioners who use exercise protocols for the assessment of recovery from concussion, it is important to recognize that in males or females, increases in reporting sadness, nervousness or feeling more emotional are not expected after exercise and may be related to concussion or a stress reaction to injury.

Separately or in conjunction with administration of a cognitive test battery, the athlete should complete a symptom questionnaire (such as the PCS) or symptom interview after a concussion both on the sideline (may be brief) and serially throughout recovery. Current recommendations for progression to physical exertion include being asymptomatic at rest for at least 24 hours. It should be pointed out that being truly asymptomatic independent of injury status is not expected for all athletes. In other words, a significant proportion of people report low levels of symptoms at any given point in time. For example, Lovell *et al*[17] examined baseline symptom reporting in 1391 male amateur athletes and 355 female amateur athletes and a sample of 260 athletes seen within 5 days of sustaining a concussion. On the PCS, the mean total score was 4.6 (median 2 (SD 7.7)) for males and 7.9 (median 4 (11.5)) for females. Most male athletes (ie, approximately 75%) scored from 0 to 5, whereas most female athletes (ie, approximately 75%) scored from 0 to 9. "Very high" symptom reporting was defined as a total score obtained by ⩽10% of athletes. The cutoff score for very high symptom reporting was 13 for males and 21 for females. Thus, on average, females report more symptoms at

Table 2 Increases or decreases in symptom reporting for 30 male and 45 female collegiate athletes after activity compared with before activity

	Males									Females								
	Increase					Decrease				Increase				Decrease				
Symptoms	4+	3	2	1	0	1	2	3	4+	4+	3	2	1	0	1	2	3	4+
Headache	0	0	13.3	0	70	3.3	3.3	6.7	3.3	0	0	2.2	8.9	66.7	6.7	8.9	2.2	4.4
Nausea	3.3	0	3.3	3.3	83.3	0	6.7	0	0	0	0	2.2	2.2	84.4	6.7	4.4	0	0
Vomiting	0	0	0	0	100	0	0	0	0	0	0	0	0	95.6	4.4	0	0	0
Balance problems	6.7	0	3.3	13.3	73.3	3.3	0	0	0	0	2.2	11.1	11.1	71.1	2.2	2.2	0	0
Dizziness	3.3	3.3	0	16.7	73.3	0	0	3.3	0	0	0	4.4	15.6	71.1	6.7	0	2.2	0
Fatigue	3.3	6.7	16.7	26.7	26.7	0	10	6.7	3.3	15.5	4.4	13.3	17.8	22.2	11.1	6.7	2.2	6.6
Sensitivity to light	0	0	0	6.7	80	6.7	6.7	0	0	0	0	2.2	2.2	80	13.3	2.2	0	0
Sensitivity to noise	0	0	0	3.3	96.7	0	0	0	0	0	0	0	0	91.1	4.4	2.2	0	2.2
Irritability	0	0	0	3.3	83.3	3.3	6.7	0	3.3	0	0	2.2	4.4	68.9	8.9	4.4	11.1	0
Sadness	0	0	0	3.3	90	3.3	3.3	0	0	0	0	0	0	71.1	15.6	4.4	4.4	4.4
Nervousness	0	0	0	3.3	83.3	3.3	6.7	3.3	0	0	0	0	0	68.9	13.3	13.3	2.2	2.2
Feeling more emotional	0	0	3.3	3.3	90	0	0	0	3.3	0	0	0	0	68.9	13.3	8.9	6.7	2.2
Numbness and tingling	6.7	0	3.3	13.3	76.7	0	0	0	0	0	4.4	0	11.1	84.4	0	0	0	0
Feeling mentally foggy	0	3.3	3.3	3.3	76.7	0	3.3	6.7	3.3	0	0	0	13.3	71.1	6.7	4.4	0	4.4
Difficulty concentrating	0	0	0	6.7	73.3	3.3	10	3.3	3.3	0	0	4.4	11.1	66.7	6.7	4.4	2.2	4.4
Visual problems	0	0	3.3	0	86.7	0	6.7	3.3	0	0	0	0	4.4	88.9	6.7	0	0	0

Data are percentages of athletes who reported an increase or decrease, of a certain magnitude (eg, 2 points), after the exercise protocol.

What is known on this topic

- Consensus-based guidelines for managing concussions emphasize that the athlete should be asymptomatic at rest before proceeding to light aerobic exercise.
- A graduated protocol of increasing cardiovascular exertion, followed by contract drills, is recommended.
- General suggestions for these protocols have been made, but specific protocols have not been studied from a sports science perspective.

What this study adds

- We present the British Columbia Concussion Rehabilitation Programme, which uses a standardized cognitive and exercise test protocol designed to indicate when an athlete should progress to sport-specific exercise after a concussion.
- This study documents the effects of cognitive exertion and exercise on reporting of post-concussion-like symptoms in uninjured amateur athletes.

baseline than males. The concept of being asymptomatic at rest and after activity should be clarified for practitioners to include expected patterns of symptoms that may differ for males and females. In addition to increases in balance problems and numbness and tingling, increases of 1–4 points in symptom severity after exercise for males and females were headache (13.3% and 11.1%), nausea (10% and 4.4%) and fatigue = (43% and 41%), respectively.

In summary, somatic symptom reporting may be increased in some uninjured male and female athletes after aerobic exercise protocols. Emotional symptom reporting may decrease in some female athletes. Therefore, practitioners should note that it is possible that this pattern of change is due to the cognitive and physical response to exercise and not concussive injury. The tables in this paper represent a first step in understanding how symptoms change after exercise in uninjured athletes. These tables can be used as a preliminary benchmark when examining symptom change in athletes who engage in exercise as part of their return-to-play programme. The next step in this line of research is to study exertion-related symptom changes in concussed athletes, who are asymptomatic at rest, to identify patterns or algorithms that can be used to reliably differentiate the effects of concussion exacerbation from normal symptom changes associated with cognitive and physical exertion in both males and females.

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REFERENCES

1. **Brooks JHM,** Fuller CW, Kemp SPT, *et al*. Epidemiology of injuries in English professional rugby union: part 1 match injuries. *Br J Sports Med* 2005;**39**:757–66.
2. **Marshall SW,** Padua D, McGrath M. Incidence of ACL injuries. In: Hewett TE, Schultz SJ, Griffin LY, eds, *Understanding and preventing noncontact ACL injuries*.Champaign, IL.: Human Kinetics, 2007:5–30.
3. **de Loes M,** Dahlstedt LJ, Thomee R. A 7-year study on risks and costs of knee injuries in male and female youth participants in 12 sports. *Scand J Med Sci Sports* 2000;**10**:90–7.
4. **Parkkari J,** Pasanen K, Mattila VM, *et al*. The risk for a cruciate ligament injury of the knee in adolescents and young adults: a population-based cohort study of 46 500 people with a 9 year follow-up. *Br J Sports Med* 2008;**42**:422–6.
5. **Griffin LY,** Albohm MJ, Arendt EA, *et al*. Understanding and preventing noncontact anterior cruciate ligament injuries: a review of the Hunt Valley II meeting, January 2005. *Am J Sports Med* 2006;**34**:1512–32.
6. **Flynn RK,** Pedersen CL, Birmingham TB, *et al*. The familial predisposition toward tearing the anterior cruciate ligament: a case control study. *Am J Sports Med* 2005;**33**:23–8.
7. **Khoschnau S,** Melhus H, Jacobson A, *et al*. Type I Collagen α1 Sp1 Polymorphism and the Risk of Cruciate Ligament Ruptures or Shoulder Dislocations. *Am J Sports Med* 2008;**36**:2432–6.
8. **Mokone GG,** Gajjar M, September AV, *et al*. The Guanine-thymine dinucleotide repeat polymorphism within the tenascin-C gene is associated with Achilles tendon injuries. *Am J Sports Med* 2005;**33**:1016–21.
9. **Mokone GG,** Schwellnus MP, Noakes TD, *et al*. The COL5A1 gene and Achilles tendon pathology. *Scand J Med Sci Sports* 2006;**16**:19–26.
10. **September AV,** Cook J, Handley CJ, *et al*. Variants within the *COL5A1* gene are associated with Achilles tendinopathy in two populations. *Br J Sport Med* 2009;**43**:357–65.
11. **Raleigh SM,** van der Merwe, Ribbans WJ, *et al*. Variants within the *MMP3* gene are associated with Achilles tendinopathy: Possible interaction with the *COL5A1* gene. *Br J Sports Med* 2009;**43**:514–20.
12. **Hoffmann A,** Gross G. Tendon and ligament engineering in the adult organism: mesenchymal stem cells and gene-therapeutic approaches. *Int Orthop* 2007;**31**:791–7.
13. **Frank CB.** Ligament structure, physiology and function. *J Musculoskelet Neuronal Interact* 2004;**4**:199–201.
14. **Myllyharju J,** Kivirikko KI. Collagens and collagen-related diseases. *Ann Med* 2001;**33**:7–21.
15. **Mann V,** Ralston SH. Meta-analysis of COL1A1 Sp1 polymorphism in relation to bone mineral density and osteoporotic fracture. *Bone* 2003;**32**:711–17.
16. **Mann V,** Hobson EE, Li B, *et al*. A COL1A1 Sp1 binding site polymorphism predisposes to osteoporotic fracture by affecting bone density and quality. *J Clin Invest* 2001;**107**:899–907.
17. **Lian K,** Zmuda JM, Nevitt MC, *et al*. Type I collagen alpha1 Sp1 transcription factor binding site polymorphism is associated with reduced risk of hip osteoarthritis defined by severe joint space narrowing in elderly women. *Arthritis Rheum* 2005;**52**:1431–6.
18. **Speer G,** Szenthe P, Kosa JP, *et al*. Myocardial infarction is associated with Spl binding site polymorphism of collagen type 1A1 gene. *Acta Cardiol* 2006;**61**:321–5.
19. **Tilkeridis C,** Bei T, Garantziotis S, *et al*. Association of a COL1A1 polymorphism with lumbar disc disease in young military recruits. *J Med Genet* 2005;**42**:e44.
20. **Skorupski P,** Krol J, Starega J, *et al*. An alpha-1 chain of type I collagen Sp1-binding site polymorphism in women suffering from stress urinary incontinence. *Am J Obstet Gynecol* 2006;**194**:346–50.
21. **Lahiri K,** Nurnberger JI. A rapid non-enzymaticmethod for the preparation of HMW DNA from blood for RFLP studies. *Nucleic Acids Res* 1991;**19**:5444.
22. **Posthumus M,** September AV, Schwellnus MP, *et al*. Investigation of the Sp1-binding site polymorphism within the *COL1A1* gene in participants with Achilles tendon injuries and controls. *J Sci Med Sport* 2009;**12**:184–9.
23. **Collins M,** Posthumus M, Schwellnus MP. The *COL1A1* gene and acute soft tissue ruptures. *Br J Sports Med* Published Online First: 4 February 2009. doi:10.1136/bjsm.2008.056184.
24. **Meeuwisse WH.** Assessing causation in sport injury: a multifactorial model. *Clin J Sport Med* 1994;**4**:166–70.
25. **Lo IK,** Marchuk L, Hart DA, *et al*. Messenger ribonucleic acid levels in disrupted human anterior cruciate ligaments. *Clin Orthop Relat Res* 2003;**407**:249–58.