Impact of youth sports specialisation on career and task-specific athletic performance: a systematic review following the American Medical Society for Sports Medicine (AMSSM) Collaborative Research Network's 2019 Youth Early Sport Specialisation Summit

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ABSTRACT

Objective The impact, positive or negative, of youth sport specialisation (YSS) on short-term and long-term performance is not fully understood; however, the desire to maximise performance goals is generally considered the primary reason children and adolescents specialise at a young age. We performed a systematic review of original research to establish the association of YSS and task-focused or career-focused performance outcomes.

Design Systematic review.

Data sources Databases searched include PubMed, EMBASE, Cochrane, CINAHL and SPORTDiscus.

Eligibility criteria We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to identify peer-reviewed research articles published in English between 1 January 1990 and 31 December 2018 that reported original findings on the association of YSS and performance outcomes. Studies without an explicit measure of sport specialisation, for example, volume measures without measuring sport specialisation, were excluded.

Results Twenty-two articles were included in the final review; 15 addressed career performance outcomes and 7 considered task performance outcomes. All identified studies were cross-sectional or retrospective in design. The proportion of elite athletes who specialised early ranged between 7% and 85%, depending on sport and definition of specialisation. Elite athletes often specialised between the ages of 14 and 15 compared with their non-elite or semi-elite peers who typically specialised prior to 13 years. In addition, neuromuscular control, anterior reach asymmetry and physical task outcomes did not differ by specialisation status.

Conclusion The volume and methodological rigour of published research in this field are limited. Our review suggests that YSS is not required to achieve success at elite levels. YSS also does not appear to improve task-related performance (eg, anterior reach, neuromuscular control) outcomes for specialised athletes when compared with non-specialised athletes during childhood and adolescence.

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> "Tiger [Woods] has come to symbolize the idea that the quantity of deliberate practice determines success—and its corollary, that the practice must start as early as possible […] we also need more Rogers [Federer]: people who start broad and embrace diverse experiences and perspectives while they progress." (David Epstein, from his book Range)

INTRODUCTION

The well-known biographies of elite athletes who started playing a sport at a young age are associated with a period in our history where many youth athletes choose to focus on a single sport at a young age. Many are familiar with the impressive success stories of professional athletes such as Venus and Serena Williams, Tiger Woods and Wayne Gretzky who were introduced to their respective sport as very young kids. These athletes showed early promise and dedicated their childhood to developing and competing solely in that sport. Yet, the paths to elite success look drastically different for many other highly successful professional athletes such as LeBron James (basketball and football) and Abby Wambach (soccer and basketball) who did not specialise in one sport at a young age but rather competed in multiple sports through high school.

Specialisation is 'intense training in a single sport at the exclusion of others' and is commonly viewed as a mechanism for maximising athletic performance potential. Athletes, parents and coaches generally believe specialisation is important, and perhaps necessary, for increasing skill in a specific sport often with the goal of making a high school team or for obtaining a collegiate athletic scholarship.[1–3]

The benefits of participation in youth sports are well described. In the USA, an estimated 60 million youth between the ages of 6 and 18 years participate in organised athletics and 8 million adolescents participate in high school sports.[4] Yet, only an estimated 6% of high school athletes go on to participate in National Collegiate Athletic Association (NCAA) sports and <2% of these athletes make it to the elite level beyond college (eg, participation

in professional sports). Only 2% of high school athletes receive some form of athletic scholarship to compete in college.[5] The limited number of college athletic scholarships may fuel parent and youth desires for youth to specialise at an early age.

Research on expertise and skill acquisition has had a profound impact on youth sport programmes and systems. The work of Ericsson *et al*[6] in music popularised the early specialisation movement in sport by suggesting that the volume of intense, domain-specific practice was the main determinant of skill acquisition and expertise in a domain. When applied to sport, this approach assumed that high amount of deliberate practice in one sport at a young age was necessary to attain expertise in a particular sport.[7–10] This body of research has promoted the notion that large quantities of intensive sport-specific practice may be the sole training activity that is linked to development in sport and is a prerequisite for adult elite performance. Deliberate practice represents the cornerstone of the early specialisation pathway, and the relationship between early specialisation and intense involvement in deliberate practice has been tested extensively over the last 20 years (see Ford and Williams [11] for a review).

Many groups have questioned the necessity of this pathway to elite performance. Alternatively, to maximise performance in a sport, youth athletes should not only focus on sport-specific practice but also engage in free, unstructured play activities and participate in a variety of sports.[4 12–14] In addition to being a viable pathway towards elite status, the notion of 'sport sampling' has many positive physical and psychosocial outcomes. Although evidence supporting the positive outcomes of a diversification pathway in youth sports has increased, the perceived need for early specialisation in a sport as a prerequisite for expertise has persisted. There has been some suggestion that an accumulation of hours related to sport-specific activity is important to achieve elite level success, and sport specialisation is one pathway to accumulate these hours. However, accumulation can also occur through a diversified pathway approach (eg, sport sampling) or possibly 'specialised sampling', which has been shown to lead to elite level success in youth soccer players.[15] Specialised sampling refers to participation in a broad range of sport-specific activities that foster domain-specific learning, including free play, sport-specific training and other miscellaneous activities related to the sport. Given these various approaches towards elite performance, there is a need for a comprehensive evaluation of the influence of youth sport specialisation on performance and behavioural outcomes among youth.

This review is a product of the American Medical Society for Sports Medicine Collaborative Research Network's 2019 Youth Early Sport Specialisation Summit. The goals of that conference were to (1) conduct and present a rigorous review of the current scientific knowledge and (2) develop a research agenda to drive future research efforts based on existing evidence in the field of youth athlete training and development. The purpose of this systematic review was to determine whether sport specialisation impacted, positively or negatively, career and task-specific performance outcomes in youth athletes.

METHODS

Search strategy

This systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. PubMed, EMBASE, Cochrane and EBSCO-CINAHL databases were electronically searched on 4 October 2018 and EBSCO-Sport Discus was searched on 11 October 2018. A secondary search of these databases was conducted on 20 June 2019 to identify any articles published through the end of 2018. Table 1 provides the search strategy and number of articles identified in the original and secondary searches. This strategy followed that of Fabricant *et al*,[16] but was modified to include search terms used in Bell *et al*'s[17] meta-analysis and to identify performance instead of injury outcomes. Reference lists of prior literature reviews, expert committee statements and position statements were reviewed for potential article identification. Authors were also allowed to refer studies into identification. All Medical Subject Heading (MeSH) terms were included and filters requiring articles to be published in peer-reviewed literature, English language version of the full text and articles published after 1 January 1990 were used.

Study selection and data abstraction

All search results were transferred into a central endnote library; duplicate articles were removed. Initial screening of the retrieved title and abstract using predefined inclusion and exclusion criteria was conducted by two authors (SAK and KN). Inclusion criteria were (1) original research articles, (2) youth (<18 years) study population unless the study participants were still participating in sport and sport specialisation exposure occurred before the age of 18 years and (3) a measure or indicator of the association between sports specialisation and subsequent athlete performance. Studies were excluded from consideration if they did not include an explicit measure of sport specialisation (eg, studies that reported training volume measures without assessing sport specialisation were excluded). Additionally, studies that did not link some aspect of athletic performance and/or achievement to specialisation were excluded from consideration for this review.

SAK conducted a full-text review of the remaining potentially relevant articles and abstracted data from each study meeting the inclusion and exclusion criteria. Abstracted information included general characteristics of each study, including the sample or population, sample size, demographic characteristics (age, sport, sex, gender) of participants, definition of sport specialisation, percentage of athletes who specialised and potentially confounding information as appropriate. A level of evidence was assigned to each study based on the 2011 Oxford Centre for Evidence-Based Medicine scale.

Quality scoring

Risk of bias was assessed via an adapted Downs and Black scale as used and described in the Bell *et al*'s meta-analysis.[17 18] However, one question was removed from quality scoring totals (eg, 'Was an attempt made to blind those measuring the main outcomes of the intervention?') as it was determined to not apply to this review. Thus, quality scoring was conducted based on an adapted 15-item version of the scale. Studies meeting fewer than 60% of the adapted criteria were classified as low quality, 60%–74.9% as moderate quality and >75% as high methodological quality (table 2).

Definitions of sport specialisation

Sport specialisation has been inconsistently defined in the literature. All definitions were eligible for inclusion in this review (see table 2). Most commonly, specialisation was addressed by comparing multisport athletes versus single-sport athletes. One study defined specialisation as quitting other sports to focus on one sport, while others identified specialisation as exclusive participation in a main sport. Few studies included an age restriction on exclusive participation in a main sport (eg, before 12 or 14 years of age) to be considered as specialised. Most recently,

Table 1 Search strategy

Search terms (including MeSH terms)		Number of identified studies	
Date of database search	Reference database	1 January 1990 to 4 October 2018	4 October 2018 to 31 December 2018*
1. Young OR youth OR paediatric OR immature OR high school OR child or adolescent	PubMed	3 189 034	78 830
	EMBASE	3 336 042	264 900
	Cochrane	287 477	5 647
	EBSCO-CINAHL	855 936	30 758
	EBSCO-SPORTDiscus	90 420	1 527
2. #1 AND (athlete OR sports OR athletes)	PubMed	80 238	2 588
	EMBASE	52 692	5 835
	Cochrane	6 284	322
	EBSCO-CINAHL	19 493	1 479
	EBSCO-SPORTDiscus	31 305	629
3. #2 AND (specialization OR specialisation OR free play OR single-sport OR year-round OR deliberate practice)	PubMed	469	18
	EMBASE	282	13
	Cochrane	116	35
	EBSCO-CINAHL	171	42
	EBSCO-SPORTDiscus	326	13
4. #3 AND (performance OR talent OR elite OR expert OR expertise OR skill-acquisition OR scholarship OR attrition OR persistence OR longevity)	PubMed	194	13
	EMBASE	122	10
	Cochrane	93	28
	EBSCO-CINAHL	71	25
	EBSCO-SPORTDiscus	176	11

*There may be slight overlap in counts between the initial and secondary searches due to inability to refine search engine to precise date in EMBASE, Cochrane, CINAHL and SPORTDiscus databases.

the Jayanthi 3-point and 6-point specialisation scales[19] have been used by many authors to identify sport specialisation.[20–22]

Performance outcomes

Performance outcomes were classified into two categories: career and task performance. Career outcomes included outcomes that described an athlete's career trajectory such as elite sport participation (NCAA Division 1, Professional and/or International) and longevity of their career. Also included in this category were studies which divided cohorts of athletes by career trajectory (eg, elite vs semi-elite and/or non-elite) as opposed to specialisation status and reported mean age at specialisation for these groups. Task performance outcomes included performance of specific tasks addressing functional movement (eg, as measured by the Landing Error Scoring System (LESS)), dynamic balance (eg, as measured on the Y-balance test), mental toughness, fitness and gross motor coordination.

RESULTS

Search results

The search criteria resulted in 743 articles for potential inclusion; additionally, four articles were identified by writing group members, which highlighted deliberate practice; all were published in the 1990s but did not appear in the search results. After removing duplicates, 467 abstracts were screened to assess whether they met the prespecified inclusion and exclusion criteria. This process identified 116 articles for full-text review, of which 22 were included in the final synthesis. Original research articles were primarily excluded after full-text review due to the lack of a specific definition of sport specialisation (n=28) and lack of a performance-based outcome measure (n=16) (figure 1).

Overall study characteristics

An overall summary of the sport specialisation and performance studies is provided in table 2. All identified studies were cross-sectional (level III) or retrospective epidemiological (level IV); no prospective studies were identified. Fifteen of the 22 studies addressed career performance outcomes,[22–36] whereas the remaining 7 looked at the effect of sport specialisation on specific task performances.[20 21 37–41] Studies ranged from single-sport investigations in basketball, soccer, volleyball, field hockey, golf, track and field and ice hockey to those involving numerous sports. When the percentage of specialised athletes was reported, percentages of specialised or highly specialised athletes ranged from 12% to 85% of the study population. Most studies defined specialisation as participating in a single sport, while one required the athletes to have quit other sports to focus on one sport.[25] Two studies required specialisation to have occurred by a specific age of 12 or 14 years.[23 38] Three studies used the Jayanthi 3-point scale to define sport specialisation level as low, moderate or high.[20–22]

Youth sport specialisation and career performance

Studies assessing the association between sport specialisation and career performance are summarised in table 3. Multiple studies reported the percentage of athletes at the elite level who specialised at a young age. Post *et al*[22] reported that only 17% of NCAA Division 1 athletes from a midwestern university were highly specialised in ninth grade; this proportion increased throughout

Table 2 Summary of performance studies

Study	N	LOE	Adjusted Downs and Black score (%)	Study period	Sport(s)	Age, mean (SD)	Sex, n (%)	% (highly) specialised	Performance measure	Specialisation definition
Beese *et al*[37]	40	4	80	NS	Youth soccer	15.2 (1.2)*	Female: 40 (100)	53	Task	Multi vs single competitive sport for at least 1 year
Black *et al*[23]	91	3	47	NS	Professional and collegiate ice hockey	22.8 (NS)	Male: 91 (100)	12	Career	Participation in primary sport at the exclusion of other sports at or before 12 years old
Bridge and Toms[24]	1006	3	47	NS	Youth athletics, football, hockey, netball, rugby union, swimming, etc	23 (6)	Male: (46) female: (54)	n/a	Career	Multi vs single sport
Buckley *et al*[25]	3090	3	73	2015–2016	HS and collegiate: numerous unspecified professional: hockey and MLB	HS: 15.3 (1.4) collegiate: 19.6 (1.3) professional: 23.6 (3.5)	Male: 2516 (81) female: 574 (19)	HS: 45.2 collegiate: 67.7 professional: 46.0	Career	Quit other sports to focus on one sport
Buhrow *et al*[38]	102	3	73	NS	Collegiate swimming/ diving, golf, basketball, track and field/cross-country, softball, tennis, football, wrestling and soccer	20.1 (NS)	Male: 44 (43) female 58 (57)	82	Task	Specialise before 14
Coutinho *et al*[26]	60	3	87	NS	Portuguese semi-professional volleyball	n/s	Male: 30 (50) female: 30 (50)	n/a	Career	Exclusive participation in main sport
Cupples *et al*[27]	224	3	75	NS	Australian professional rugby	25.6 (3.6)*	Male: 224 (100)	n/a	Career	Exclusive participation in main sport
DiStefano *et al*[39]	355	3	80	NS	Youth soccer and basketball	11 (2)*	Male: 122 (34); female: 233 (66)	26	Task	Multi vs single sport in past calendar year
Fransen *et al*[40]	735	3	60	NS	NS (youth)	NS (range: 6–12)	Male: 735 (100)	61	Task	Multi vs single sport
Gorman *et al*[41]	184	3	80	NS	NS (HS)	15.7 (1.2)*	Male: 136 (74); female: 48 (26)	50	Task	Multi vs single sport
Gullich *et al*[31]	1558	3	73	1999; 2002	All German Olympic sports	24.4 (4.8)	Male: (57) female: 443)	n/a	Career	Exclusive participation in main sport
Güllich and Emrich[28]	54	3	47	2002; 2012	German Olympic and national field hockey	24.2 (3.1)*	Male: 54 (100)	n/a	Career	Exclusive participation in main sport
Güllich[29]	166	3	73	NS	All German Olympic sports	24.6 (4.6)*	Male: 86 (52) female: 80 (48)	n/a	Career	Exclusive participation in main sport
Gullich[30]	264	3	80	NS	German national track and field	23.5 (4.4)*	Male: 146 (55) female: 118 (45)	n/a	Career	Exclusive participation in main sport
Haugaasen *et al*[32]	558	3	67	NS	Norwegian elite youth soccer	16.8 (1.3)*	Male: 558 (100)	n/a	Career	Exclusive participation in main sport
Hayman *et al*[33]	8	3	60	NS	Elite youth UK golf	18.8 (2.1)	Male: 8 (100)	n/a	Career	Exclusive participation in main sport
Hornig *et al*[34]	102	3	53	2011/2013	German professional soccer	27.8 (4.2)	Male: 102 (100)	n/a	Career	Multi vs single sport
Martin *et al*[35]	1036	3	73	NS	Division 1 collegiate football, track and field, soccer, cross-country, swimming/diving, baseball, wrestling, basketball, golf, tennis, rowing, gymnastics, volleyball, field hockey, hockey, softball, figure skating	NS	Male: 559 (54) female: 466 (45)	42	Career	No definition
Miller *et al*[21]	295	3	80	NS	HS basketball, soccer, volleyball, tennis	15.6 (1.2)	Male: 117 (40) female: 178 (60)	28.4 (single sport); 36.2 (Jayanthi 3-point); 54.9 (Jayanthi 6-point)	Task	Multi vs single sport Jayanthi 3-point scale, Jayanthi 6-point scale

Continued

Table 2 Continued

Study	N	LOE	Adjusted Downs and Black score (%)	Study period	Sport(s)	Age, mean (SD)	Sex, n (%)	% (highly) specialised	Performance measure	Specialisation definition
Peckham *et al*[20]	574	3	73	2016–2017	HS soccer, volleyball, basketball, tennis, football	15.6 (1.0)*	Male: 245 (43) female: 329 (57)	31	Task	Jayanthi 3-point scale
Post *et al*[22]	343	4	87	NS	Division 1 collegiate basketball, golf, ice hockey, soccer, tennis, football, softball, wrestling, volleyball	NS	Male: 228 (66); female: 115 (34)	41.1	Career	Jayanthi 3- point scale
Rugg *et al*[36]	237	4	73	2008–2015	Professional basketball	20.83 (1.3)*	Male: 237 (100)	85	Career	Multi vs single sport in HS

*Weighted mean (SD) of multiple groups.
HS, high school; LOE, level of evidence; MLB, major league baseball; n/a, not applicable; NS, not stated.

the athletes' high school careers with approximately 41% of D1 athletes highly specialised by their senior year. Martin *et al*[35] found a similar proportion of D1 athletes, 42%, specialised at some point prior to college—though this study did not report the definition of specialisation. According to a study conducted by Black *et al*,[23] 24% of NCAA D1 hockey players specialised before the age of 14 years and 12% specialised before the age of 12 years. Bridge and Toms[24] reported that a large group of athletes 16–18 years of age who participated in a variety of sports were between 1.4 and 3.7 times more likely to participate in elite sport if they participated in multiple sports between the ages of 11 and 15 years.

Three studies reported sport specialisation percentages in professional athletes. Black *et al*[23] found that 24% of professional hockey players specialised before 14 years of age and only 5% specialised before 12 years. In contrast, Buckley *et al*[25] noted that 88% of USA hockey players specialised and 45% of USA baseball players specialised at some point in their athletic career by quitting other sports to focus on one sport. Rugg *et al*[36] used publicly available data for NBA athletes who were first round draft picks; 15% of the players participated in more than one sport in high school compared with 85% who were specialised in basketball in high school. Of interest, those who were multisport athletes in high school played in a greater proportion of games (78.4% vs 72.8%, p<0.001) and had increased longevity in the NBA (95% vs 81%, p=0.03, were still playing at the time of data collection).

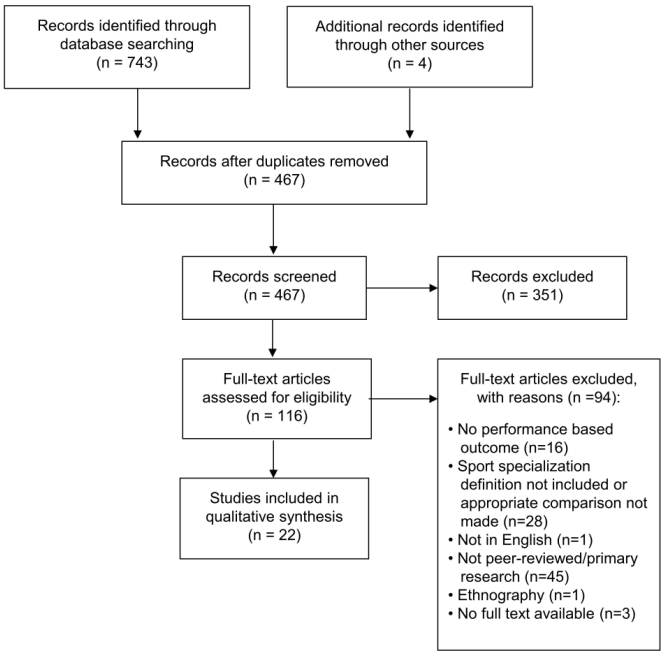

Figure 1 Flow chart for study inclusion in systematic review.

Eleven studies reported mean age of specialisation in elite groups of athletes (eg, NCAA D1 athletes, professional athletes, Olympic medalists) relative to age of specialisation in a semi-elite and/or non-elite group of athletes.[23 25–34] In all statistically significant comparisons, the elite group specialised at a later age than the non-elite or semi-elite groups. For example, Hornig *et al*[34] reported that elite soccer players specialised on average at 14.3 years of age compared with 9.9 (SD=7.2) in the non-elite comparison group. Among German Olympic medalists and non-medalists, Güllich[29] noted, respectively, mean ages of specialisation of 14.8 (SD=6.0) years and 11.9 (SD=5.5) years (p<0.01).

Youth sport specialisation and task performance

Of the seven studies that addressed task-specific performance metrics, three assessed the association between functional movement and sport specialisation using the LESS.[20 37 39] Based on the mean total number of landing errors, the three studies did not observe significant differences between specialised and non-specialised athletes; however, one study[39] noted that multisport athletes were more likely to have better neuromuscular control than single-sport athletes when categorising landing error scores as good and poor where LESS scores ≥5 were considered poor and scores <5 were good (OR=2.5, 95% CI: 1.9 to 3.1) (table 4).

One of the two studies that compared Y-balance test results reported a difference in anterior reach asymmetry; male single-sport athletes had greater asymmetry than male multisport athletes.[21] When the athletes were grouped on the Jayanthi 3-point and 6-point specialisation scale, unspecialised and low specialised athletes had significantly lower asymmetry than specialised and highly specialised athletes. Neither study, however, detected a difference in the anterior reach by specialisation status.[21 41]

One study found single-sport soccer players had lower mean standing long jump performances than soccer players who participated in other sports (p<0.01).[39] In contrast, the same study detected no difference in agility time for single-sport and multisport basketball players. Fransen *et al*[40] compared fitness and gross motor coordination performances of youth athletes of different ages who participated in multiple versus single sports; no differences were detected in the sit and reach test, push-ups, sit-ups, standing long jump, shuttle run and motor quotient (coordination) in athletes 6–8 or 8–10 years of age. Handgrip

Table 3 Career performance outcomes by specialisation status and age at specialisation for elite versus sub-elite athletes

Study	Population (N)	Outcome measure description	Specialised/ single sport/ high	Moderately specialised	Unspecialised/ multisport/ low	P value
Black *et al*[23]	Professional and collegiate ice hockey (n=91)	Percentage professional hockey specialise before age 14	24%			–
		Percentage professional hockey specialise before age 12	5%			–
		Percentage NCAA D1 hockey players specialise before age 14	24%			–
		Percentage NCAA D1 hockey players specialise before age 12	12%			–
		Percentage NCAA DIII hockey players specialise before age 14	28%			–
		Percentage NCAA DIII hockey players specialise before age 12	12.5%			–
Bridge and Toms[24]	Youth athletes (n=1006)	Odds of elite sport at 16–18 if playing two sports at age 11	REF		1.6 (1.2, 2.2)	<0.05
		Odds of elite sport at 16–18 if playing two sports at age 13	REF		1.4 (1.1, 2.0)	<0.05
		Odds of elite sport at 16–18 if playing two sports at age 15	REF		1.6 (1.2, 2.2)	<0.05
		Odds of elite sport at 16–18 if playing three sports at age 11	REF		2.2 (1.4, 3.4)	<0.05
		Odds of elite sport at 16–18 if playing three sports at age 13	REF		2.1 (1.4, 3.1)	<0.05
		Odds of elite sport at 16–18 if playing three sports at age 15	REF		2.1 (1.4, 3.1)	<0.05
		Odds of elite sport at 16–18 if playing four sports at age 11	REF		2.1 (1.2, 3.8)	<0.05
		Odds of elite sport at 16–18 if playing four sports at age 13	REF		3.2 (1.8, 5.8)	<0.05
		Odds of elite sport at 16–18 if playing four sports at age 15	REF		3.7 (2.1, 6.6)	<0.05
Buckley *et al*[25]	HS and collegiate athletes; professional hockey and baseball (n=3090)	Percentage professional MLB specialised	45.4%			–
		Percentage professional USA hockey specialised	87.5%			–
Martin *et al*[35]	Div I collegiate athletes (n=1036)	Percentage collegiate athletes specialised	41.9%		58.1%	–
Post *et al*[3]	Div I collegiate athletes (n=343)	Percentage D1 athletes specialised in 9th grade	16.9%	53.5%	29.6%	–
		Percentage D1 athletes specialised in 10th grade	28.0%	50.4%	21.6%	–
		Percentage D1 athletes specialised in 11th grade	35.6%	45.6%	18.8%	–
		Percentage D1 athletes specialised in 12th grade	41.1%	41.7%	17.2%	–
Rugg *et al*[36]	NBA first round picks (n=237)	Percentage of games played	72.8%		78.4%	<0.001
		Percentage athletes still playing	81.1%		94%	0.03

Study	Population (N)	Mean age at specialisation comparisons	Elite	Semi-elite comparator	Non-elite comparator	P value
Black *et al*[23]	Professional and collegiate ice hockey (n=91)	Professional hockey	14.1 (NS)			–
		NCAA D1 hockey	14.5 (NS)			–
		NCAA DIII hockey	14.6 (NS)			–
Buckley *et al*[25]	HS and collegiate athletes; professional hockey and baseball (n=3090)	HS athletes	12.7 (2.4)			–
		Collegiate athletes	14.8 (2.5)			–
		Professional athletes	14.7 (2.4)			–
		Baseball professional vs collegiate vs HS	14.9 (2.2)	15.4 (1.9)	12.3 (2.3)	<0.001
		Professional hockey vs collegiate	13.4 (3.2)	13.3 (2.9)	–	0.65
Coutinho *et al*[26]	Portuguese semi-professional volleyball (n=60)	Female (skilled vs less skilled)	14.0 (2.1)		13.0 (2.7)	>0.05
		Male (skilled vs less skilled)	15.0 (2.1)		12.2 (1.7)	0.001
Cupples *et al*[27]	Professional Australian rugby (n=224)	Australian professional rugby league	15.6 (2.4)			–
Hornig *et al*[34]	German professional soccer (n=102)	National team vs professional team vs elite amateur	14.3 (9.2)	10.9 (6.5)	9.9 (7.2)	<0.05*
Güllich[29]	German Olympic sport (n=166)	International medalists vs non-medalists	14.8 (6.0)		11.9 (5.5)	<0.01
Gullich *et al*[31]	German Olympic sport (n=1558)	World class vs National class	14.4 (6.6)		12.1 (5.5)	<0.01
Güllich and Emrich[28]	German Olympic/National field hockey (n=54)	Olympic champions vs World Class vs National	15.0 (8.7)*†	13.3 (6.5)†	9.4 (4.6)	0.04*; 0.51†
Gullich[30]	German national T&F (n=264)	Strong vs weak responders juniors (ages 13–17)	13.0 (5.8)		12.7 (6.2)	>0.05
		Strong vs weak responders seniors (ages 19–23+)	15.9 (7.6)		10.9 (5.2)	<0.01
Haugaasen *et al*[32]	Norwegian elite youth soccer (n=558)	Professional vs non-professional	13.1 (1.9)		12.1 (2.2)	<0.05
Hayman *et al*[33]	Elite youth UK golf (n=8)	Adolescent amateur male	16 (NS)		–	–

*Significance between elite and non-elite comparator.
†Significance between elite and semi-elite comparator.
HS, high school; MLB, major league baseball; NCAA, National Collegiate Athletic Association; NS, not stated.

strength was better, on average, in multisport compared with single-sport youth 6–8 years of age but not for any other age group. Among ten 12-year olds, in contrast, multisport athletes performed better than single-sport athletes in push-ups, standing long jumps, agility shuttle run, endurance shuttle run and the motor quotient.

Quality scoring

Based on the adapted Downs and Black Quality Index, 4/22 (18%) articles were assessed as low methodological quality, 10/22 (45%) were considered of moderate methodological quality and only 8 (36%) were judged high in methodological quality.

DISCUSSION

The peer-reviewed literature related to youth sport specialisation and performance outcomes among athletes was systematically reviewed. Today's youth sport landscape promotes the notion that youth must specialise in one sport at a young age in order to compete and succeed at elite levels and even at younger ages (eg, make club or high school sport teams). Although the existing

Table 4 Task performance outcomes by specialisation status

Study	Population (n)	Outcome measure description	Specialised/single sport/ high	Moderately specialised	Unspecialised/ multisport/low	P value
Beese *et al*[37]	Youth soccer (n=40)	Continuous LESS score	6.8 (1.8)		6.1 (1.9)	0.15
Buhrow *et al*[38]	Collegiate athletes (n=102)	Physical subscale mental toughness	28.7 (3.4)		29.1 (4.1)	0.66
		Mental subscale mental toughness	46.1 (6.9)		47.8 (7.0)	0.28
		Emotional subscale mental toughness	58.8 (7.5)		59.3 (9.7)	0.79
DiStefano *et al*[39]	Youth soccer and basketball (n=355)	OR neuromuscular control (LESS=good/poor)	REF		2.5 (1.9, 3.1)	<0.01
		Total number of landing errors	6.4 (1.7)		6.1 (1.8)	0.1
		Agility time; basketball (s)	12.0 (1.0)		12.2 (1.2)	>0.05
		Long jump distance; soccer only (cm)	130 (21)		139 (23)	<0.01
Fransen *et al*[40]	Youth athletes (n=735)	6–8 years sit and reach test (cm)	20.3 (5.4)		19.2 (5.1)	>0.05
		6–8 years knee push-ups (n/30 s)	19.9 (5.9)		21.4 (6.2)	>0.05
		6–8 years sit-ups (n/30 s)	15.5 (7.0)		15.2 (9.0)	>0.05
		6–8 years handgrip strength (kg)	14.4 (3.2)		15.8 (3.9)	<0.05
		6–8 years standing broad jump (cm)	121.0 (68.5)		124.1 (19.7)	>0.05
		6–8 years shuttle run test (s)	23.8 (1.9)		23.6 (2.3)	>0.05
		6–8 years endurance shuttle run test (min)	4.9 (2.3)		5.09 (2.2)	>0.05
		6–8 years motor quotient (points)	103.7 (14.2)		104.9 (13.2)	>0.05
		8–10 years sit and reach test (cm)	18.5 (5.4)		19.4 (5.4)	>0.05
		8–10 years knee push-ups (n/30 s)	25.3 (5.6)		27.0 (6.0)	>0.05
		8–10 years sit-ups (n/30 s)	21.1 (5.8)		22.8 (6.8)	>0.05
		8–10 years handgrip strength (kg)	18.5 (3.3)		19.2 (3.3)	>0.05
		8–10 years standing broad jump (cm)	137.7 (17.4)		141.2 (17.5)	>0.05
		8–10 years shuttle run test (s)	22.2 (1.7)		21.9 (1.6)	>0.05
		8–10 years endurance shuttle run test (min)	6.2 (2.2)		6.7 (2.1)	>0.05
		8–10 years motor quotient (points)	100.9 (12.4)		104.4 (13.3)	>0.05
		10–12 years sit and reach test (cm)	17.19 (5.5)		17.36 (5.5)	>0.05
		10–12 years knee push-ups (n/30 s)	28.9 (6.6)		30.6 (6.3)	<0.01
		10–12 years sit-ups (n/30 s)	24.8 (6.9)		26.2 (8.0)	>0.05
		10–12 years handgrip strength (kg)	23.2 (4.3)		23.9 (4.2)	>0.05
		10–12 years standing broad jump (cm)	152.5 (19.7)		158.8 (16.4)	<0.01
		10–12 years shuttle run test (s)	21.3 (1.4)		20.9 (1.3)	<0.01
		10–12 years endurance shuttle run test (min)	7.3 (2.6)		7.9 (2.1)	<0.05
		10–12 years motor quotient (points)	101.8 (11.2)		107.1 (12.2)	<0.01

Continued

Table 4 Continued

Study	Population (n)	Outcome measure description	Specialised/single sport/ high	Moderately specialised	Unspecialised/ multisport/low	P value
Gorman *et al*[41]	HS athletes (n=184)	Composite reach score (%LL)	97.1 (8.2)		97.1 (8.4)	0.98
		Anterior reach score (%LL)	75.5 (7.1)		76.4 (7.9)	0.33
		Posteromedial reach score (%LL)	108.2 (10.3)		109.1 (10.2)	0.65
		Posterolateral reach score (%LL)	107.4 (11.4)		105.8 (11.1)	0.29
		Anterior difference (cm)	2.8 (2.2)		3.6 (3.8)	0.09
		Posterior difference (cm)	4.6 (4.4)		4.3 (3.8)	0.63
		Posterolateral difference (cm)	4.3 (4.3)		5.0 (4.2)	0.23
Miller *et al*[21]	HS athletes (n=295)	Anterior reach asymmetry MALES (cm) (single/multi)	4.6 (0.5)		3.1 (0.3)	<0.05
		Anterior reach asymmetry FEMALES (cm) (single/multi)	2.8 (0.3)		2.9 (0.2)	>0.05
		Anterior reach distance MALES (%LL) (single/multi)	63.6 (1.3)			>0.05
		Anterior reach distance FEMALES (%LL) (single/multi)	67.0 (0.8)			>0.05
		Anterior reach asymmetry (cm) (Jayanthi 6-point)	3.6 (0.2)		2.7 (0.2)	0.002
		Anterior reach distance FEMALES (%LL) (Jayanthi 6-point)	67.4 (0.6)		66.8 (0.7)	>0.05
		Anterior reach distance MALES (%LL) (Jayanthi 6-point)	63.4 (0.8)		61.8 (0.8)	>0.05
		Anterior reach distance MALES (%LL) (Jayanthi 3-point)	63.8 (1.0)	62.3 (1.1)	61.5 (1.0)	>0.05
		Anterior reach distance FEMALES (%LL) (Jayanthi 3-point)	68.1 (0.8)	66.3 (0.9)	66.7 (0.8)	>0.05
		Anterior reach asymmetry (cm) (Jayanthi 3-point); cm	3.1 (0.3)	3.8 (0.3)	2.6 (0.3)	0.009
Peckham *et al*[20]	HS athletes (n=574)	Adjusted mean LESS score	5.1 (2.0)	5.3 (1.9)	5.6 (2.1)	>0.05

HS, high school; LESS, Landing Error Scoring System.

body of research is relatively limited, the results of this review suggest that youth sport specialisation is not necessary to achieve success at elite levels and may not improve task-related performances compared with athletes who participate in multiple sports through childhood. Moreover, there is a strong need for experts and researchers in this area to improve the methodological rigour of sport specialisation research (see Conclusions 1–3, table 5).

Table 5 Conclusions and recommendations

Conclusions and recommendations from systematic review of studies of the association between YSS and performance outcomes	
Conclusion 1 (Substantive) Despite common beliefs otherwise, a growing body of literature suggests YSS is not a necessary pathway to achieve elite (D1 collegiate, professional, national) performance in a sport. Youth who specialise early and those who do not specialise until mid-adolescence both achieve elite performance; however, the reasons why both competing pathways lead to elite success have yet to be elucidated. The consistency and strength of the available evidence are sufficient to justify the notion that YSS is not a prerequisite to participate in sport at the highest level.	**Recommendation 1 (Substantive)** We recommend consistent, multifaceted implementation of messaging, which addresses the inaccurate assumption that YSS is necessary to achieve elite performance outcomes. Prospective research needs to be conducted to assess both the specialisation and sport sampling pathways to elite performance, to better understand whether multisport athletes are simply better athletes predestined for future success and/or if YSS may be helpful or appropriate for a specific subset of youth.
Conclusion 2 (Substantive) More research is needed to better understand the sport-specific associations between YSS and level of athletic performance. Current, limited evidence suggests YSS does not improve various motor and neuromuscular control tasks. No studies directly addressing the association between YSS and sport-specific skill development were identified. Though in certain sports (eg, gymnastics, ice skating) there is some evidence to suggest that early, focused sport-specific skill development might influence success at the elite level for a select group of athletes who can avoid injury and psychosocial pressure related to performance outcomes.	**Recommendation 2 (Substantive)** We recommend the implementation of focused, sport-specific research addressing the effect of YSS on skill development and training volume, and its association with level of athletic performance. There is limited evidence assessing the impact of YSS on level of athletic performance by sport. This knowledge is essential to fully understand the potential benefits and risks of YSS for focused skill development and continued participation in certain sports, especially those for which peak performance is thought to occur at a young age.
Conclusion 3 (Methodologic)* To further refine the scientific base, there is a need for methodological studies to improve methods for the assessment of YSS and YSS-related outcomes. There is a need to establish methods that provide valid, consistent and reliable, various measures of YSS and YSS-related outcomes across a variety of sports, ages or age groups, and settings (eg, youth leagues or clubs, high school, collegiate). Improved measurement of YSS and YSS outcomes will facilitate improved future research quality and the synthesis and meta-analysis of literature in the future.	**Recommendation 3 (Methodologic)** **3A**. We recommend publishing a compendium of recommended definitions and methods for assessing YSS and YSS-related outcomes. **3B**. We recommend research aimed at establishing and refining the validity, consistency and reliability, of various methods for measuring YSS and YSS-related outcomes, in a variety of ages, sports and sport settings.

*This conclusion is additionally endorsed by the YESSS writing group that assessed the association between YSS and injury risk, termination and well-being.
YSS, youth sport specialisation.

Impact of youth sport specialisation on career performance outcomes

The percentage of elite athletes who specialised in their given sport at a young age is variable. Estimates from studies included in this review ranged from 12% of NCAA D1 hockey players specialising before the age of 12 years (from a sample of n=91 athletes)[23] to 85% of NBA athletes specialising in high school (from a sample of n=237 athletes).[36] There may be a sport-specific effect on the percentage of athletes who specialise at a young age, especially among those sports where peak performance occurs relatively early (eg, gymnastics, ice skating, perhaps diving). Unfortunately, rates of specialisation are not well documented for all sports and may differ by sport. For example, Buckley *et al*[25] found that nearly 88% of professional hockey players specialised at some point in their career, whereas Black *et al*[23] found that 24% of professional hockey players specialised before 14 years and only 5% specialised before 12 years.

When considering mean age of specialisation among athletes at the elite level compared with semi-elite or non-elite levels, there was no evidence that youth sport specialisation was associated with a greater likelihood of participation at the elite level (Conclusion 1, table 5). In fact, elite athletes were more likely to specialise later than their non-elite counterparts. Most of these studies, however, relied on cross-sectional surveys or historical recall by elite athletes to assess age at specialisation. As a result, several important issues or factors remain unknown. Do a greater proportion of children and adolescents who specialise early make it to the elite level? What is the number of talented youth who specialise, but do not make it to the elite level due to injury, burn-out and perhaps familial factors? Are youth multisport athletes who make it to the elite level simply better athletes or do elite athletes who specialised at a young age need to do so to have an opportunity for long-term success? It does appear evident, however, that specialisation is not the only means to elite athletic success. Bridge and Toms[24] determined that athletes who participated in two to four sports between 11 and 15 years of age were more likely to reach elite sport participation than their single-sport counterparts. Further, the role of sex and gender may influence the experience of youth sport specialisation based on differences of ages achieving developmental milestones between girls and boys. Gender roles likely also influence sports participation in rules of sport and behaviours of physical activity. Prospective research needs to be conducted to better understand the specialisation and sampling pathways and long-term athlete performance.

Impact of youth sport specialisation on task performance outcomes

Only seven articles included in this review addressed the effect of early sport specialisation on specific motor tasks, including components of physical fitness and coordination. Most studies failed to detect a difference in task performance outcomes between specialised and non-specialised athletes. When differences were noted, multisport athletes tended to perform better than single-sport athletes on task-specific outcomes. Interestingly, Fransen *et al* found no consistent differences in specific fitness tests and coordination among 6- to 8-year and 8-year to 10-year-old boys, but noted that 10-year to 12-year olds participating in several sports performed better than peers participating in a single sport in several fitness and motor coordination tests.[40] Nevertheless, these results do not necessarily imply that early sport sampling leads to better fitness and gross motor coordination; it is equally possible that youth more proficient in fitness and coordination tests are more likely to participate in a variety of sports. Additionally, the sample of youth included those participating in sport clubs as well as those in primary schools. Potential sport-specific effects were mitigated without controlling for varying levels of coordination and specific sport participation. Well-designed, prospective, sport-specific research is needed to more fully assess the impact of early sport sampling versus specialisation on fitness and performance outcomes including gains within a given sport. On the contrary, it is possible that standardised fitness and coordination tests are not highly correlated with sport-specific skills.

This systematic review revealed no studies that addressed the acquisition and development of sport-specific skill relative to specialisation status (eg, shooting percentage among basketball players or pitching accuracy among youth pitchers). This is a major shortcoming as the development of sport-specific skills is a common argument in support of early sport specialisation.[1] In the context of the observations of Ericsson *et al*,[6] more hours in specific activities related to music and chess has a positive effect on performance in the respective tasks, which is arguably a benefit of sport specialisation. Although there is general discussion suggesting that those who specialise in one sport perform better than peers during youth,[11] it remains to be demonstrated that intense involvement in a specific sport versus participation in several sports leads to better long-term performance outcomes. With a lack of research addressing sport-specific skill development among specialised and non-specialised athletes, this remains a necessary, yet open, area for research (Conclusion 2 and Recommendation 2, table 5).

Methodological inconsistencies and needs in sport specialisation research

Study design

This review did not identify any prospective studies looking at the effect of youth sport specialisation on specific task performance (eg, neuromuscular control) or career performance outcomes. Most studies were cross-sectional and/or relied on retrospective observational survey data. Relatively few studies specifically addressed the effect of sport specialisation on athletic success at the elite level; those that did were limited by inconsistent definitions of sport specialisation and an inability to discriminate between potential sport-specific differences. Differences in effects of youth sport specialisation by sex and gender were not able to be concluded. More methodological studies are needed to establish reliable methods for studying effects of youth sport specialisation on performance and other important outcomes.

Definition of youth sport specialisation

Sport specialisation is commonly defined as 'participation in a single sport at the exclusion of other sports'; however, this definition is not exclusively agreed on or applied in the existing literature. A majority of the studies included in this review relied on self-report of the number of sports played (multisport vs single-sport or exclusive participation in a main/single sport) to define specialisation. However, an athlete's response to number of sports played does not fully address the spectrum of concerns related to sport specialisation. Jayanthi 3-point definition attempts to capture the continuum of specialisation by addressing whether an athlete has quit other sports to focus on one sport, considers his/her primary sport more important than other sports and trains/participates in his/her primary sport more than 8 months out of the year. This definition also has limitations, in that most athletes who make

it to an elite performance level often end up specialising at some point during their careers. Also, it may not adequately capture all important elements for defining sport specialisation. For example, this review suggests that specialisation occurs somewhere between 14 and 15 years of age for elite athletes; as such, some groups have advocated for adding age restrictions to the definition of specialised athletes.[42] Moreover, none of the definitions consider the role an athlete's weekly or yearly volume of training and/or sport-related activity may play in the specialisation paradigm. Other elements such as athlete autonomy in training decisions or developmental stages may be important as well, but studies addressing these elements are scarce or non-existent. There is a strong need for methodological studies to help improve the methods of assessment of youth sport specialisation and outcomes (eg, performance, well-being, overuse injury) that may be associated with specialisation (Conclusion 3 and Recommendation 3, table 5). The lack of a sufficiently specific definition of specialisation and the heterogeneity of the definitions used in the studies likely contributed to the inability to conduct a meta-analysis to assist in quantifying the effects of specialisation on athlete performance.

Limitations

We acknowledge several limitations. The studies we included were at risk for certain biases related to sport specialisation and maximisation of performance. To keep the review focused, inclusion criteria required studies to specifically address sport specialisation. Earlier studies addressing the concept of deliberate practice and volume of training were not included. Additionally, methodological and design limitations in the included studies mean it is impossible for any scientist to draw very strong precise (in relation to age, training volume) conclusions. Different definitions of specialisation may have led to variable outcomes, while reliance on surveys and historical recall precluded the assessment of causal associations between sport specialisation and performance.

CONCLUSION

We conclude the following:

1. Youth sport specialisation is not prerequisite for success at more elite levels.
2. Elite athletes often specialise between 14 and 15 years of age.
3. Sport specialisation may not lead to better task performance among youth who specialise compared with those who participate in multiple sports.

What is already known

- There is a trend within youth sports to emphasise early sport specialisation as the method to improve performance.
- Fewer than 2% of collegiate athletes continue their careers at an elite level beyond college sport.

What are the new findings

- Youth sport specialisation is not prerequisite for success at the elite level—elite athletes often do not specialise until 14–15 years.
- Youths who specialise in a sport do not necessarily have superior task performance (such as anterior reach or standing broad jump) than those youths who play multiple sports.

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REFERENCES

1 Brooks MA, Post EG, Trigsted SM, *et al*. Knowledge, attitudes, and beliefs of youth Club athletes toward sport specialization and sport participation. *Orthop J Sports Med* 2018;6.
2 Bell DR, Post EG, Trigsted SM, *et al*. Parents' awareness and perceptions of sport specialization and injury prevention recommendations. *Clin J Sport Med* 2018;1.
3 Post EG, Trigsted SM, Schaefer DA, *et al*. Knowledge, attitudes, and beliefs of youth sports coaches regarding sport volume recommendations and sport specialization. *J Strength Cond Res* 2018;1.
4 DiFiori JP, Benjamin HJ, Brenner J, *et al*. Overuse injuries and burnout in youth sports: a position statement from the American medical Society for sports medicine. *Clin J Sport Med* 2014;24:3–20.
5 National Collegiate Athletic Association. NCAA recruiting facts, 2018. Available: https://www.ncaa.org/sites/default/files/Recruiting%20Fact%20Sheet%20WEB.pdf [Accessed 10 Nov 2018].
6 Ericsson KA, Krampe RT, Tesch-Römer C. The role of deliberate practice in the acquisition of expert performance. *Psychol Rev* 1993;100:363–406.
7 Deakin JMC S. A search for deliberate practice. In: Starkes KAE J, ed. *Expert performance in sports: advances in research on sport expertises*. Champaign, IL: Human Kinetics, 2003.
8 Starkes JL, Deakin JM, Allard F, *et al*. *Deliberate practice in sports: what is it anyway. in: the road to excellence: the acquisition of expert performance in the arts and sciences, sports, and games*, 1996: 81–106.
9 Ward P, Hodges NJ, Starkes JL, *et al*. The road to excellence: deliberate practice and the development of expertise. *High Ability Studies* 2007;18:119–53.
10 Helsen WF, Starkes JL, Hodges NJ. Team sports and the theory of deliberate practice. *J Sport Exerc psychol* 1998;20:12–34.
11 Ford PR, Williams AM. *Sport activity in childhood: early specialization and diversification*. Routledge Handbook of Talent Identification and Development in Sport: Routledge, 2017: 116–32.

12 Brenner JS. Council on sports M, fitness. sports specialization and intensive training in young athletes. *Pediatrics* 2016;138.
13 Côté J, Lidor R, Hackfort D. ISSP position stand: to sample or to specialize? seven postulates about youth sport activities that lead to continued participation and elite performance. *Int J Sport Exerc Psychol* 2009;7:7–17.
14 Valovich McLeod TC, Decoster LC, Loud KJ, *et al*. National athletic trainers' association position statement: prevention of pediatric overuse injuries. *J Athl Train* 2011;46:206–20.
15 Sieghartsleitner R, Zuber C, Zibung M, *et al*. "The Early Specialised Bird Catches the Worm!" – A Specialised Sampling Model in the Development of Football Talents. *Front Psychol* 2018;9:188.
16 Fabricant PD, Lakomkin N, Sugimoto D, *et al*. Youth sports specialization and musculoskeletal injury: a systematic review of the literature. *Phys Sportsmed* 2016;44:257–62.
17 Bell DR, Post EG, Biese K, *et al*. Sport specialization and risk of overuse injuries: a systematic review with meta-analysis. *Pediatrics* 2018;142:e20180657.
18 Downs SH, Black N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. *J Epidemiol Community Health* 1998;52:377–84.
19 Jayanthi N, Pinkham C, Dugas L, *et al*. Sports specialization in young athletes: evidence-based recommendations. *Sports Health* 2013;5:251–7.
20 Peckham KJ, DiStefano LJ, Root HJ, *et al*. The influence of sport specialization on landing error scoring system scores in high school athletes. *Athl Train Sports Health Care* 2018;10:253–9.
21 Miller MM, Trapp JL, Post EG, *et al*. The effects of specialization and sex on anterior Y-Balance performance in high school athletes. *Sports Health* 2017;9:375–82.
22 Post EG, Thein-Nissenbaum JM, Stiffler MR, *et al*. High school sport specialization patterns of current division I athletes. *Sports Health* 2017;9:148–53.
23 Black S, Black K, Dhawan A, *et al*. Pediatric sports specialization in elite ice hockey players. *Sports Health* 2018;1941738118800446.
24 Bridge MW, Toms MR. The specialising or sampling debate: a retrospective analysis of adolescent sports participation in the UK. *J Sports Sci* 2013;31:87–96.
25 Buckley PS, Bishop M, Kane P, *et al*. Early Single-Sport specialization: a survey of 3090 high school, collegiate, and professional athletes. *Orthop J Sports Med* 2017;5.
26 Coutinho P, Mesquita I, Fonseca AM, *et al*. Expertise development in Volleyball: the role of early sport activities and players' age and height. *Kinesiology* 2015;47:215–25.
27 Cupples B, O'Connor D, Cobley S. Distinct trajectories of athlete development: a retrospective analysis of professional rugby League players. *J Sports Sci* 2018;36:2558–66.
28 Güllich A. Many roads lead to Rome – developmental paths to Olympic gold in men's field hockey. *Eur J Sport Sci* 2014;14:763–71.
29 Güllich A. International medallists' and non-medallists' developmental sport activities – a matched-pairs analysis. *J Sports Sci* 2017;35:2281–8.
30 Gullich A. Sport-specific and non-specific practice of strong and weak responders in junior and senior elite athletics - A matched-pairs analysis. *J Sports Sci* 2018:1–9.
31 Güllich A, Emrich E. Considering long-term sustainability in the development of world class success. *Eur J Sport Sci* 2014;14:S383–97.
32 Haugaasen M, Toering T, Jordet G. From childhood to senior professional football: elite youth players' engagement in non-football activities. *J Sports Sci* 2014;32:1940–9.
33 Hayman R, Polman R, Taylor J, *et al*. Development of elite adolescent golfers. *Talent Dev Excellence* 2011;3:249–61.
34 Hornig M, Aust F, Güllich A. Practice and play in the development of German top-level professional football players. *Eur J Sport Sci* 2016;16:96–105.
35 Martin EM, Ewing ME, Oregon E. Sport experiences of division I collegiate athletes and their perceptions of the importance of specialization. *High Ability Studies* 2017;28:149–65.
36 Rugg C, Kadoor A, Feeley BT, *et al*. The Effects of Playing Multiple High School Sports on National Basketball Association Players' Propensity for Injury and Athletic Performance. *Am J Sports Med* 2018;46:402–8.
37 Beese ME, Joy E, Switzler CL, *et al*. Landing error scoring system differences between Single-Sport and Multi-Sport female high School–Aged athletes. *J Athl Train* 2015;50:806–11.
38 Buhrow C, Digmann J, Waldron JJ, *et al*. The relationship between sport specialization and mental Toughness in college athletes. *Int J Exerc Sci* 2017;10:44–52.
39 DiStefano LJ, Beltz EM, Root HJ, *et al*. Sport sampling is associated with improved landing technique in youth athletes. *Sports Health* 2018;10:160–8.
40 Fransen J, Pion J, Vandendriessche J, *et al*. Differences in physical fitness and gross motor coordination in boys aged 6–12 years specializing in one versus sampling more than one sport. *J Sports Sci* 2012;30:379–86.
41 Gorman PP, Butler RJ, Rauh MJ, *et al*. Differences in dynamic balance scores in one sport versus multiple sport high school athletes. *Int J Sports Phys Ther* 2012;7:148–53.
42 LaPrade RF, Agel J, Baker J, *et al*. AOSSM early sport specialization consensus statement. *Orthop J Sports Med* 2016;4.