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1 **Title:** High sport specialization is associated with more musculoskeletal injuries in Canadian high
2 school students.

3
4

5 **Abstract:**

6

7 **Objective:** To describe levels of sport specialization in Canadian high school students and
8 investigate if sport specialization and/or sport participation volume is associated with history of
9 musculoskeletal injury and/or concussion.

10 **Design:** Cross-sectional study.

11 **Setting:** High schools, Alberta, Canada.

12 **Participants:** High school students (14-19 years) participating in various sports.

13 **Independent variables:** Level of sport specialization (high, moderate, low), Sport participation
14 volume (hours per week and months per year).

15 **Main outcome measures:** 12-month injury history (musculoskeletal and concussion).

16 **Results:** Of the 1504 students who completed the survey, 31% were categorized as highly
17 specialized (7.5% before age 12). Using multivariable negative binomial regression (adjusted for
18 sex, age, total yearly training hours, and clustering by school), highly specialized students had a
19 significantly higher musculoskeletal injury rate (IRR= 1.36, 95% CI: 1.07-1.73) but not lower
20 extremity injury or concussion rate, compared with low specialization students. Participating in
21 one sport for more than 8 months of the year significantly increased the musculoskeletal injury
22 rate (IRR= 1.27, 95% CI: 1.02-1.58). Increased training hours significantly increased the
23 musculoskeletal injury rate (IRR= 1.18, 95% CI: 1.13-1.25), lower extremity injury rate (IRR=
24 1.16, 95% CI: 1.09-1.24) and concussion rate (IRR= 1.31, 95% CI: 1.24-1.39).

25 **Conclusions:** Approximately 1/3 of Canadian high school students playing sport were categorized
26 as highly specialized. The musculoskeletal injury rate was higher for high compared with low sport
27 specialization students. Musculoskeletal injuries and concussion were also more common in
28 students who train more and spend greater than 8 months per year in one sport.

29

30 Key words: Sport Specialization, youth, injury, athletic

31

32

33

34 **Introduction**

35

36 Participation in organized sport can have many potential benefits for youth including enhanced
37 physical, psychological, and social development.¹ However, the benefits depend on a positive
38 experience and a common concern is the increasingly performance-focused environment. Many
39 have suggested youth sport has become over commercialized and professionalized,² with the
40 experience for many now mimicking adult performance-driven environments. A specific concern
41 is increasing rates of sport specialization with associated increases in training and competition
42 volume/intensity as parents and youth feel the need to make early choices in the hope of a
43 perceived performance advantage.³

44

45 A recent consensus statement defines sport specialization as “intentional and focused participation
46 in a single sport for a majority of the year that restricts opportunities for engagement in other sports
47 and activities”.⁴ The most common age-based threshold for defining early sport specialization is
48 before the age of 12.⁵ Many experts have advised against early sport specialization in youth due to
49 concerns about increased injury risk,^{6,7} thought to result from high volume/intensity of repetitive
50 homogenous loads and/or reduced range of motor skill development. Specific recommendations
51 exist to limit volume of participation including limits on hours per week and not playing one sport
52 more than 8 months of the year.^{8,9} However, evidence for these volume recommendations is
53 limited in many populations.

54

55 A recent meta-analysis concluded highly specialized youth were more likely to report a history of
56 injury associated with sport participation.³ Subsequent reviews agree with evidence of increased
57 risk of overuse injury¹⁰ and lower extremity injury specifically.¹¹ However, these reviews
58 acknowledge limitations in the evidence including a lack of adjustment for confounding due to
59 training and competition volume and a lack of studies specifically investigating early
60 specialization. It has also recently been highlighted that links to injury are likely to vary depending
61 on the specific context (e.g., age, sport, location) and method used to categorize specialization.⁵ In
62 fact, a recent study did not show any association between early sport specialization and injury
63 history⁸ and one study in a youth academy football setting reported those that were highly
64 specialized were less likely to report previous sport-related injury.¹² In the only study we are aware

65 of in Canadian youth, no association between level of sport specialization and injury history was
66 reported.¹³ Additionally, a recent study highlighted the relationship between level of sport
67 specialization and sport-related concussion remains largely unexplored.¹⁴ As a result, there is a
68 need for further research in specific contexts to better understand rates of sport specialization (and
69 specifically early specialization), youth sport participation volume, and links with injury (including
70 concussion).

71
72 The objectives of this study were to investigate in Canadian high school students (1) levels of sport
73 specialization/early sport specialization and sport participation volume and (2) if sport
74 specialization and/or participation volume is associated with history of musculoskeletal injury
75 and/or concussion.

76 77 **Methods**

78 *Participants*

79
80 Participants included high school students, ages 14-19 years, recruited from 33 schools in Alberta,
81 Canada (28 public, 5 private) (additional details previously reported in Black et al. ¹⁵).

82 83 *Procedures*

84
85 This was a secondary analysis of a cross-sectional study that examined sport and recreational
86 (S&R) activity participation and injury rates in Canadian high school students.¹⁵ Ethics approval
87 was obtained from the Conjoint Health Research Ethics Board at the University of Calgary
88 (REB17-1948), the Health Research Ethics Board at the University of Alberta (REB Pro00080524)
89 and all participating high school ethics boards. Participants completed an anonymous online
90 questionnaire during class time that included questions on demographics (including height and
91 weight), details on S&R activity participation for their top three sports (including average hours
92 per week and total months per year), sports specialization status, musculoskeletal injuries, and
93 concussions sustained through S&R activities in the previous one-year. The questionnaire was
94 adapted from a previously validated survey (face and content validation) that was administered in

95 a similar population in 2004.¹⁶ Additionally, the current survey was pilot tested in one high school
96 (n=143 students) following further face validation by four researchers and concussion experts.

97
98 Participants were categorized as either low, moderate, or highly specialized based on their
99 responses to a series of yes-or-no questions;⁸ “Can you choose one main sport that is more
100 important than the others?”, “Do you train/compete more than 8 months out of the year in one
101 sport?”, “Have you quit other sports to focus on your main sport?” (Participants who indicated
102 they had quit other sports were also asked at what age) and “Have you only ever trained/competed
103 in one sport?”. In response to each question a “Yes” answer was scored as 1, and a “No” answer
104 was scored as 0. A total score of 0 or 1 indicated low, a score of 2 indicated moderate, and a score
105 of 3 indicated high specialization (note the maximum score is 3 as a yes answer to both the last
106 two questions is not plausible). The age at which highly specialized participants quit all other
107 sports was used to explore the prevalence of early specialization, which we defined as being highly
108 specialized prior to 12 years of age. This is a commonly reported age-based threshold for defining
109 early sport specialization^{5,17} and is also the age students typically enter junior high school in
110 Canada presenting the opportunity for increased sports participation and competition level.

111
112 Injuries were defined as any musculoskeletal injury or concussion sustained in a S&R activity in
113 the previous one-year (regardless of missed participation or medical attention). Participants were
114 asked to report all injuries sustained through a S&R activity in the previous year, including body
115 part. Participants were also asked to report all concussions that they had ever sustained through a
116 S&R activity; however, only concussions sustained within the previous 12-months were included
117 in the analyses. Three injury definitions are presented including all musculoskeletal injuries, lower
118 extremity musculoskeletal injuries, and concussions.

119
120 *Statistical Analysis*

121
122 Data were collected using the REDCap (Research Electronic Data Capture) tool hosted at the
123 University of Calgary. REDCap is a secure, web-based application designed to support data
124 capture for research studies.¹⁸ To be included in the study, participants needed complete data for
125 all three questions that were used to determine sport specialization category, data supporting

126 number of previous injuries and concussions, and S&R participation. Statistical analyses were
127 completed using Stata/SE 14.2 for Mac (StataCorp, College Station, TX). Descriptive statistics,
128 including frequencies, proportions, means (SD) and medians (range) were reported as appropriate
129 for sex, age, grade, height, body mass index (BMI), total yearly training hours and sport
130 specialization category. A Kruskal-Wallis chi-squared test and Dunn's post-hoc test were used to
131 examine median differences in yearly training hours between sport specialization groups. Crude
132 incidence rates (IR) with 95% confidence intervals (CI) were estimated (adjusted for clustering by
133 school) for all musculoskeletal injuries, lower extremity musculoskeletal injuries, and concussions
134 for each of the specialization categories, stratified by sex. The IRs were defined as number of
135 injuries per 100 participants per year.

136
137 Separate multivariable negative binomial regression analyses (adjusting for sex, age, total yearly
138 training hours, and clustering by school) were performed for each injury definition to assess if
139 sport specialization category was associated with injury. Outcomes are presented as incidence rate
140 ratios (IRRs) and associated 95% CIs. The IRRs represent the comparison between sport
141 specialization categories, using low specialization as the reference category. Additional
142 exploratory analyses (using the same methods as described above) investigated the relationship
143 between injury rates and early (before 12 years) versus late specialization in highly specialized
144 participants. It should be noted that, although participants had the opportunity to report 'Other' or
145 'Prefer not to say' for their sex (Table 1), only participants who reported 'Female' or 'Male' are
146 included in the crude and multivariable analyses (Tables 2-4) due to the low number of participants
147 (n=12) reporting in the other categories.

148
149 Finally (using the same analysis as described above) the relationship between injury rates and
150 participation volume was investigated. The volume variable was dichotomized as high or low
151 based on participants responding yes or no, respectively, to 'Do you train/compete more than 8
152 months out of the year in one sport?'. This is a commonly recommended volume threshold reported
153 in youth sport for reducing injury risk ⁷.

154
155 **Results**

156 Of the 2029 students who attempted the survey, 1504 students (median age=16, range=14-18,
157 male=49%) representing a wide range of sports completed the specialization, injury, and sport
158 participation questions. Twelve students who reported ‘Other/Prefer not to say’ for sex were not
159 included in the analysis due to low numbers. Of the remaining 1,492 students, 20 did not report
160 any information regarding previous musculoskeletal injuries but did report data on previous
161 concussions and thus they were retained in this analysis only. The ten most common sports were
162 basketball (10.8%), badminton (7.1%), soccer (7.1%), volleyball (6.4%), dance (5.4%), running
163 (5.2%), ice hockey (5.1%), swimming (4.3%), American football (3.8%) and alpine skiing (3.6%).
164 Thirty one percent (n=462) of students were categorized as highly specialized, 37 percent (n=555)
165 moderately specialized and 32 percent (n=487) low specialized (Table 1). There was a significant
166 difference in median yearly training hours between specialization groups ($\chi^2=252.7$, $p<0.01$, $df=2$).
167 The highly specialized group reported significantly more yearly training hours than the low
168 (median difference = 200 hr/yr, 95% CI 174 -226; $p<0.01$) and the moderately (median difference
169 = 124, 95% CI 94-154 hr/yr; $p<0.01$) specialized groups (Table 1). The moderately specialized
170 group also reported significantly more yearly training hours than the low specialized group. Thirty-
171 eight percent of the highly specialized group were classified as early specialized (quit all other
172 sports prior to age 12 years) (Figure 1). Dance (n=68, 14.8%), soccer (n=60, 13.0%), basketball
173 (n=55, 12.0%), ice hockey (n=55, 12.0%), and volleyball (n=30, 6.5%) were the five most common
174 sports within the highly specialized group.

175

176 [Placeholder – Table 1]

177 [Placeholder – Figure 1]

178

179 Forty-six percent (n=682) of students reported a history of a musculoskeletal injury in the previous
180 year and 14.6% (n=218) reported at least one concussion. In total, 1133 musculoskeletal injuries
181 were reported with 677 (60%) reported as lower extremity injuries (ankle=22.6%, knee=16.9%).
182 Additionally, there were a total of 260 concussions reported. The overall musculoskeletal injury
183 rate (with 95% CIs adjusted for cluster by school) was 77.0 injuries/100 participants/year (95%
184 CI: 68.4-86.6), lower extremity musculoskeletal injury rate was 46.0 injuries/100 participants/year
185 (95% CI: 40.4-52.4), and the concussion rate was 17.4 injuries/100 participants/year (95% CI:
186 15.4-19.7). Table 2 reports the rate of injuries by specialization category.

187

188 [Placeholder – Table 2]

189

190 After adjusting for confounders, highly specialized students had a significantly higher
191 musculoskeletal injury rate (IRR= 1.36, 95% CI: 1.07-1.73), but not lower extremity injury or
192 concussion rate compared with low specialization students (Table 3). Between those who
193 specialized early (before age 12 years; n=113) and those who specialized later within the highly
194 specialized group specifically, there was no significant difference in the rate of all musculoskeletal
195 injuries (IRR=0.87, 95% CI: 0.63-1.21), lower extremity musculoskeletal injuries (IRR=0.90, 95%
196 CI: 0.66-1.21) or concussions (IRR=0.85, 95% CI: 0.49-1.44). Females had a significantly higher
197 reported rate of history of lower extremity musculoskeletal injury (IRR= 1.47, 95% CI: 1.18-1.85)
198 and significantly lower reported rate of concussion (IRR= 0.70, 95% CI: 0.52-0.92) (Table 3)
199 compared with males.

200

201 Increased training hours significantly increased the musculoskeletal injury rate (IRR= 1.18, 95%
202 CI: 1.13-1.25), lower extremity injury rate (IRR= 1.16, 95% CI: 1.09-1.24) and concussion rate
203 (IRR= 1.31, 95% CI: 1.24-1.39) per every 2-hour increase of weekly training hours, calculated
204 from total reported yearly training hours (Table 3). Participating in one sport for more than 8
205 months of the year significantly increased the musculoskeletal injury rate (IRR= 1.27, 95% CI:
206 1.02-1.58) (Table 4).

207

208 [Placeholder – Table 3]

209 [Placeholder – Table 4]

210

211 **Discussion**

212 The prevalence of high sport specialization in this group of Canadian high school students was
213 31%, similar to a previous report in American high school students.¹⁹ However, this is more than
214 double the prevalence (13%) reported in a similar study that included high school students²⁰ and
215 almost double the prevalence (18%) reported in Canadian junior high school students.¹³ These
216 studies used similar methods to categorize specialization, thus differences are likely due to
217 variations in contexts (e.g., age, sports, level of competition, school sizes). Differences in the

218 prevalence of specialization across different school sizes and sports have been reported
219 previously¹⁹. Additionally, higher levels of sport specialization are expected in adolescents as they
220 get older.

221
222 Over one third (38.5%) of the highly specialized group were classified as early specialized (before
223 age 12) (Figure 1), representing 7.5% of our full sample. Previous evidence as to the prevalence
224 of early specialization is limited and it is difficult to compare studies due to differences in methods
225 used to categorize specialization and a lack of consensus as to what defines early. In a previous
226 study in the sports medicine literature targeting 11 to 13 year old's, using a similar definition of
227 specialization, 25% were classified as highly specialized early.⁸ Higher levels of early
228 specialization, based on a similar definition, have been reported in specific sports such as youth
229 climbing (69%).²¹ In our sample, five sports (dance, soccer, basketball, ice hockey, and volleyball)
230 contributed most of the early specialized students suggesting a bias towards certain sports.

231
232 Highly specialized students were 36% more likely to report a history of any musculoskeletal injury
233 after adjusting for confounding variables. Based on the use of a similar method to categorize sport
234 specialization, this agrees with previous reports that highly specialized adolescents of a similar age
235 are more likely to report a history of any injury.²² Injuries in youth who specialize in one sport
236 may increase due to periods of rapid growth, high repetition of sport specific movement patterns,
237 and/or compromised development of foundational movement capabilities.²³ Being highly
238 specialized did not however, increase the likelihood of reporting lower extremity musculoskeletal
239 injuries or concussion. This contrasts with several previous studies in high school students
240 reporting links to a history of knee and other lower extremity injuries.^{19,20,24} The difference in these
241 findings may be due to differences in injury definitions (e.g., acute versus gradual onset) and/or
242 the sports included. For example, a recent study suggested a link between specialization and injury
243 in youth volleyball but not basketball.²⁵ Contrasting findings may also be due to a lack of
244 adjustment for confounding variables in some previous studies (especially hours of participation).
245 Readers should note that while not statistically significant, our point estimates suggested high and
246 moderately specialized students were approximately 30% more likely to report a history of lower
247 extremity injury compared with students reporting low specialization. The uncertainty in these
248 estimates suggest our data are more likely compatible with an increase in the likelihood of injury

249 history than not, and the lack of statistical significance may be due to fewer lower extremity
250 injuries.

251

252 In agreement with our findings, the only previous study we are aware of to investigate a link
253 between specialization and concussion history reported no independent association.¹⁴ It seems
254 clear that any link to concussion is likely to be sport specific and further studies focused on specific
255 sports are needed (only 9% of the participants in our sample participated in collision sports).
256 Additionally, if high specialization (particularly at younger ages) is driving increases in volume
257 and/or intensity of participation, this provides some rationale that the risk of concussion in some
258 sports may increase. For example, injury rates have been shown to increase with the level of
259 competition in rugby union²⁶ likely due to the increased intensity and magnitude of impacts.

260

261 A common recommendation in youth sport participation guidelines is not to participate in one
262 sport for more than 8 months of the year;⁷ however, the empirical evidence for this in specific
263 populations appears limited. There has been a study specific to youth baseball pitchers that
264 reported a five-fold increase in injuries for those that pitched more than 8 months of the year.²⁷
265 There appears to have been only one study specifically addressing this question focused on high
266 school students who participated in soccer, basketball, tennis, and volleyball. Those participating
267 for more than 8 months a year had 2 to 3 times the odds of reporting a history of knee or hip
268 injury.¹⁹ In younger populations (mean age 12.6 to 13.7 years), again across a range of sports,
269 those who participated more than 8 months in a single sport were also more likely to report a
270 history of injury.^{8,22} The current study found high school students playing a sport for more than 8
271 months of the year were 26% more likely to report a history of any musculoskeletal injury,
272 providing additional support for this common recommendation in this age group. Further in line
273 with previous reports we found that students with more training hours were more likely to report
274 a history of injury as were female students.^{9,13} The increased rate of injuries in female students
275 may be due to biomechanical and/or neuromuscular differences resulting from a combination of
276 biological and/or environmental factors at play during adolescence.²⁸

277

278 A strength of this study is the relatively large sample size and use of a validated questionnaire;
279 however, there are limitations. We used a cross-sectional design, which is not suitable for

280 establishing cause and effect between specialization and injury. Further, we relied on recall of
281 injury and participation history, which has risk of recall bias and did not allow us to differentiate
282 acute versus gradual onset injury. Additionally, the questionnaire allowed reporting of up to 4
283 musculoskeletal injuries in the past year. Any participant who reported sustaining more than 4
284 injuries was categorized as having 5 injuries (n=13). While this may have underestimated the
285 actual injury burden, this only accounted for 0.7% of our total sample. We also included many
286 sports in the study, and it is likely the structure and rules in different sports affect specialization
287 and injury rates. Finally, while we used a commonly reported method to categorize specialization
288 further validation of this approach has been recommended.⁸ We did have a small number of
289 students categorized as highly specialized who reported a low number of training hours, which is
290 an issue that has been reported previously.⁸ We considered removing these participants but felt it
291 important to maintain the planned method of categorization and further highlight this issue.
292 Additionally, a sensitivity analysis conducted excluding these participants had no impact on the
293 reported outcomes of the study.

294

295 **Conclusion**

296 High sport specialization is common in Canadian high school students; however, early
297 specialization may not be as common as reported previously. Highly specialized students report
298 more musculoskeletal injuries but not concussions in the previous year. Females, those playing
299 one sport more than 8 months of the year, and those with more training hours, also report more
300 musculoskeletal injuries.

301

302 Figure Legends List:

303

304 Figure 1: Age that highly specialized participants reported quitting all other sports

305

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