Review

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Scoping review of lacrosse: match demands, physical performance and injury surveillance

Supplementary Information

The online version of this article (https://doi.org/10.1007/s12662-023-00937-z) contains supplementary material, which is available to authorized users.

Introduction

Lacrosse is a traditional indigenous people's game and is seen as a key element of cultural identity and spiritual healing to Native Americans. The sport itself is regarded as the fastest sport on two feet (Steinhagen, Meyers, Erickson, Noble, & Richardson, 1998), it is a stick and ball invasion-based team sport where players use fast dynamic movements and stick manipulation, of their own stick, to score a goal against opponents. Globally, lacrosse has had a rapid growth in participation rates since the early 2000s (Lacrosse, 2021). Participation in field lacrosse (FL) has increased by 325% since 2001, with a 59% increase in collegiate participation over a similar time period (US Lacrosse Participation Survey: A Review of National Lacrosse Participation, 2017). Furthermore, with 85 member-national bodies reporting to World Lacrosse and its involvement in large multinational, multisport events (such as The World Games) could further increase participation. Moreover, there is a long developmental process within the sport, including youth, college, club (amateur and semi-professional), professional and international.

Traditional FL which is the largest version of the sport, consists of 10 vs. 10 players as per World Lacrosse FL rules; however there are collegiate differences with National Collegiate Athletic Association (NCAA) rules highlighting women's lacrosse is played with 12 vs. 12 players. Generally, FL is played on a pitch 91.4-m × 55-m playing four 15- to 20-minute quarters, with matches frequently played at youth, club, collegiate and international competitive levels. However, this is not the only variant of the sport, with box lacrosse (BL), which is an indoor variant played inside the confines of an ice hockey rink (61-m × 30-m) with 19 players in a match squad, with 5 runners playing at any one time (forwards, transition players and defence men), playing four 15-minute quarters. There are key rule differences between the games of FL and BL: specifically goal size is considerably smaller impacting on scoring ability; moreover, the field of play encourages more continuous play by the ball generally rebounding off the side of the arena rather than going out of play. BL typically also consists of more contact situations resulting in players protective equipment being more substantial than used for FL, which could influence the physiological load, in addition to rule modifications including fighting.

More recently, a new smaller-scale format of FL, called Sixes Lacrosse (SL) has been designed, involving 6 vs. 6 players consisting of one goalkeeper and five "outfield" players with no formal positions. Matches are played over a period of 32 min (four × 8 min quarters) on a playing area 70-m × 36-m. With the addition of a 30 s shot clock in SL adding an intensity element to the smaller-scale version similar to 3 × 3 basketball. The SL version is also more closely aligned with the Olympic Games 21st-century framework by reducing the cost and complexity of staging competitions, having potential caps on athlete attendance, which could be seen as an issue with the larger scale (10 vs. 10) version of the game. This enhances the likelihood of World Lacrosse Sixes being included in future Olympic Games (Lacrosse, 2021). As recently as September 2022, it was included as one of nine sports to present a case for inclusion in the 34th edition of the summer Olympics in Los Angeles (USA) in 2028 (Dasilva, 2022).

Within FL and SL, there are a few notable differences between men's and women's versions, which could influence match and physical characteristics and injury incidence. Firstly, based of World Lacrosse playing guidelines FL men's pitches can be a minimum of 10 meters longer than women's (110 m vs 100 m at a maximum distance). However, it is worth noting that within the American collegiate (NCAA and governing bodies) setting the optimal dimensions can vary depending on provision of space, moreover the contrasting difference in units or measurement (110 m × 60 m vs 110 yards × 60 yards) could make women's playing area larger than men's which could impact upon the match and physical requirements of FL. Secondly, women's sticks have a tighter net designed for athletes to move and pass, in comparison to men's sticks with a deeper pocket which can enable greater on-ball

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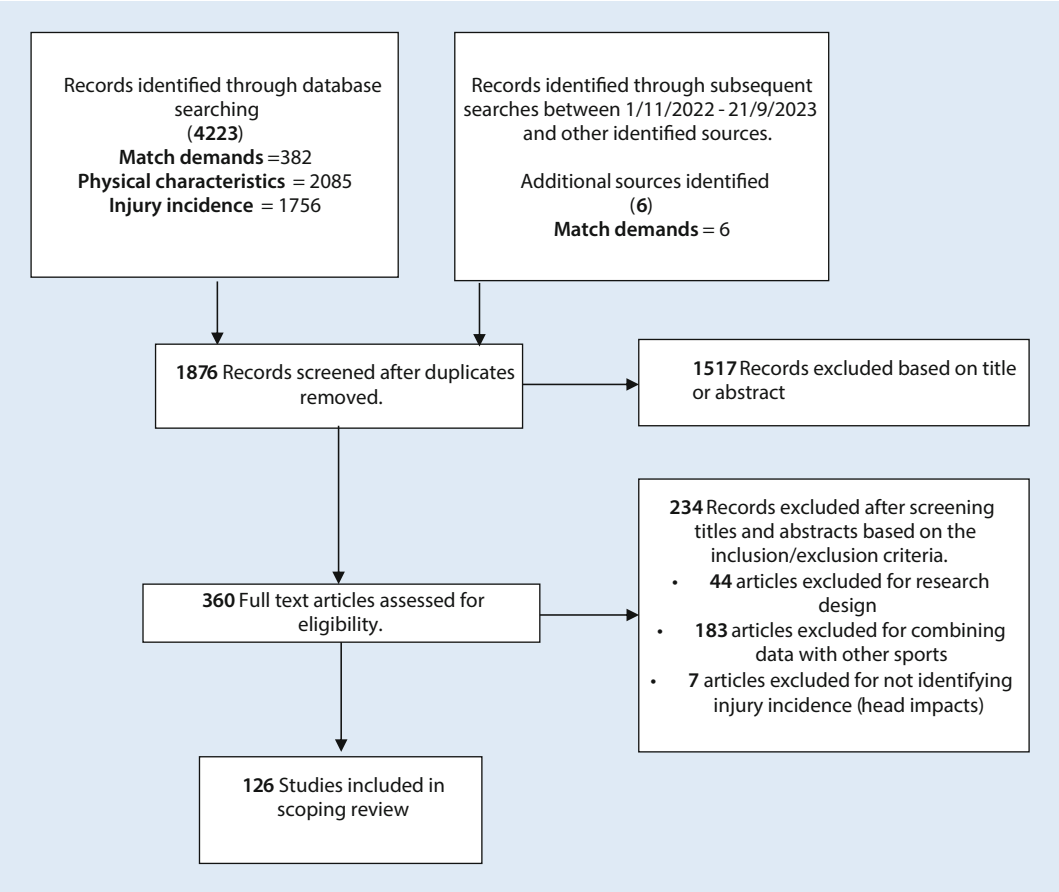

Fig. 1 ◀ Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram for study inclusion

travel or less likelihood of losing possession. Thirdly, within men's FL there are specialist players who are known as "long poles" who are typically designated the role of a defender possessing a longer stick which can be up to 1.8 m in length, designed for stopping attacking players via stick and body checks, due to the specialty nature of these outfield players could impact upon the physical match demands (especially for attacking players), although they are not present within the women's. Finally, there is reduced physicality in the women's, with body checks and body contact being illegal, resulting in the reduced need for added protection. Furthermore, although stick checks are legal, rules do apply, specifically about speed and location in proximity to the head potentially decreasing the likelihood of major head trauma. A final rule difference which could also decrease the frequency of impact injuries is the role of the shooting space, where a defender cannot block or guard the goal with the body (players can block or guard the goal with the stick) denying the attacking team the opportunity to shoot safely. This could also mean goals and turn overs in possession could also be more frequent after the shot, potentially increasing movement demands. These few examples of the rule differences could have huge implications on match performance, physical characteristics and injury incidence. Additionally, from a research practitioner perspective, these differences prevent comparison between men's and women's lacrosse.

With this growing popularity and potential for future Olympic inclusion, which could push popularity and participation across all levels of competition higher, there is a need for an understanding of the physical requirements, match demands and injury risk observations of each variant of the sport. Recently, it has been highlighted that there has been a paucity of research observing movement demands of lacrosse (Vescovi, 2022), but Vescovi (2022) did not go on to examine what studies had been performed across other areas (physical performance characteristics or injury risk characteristics) or to systematically review the state of the current literature on lacrosse. Therefore, the purpose of this scoping review is to explore the current state of the literature around lacrosse in key areas including match and training demands, physical performance, and injury incidence. We additionally aimed to identify knowledge gaps in the literature.

Methods

The latest methodological guidance for scoping reviews was followed, leading to completing the checklist of the Preferred Reporting Items for Systematic Reviews for scoping reviews (PRISMA; Tricco et al., 2018). A review protocol was not registered for the present search strategy.

Literature search strategy

Systematic literature searches were conducted in the electronic databases from inception until 31 December 22, with a secondary search from 1 November 22–21 September 23. ProQuest, PubMed, SCOPUS and institution library search tools were explored, using relevant key terms (and synonyms searched for by the Medical Subjects Headings [MeSH] database) were used in different combinations using a Boolean search strategy with the operators AND, OR:

Lacrosse, match demands, training loads, loading, match performance, physical performance, physical characteristics, performance assessment, injury incidence, injury occurrence, injury.

Additional sources that were also identified which were not present in the systematic search but determined to be relevant were also included.

Eligibility criteria and study selection

Studies were excluded if data included was combined across various sports, was retrospective analyses of injury incidence or failed to provide follow-up measures of injury incidence or relevant detail to identify measures of match or training demands and physical performance. Additionally, studies were required to be written in English and observational or experimental designs, excluding, review and report studies.

Data extraction, synthesis of results and statistical analysis

All search results were extracted and imported into Microsoft Excel (Microsoft Corporation, Redmond, WA, USA). All duplicate studies were initially excluded. Based on the title and abstracts, screening of identified articles was performed to remove nonrelevant studies identifying match demands, physical characteristics, and injury observations within lacrosse.

Following which, the included studies had the full text articles assessed by the lead author (NJR) for final inclusion.

No included studies were authored by any of the review authors, thereby limiting possible conflicts of interest. Data extracted from each article was specific to the area type, for match demands (sex, lacrosse version, competition level, sample size, if matches [and number of matches] or training were observed and assessment methods), for physical performance (sex, lacrosse version, competition level, sample size and physical performance assessments by type) and for injury incidence (sex, lacrosse version, competition level, body region of interest [global equating to all injuries], observation period and identification of injury mechanisms). The present study is largely descriptive and quantifies proportions (%) of studies.

Results

A total of 4223 studies were identified using the systematic search strategy and 6 were identified as additional resources, 388 studies were identified that characterized match or playing demands for lacrosse, 2085 studies were identified that characterized physical characteristics for lacrosse athletes and 1756 studies were identified that identified injury incidence statistics. After initial screening of titles, 22 studies were identified for match or playing demands for lacrosse, 90 studies were identified for physical characteristics and 248 studies were identified for injury incidence. Upon further abstract and full-text review, 20 studies were finally identified and included for review for match or playing demands for lacrosse, 30 studies were finally identified and included for review for physical characteristics and 76 studies were finally identified and included for injury incidence (**Fig. 1**).

Abstract

Background. Lacrosse has seen an uptake in participation in the last two decades. Moreover, with small-sided variants (box lacrosse [BL] and sixes lacrosse [SL]), with the latter being considered by the international Olympic committee. However, for athletes to perform at the highest level across the variations of lacrosse (field lacrosse [FL], BL and SL), sports coaches, practitioners and national governing bodies need to understand the demands, physical performance characteristics and injury incidence.
Objective. The objective of this scoping review is to explore the current state of the literature around lacrosse in key areas (match and training demands, physical performance and injury incidence). We additionally aimed to identify knowledge gaps in the literature.
Methods. The latest methodological guidance Preferred Reporting Items for Systematic Reviews for scoping reviews was followed. A systematic literature search was conducted in several electronic databases (ProQuest, PubMed, SCOPUS and institutional library), using relevant key terms. The present study is largely descriptive and quantifies proportions (%) of studies.
Results. Of the 4223 studies identified using the systematic search strategy, 120 studies were included within the final synthesis. 14 studies identified match or training demands across competitive levels and variations. 30 studies identified physical performance: 28 studies on FL athletes and two studies on BL. 75 studies identified injury incidence from lacrosse, all studies observed FL.
Conclusions. According to the results of this scoping review, there are large gaps within the literature that should be addressed. As international SL will be included in Olympic events this should be a focus of future research, attempting to identify match and training demands, physical performance characteristics and injury incidence. Moreover, as SL players are likely to be also participating in FL and BL, it could rapidly increase the demands placed upon players, both physically and psychologically.

Keywords
Field lacrosse · Box lacrosse · Sixes lacrosse · Sport science · Sports medicine

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Table 1 Included articles that observe match or training demands of lacrosse

Study	Sex	Version	Competition	*n*	Matches (#) or Practice	Demand Assessments
Caswell et al. (2020)	Female	Field	Youth	49	Matches (33)	Instrumented wearable sensors
Kilian, Snyman, and Miyashita (2022)	Female	Field	College	11	Matches (5)	Global positioning system
Alphin, Hudgins, and Bunn (2019)	Female	Field	College	25	Practice	Global positioning system and heart rate
Polley, Cormack, Gabbett, and Polglaze (2015)	Male	Field	Club	15	Matches (4)	Global positioning system
Hauer, Tessitore, Hauer, and Tschan (2021)	Female	Field	International	10	Matches (4)	Global positioning system
Devine, Hegedus, Nguyen, Ford, and Taylor (2022)	Female	Field	College	18	Matches (19)	Global positioning system
Hauer, Tessitore, Binder, and Tschan (2018)	Male	Box	International	12	Practice	Global positioning system
Hauer, Tessitore, Knaus, and Tschan (2020)	Male	Box	International	12	Matches (7)	Heart rate variability and Rate of perceived exertion
Akiyama, Sasaki, and Mashiko (2019)	Male	Field	International	50	Matches (3)	Global positioning system
Weldon et al. (2022)	Male	Sixes	International	25	Matches (7)	Global positioning system and heart rate
	Female			22	Matches (7)	
Calder, Duthie, Johnston, and Engel (2020)	Female	Field	College	14	Matches (7)	Global positioning system
Moon et al. (2021)	Female	Field	College	20	Practice	Energy expenditure
Akiyama, Sasaki, and Mashiko (2022)	Male	Field	Club	24	Matches (13)	Global positioning system
Zabriskie et al. (2019)	Female	Field	College	20	Practice	Energy expenditure
Thornton, Myers, and Jones (2021)	Female	Field	College	13	Matches (18)	Global positioning system
Sisson, Johnston, Noonan, and Bunn (2018)	Female	Field	College	20	Practice	Heart rate and rate of perceived exertion
Bynum, Snarr, Myers, and Bunn (2022)	Female	Field	College	13	Matches (26)	Global positioning system and match analysis
Rosenberg, Myers, and Bunn (2021)	Female	Field	College	13	Matches (93) Practice	Global positioning system and heart rate
Bunn, Reagor, and Myers (2022)	Female	Field	College	12	Matches (17)	Global positioning system and heart rate
Fields et al. (2023)	Male	Field	College	17	Matches (19) Practice	Global positioning system

Match and training demands

Across the 20 studies that were included within the review that identified match or training demands (**Table 1**), 10 studies observed male athletes and 10 studies observed female athletes match or training demands.

The total sample size was 415, with a greater proportion of females observed ($n = 260$, 62.65%) in comparison to males ($n = 155$, 37.36%); this is despite fewer studies including female participants. Observations varied across all lacrosse variants (FL, BL and SL) and all competitive levels (youth, club, college and international). The total number of matches observed was 282 with 53 male matches and 229 female matches. Finally, the most common technology to assess match and training demands was global positioning systems (GPS) ($n = 15$), with 4 studies combining GPS and heart rate monitors and one combined with rate of perceived exertion. Further studies used activity monitors ($n = 2$), wearable accelerometers ($n = 1$) and heart rate variability and subjective monitoring ($n = 2$).

Physical performance characteristics

In all, 30 studies were included within the review; descriptive information of included studies can be seen in **Table 2**. Across the included studies, there was a 50:50 split upon inclusion of male and female participants, although total sample size ($n = 910$) was weighted slightly more towards female athletes (530, 58.2%) in comparison to male (380, 41.8%). A total of 28 studies focussed on FL athletes with 2 studies observing BL. Competition levels varied between youth, club, collegiate and international levels.

Ten key physical performance characteristics were identified within the studies, the most frequent physical performance assessments included jump ($n = 11$, 17.5%), strength ($n = 10$, 15.9%) and aerobic ability ($n = 10$, 15.9%).

Injury incidence

A total of 76 studies were included within the review; descriptive information of included studies can be seen in **Table 3**.

Across the included studies, male populations were observed on 62 occasions, female populations on 59 occasions and within 8 studies participants were com-

Table 2 Included articles that identify measures of athletic performance in lacrosse player

Study	Sex	Version	Competition	*n*	Physical Performance Assessments
Akiyama et al. (2022)	Male	Field	Club	24	Sprint; Change of direction; Aerobic
Braun et al. (2015)	Female	Field	College	17	Drop landing; Change of direction; Balance
Kipp, Suchomel, and Comfort (2019)	Male	Field	College	15	Jump; Weightlifting performance
Clark, Stearne, Walts, and Miller (2010)	Male	Field	College	25	Sprint
Lisman, Wilder, Berenbach, Jiao, and Hansberger (2021)	Female	Field	College	27	Drop landing
Macaulay, Katz, Stergiou, Stefanyshyn, and Tomaghelli (2017)	Male	Box	Club	12	Shooting ability
Lockie et al. (2018)	Female	Field	Club	9	Jump; Speed; Change of direction; Aerobic
Gordon, Ambegaonkar, and Caswell (2013)	Female	Field	Youth	45	Strength; Balance
Zabriskie et al. (2019)	Female	Field	College	20	Body Composition
Dolan, Witherbee, Peterson, and Kerksick (2017)	Male	Field	College	14	Aerobic
Parker, Sisson, and Bunn (2020)	Female	Field	College	22	Aerobic; Anaerobic
Enemark-Miller, Seegmiller, and Rana (2009)	Female	Field	College	24	Flexibility; Strength; Muscular endurance; Sprint; Body Composition; Jump
Plummer & Oliver (2015)	Male	Field	Youth	10	Shooting ability
Yamada, Masuo, Nakamura, and Oda (2013)	Male	Field	College	33	Body Composition
Withers, Craig, and Norton (1986)	Male	Field	Club	26	Body type
Pontillo and Sennett (2020)	Male	Field	College	30	Balance
	Female	Field	College	18	Balance
Steinhagen et al. (1998)	Male	Field	Club	30	Body Composition; Anaerobic; Aerobic
Vescovi and Mcguigan (2008)	Female	Field	College	79	Sprint; Jump; Change of direction
Collins et al. (2014b)	Male	Field	College	54	Body Composition; Strength; Muscular endurance; Aerobic
Fields et al. (2018a)	Female	Field	College	81	Body Composition
Vescovi, Brown, and Murray (2007)	Female	Field	College	84	Sprint; Jump; Change of direction; Aerobic
Haischer, Krzyszkowski, Roche, and Kipp (2021)	Female	Field	College	19	Jump; Sprint
Sell et al. (2018)	Male	Field	College	41	Sprint; Change of direction; Aerobic; Strength; Jump; Body Composition
Talpey, Axtell, Gardner, and James (2019)	Male	Field	College	8	Jump; Strength
Marsh, Richard, Verre, and Myers (2010)	Female	Field	College	15	Shooting ability; Strength; Balance
Hoffman et al. (2009)	Female	Field	College	22	Strength; Jump; Anaerobic; Sprint; Aerobic; Change of direction
Taylor, Wright, Smoliga, DePew, and Hegedus (2016)	Male	Field	College	26	Balance
	Female	Field	College	28	Balance
Akiyama and Yamamoto (2019)	Male	Field	Club	20	Shooting ability; Strength; Jump
Hauer et al. (2018)	Male	Box	International	12	Aerobic
Moon et al. (2021)	Female	Field	College	20	Body Composition

bined. All 76 studies observed FL, predominantly youth and collegiate levels. Various injury observations were made across the included studies, over observation periods ranging from 9 days to 16 years. A total of 43 studies (57%) identified mechanisms of injury, whereas 33 studies (43%) did not identify injury mechanisms.

Discussion

The present scoping review identified 120 published articles that investigate lacrosse athletes across match demands, physical performance and injury incidence. To the best of our knowledge, this is first scoping review highlighting areas of interest that may require further investigation. Vescovi (2022) highlighted clear gaps in the literature in a commentary article, indicating further literature was required in the following areas; peak movement demands and establishing movement thresholds for each variation of the sport (including FL, BL and SL), evaluating tournament and schedule demands, assessing injury risk and match demands (across FL, BL and SL) and explore the alignment of training to match demands. The findings of the present review agree with Vescovi (2022), as there is an apparent lack of literature examining the variations lacrosse, with a focus on FL.

Table 3 Included articles that identify injury incidence within lacrosse

Study	Sex	Version	Competition	Region	Observation period	Mechanism (Yes/No)
Chorney, Sobin, Goyal, and Suryadevara (2017)	Female	Field	Collegiate	Head	10 years	No
	Male	Field			10 years	
Lutz, Demoss, Roebuck, Mason, and Eiler (2021)	Female	Field	Collegiate	Lower limb	7 years	No
Comstock, Arakkal, Pierpoint, and Fields (2020)	Female	Field	Youth	Head	10 years	Yes
Wiersma, Brou, Fields, Comstock, and Kerr (2018)	Female	Field	Youth–Collegiate	Lower limb	5 years	No
	Male	Field			5 years	
Marshall, Guskiewicz, Shankar, McCrea, and Cantu (2015)	Female	Field	Youth–Collegiate	Head	3 years	No
	Male	Field			3 years	
Collins et al. (2014a)	Female	Field	Youth	Head	1 year	No
	Male	Field			1 year	
Lincoln et al. (2014)	Female	Field	Youth	Global	10 weeks	No
	Male	Field			10 weeks	
Ryder, Gnirke, Laker, Hoffmire, and Comstock (2020)	Female	Field	Youth	Global	7 years	No
	Male	Field			7 years	
Mitchell et al. (2016)	Female	Field	Youth	Lower limb	6 years	Yes
	Male	Field			6 years	
Herman et al. (2017)	Combined	Field	Collegiate	Lower limb	8 years	No
Beynnon et al. (2014)	Female	Field	Youth–Collegiate	Lower limb	3.5 years	No
	Male	Field			3.5 years	
Deckey et al. (2020)	Female	Field	Collegiate	Torso	5 years	Yes
	Male	Field			5 years	
Twomey-Kozak, Whitlock, O'Donnell, Anakwenze, and Klifto (2021)	Combined	Field	Youth–Collegiate	Upper limb	4 years	No
Decoster, Bernier, Lindsay, and Vailas (1999)	Male	Field	Collegiate	Global	1 year	No
	Female	Field			1 year	
McCrea et al. (2013)	Male	Field	Youth–Collegiate	Head	10 years	Yes
Lisman et al. (2021)	Female	Field	Collegiate	Global	1 year	No
D'Alonzo et al. (2021)	Male	Field	Collegiate	Global	5 years	Yes
Bretzin et al. (2021)	Female	Field	Collegiate	Global	5 years	Yes
Guillaume, Lincoln, Hepburn, Caswell, and Kerr (2021)	Male	Field	Youth	Global	7 years	Yes
McGinnis, Mair, Mansell, and Collins (2020)	Male	Field	Youth	Global	12 weeks	Yes
Anderson, Wasserman, and Schultz (2019)	Female	Field	Collegiate	Lower limb	12 years	No
	Male	Field			12 years	
Kucera et al. (2019)	Combined	Field	Youth–Collegiate	Torso	10 years	Yes
Pierpoint et al. (2019)	Male	Field	Youth	Global	6 years	Yes
	Male	Field	Collegiate		9 years	
Warner et al. (2018)	Male	Field	Youth	Global	8 years	Yes
	Female	Field			8 years	
Rizzone, Ackerman, Roos, Dompier, and Kerr (2017)	Male	Field	Collegiate	Global	10 years	No
	Female	Field			10 years	
Fraser, Grooms, Guskiewicz, and Kerr (2017)	Male	Field	Collegiate	Global	6 years	Yes
	Female	Field			6 years	
Eckard, Kerr, Padua, Djoko, and Dompier (2017)	Male	Field	Collegiate	Lower limb	6 years	No
	Female	Field			6 years	
Kerr et al. (2017a)	Male	Field	Youth	Global	3 years	Yes
	Female	Field			3 years	
	Male	Field	Collegiate		5 years	
	Female	Field			5 years	

Table 3 (Continued)

Study	Sex	Version	Competition	Region	Observation period	Mechanism (Yes/No)
Kopec et al. (2017)	Male	Field	Collegiate	Upper limb	6 years	Yes
	Female	Field			6 years	
Kerr et al. (2017b)	Male	Field	Collegiate	Head	4 years	No
	Female	Field			4 years	
Kay et al. (2017)	Male	Field	Collegiate	Global	6 years	Yes
	Female	Field			6 years	
Covassin, Moran, and Elbin (2016)	Male	Field	Collegiate	Head	5 years	No
	Female	Field			5 years	
Hootman, Dick, and Agel (2007)	Male	Field	Collegiate	Head	16 years	No
	Female	Field			16 years	
Dick et al. (2007a)	Female	Field	Collegiate	Global	16 years	Yes
Dick et al. (2007b)	Male	Field	Collegiate	Global	16 years	Yes
Yard and Comstock (2006)	Combined	Field	Youth	Global	13 years	No
Kerr et al. (2018b)	Female	Field	Youth	Global	1 year	Yes
	Male	Field			1 year	
Swenson et al. (2013)	Female	Field	Youth	Lower limb	6 years	Yes
	Male	Field			6 years	
Agel, Rockwood, and Klossner (2016)	Female	Field	Collegiate	Lower limb	9 years	Yes
	Male	Field			9 years	
Covassin, Swanik, and Sachs (2003)	Female	Field	Collegiate	Head	3 years	No
	Male	Field			3 years	
Gwinn, Wilckens, McDevitt, Ross, and Kao (2000)	Female	Field	Collegiate	Lower limb	6 years	Yes
	Male	Field			6 years	
Mertz et al. (2022)	Female	Field	Collegiate	Head	5 years	No
Zynda, Petit, Anderson, Tomczyk, and Covassin (2021)	Female	Field	Collegiate	Head	3 years	No
	Male	Field			3 years	
Slauterbeck et al. (2019)	Female	Field	Youth	Global	1 year	Yes
	Male	Field			1 year	
Putukian, D'Alonzo, Campbell-McGovern, and Wiebe (2019)	Female	Field	Collegiate	Head	5 years	No
	Male	Field			5 years	
Bretzin et al. (2018)	Female	Field	Youth	Head	1 year	No
	Male	Field			1 year	
Goodman et al. (2018)	Female	Field	Collegiate	Upper limb	5 years	Yes
	Male	Field			5 years	
Mauntel et al. (2017)	Female	Field	Collegiate	Lower limb	6 years	Yes
	Male	Field			6 years	
Gardner, Chan, Sutton, and Blaine (2016)	Male	Field	Collegiate	Upper limb	5 years	No
Hibberd, Kerr, Roos, Djoko, and Dompier (2016)	Female	Field	Collegiate	Upper limb	6 years	Yes
	Male	Field			6 years	
Wasserman, Kerr, Zuckerman, and Covassin (2016)	Female	Field	Collegiate	Head	5 years	No
	Male	Field			5 years	
Zuckerman et al. (2015)	Female	Field	Collegiate	Head	5 years	Yes
	Male	Field			5 years	
Xiang, Collins, Liu, McKenzie, and Comstock (2014)	Female	Field	Youth	Global	4 years	Yes
	Male	Field			4 years	
Roach et al. (2014)	Male	Field	Collegiate	Lower limb	4 years	No
Lincoln, Caswell, Almquist, Dunn, and Hinton (2013)	Male	Field	Youth	Head	2 years	Yes
Marar, McIlvain, Fields, and Comstock (2012)	Female	Field	Youth	Head	2 years	Yes
	Male	Field			2 years	

Table 3 (Continued)

Study	Sex	Version	Competition	Region	Observation period	Mechanism (Yes/No)
Lincoln, Hinton, Almquist, Lager, and Dick (2007)	Male	Field	Youth	Head	4 years	Yes
	Male	Field	Collegiate		4 years	
	Female	Field	Collegiate		4 years	
Mitchell et al. (2016)	Female	Field	Youth	Lower limb	7 years	Yes
	Male	Field			7 years	
Beynnon, Vacek, Murphy, Alosa, and Paller (2005)	Female	Field	Youth	Lower limb	5 years	No
	Male	Field			5 years	
	Female	Field	Collegiate		5 years	
	Male	Field			5 years	
Hinton, Lincoln, Almquist, Douoguih, and Sharma (2005)	Female	Field	Youth	Global	3 years	Yes
	Male	Field			3 years	
Matz and Nibbelink (2004)	Female	Field	Collegiate	Global	2 years	No
Fakhre et al. (2020)	Female	Field	Collegiate	Upper limb	10 years	No
	Male	Field			10 years	
Kerr et al. (2017c)	Male	Field	Collegiate	Global	6 years	Yes
Kerr et al. (2018a)	Female	Field	Collegiate	Global	6 years	Yes
Master et al. (2021)	Combined	Field	Collegiate	Global	4 years	Yes
Herman, Caswell, Kelshaw, Vincent, and Lincoln (2022)	Female	Field	Youth	Head	3 years	No
Sanomura, Hosokawa, Nakamura, and Fukubayashi (2013)	Female	Field	Collegiate	Global	2 years	Yes
Kerr et al. (2022)	Female	Field	Youth	Lower limb	8 years	Yes
	Male	Field			8 years	
Cheney et al. (2021)	Male	Field	International	Global	11 days	Yes
Webb, Davis, Westacott, Webb, and Price (2014)	Male	Field	International	Global	9 days	Yes
Li, Goodman, Lemme, and Owens (2019)	Female	Field	Collegiate	Upper limb	5 years	Yes
	Male	Field			5 years	
Bartley et al. (2017)	Male	Field	Youth	Global	11 years	Yes
Audlin, Tipirneni, and Ryan (2021)	Combined	Field	Youth	Head	2 years	No
	Combined	Field	Collegiate		2 years	
Bano, McAdams, Roberts, Yang, and McKenzie (2020)	Female	Field	Youth	Global	16 years	Yes
	Male	Field			16 years	
Cooley, Beranek, Warpinski, Alexander, and Esquivel (2019)	Female	Field	Club	Head	11 years	Yes
	Male	Field			11 years	
Scheffler, Wolter, Namavarian, Propst, and Chan (2019)	Combined	Field	Youth	Head	10 years	No

Furthermore, there is a lack of diverse investigations across competitive levels, with a focus on youth and collegiate levels with a small amount of evidence investigating international and club levels which requires further investigation.

Match demands

Across the included literature, the studies examining the match demands have been the most comprehensive between the competitive levels. Although the number of included studies investigating match demands was far fewer than the number of articles investigating physical performance and injury incidence. However, the application of appropriate technology is a key factor in determining playing demands; the most frequently used technology in investigating match characteristics is global positioning systems (GPS) with or without heart rate monitoring (Cummins, Orr, O'Connor, & West, 2013), which provides objective measures of match performance. Ten of the 14 studies included the use of GPS, although further examination on the frequency and accuracy of the GPS devices used by the research should be sought in more specific systematic review (Johnston, Watsford, Kelly, Pine, & Spurrs, 2014; Johnston et al., 2012; Rampinini et al., 2015; Vickery et al., 2014). The four other assessments of match demands included the use of accelerometer to establish energy expenditure ($n = 2$), head kinematics using a wearable accelerometer during the match ($n = 1$) and a single study observing changes in heart rate variability and rating of perceived exertion across a BL competition. Out of the four other assessments identified, observing subjective and objective measures of load and

Table 4 Preliminary and advanced topics for research on lacrosse

Preliminary	Advanced
Identification of peak and average match demands (FL, BL and SL)	Clustering of movement demands in competitive matches and identifying sequential movement patterns (FL, BL and SL)
Identify if typical training practices meet competitive match demands (FL, BL and SL)	Establish novel training practices that can meet competitive demands, including worst case scenario situations (FL, BL and SL)
Identify typical training and playing loads (objective and subjective) for a single variation of lacrosse (FL, BL and SL)	Determine the effect of concurrently training multiple versions of lacrosse (FL, BL and SL)
Establish a battery of physical performance tests that can be used for lacrosse athletes across competition levels (youth, collegiate and international)	Provide large normative data sets for physical performance assessments across variations of lacrosse (FL, BL and SL) and competition levels
Observe the effects of a single match (FL, BL and SL) on measures of athletic performance (i.e. acute fatigue)	Observe the effects of a multiple matches and/or fixture congestion (FL, BL and SL) on measures of athletic performance (i.e., chronic fatigue)
Establish key injury occurrences and associated mechanisms (FL, BL and SL)	Identify if specific training practices can prevent injury events (FL, BL and SL)

FL Field lacrosse, *BL* Box lacrosse, *SL* Sixes lacrosse

recovery during a competition scenario has high practical relevance (Hauer et al., 2020), with both measures of heart rate variability and rating of perceived exertion being valid and reliable in assessing an athlete's load and recovery status.

There is a pressing demand to establish known values on playing demands across the variations of the sport, with the potential future inclusion of SL in the Olympics, athletes are currently preparing themselves to play this new version, with the potential to become Olympic athletes. This means current players are participating in multiple variants with instances of players participating in all three formats at club, collegiate and international competitions. Only recently, players have been simultaneously participating in SL and BL at an international competitive level, while also being in the middle of their domestic club (FL) league.

This could be placing an extremely high physical and psychological demand upon the players, and it may not be in their best interest from a wellbeing perspective, with the potential for injury or illness (Gabbett, 2016). Practitioners and national governing bodies need to have required information upon the physical demands and loading or recovery across lacrosse variations to be able to make informed decisions on athlete wellbeing and athlete education to mitigate any potential negative effects of playing multiple variants. It would also be recommended for national governing bodies to design and cooperate on competitive schedules, recognising the role of multivariant athletes and the need for recovery periods between periods of high fixture congestion or tournament participation. Furthermore, if practitioners are attempting to prepare athletes of any competitive level (youth, club, collegiate and international) for any one of the lacrosse variations, they need to understand the demands of the sport, even more so if they are attempting to prepare athletes for multiple variations of the sport. This includes determining peak movement demands and establishing movement thresholds as described by Vescovi (2022), which has been performed in other team sports (such as rugby union, rugby league, soccer and Australian rules football) (Aughey, 2011; Cahill, Lamb, Worsfold, Headey, & Murray, 2013; Cummins et al., 2013; Cunniffe, Proctor, Baker, & Davies, 2009; Gabbett, 2015; Jones, West, Crewther, Cook, & Kilduff, 2015; Malone et al., 2018; Wisbey, Montgomery, Pyne, & Rattray, 2010).

Physical performance

Across the articles that observed measures of physical performance characteristics, there is a lack of literature identifying youth and international level lacrosse athletes. This can likely be explained by a lack of funding or specialist support at these levels, with collegiate sport having the potential in-house support and options being available to club athletes who may also be associated with colleges or private practitioners. This immediately highlights that there is a lack of understanding of what physical qualities underpin international lacrosse athletes, i.e. practitioners might not be able to prescribe training appropriately, resorting to using normative data from alternative sports (such as field or ice hockey). If there is a lack of direction on appropriate training, it could mean that athletes are wasting time on inappropriate training, potentially missing key performance indicators, while also losing out on beneficial training time. Further to this any misinformed training practises could be exacerbating previous issues identified around loading, by generating unnecessary fatigue without beneficial adaptations, potentially increasing the risk of injury and reducing player wellbeing.

Across the tests for physical performance, measures of jumping ability, strength and aerobic ability were assessed most frequently. However, there was limited consistency in the different assessment types, with tests for vertical jump performance including 3D motion and combined force plate assessment, force plate assessment, a Vertec device (Sports Imports, Columbus, OH, USA), Just Jump device (Probotics Inc, Huntsville, AL, USA), and a T.K.K. jump meter (Takei Scientific Instruments Co., Ltd., Niigata, Japan). Measures of strength were carried out using both single and multijoint assessments, with single joint assessments utilising handheld dynamometry and isokinetic devices. Multijoint assessments included isometric mid-thigh pull using force plates, conventional upper and lower maximal strength assessments (1 repetition max [RM], 3 RM). Aerobic ability was assessed using lab-based tests such as Bruce protocol treadmill VO_2 max test and Astrand protocol treadmill VO_2 max test, where VO_2 max is the the maximum or optimum rate at which the body can use oxygen. As

well as field-based tests including, 12-minute Cooper run, Yo-Yo intermittent recovery test, multistage shuttle run, 2-minute shuttle repeats, 1-mile time trial and 1.5-mile time trial. The variety in assessment type and performance makes the job for practitioners much harder when attempting to compare to normative data to prescribe training, as it is difficult to compare between the different devices identified, e.g. jump height (McMahon, Jones, & Comfort, 2016), isometric vs conventional strength testing (Wang et al., 2016), or between lab and field-based aerobic assessments (Boullosa et al., 2013). Therefore, future research should not only look to use standardised methods of physical performance testing that have high utility in the field but data sets of other team sport athletes, as well as attempting to recruit large meaningful sample sizes that could provide normative data for lacrosse athletes across competitive levels. To achieve such recommendations practitioners should begin by defining and identifying a battery of performance tests, using predetermined valid and reliable methods (potentially including appropriate sports technology) and establishing institutional standard operating procedures, for practitioners to be able to appropriately identify physical performance needs for athletes. Recruiting large and meaningful sample sizes is an issue within sport science and is generally difficult, but if institutional standard operating procedures are defined and continually used then over time a large and meaningful sample size can be established. A further recommendation would be for appropriate collaboration between practitioners or to research groups who could look to test multiple teams providing individual feedback to each team but take the grouped anonymous data to provide normative and benchmarks data using larger collected samples.

Injury incidence

Injury incidence literature has so far focused on FL at youth and collegiate levels, with no articles found using the present search strategy identifying injury incidence in BL and SL. With only single studies identifying club and international level injury incidence, this highlights an urgent need for studies examining injury incidence at these levels, especially at the international levels with an increased number of international competitions to include all formats of lacrosse. Moreover, with the potential for SL inclusion at future Olympic events understanding the types of injuries that are occurring in this version will be imperative, especially to correspond to the IOC's aim of promoting health and wellbeing. Similarly, understanding the injury occurrence in BL is important as, arguably, the rule modifications are likely to increase the frequency of contact situations and could therefore result in a wider variety of injury events.

Global injury surveillance studies have been observed most frequently; however, the frequency of studies examining specific body regions indicates the expected injury types could highlight training needs for athletes with regards to injury risk reduction, specifically head and lower limb injures being most frequently examined. The most frequently identified head injuries are concussions, followed by facial contusions, cuts and abrasions. Lower limb injuries frequently identified knee injuries (anterior cruciate ligament, medial collateral ligament and meniscus), followed by ankle injuries and muscular strains. However, only 56% of the included studies attempted to highlight potential mechanisms of injury; this limits the usefulness of injury observation studies as the mechanism can dictate if and how an injury could be preventable. Therefore, future research should attempt to categorise injury mechanisms across variants (including any potential differences between men's and women's lacrosse) and determine how any rule changes and gameplay changes of the variants might influence injury incidence, which would aid practitioners in their injury prevention practises.

Limitations

The present scoping review is not without its limitations; primarily, the search and data extraction were performed by a single individual, who only has practise-based experience in one version of lacrosse (SL). This firstly could have led to results having missed relevant articles within the literature search or overlooked articles that could have added meaningful data upon the other versions of lacrosse (BL and SL), which have been observed less frequently in the literature. Moreover, as the individual who performed the search only has experience in SL, this could have meant the search strategy was biased towards this format of game, again meaning that key articles may have been missed during the literature search. However, a thorough systematic search of the literature was performed and without bias towards any single variant of lacrosse hoping to overcome this limitation. A secondary limitation and recommendation for future investigation is to perform study quality assessment, which could form part of further exploratory analyses of the literature in a systematic review.

Conclusion

The present scoping review highlights that there are gaps within the literature that should be addressed, especially with the increasing participation numbers and future inclusion in multinational events. Across included articles the competitive levels and variations of lacrosse observed is varied for match demands, physical performance and injury incidence. It could be argued with future inclusion of international SL in Olympic events that this should be a focus of future research, attempting to identify match and training demands, physical performance characteristics and injury incidence. This will enable appropriate prescription of training (both sports-based training and physical preparation) to optimise athletic performance and mitigate injury risk. Moreover, as SL could be a future Olympic event, this could encourage FL and BL players to take up this variation as well. If this is in addition to FL and BL, it could rapidly increase the demands placed upon players, both physically and psychologically. Therefore, greater insight should be sought on these demands

that are being placed upon players including match and training demands and injury incidence; this information could be used by coaches and national governing bodies to provide appropriate education to players to enable playing decisions to optimise player wellbeing. Following the example set by Vescovi (2022), **Table 4** is a call for preliminary research followed by more advanced topics for future investigations to focus upon (**Table 4**).

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Declarations

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