What is needed to reduce the risk of anterior cruciate ligament injuries in children? – Hearing from experts

Heering, T., Lander, N. J., Barnett, L. M. & Duncan, M

Original citation:
Heering, T, Lander, NJ, Barnett, LM & Duncan, M 2023, 'What is needed to reduce the risk of anterior cruciate ligament injuries in children? – Hearing from experts', Physical Therapy in Sport, vol. 61, pp. 37-44.
https://doi.org/10.1016/j.ptsp.2023.02.007

DOI 10.1016/j.ptsp.2023.02.007
ISSN 1466-853X

Publisher: Elsevier

Physical Therapy in Sport 61 (2023) 37–44

Contents lists available at ScienceDirect

Physical Therapy in Sport

journal homepage: www.elsevier.com/ptsp

What is needed to reduce the risk of anterior cruciate ligament injuries in children? – Hearing from experts

Theresa Heering [a, b, c, *], Natalie Lander [d], Lisa M. Barnett [b, c, e, 1], Michael J. Duncan [a, 1]

[a] Coventry University, Centre of Sport, Exercise and Life Science, Coventry, UK
[b] Deakin University, School of Health and Social Development, Victoria, Melbourne, Australia
[c] Deakin University, Institute for Health Transformation, Victoria, Melbourne, Australia
[d] Deakin University, School of Exercise and Nutrition Sciences, Australia
[e] Deakin University, Institute for Physical Activity and Nutrition (IPAN), Australia

ARTICLE INFO

Article history:
Received 8 December 2022
Received in revised form
17 February 2023
Accepted 18 February 2023

Handling Editor: Dr L Herrington

Keywords:
ACL tears
Primary prevention
Paediatrics
Semi-structured interviews

ABSTRACT

Objective: Anterior cruciate ligament (ACL) injuries are an emerging health problem in children. Acknowledging considerable gaps in knowledge, the aim of this study was to examine the current knowledge on childhood ACL injury, and to explore risk assessment and reduction strategies, with experts in the research community.
Design: Qualitative study; semi-structured expert interviews.
Methods: Interviews with seven international, multidisciplinary academic experts were conducted from February until June 2022. A thematic analysis approach organized verbatim quotes into themes using Nvivo Software.
Results: Gaps in knowledge on the actual injury mechanism, and influence of physical activity behaviours, constrain targeted risk assessment and reduction strategies in childhood ACL injuries. Strategies to examine and reduce the risk of ACL injury included: examining an athletes' whole-body performance, moving from constraint (e.g., squat) to less constraint (e.g., single-leg) tasks, making assessments into children's context, building a movement repertoire at young age, performing risk reduction programs, multiple sports, and prioritising rest.
Conclusion: Research is urgently warranted on the actual injury mechanism, reasons for ACL injuries in children, and potential risk factors to update risk assessment and reduction strategies. Further, educating stakeholders on risk reduction strategies could be essential to address the increasing occurrence of childhood ACL injuries.

1. Introduction

Anterior cruciate ligament (ACL) injuries are an emerging health problem in children and early-adolescents (Dhillon et al., 2022; Maniar et al., 2022). Despite efforts to reduce the risks of ACL injuries, annual growth rates in ACL injury prevalence have increased in children and are higher, proportionally, compared to adolescents and adults (Maniar et al., 2022). Further, the risk of a subsequent ACL injury, either ipsilateral or contralateral, are high with children of a younger age (<15 years) at the time of the primary injury and those of female sex - elevating the risk of secondary injury even further (Dekker et al., 2018; Dhillon et al., 2022; Patel et al., 2020). The literature is limited in the cause of injury, but ACL injuries in childhood seem to occur during organised and unorganised sporting activities (Shaw & Finch, 2017). In this article ‘childhood’ refers to children aged 5–14 years in accordance with the age categories used by epidemiological studies on ACL injury occurrence (Maniar et al., 2022; Shaw & Finch, 2017; Zbrojkiewicz et al., 2018).

At the same time, physical activity (PA) levels are declining in children and recommendations by the World Health Organisation (e.g., 60min of moderate to vigorous PA per day) are widely not met (Guthold et al., 2020; World Health Organization, 2019). One of the purported reasons for the declining levels of PA observed in children, which may be potentially linked to ACL injury risk, is inadequate development of movement proficiency (Bolger et al., 2021).

* Corresponding author. Priory Street, CV1 5FB, Coventry, UK.
E-mail address: heeringt@uni.coventry.ac.uk (T. Heering).
[1] Shared senior authorship.

https://doi.org/10.1016/j.ptsp.2023.02.007

Without possessing the underpinning movement skill proficiency a child will theoretically experience suboptimal movement patterns in more advanced tasks and specialized skills such as those seen in most sports (Cook et al., 2006; Stodden et al., 2008). Hence, it could be questioned whether children are adequately prepared for youth sport participation and accordingly, whether limited movement proficiency may contribute to the increasing prevalence in ACL injuries observed in active children.

Despite increasing injury rates, children seem to be an under researched cohort regarding sporting injuries in general and ACL injuries specifically. There are few epidemiology studies examining sport injury rates in childhood (Rössler et al., 2016a). To the best of our knowledge, the actual injury mechanism of ACL injury has not been examined specifically for children and is consequently unknown. The extant literature appears to assume that the mechanism in children is similar to that in adolescents and adults (Dhillon et al., 2022). However, childhood is a unique developmental phase and without understanding the true mechanism of ACL injury in children and the corresponding risk factors, risk reduction strategies remain unspecific as the target is unclear (Arundale et al., 2022).

In an effort to reduce the risk of primary ACL injury, multiple risk reduction programs have been designed for adolescents and adults (Huang et al., 2020; Lopes et al., 2018), but rarely specific to children. A neuromuscular training program, the CORE intervention, for sport-related injuries in middle and high school (mean age = 14.0 ± 1.7 years) offered protection against knee injuries (Barber Foss et al., 2018). More specific to our target population aged under 13 years, a football specific risk reduction program was adjusted for children (FIFA 11+ kids) (Rössler et al., 2016b, 2018). After implementing the FIFA 11+ kids program, Rössler et al. observed a 48% decrease in football specific injuries in children aged 7- to 13 years (Rössler et al., 2018). This program meets recommendations to implement risk reduction programs as early as possible, e.g., in pre-adolescence, to pre-program safe movement patterns (Bergeron et al., 2015; Myer et al., 2013). Furthermore, a current review critiqued that many exercises in risk reduction programs do not target the actual ACL injury mechanisms, and therefore, need updating (Dischiavi, Wright, Heller, & et al., 2022).

To address the gaps in understanding relating to ACL injury in childhood, we acknowledge the need to examine what is known and what is needed to provide a foundation for effective injury risk assessment and reduction strategies in children. An important first step was taken by the International Olympic Committee (IOC) who provided a consensus statement with four formulated research priorities to improve prevention and outcomes of paediatric ACL injury (Ardern et al., 2018). The current study aims to address research priority number one: *identify injury mechanisms and modifiable risk factors for ACL injury, combined injuries and knee reinjuries* (Ardern et al., 2018). This qualitative research aims to add detail and topics to those already addressed in the IOC consensus publication by consulting experts in the field who perform ACL injury research and who can provide more insights and context around current problems and future direction needed to advance the field. Through their experience, experts have intuitive knowledge that arises from a deep understanding of the current research landscape (Bruce et al., 2008). Expert interviews are specifically valuable when there is little, or conflicting knowledge, where consensus is lacking for "best practice" and to develop practical guidelines (Baker et al., 2006). Accordingly, the aim of this research was to explore (i) the current knowledge and (ii) strategies to assess and reduce the risk of ACL injuries in children, with experts in the research community.

2. Methods

2.1. Study design

We conducted semi-structured interviews with academic experts in the field of ACL injury risk to explore professional knowledge of ACL injury characteristics and scenarios, screening and risk reduction strategies, as well as future research directions. The research was carried out in accordance to the Declaration of Helsinki and ethics approval was obtained from the relevant Human Research Ethics Committees (HEAG-H 138_2021; P125854).

2.2. Participants

World leading academic experts on ACL injuries were identified through the expertscape.com homepage using the search terms "anterior cruciate ligament injury". To ensure the experts held relevant information on ACL injuries in children, their publication list was screened for relevant publication/s. Publication titles and abstract were perused, and experts were eligible if they studied human participants aged 5–14 years. The selected experts research needed to be related to risk reduction (e.g., risk factors, intervention programs, consensus statements) of primary ACL injuries. This process reduced the potential list from 118 to 27 experts. When identified as suitable for participation, experts were invited via e-mail. E-mail addresses were obtained from recent publications or institutional profiles. The initial contact included a participant information sheet and consent form which participants completed digitally to confirm participation. Twenty-seven experts (19% female) with a variety of backgrounds, e.g., medicine or physiotherapy were identified as eligible to invite according to their expertscape profile. There was no response from 17 experts, two declined participation, one asked for the interview guide but did not reply to the follow-up invitation to participate, and seven experts (14% female) agreed to participate.

2.3. Data collection and analysis

Interviews were conducted by the first author via Zoom between February and June 2022 with an average duration of 30–45 min. The interviews followed a pre-designed interview guide (Appendix A) developed based on guidelines by Kallio et al. (Kallio et al., 2016). The conversational nature of semi-structured interviews allows for obtaining comparable and reliable data by asking follow-up questions according to the experts responses, whilst making sure that relevant topics from the interview were covered (Kallio et al., 2016). To ease into the interview, experts first reported on their background, current occupation and training, and about their research interest. The interview then progressed to more in-depth questions. For instance, "What is your perception of current trends of youth ACL injuries? (Youth = aged 6–13 years)" and "What is your recommended strategy to identify someone at risk of ACL injury?". Audio-recordings and interview transcription was extracted from Zoom and modified by the first author to ensure accuracy of the content. Copies of interview transcripts were shared with participants who expressed interest (4/7 experts) for their approval prior to data analysis.

Interview transcripts were organised with NVivo Software (QSR International Pty Ltd., Victoria, Australia). Extracted information on the expert's background included sex, country of residence, occupational training, current occupation and their typical participant, athlete, or patient group. A hybrid (deductive and inductive) thematic analysis approach was used for data analysis (Braun & Clarke, 2006). To maintain a focus on the purpose of the research (i.e., to explore professional knowledge of ACL injury characteristics and scenarios, screening and risk reduction strategies) an analysis framework was based on the interview questions. The pre-existing sections of the framework were: ACL injury characteristics, ACL injury risk factors and their assessment, and risk reduction strategies. Additionally, each section includes the expert's recommendations for future research direction. Following the guidelines by Braun and Clark (Braun & Clarke, 2006), a six step inductive approach was used to determine codes relevant to the framework. The first author selected appropriate quotes from the raw data that conveyed the essence of each theme. The research team discussed the suitability of codes and themes according to the verbatim quotations from the interview transcripts and the alignment with the research aim. Continued revisions and refinement of the themes were performed.

3. Results and discussion

The current study presents unique insights into the knowledge on ACL injury in children, by hearing the voices of experts in the field. Seven academic experts (six male) were interviewed from five countries (United Kingdom, United States, Norway, Japan, Australia) with occupational training in athletic training, physiotherapy, or medicine. The experts research interest ranged from ACL injury management to underlying factors of ACL injury occurrence and prevention or rehabilitation strategies. The patient or participant groups that the experts worked with were elite and/or recreational athletes from childhood onwards. All experts had published numerous peer-reviewed articles, had been involved in research for more than 10 years and are or have been involved with teaching (lecturer, associate-/professor) at universities around the globe. As such the experts have portrayed the current ACL research knowledge from a variety of fields and perspectives. The following sections are structured according to the analysis framework (Fig. 1). Verbatim quotes for each theme can be found in Appendix B.

3.1. ACL injury characteristics

The experts expressed that '*The numbers continue to go up in developed countries – each year*'. The experts referred to different age ranges where dramatic increases in ACL injury occur, e.g., *'from 11 to 17 years of age'* (EX2) or *'under 20s and probably more around that sort of 13- to 16-year-old age group'* (EX6) and another expert implied that the actual numbers are still relatively small in children. However, a recent epidemiological study reported the largest annual growth rates for ACL injuries were in children aged 5–14 years compared to adolescents and young adults (Maniar et al., 2022). In line with that study, one surgeon stated: *'20 years ago, I wasn't doing this many paediatric ACL reconstructions in really young kids, but it just seems over the years I've been … I see more … I think my youngest ACL is five.'* (EX5).

Concerning the injury mechanism, the expert's mentioned that *'the ACL injury mechanism is currently unknown in childhood'*. Paediatric ACL injuries were reported to occur in sport settings with a non-contact mechanism (Dhillon et al., 2022; Shaw & Finch, 2017). However, detailed examinations on movement, body position, weight bearing status of the injured leg at time of injury are missing for children. This knowledge is vital for targeted risk assessment and reduction strategies. One surgeon suggested that *'Landing is not the main injury mechanism - it's a cutting maneuver' (EX6).*

Regarding those that get injured, one surgeon stated that *'The vast majority of the injuries are coming from a group that's actually quite active' (EX3).* In line with that statement, previous literature suggested that ACL injury occurrence in childhood is increasing due to increasing participation in youth sports (Maniar et al., 2022). Here, contact sports such as team ball sports and high impact landings like in gymnastics are considered to be high risk sports (Montalvo et al., 2019). The experts suggested further that a previous ACL injury or a family history of ACL injury are linked to increased risk of injury. Further, one expert mentioned that the onset of maturation will increase the risk of injury, especially in females compared to males.

Lastly, the experts indicated that '*Reasons for increased ACL occurrence in children are multifactorial*'. One expert implied that changes in PA modalities to more protective and risk adverse PA, and general lifestyle changes to less active and more sedentary lifestyles increase the injury risk. These changes have led to PA becoming a single, formalised or set part of the day (e.g., sports training) instead of a habitual or incidental part of our daily lives. This abrupt transition from sedentary activities to formalised and intense PA, has the potential to overstrain children's body's and consequently, lead to ACL injury. In line with that comment, Bloemers and colleagues found that low habitual PA had a strong association with overall sporting injuries in children aged 9–12 years (Bloemers et al., 2012). One explanation for their findings

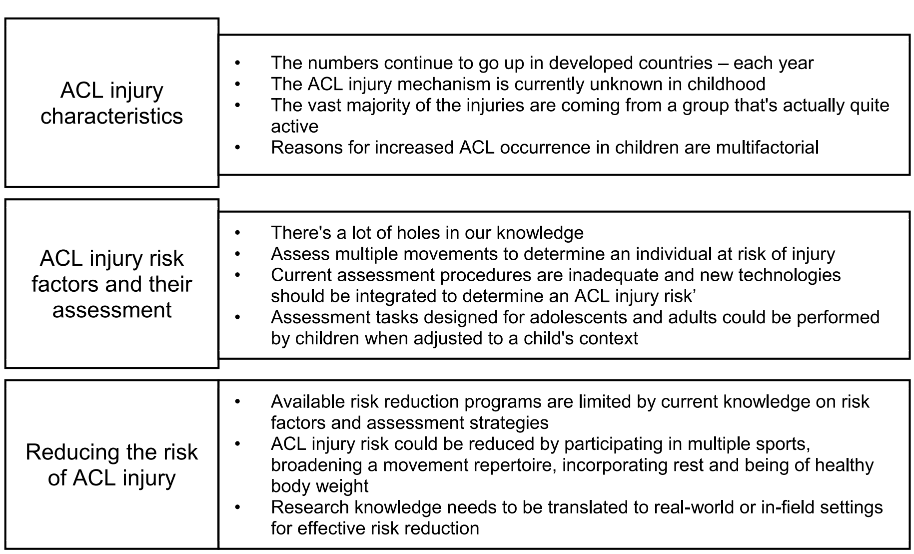

Fig. 1. Analysis framework and the according themes.

could be the limited development of movement proficiency in skills considered as foundational for PA (Hulteen et al., 2018). Two experts mentioned that a reduced movement repertoire limits an athlete's movement response in scenarios with increased ACL loading. Thus, children with limited proficiency in a repertoire of movements seem to be not adequately prepared for the demands of youth sport participation. However, this association has not been investigated in an ACL injury context yet. Accordingly, **the first recommendation from this paper** is to examine the actual ACL injury mechanism of children and investigate influences of changing PA modalities such as more abrupt transition from sedentary to demanding sport activities on ACL injury risk (Table 1).

3.2. ACL injury risk factors and their assessment

The experts indicated multiple risk factors divided into extrinsic or intrinsic risk factors (Table 2) but expressed that *'There's a lot of holes in our knowledge'*. One expert critiqued the lack of consistency when examining risk factors and stated: "*Some [risk factors] have been studied by age, some have been studied by maturity, some have only been studied up to age 12 or 13 and then nothing, some have only been studied in older age groups and then nothing before." (EX2)*. Further, three experts questioned the research focus on prominent, discrete risk factors such as knee kinematics and kinetics. A recent meta-analysis concluded that this focus might not be justified and no association between knee abduction kinematics and kinetics and sustaining a future ACL injury was found in adolescents and adults (Cronström et al., 2020). In agreement, the experts in the present study suggested to examined risk factors more holistically, in combination and not as discrete risk factors. To apply a holistic view, one expert mentioned that risk factors that have been neglected previously, and that are consequently not well understood, need revisiting. For example, family history of ACL injury increases the risk of ACL injury in an active athlete by 2.5 times (Hasani et al., 2022). Whether genetic or environmental factors are responsible is not fully understood. Based on a recent population based cohort study, Ahn and colleagues suggest that genetic and environmental factors potentiate each other (Ahn et al., 2021). The authors indicate that an injury history paired with behavioural risk factors like increased BMI or PA participation increase the risk of ACL injury further than family history or behavioural risk factors alone (Ahn et al., 2021). This relationship should be examined further, as family history could be an "easy to measure" variable. Additionally, the development of risk factors needs further investigation. One expert (EX2) stated that we need better knowledge about which and how risk factors developed before the injury. Some key risk factors have been investigated, but more longitudinal approaches are warranted (Holden et al., 2016). Additionally, one expert noted that according to the limited understanding of risk factors, only a relative risk of ACL injury can be described, but ACL injuries cannot be predicted. Hence, the **second recommendation** is to (re-) examine risk factors. Deeper understanding is needed on the influence of family injury history, genetic factors, and risk factor development before, during and after maturation.

Available risk assessment tools are limited by the sparsity in current knowledge on the injury mechanism, the focus on distinct risk factors, and use of laboratory settings. The use of available assessment tools is discussed in the literature with conflicting findings (McCunn et al., 2016). The experts recommended *'Assess multiple movements to determine an individual at risk of injury'* for assessing injury risk. One expert suggested to *"examine multiple tasks transferring from constraint-based tasks (e.g., squat) to less constraint-based tasks" (EX1)* and include change in direction and single-leg movements. Assessment tasks reported by experts varied from balance, change in direction, jump-landing tasks to muscle strength measures. Additionally, one expert shared that a whole-body performance (not focusing on lower body movement only) should be compared to an "optimal movement strategy" *(EX1)*. In an effort to provide comparable norm data, Hannon et al. collected normative hip and knee strength data for adolescent females in two age groups (e.g. 10–14, and 15–18 years) (DeLang et al., 2021). However, norm data for multiple assessment tasks and populations is warranted. Additionally, the task environment, an athlete's background and cognitive focus should be considered.

Further, the experts critiqued that the *'current assessment procedures are inadequate and new technologies should be integrated to determine an ACL injury risk'*. Currently ACL injury risk is commonly assessed in laboratory settings with technologies such as 3D or 2D motion capture. Even though 3D motion capture is considered the gold standard of motion analysis, one expert (EX2) criticised that laboratory measures do not reflect the actual injury environment and are not very accurate in examining joint angles. Another expert mentioned that laboratory settings are restricting the assessment.

> *"I use an example; [...] they said, all the literature does 45-degree cuts. And we said: 'Yeah, that's because every laboratory is constrained by its size. I'm going to show you now the last ... 20 netball players who injured their ACLs and not a single one of them is doing a 45-degree cut." (EX1)*

To overcome those restrictions, another expert (EX5) highlighted the potential of wearable devices, e.g., in t-shirts, to track the frequency of sprints and change directions. Additionally, one expert (EX4) noted that mobile phone apps have good accuracy to examine jump landing mechanics and kinetics outside a laboratory setting. One surgeon (EX3) mentioned that they use artificial intelligence to determine the risk of reinjury after an ACL reconstruction.

Lastly, the experts indicated that *'Assessment tasks designed for adolescents and adults could be performed by children when adjusted to a child's context'. The tasks need to be restructured to be child appropriate, e.g., more fun and aligned with children's play and games.*

Table 1
Recommendations for future research in childhood ACL injury research; Abbreviation: *ACL* Anterior Cruciate Ligament.

Recommendation	Example
1 Examine the actual ACL injury mechanism in children and potential reasons	Examine movement, body position, weight bearing status of the injured leg at time of injury and reasons for childhood ACL injury including the role of cultural and society changes, and movement experiences
2 (Re-) examine risk factors	Understand factors like family history, and risk factor development better e.g., use longitudinal research approaches. Additionally, explore new options e.g., motor skill proficiency
3 Update risk assessment strategies	Use test batteries moving from constraint to less constraint tasks, examine whole-body movement and compare to an optimal movement strategy, provide norm data for various tasks and populations
4 Update risk reduction strategies	Update risk reduction interventions, and promote multiple sport participation, building a movement repertoire, prioritising rest and taking time off, educate coaches, athletes and parents about ACL injury risk, assessment and reduction strategies, and examine practitioners needs for effective risk reduction strategies

Table 2
Verbatim quotes by the experts on ACL injury risk factors divided into internal and external risk factors; Abbreviation: *ACL* Anterior Cruciate Ligament, *BMI* Body Mass Index, *EX* Expert.

Risk factor	Example quote
External risk factors	
Shoes and surfaces	“The equipment and the surfaces – so, shoe equipment.” (EX6)
Growing up in an active family	“We know that families with ACL tears then have children with ACL tears that may be as much environmental. Moms who play soccer … their kids [are] more likely to play soccer probably. And so, it's not so much genetic as it is environmental but there may also be fairly significant genetic things.” (EX5) “What it is about family history - we don't quite know.” (EX6)
Greater sport exposure	“The number one factor is exposure. The more you play sports, the more likely you are to injure your ACL. The same way that the more you drive, the more likely you are to get into a car accident, right?” (EX7)
Participating in high-risk sports	“If you play pivoting sports there is a bigger chance. Especially when you land after jumps, or when you do right left fakes. So, that's the extrinsic main factor.” (EX1) “The sporting culture as well as the type of sports that they play.” (EX7)
Internal risk factors	
Anatomical risk factors	“There is a limit to how much anatomy, in my opinion anyway, how much anatomy adds to this issue. Because I've done a lot of studies on bone anatomy, also on ligaments in this case, and cartilage and you cannot find a specific pattern.” (EX3) “[if] tibial length was really long than that's another risk. Again, that's easy we can just measure it.” (EX4)
Physical characteristics	“Some of these physical characteristics like differences in body composition, laxity, and sex differences in ACL size, which is what I studied, you know. So, there's different things about the structural quality of the ACL; the size, laxity and its function. […] There's pretty strong evidence that BMI, and laxity … that together, they are stronger predictor of those who go on to get injured.” (EX2)
(Bio-)mechanical risk factors	“I do think that specially girls who are landing with excessive knee valgus, they're more likely to suffer an ACL injury. Those who cannot control the trunk very well. So, they're leaning over the landing leg. Again, biomechanically that makes sense that they create larger torques.” (EX7)
Genetic risk factors	“Of course, there is also genetic risk factor in the sense that the ACL injuries seems to be running into families.” (EX3) “If we start getting saliva or soft tissue samples of everyone with ACL tear, we might start recognizing certain types of genetic features that …, or genetic patterns that are associated with ACL tears. So, I suspect there's, there's a lot of environmental and potentially genetic factors that may contribute [to ACL injuries].” (EX5)
Sex differences	“There's genetics and there's hormones and there's body composition that precipitate those sex differences. Things that are part of that sex differentiation with growth and development that contributes to that.” (EX2) “One [risk factor] possibly is menarche and how that can start at early stages.” (EX7)
Neuromuscular risk factors	“Nobody has really been able to tie muscle strength to ACL injury but you can't tell me that muscle strength, and the ability, you know, the ability of the dynamic muscle system to stabilize the knee is not important. […] So, it's not so much BMI, it has to do with the lean mass that's available to control that body weight.” (EX2) “When you look at hamstrings … females tend to have more fatty infiltration in their hamstrings. And so, that would mean the same volume of hamstring that you really have less muscular content in there. And so, is that partly why the hamstrings are falling behind during adolescence?” (EX2)
Neuromuscular maturation	“I think the taller kids, obviously taller … I suspect that relates to neuromuscular maturation, catching up with skeletal growth. So, if you're taller maybe you need longer … for your neuromuscular system to mature, to cope with that increased height and the longer levers and therefore potentially greater torque across the joints.” (EX6) “I don't know, slower reaction time … from brain to the central nervous system to the knee. Some people are just: ‘That's enough to tear ACL.’” (EX4)
Being fatigued	“I think fatigue probably contributes to ACL tear as well, but I think we need more data on that” (EX5)

Additionally, two experts highlighted the importance of age-appropriate task instructions. The task instruction should reflect children's context and should be minimal as too many instructions might hinder the natural movement patterns of children. Hence, **the third recommendation** is to examine batteries of tasks instead of continuing to focus on single tasks to determine ACL injury risk and design ACL risk assessment tools for children according to actual injury mechanism. A battery of tasks should start with assessing constraint task, e.g., body weight squat, and move to more complex and demanding tasks (e.g., unanticipated side-cutting).

3.3. Reducing the risk of injury

‘Available risk reduction programs are limited by current knowledge on risk factors and assessment strategies’ and are consequently, unspecific and generic (Dischiavi et al., 2022). One expert named it ‘*kind of a shotgun approach, because that's the best we know right now [but with better knowledge on risk factors] we can be much more targeted in our prevention strategies.’ (EX2).*

The experts shared that multiple programs have been designed and currently focus on improving motor performance such as neuromuscular or landing performance. A *“two birds with one stone” (EX7)* approach – reducing the risk of injury and improving performance. One example in child athletes is the FIFA 11+ Kids protocol (Rossler et al., 2015). The program was tested with children aged 7–13 years and seemed successful in reducing the risk of overall football injuries by 48–57% (Al Attar et al., 2022; Rössler et al., 2018) and more specific to an ACL injury mechanism, reduced the risk of non-contact injuries by 53% (Beaudouin et al., 2019). This example is football specific and similar approaches are warranted for younger populations, as young as 5 years old, and other sport environments. Despite the effectiveness of risk reduction programs in youth athletes (Petushek et al., 2019; Rossler et al., 2014), the experts conclude that current programs need updating to be more targeted to athletes at risk of injury.

In addition to performing risk reduction programs, *‘ACL injury risk can be reduced by participating in multiple sports, improving movement repertoire, incorporating rest and being of healthy body weight’*. In line with current research (Carder et al., 2020; Normand et al., 2017), two experts (EX1/5) suggested that participation in multiple sports and exposure to various physical activities reduces the risk of ACL injuries by generating a larger movement repertoire. Proficiency in a larger movement repertoire is associated with developing and maintaining a health-enhancing PA habits across the life span (Hulteen et al., 2018) and potentially, with lower risk of ACL injuries. Two experts (EX1/4) stated that an athlete without foundational skills like maintaining single-leg balance or performing a body weight squat, is at risk of injury. An athlete that specialises early in a single-sport is at increased risk of injury (Carder et al., 2020) and “[has] one solution to a movement problem, and [no] repertoire of solutions.” (EX1) limiting the movement response in scenarios with increased ACL loading. Accordingly, another expert suggested that: *"Programmes [that] introduce fitness to kids at a young age including some variety of activities might [be used] to … prepare their joints and muscles and everything else for more rigorous activities, and maybe lower the risk of injuries." (EX5)*. Another important strategy to reduce the risk injury mentioned by an expert (EX5) is taking time off and prioritising rest to allow for adequate recovery. Additionally, one expert (EX6) suggested that an increased body weight (e.g., overweight and obesity) increases the forces on the joints and ligaments and consequently, increased ACL injury risk. Accordingly, reducing the body weight to a "normal" weight status can be crucial for some individuals.

Lastly, for effective risk reduction practice, *'Research knowledge needs to be translated to real-world or in-field settings'* to individuals working with the athletes. The experts recommended educating clubs, coaches, athletes and parents about their options to examine and reduce the risk of ACL injuries. This strategy was considered crucial in reducing the risk of injuries. Risk reduction strategies should also include promoting multiple sport participation (EX1/5), building a movement repertoire at young age (EX1/4), taking time off single sport training (EX5), changing to a lower risk sport if needed (EX5) and weight reduction for some athletes who may be at risk of injury due to higher BMI (EX6). Accordingly, the **fourth recommendation** is updating risk reduction strategies to be more targeted and less generic. Questions around who to target and at what time (e.g., only pre-season, pre-pubertal) need to be answered. One expert (EX5) suggested that effectiveness of new programs could be tested with athletes that are knowingly at high-risk of ACL injury, e.g., athletes with a previous ACL injury. Additionally, understanding *"What are the drivers towards people doing this very structured, very specialized, very mono sports approach?" (EX1)* and moving away from early-specialisation towards a more unstructured and multisport approach with reducing the intensity of training could reduce the risk of injury. One expert summarised it as *"[making] sport more fun and less … life and death at a young age" (EX6)* and emphasising skill development instead of winning competitions.

Finally, one expert shared another thought: '*Academia drives more academic process' (EX1)*. Despite limited success to ACL injury risk reduction, the same tasks and tools are used for research instead of exploring novel paths. This process is reinforced by some "prominent" researcher voices in the field, and by difficulties to publish work that dispute findings from those prominent researchers, which further restricts the field of ACL injury risk reduction.

> *"We do a systematic review, which fundamentally says this: 'So, your bilateral drop jump.' […], and then we go: 'Okay, well, that's the strongest thing in the literature, we must do that.' Instead of going 'But twenty people have already done bilateral drop jump and got nowhere, perhaps we should rethink the paradigm.'." (EX1)*

3.4. Strengths and limitations

The insight provided by world leading experts in the field should be considered the main strength of the current study. The experts came from a variety of backgrounds providing perspectives from medical, athletic training and physiotherapeutic backgrounds allowing for a range of views. Seven interviews might be considered by some as a study limitation. However, for in-depth interviews with world leading experts this represents a considerable intellectual resource, and a level of experience and evidence on the topic in question which is not commonplace. For research such as that presented here, a sample size of five participants has been cited as the minimum where perspectives from experts are concerned (Morse, 2000). The comprehensive methodology ensured that top ranked experts were invited and participated (determined by the methodology of expertscape.com). However, the homepage ranks experts based on publication output and that process is not without limitation (e.g., publication bias with more publications from minority world countries (Draper et al., 2022)) itself. An additional expert search through non-English language platforms (similar to expertscape - if these platforms exist) could have theoretically unearthed experts from a bigger range of countries which would have contributed to a fuller picture of the ACL environment for youth. Further, only one female perspective was included in the interviews, although this is in line with the low female research representation in sport science research in general (Martínez-Rosales et al., 2021). Additional interviews may have added further to the results presented here but the level of expertise required to give informed views on the topic of ACL risk in children is not commonplace and as such the pool of potential experts in this field is relatively small. A further limitation is that a practitioner's view, for instance from coaches, is missing in the current study, even though the experts hold experience with working with athletes as practitioners.

4. Conclusion

The present study, hearing from experts in the field of ACL injury research, presents a unique perspective on ACL injury risk in paediatric populations which, to date, has not been forthcoming in the literature. The present study extends what had been presented in current ACL injury research and position statements on ACL injuries in childhood (Ardern et al., 2018) by revealing the limited understanding of the actual injury mechanism, the influence of changing PA modalities such as more abrupt transition from sedentary to demanding sport activities, the handling of risk factors, and limitations of current risk assessment and reduction strategies in childhood. Previous research focuses on prominent risk factors and ignores underpinning movement experiences. Such an approach does not consider interactions between the individual, the environment and the tasks they are undertaking, nor do they adequately consider the movement background/history of the child. Accordingly, future research should aim to i) examine the actual ACL injury mechanism in children and potential reasons, ii) to (re-) examine risk factors, iii) to update risk assessments with examining a range of skills, the whole-body performance of an individual and compare that to an "optimal performance" and iv) update risk reduction strategies specifically to children's needs. A better understanding of actual injury mechanism and risk factors will help to improve risk reduction strategies. In summary, there is critical need to understand the actual injury mechanism and associated risk factor to inform more targeted and specific risk reduction strategies that address the increasing risk of ACL injury in children effectively.

Contributors

All authors contributed to the study conceptualisation, critical revisions of the manuscript and approved the final version of the manuscript. The first author performed the data collection, thematic analysis and drafted the first manuscript. The second and third author were involved in thematic analysis and redefining themes.

Funding

The first author is supported by a Cotutelle Doctoral scholarship from Coventry University and Deakin University.

Ethical statement

The research was carried out in accordance to the Declaration of Helsinki and ethics approval was obtained from the relevant Human Research Ethics Committees (HEAG-H 138_2021; P125854).

Participants received a participant information sheet and consent form digitally on study invitation and completed and returned the consent form to confirm participation. Signed consent forms are stored by the first author.

Ethical approval

Ethical approval was granted from the relevant ethics committees related to the institutions where this research has been performed. All participants signed the according consent form voluntarily prior to participation.

Declaration of competing interest

None declared.

Acknowledgement

We acknowledge and thank all the expert interviewees who gave their time to participate in this study.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ptsp.2023.02.007.

References

Ahn, H. S., Lee, D.-H., Kazmi, S. Z., et al. (2021). Familial risk and its interaction with body Mass Index and physical activity in anterior cruciate ligament injury among first-degree relatives: A population-based cohort study. *The American Journal of Sports Medicine, 49*(12), 3312–3321. https://doi.org/10.1177/03635465211032643

Al Attar, W. S. A., Bizzini, M., Alzahrani, H., et al. (2022). The FIFA 11+ kids injury prevention program reduces injury rates among male children soccer players: A clustered randomized controlled trial. *Sports Health Multidiscip Approach.* , Article 194173812211092. https://doi.org/10.1177/19417381221109224

Ardern, C. L., Ekås, G. R., Grindem, H., et al. (2018). International Olympic Committee consensus statement on prevention, diagnosis and management of paediatric anterior cruciate ligament (ACL) injuries. *British Journal of Sports Medicine, 52*(7), 422–438. https://doi.org/10.1136/bjsports-2018-099060, 2018.

Arundale, A. J. H., Silvers-Granelli, H. J., & Myklebust, G. (2022). ACL injury prevention: Where have we come from and where are we going? *Journal of Orthopaedic Research, 40*(1), 43–54. https://doi.org/10.1002/jor.25058

Baker, J., Lovell, K., & Harris, N. (2006). How expert are the experts? An exploration of the concept of "expert" within Delphi panel techniques ;Lovell, Karina;Harris, Neil. *Nurse Researcher, 14*(1), 59–70. https://doi.org/10.7748/nr2006.10.14.1.59.c6010

Barber Foss, K. D., Thomas, S., Khoury, J. C., et al. (2018). A school-based neuromuscular training program and sport-related injury incidence: A prospective randomized controlled clinical trial. *Journal of Athletic Training, 53*(1), 20–28. https://doi.org/10.4085/1062-6050-173-16

Beaudouin, F., Rössler, R., aus der Fünten, K., et al. (2019). Effects of the '11+ kids' injury prevention programme on severe injuries in children's football: A secondary analysis of data from a multicentre cluster-randomised controlled trial. *British Journal of Sports Medicine, 53*(22), 1418–1423. https://doi.org/10.1136/bjsports-2018-099062

Bergeron, M. F., Mountjoy, M., Armstrong, N., et al. (2015). International Olympic Committee consensus statement on youth athletic development. *British Journal of Sports Medicine, 49*(13), 843–851. https://doi.org/10.1136/bjsports-2015-094962

Bloemers, F., Collard, D., Paw, M. C. A., et al. (2012). Physical inactivity is a risk factor for physical activity-related injuries in children. *British Journal of Sports Medicine, 46*(9), 669–674. https://doi.org/10.1136/bjsports-2011-090546

Bolger, L. E., Bolger, L. A., O'Neill, C., et al. (2021). Global levels of fundamental motor skills in children: A systematic review. *Journal Sports Science, 39*(7), 717–753. https://doi.org/10.1080/02640414.2020.1841405

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Bruce, J., Langley, G., & Tjale, A. (2008). The use of experts and their judgments in nursing research: An overview. *Curationis, 31*(4), 57–61.

Carder, S. L., Giusti, N. E., Vopat, L. M., et al. (2020). The concept of sport sampling versus sport specialization: Preventing youth athlete injury: A systematic review and meta-analysis. *The American Journal of Sports Medicine, 48*(11), 2850–2857. https://doi.org/10.1177/0363546519899380

Cook, G., Burton, L., & Hoogenboom, B. (2006). Pre-participation screening: The use of fundamental movements as an assessment of function - part 1. *North American Journal of Sports Physical Therapeut, 1*(2), 62–72.

Cronström, A., Creaby, M. W., & Ageberg, E. (2020). Do knee abduction kinematics and kinetics predict future anterior cruciate ligament injury risk? A systematic review and meta-analysis of prospective studies. *BMC Musculoskeletal Disorders, 21*(1), 563. https://doi.org/10.1186/s12891-020-03552-3

Dekker, T. J., Rush, J. K., & Schmitz, M. R. (2018). What's new in pediatric and adolescent anterior cruciate ligament injuries? *Journal of Pediatric Orthopaedics, 38*(3), 185–192. https://doi.org/10.1097/BPO.0000000000000792

DeLang, M. D., Hannon, J. P., Goto, S., et al. (2021). Female adolescent soccer players utilize different neuromuscular strategies between limbs during the propulsion phase of a lateral vertical jump. *International Journal of Sports Physical Therapeut, 16*(3), 695–703. https://doi.org/10.26603/001c.22134

Dhillon, M. S., Rangasamy, K., Rajnish, R. K., et al. (2022). Paediatric anterior cruciate ligament (ACL) injuries: Current concepts review. *Indian Journal of Orthopaedics, 56*(6), 952–962. https://doi.org/10.1007/s43465-022-00611-w

Dischiavi, S. L., Wright, A. A., Heller, R. A., et al. (2022). Do ACL injury risk reduction exercises reflect common injury mechanisms? A scoping review of injury prevention programs. *Sports Health Multidiscip Approach, 14*(4), 592–600. https://doi.org/10.1177/19417381211037966

Draper, C. E., Barnett, L. M., Cook, C. J., et al. (2022). Publishing child development research from around the world: An unfair playing field resulting in most of the world's child population under-represented in research. *Infant and Child Development*, e2375. https://doi.org/10.1002/icd.2375

Guthold, R., Stevens, G. A., Riley, L. M., et al. (2020). Global trends in insufficient physical activity among adolescents: A pooled analysis of 298 population-based surveys with 1·6 million participants. *Lancet Child Adolesc Health, 4*(1), 23–35. https://doi.org/10.1016/S2352-4642(19)30323-2

Hasani, S., Feller, J. A., & Webster, K. E. (2022). Familial predisposition to anterior cruciate ligament injury: A systematic review with meta-analysis. *Sports Medicine*. https://doi.org/10.1007/s40279-022-01711-1

Holden, S., Boreham, C., & Delahunt, E. (2016). Sex differences in landing biomechanics and postural stability during adolescence: A systematic review with meta-analyses. *Sports Medicine, 46*(2), 241–253. https://doi.org/10.1007/s40279-015-0416-6

Huang, Y.-L., Jung, J., Mulligan, C. M. S., et al. (2020). A majority of anterior cruciate ligament injuries can Be prevented by injury prevention programs: A systematic review of randomized controlled trials and cluster–randomized controlled trials with meta-analysis. *The American Journal of Sports Medicine, 48*(6), 1505–1515. https://doi.org/10.1177/0363546519870175

Hulteen, R. M., Morgan, P. J., Barnett, L. M., et al. (2018). Development of foundational movement skills: A conceptual model for physical activity across the lifespan. *Sports Medicine, 48*(7), 1533–1540. https://doi.org/10.1007/s40279-018-0892-6

Kallio, H., Pietilä, A.-M., Johnson, M., et al. (2016). Systematic methodological review: Developing a framework for a qualitative semi-structured interview guide. *Journal of Advanced Nursing, 72*(12), 2954–2965. https://doi.org/10.1111/jan.13031

Lopes, T. J. A., Simic, M., Myer, G. D., et al. (2018). The effects of injury prevention programs on the biomechanics of landing tasks: A systematic review with meta-analysis. *The American Journal of Sports Medicine, 46*(6), 1492–1499. https://doi.org/10.1177/0363546517716930

Maniar, N., Verhagen, E., Bryant, A. B., et al. (2022). Trends in Australian knee injury rates: An epidemiological analysis of 228,344 knee injuries over 20 years. *Lancet Reg Health - West Pac, 21*, 1–11. https://doi.org/10.1016/j.lanwpc.2022.100409

Martínez-Rosales, E., Hernández-Martínez, A., Sola-Rodríguez, S., et al. (2021). Representation of women in sport sciences research, publications, and editorial leadership positions: Are we moving forward? *Journal of Science and Medicine in Sport, 24*, 1093–1097. https://doi.org/10.1016/j.jsams.2021.04.010

McCunn, R., aus der Fünten, K., Fullagar, H. H. K., et al. (2016). Reliability and association with injury of movement screens: A critical review. *Sports Medicine, 46*(6), 763–781. https://doi.org/10.1007/s40279-015-0453-1

Montalvo, A. M., Schneider, D. K., Webster, K. E., et al. (2019). Anterior cruciate ligament injury risk in sport: A systematic review and meta-analysis of injury incidence by sex and sport classification. *Journal of Athletic Training, 54*(5), 472–482. https://doi.org/10.4085/1062-6050-407-16

Morse, J. M. (2000). Determining sample size. *Qualitative Health Research,* (10), 3–5.

Myer, G. D., Sugimoto, D., Thomas, S., et al. (2013). The influence of age on the effectiveness of neuromuscular training to reduce anterior cruciate ligament injury in female athletes: A meta-analysis. *The American Journal of Sports Medicine, 41*(1), 203–215. https://doi.org/10.1177/0363546512460637

Normand, J. M., Wolfe, A., & Peak, K. (2017). A review of early sport specialization in relation to the development of a young athlete. *International Journal of Kinesiology & Sports Science, 5*(2). https://doi.org/10.7575/aiac.ijkss.v.5n.2p.37

Patel, N. M., Bram, J. T., Talathi, N. S., et al. (2020). Which children are at risk for contralateral anterior cruciate ligament injury after ipsilateral reconstruction? *Journal of Pediatric Orthopaedics, 40*(4), 162–167. https://doi.org/10.1097/

BPO.0000000000001364
Petushek, E. J., Sugimoto, D., Stoolmiller, M., et al. (2019). Evidence-based best-practice guidelines for preventing anterior cruciate ligament injuries in young female athletes: A systematic review and meta-analysis. *The American Journal of Sports Medicine, 47*(7), 1744–1753. https://doi.org/10.1177/0363546518782460
Rossler, R., Donath, L., Bizzini, M., et al. (2015). A new injury prevention programme for children's football - FIFA 11+ kids - can improve motor performance: A cluster-randomised controlled trial. *FIFA*.
Rössler, R., Donath, L., Bizzini, M., et al. (2016b). A new injury prevention programme for children's football – FIFA 11+ kids – can improve motor performance: A cluster-randomised controlled trial. *Journal Sports Science, 34*(6), 549–556. https://doi.org/10.1080/02640414.2015.1099715
Rossler, R., Donath, L., Verhagen, E., et al. (2014). Exercise-based injury prevention in child and adolescent sport: A systematic review and meta-analysis. *Sports Medicine, 44*(12), 1733–1748. https://doi.org/10.1007/s40279-014-0234-2
Rössler, R., Junge, A., Bizzini, M., et al. (2018). A multinational cluster randomised controlled trial to assess the efficacy of '11+ kids': A warm-up programme to prevent injuries in children's football. *Sports Medicine, 48*(6), 1493–1504. https://doi.org/10.1007/s40279-017-0834-8
Rössler, R., Junge, A., Chomiak, J., et al. (2016a). Soccer injuries in players aged 7 to 12 Years: A descriptive epidemiological study over 2 seasons. *The American Journal of Sports Medicine, 44*(2), 309–317. https://doi.org/10.1177/0363546515614816
Shaw, L., & Finch, C. (2017). Trends in pediatric and adolescent anterior cruciate ligament injuries in Victoria, Australia 2005–2015. *International Journal of Environmental Research and Public Health, 14*(6), 599. https://doi.org/10.3390/ijerph14060599
Stodden, D., Goodway, J., Langendorfer, M., et al. (2008). A developmental perspective on the role of motor skill competence in physical activity: An emergent relationship. *Quest, 60*, 290–306. https://doi.org/10.1080/00336297.2008.10483582
World Health Organization. (2019). *Global action plan on physical activity 2018-2030: More active people for a healthier world*. World Health Organization.
Zbrojkiewicz, D., Vertullo, C., & Grayson, J. E. (2018). Increasing rates of anterior cruciate ligament reconstruction in young Australians, 2000–2015. *Medical Journal of Australia, 208*(8), 354–358. https://doi.org/10.5694/mja17.00974