The association between sport specialisation and movement competency in youth; a systematic review

Sport Specialisation and movement competency in youth

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Abstract

Negative long-term outcomes have been reported following sport specialisation including increased injury risk. The underlying mechanisms remain unclear; however, fewer exposures to broad ranging movement patterns and reductions in movement competency have been suggested. This review synthesised the evidence to examine if an association is present between sport specialisation and movement competency.

A systematic electronic database search was conducted using combinations of the key words *early speciali?ation, sport speciali?ation, early sport speciali?ation, single sport, high school, youth, adolescen**, *movement competenc*, movement ability, movement control, movement pattern, physical performance, coordination, fitness, motor skill, motor development, movement performance, neuromuscular control, balance, asymmetr*.*

Thirteen articles met the inclusion criteria and were included. Four studies reported no significant differences in movement competency based on specialisation status, while seven showed some measures of movement competency differed but not others. The remaining two studies concluded that adult athletes who participated in two or more sports during high school exhibited better movement competence than those who specialised in a single sport. Multisport athletes commonly displayed improved jump mechanics and performance compared to those competing in a single sport (6/9 studies).

Consistent differences in movement competence based on level of sport specialisation were not shown; however, sport specialisation may result in poorer jump mechanics/performance than playing multiple sports. Further research is needed across a greater range of sports, and consistent definitions of both movement competence and the level of sport specialisation are required to improve our ability to compare and contrast different studies.

Key words

Single-sport, multi-sport, motor development, motor control, adolescents

1. INTRODUCTION

Sport specialisation involves intensive year-round participation in a single sport to the exclusion of all others [1]. Of particular interest is the reported increase in the prevalence of 'early' specialisation, occurring before adolescence [1-4]. While the intentions may be to increase the chances of future athletic success, evidence suggests that realisation as an adult is not linked to achievement in youth [5, 6]. Numerous studies have also reported links between youth who specialise in a single sport and negative long-term outcomes including burnout, sport cessation and increased injury risk [7-9]. The underlying mechanisms to explain the reasons for these negative consequences associated with sport specialisation remain unclear.

Research has largely focused on the long-term psycho-social effects of early specialisation in youth and the associated injury risk [9-12]. Young athletes who specialise in a single sport are subjected to increased exposure and intensity of competition, potentially magnifying their risk of injury [13-16]. Specifically, overuse injuries likely develop due to repetitive loading in distinct movement patterns and/or affordance of insufficient recovery [4, 14]. Training exclusively in one sport during childhood may also lead to the development of aberrant movement patterns and limb asymmetries [4, 17] and compromise the development of foundational physical capacities and perceptual-cognitive skills [4, 17]. This narrow focus could lead to a reduced movement competence and a decreased ability to perform a variety of physical activities and fundamental movement skills [18]. Conversely, diverse sport participation during childhood and adolescence has been linked to enhanced movement skill development, across a greater range of foundational physical capacities and skills [19]. Nonetheless, our understanding of the effects of early sport specialisation on the development of movement skill is limited.

The suggestion that early sport specialisation in youth affects movement development is plausible; however, there is no clear literature synthesis to determine the nature of this relationship. Some studies report a negative effect of early specialisation on movement competency [4], while others report no significant difference between early specialised and non-specialised youth athletes [7]. Studies involving elite adult athletes indicate the potential for chronic alterations in movement patterns due to sports specialisation, especially if this occurs at a young age. For example, elite adult volleyball players have shown greater upper and lower limb strength asymmetries compared to non-elite players [20]. This suggests early specialised youth volleyball players may present with greater lower limb asymmetries than those with a more diverse sporting background. In other sports, such as gymnastics, early specialised athletes may show improved balance [21], implying that movement patterns developed in early specialised athletes are sport specific.

Therefore, the aim of this study was to systematically review the current evidence for an association between sport specialisation and movement competency in youth to give a clear synthesis, with a view towards informing future research and practice recommendations.

2. METHODS

The inclusion criteria for this review were defined prior to commencement of the literature search in accordance with the guidelines specified by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [22].

2.1 Search Strategy

Initial searches were carried out in November 2019 using the Web of Science, SPORT Discuss, Scopus, and Medline (via EBSCO) electronic databases. A secondary search was conducted in March 2020 using the same databases and identical search criteria, to find any additional studies that had been published in this time. The reference lists of included articles were also scanned. The search terms and specified combinations included: *early speciali?ation, sport speciali?ation, early sport* *speciali?ation, single sport, high school, youth, adolescen**; with the following keywords for movement competency: *movement competenc*, movement ability, movement control, movement pattern, physical performance, coordination, fitness, motor skill, motor development, movement performance, neuromuscular control, balance, asymmetr**. An example of the search strategy is presented in Appendix 1.

2.2 Eligibility Criteria

Articles were only included where they were original, peer reviewed, and published in English. Opinion pieces, position statements, editorials, and reviews were excluded. Studies were required to report sport participation and some classification of sport specialisation when participants were aged 18 years or younger, and an assessment of movement competency was also required. Due to the lack of consistency in the definition and methods used to measure movement competency, this was left broad to include measures of movement skill or control and coordination, balance or physical performance (for example muscular strength and endurance). Furthermore, due to the range of methods used to classify sport specialisation status, any measure of sport participation in youth that allowed quantification of specialisation was included.

2.3 Study Selection

Potential articles of interest were selected by scanning the titles of publications from search results and the reference lists of included articles, which were then downloaded to Endnote. At this point duplicates were removed, article type and peer review status were checked, and abstracts were scanned against the eligibility criteria. The remaining articles were then read in full to ensure they met the inclusion criteria. Article selection was completed by a single author [AZ] and cross-checked by a second author [CW]. Any disagreements were discussed with all authors until a consensus was reached.

2.4 Data Collection Process

Data extraction was initially completed by a single author [AZ], then cross-checked by a second author [PR]. This included descriptive information on methodology, when and where the study took place, participants (age, level of participation, sport, gender), how sport specialisation was classified and measured, key outcome measures (including movement competency tests, variables and measures used), statistical analysis, key findings, level of specialisation of participants, and conclusions.

Due to the large range of measures and definitions used for ‘movement competency’ and ‘specialisation’, the results of different studies were described and compared based on the methods used, rather than performing meta-analysis which would be subject to large heterogeneity.

2.5 Study Quality and Risk of Bias Assessment

An adapted checklist based on previous research [23] was used to analyse risk of bias and quality of included studies. This tool was chosen due to the typically non-randomised, observational nature of the existing research. Items in the checklist were evaluated on 16 points, with each scored 1 if a criterion was met or 0 if it was not met. Scores of 11-16; 6-10; and 0-5 were classified as low, satisfactory and high risk of bias respectively. Each study was scored independently by two authors [AZ and PR], with any disagreements discussed until a consensus was reached. Explanations of the interpretations and how each point was assessed are outlined in Appendix 2.

3. RESULTS

3.1 Study selection

296 potentially relevant articles were originally identified. After duplicates were removed, 214 articles remained. Following abstract screening, 26 articles were included in a full text review. The reference lists of these articles were also scanned and revealed one additional article. A total of 13 articles met the eligibility criteria for this review (Figure 1).

INSERT FIGURE 1 ABOUT HERE

3.2 Characteristics of included studies

The results of individual studies are reported in Table 1. Of the 13 included, only one followed a prospective design [24], with the remaining cross-sectional and/or retrospective. The most commonly investigated sports were football (soccer) (n=7) [3, 7, 24-28], basketball (n=7) [3, 24-29] and volleyball (n=6) [3, 24, 26-29]. Two studies included only one sport; football [7], and gymnastics [30]. Eight included multiple sports [3, 24-29, 31] and three did not report the sport [32-34]. The majority involved early to mid-adolescent participants (age range 12 to 16) [3, 7, 24, 27, 28, 31-33], with three studies including younger participants (as young as 6 years in one study) [25, 30, 34]. Two retrospective studies included adults (aged 19-25), who were grouped based on high school sport participation [26, 29].

INSERT TABLE 1 ABOUT HERE

3.3 Methods used to classify specialisation

The most commonly applied methods were self-reported single/multi-sport (n=11) [3, 7, 24-27, 29, 31-34], the Jayanthi 3-point scale (n=3) [27, 28, 30], and Jayanthi 6-point scale (n=1) [27]. The Jayanthi 3-point scale classifies athletes on a continuum of high, moderate, or low specialised, while the 6-point scale classifies athletes as specialised or not specialised [9]. Ratings on both scales are based on answers to a series of questions developed to cover the key aspects of the definition of specialisation, participating in a single sport, year-round, and at the exclusion of other sports. One study used all three of these methods to classify athletes; where the percentage of athletes classified as highly specialised varied based on whether this was defined as single sport (28%), using the 3-point scale (36%), or 6-point scale (55%) [27].

'Early' specialisation was discussed in seven of the included studies [3, 7, 24, 27, 30, 32, 34]; however, there were no consistent definitions of what age (or stage) is considered 'early'. The definition used was often vague and varied from being at a young age [7, 27, 30, 32, 34], before periods of rapid growth, prior to or during puberty [3, 24].

3.4 Movement competency measures

The definition and method used to measure movement competency also varied between studies. Nine included qualitative measures to classify how well a movement was performed [3, 7, 24-26, 28-31], while four used purely quantitative outcomes of performance [27, 32-34]. Jump landing mechanics was most commonly used as primary measure for movement competence [3, 7, 24-26, 28], including the Landing Error Scoring System (LESS) [7, 25, 26, 28], or 3D motion analysis [3, 24]. Other tests used were the lower and upper body Y-balance test (n=3) [27, 30, 33], broad jump distance (n=2) [25, 34] and vertical jump height (n=2) [30, 32]. Muscular endurance was assessed in three studies, including the number of repetitions performed in push ups [30, 34], pull ups [30], sit ups [34], or the duration of abdominal hollow hold [30] or front plank [30, 32].

3.5 Risk of Bias and Quality Analysis

Eleven studies were identified as having a low risk of bias [3, 7, 24-28, 30-34], with three scoring 15/16 [3, 24, 25]. Detailed results are shown in Appendix 3. Fransen et al. [34] and Triplett et al. [29] were identified as having 'satisfactory' and 'high' risk of bias respectively. The item which consistently scored poorly across studies was the confounding factors. Potential confounding factors were defined prior to assessment as stage of maturation, injury history, training and game exposure, length of specialisation, and gender.

3.6 Synthesis of results

Four studies found no significant difference in movement competency between specialised and non-specialised athletes [7, 28, 31, 33]. Of the remaining studies, seven showed some measures of movement competence were worse in high specialised athletes, but other measures did not differ [3, 24, 25, 27, 30, 32, 34]. Some differences were evident in measures of jump landing mechanics and performance, LESS, muscular strength and endurance, Y-balance, aerobic endurance, and flexibility. Only two studies showed consistent between group differences, concluding that adult athletes who participated in two or more sports during high school showed better movement quality in the LESS [26] and functional movement screen (FMS) [29] compared to adult athletes who specialised in a single sport during high school. Tests which consistently showed no difference based on level of specialisation included vertical jump and hop height [30, 32, 34], time taken for tests of agility [25, 30], front plank [30, 32], 10x5m shuttle run, walking backwards, moving sideways, or jumping sideways [34].

3.6.1 Tests of jump and landing competency

Five studies investigated the association between sport specialisation and movement quality during jumping and/or landing, measured using the LESS [7, 25, 26, 28, 30]. The results were inconsistent, with two studies reporting significantly decreased LESS performance in specialised individuals [25, 26]. The remaining three studies reported no significant difference based on specialisation [7, 28, 30]. DiStefano et al. [25] compared LESS outcomes as a dichotomous variable (good [<5 errors] vs bad) and a continuous outcome based on the number of errors. When analysed as a dichotomous variable, multi-sport athletes were 2.5 times more likely to display 'good' control compared to sport specialised individuals [25] however no differences were seen when analysing LESS score as a continuous variable. Additionally, Herman et al. [26] reported significantly fewer errors with each additional sport played. However, most studies did not indicate significant difference in LESS when it was scored as a continuous outcome [7, 25, 28, 30].

Two additional studies analysed jump landing mechanics using 3D motion analysis [3, 24]. DiCesare et al. [24] was the only prospective study included in this review. They reported significantly greater pre- to post-pubertal increases in highly specialised players knee abduction range of motion and moment. Highly specialised players also showed a significantly lower pre- to post-pubertal increases in knee extensor moment. DiCesare et al. [3] also reported significantly greater joint coupling angle variability in highly specialised athletes for hip and knee flexion, knee flexion and abduction, and knee flexion and internal rotation. No significant differences were seen during jump landings in knee internal rotation moment [24], or joint coupling angle variability of knee flexion and ankle flexion, hip flexion and knee abduction, or knee abduction and knee internal rotation [3].

Broad jump distance was significantly less in highly specialised football players [25] and highly specialised 10-12 year olds across a range of sports [34]. However no significant difference was seen in broad jump distance in younger athletes [34]. In a further study, including a variety of sports, hop distances were significantly lower in highly specialised compared to moderately specialised athletes on the right leg but not the left [30].

3.6.2 Tests of balance

Reach distance during the lower body Y-balance test was evaluated in three studies [27, 30, 33]. Two of these included reach asymmetries [27, 33] and one focused solely on anterior reach [27]. Two studies identified significantly reduced reach distances [30] and increased reach asymmetry [27] in highly specialised athletes, while the third reported no significant differences in these outcome measures [33]. This suggests there is very limited evidence of a relationship between Y-balance reach distance and specialisation.

3.6.3 Other movement tests

Muscular endurance tests showed inconsistent results with significantly poorer performance in the push up test by highly specialised athletes in one study [34], but not another [30]. Fransen et al. [34] also reported significantly poorer performance in highly specialised 10-12 year old athletes for the endurance shuttle run test and motor quotient; however, there were no observed differences in younger age groups. Sugimoto et al. [32] reported significantly lower knee extensor strength in the right knee for highly specialised athletes, but not in the left knee, or the knee flexors, hip adductors, or hip abductors in both legs. Range of motion at the ankle [32] and shoulder [30] was greater in more highly specialised athletes, but no significant differences were observed at the knee [32]. Barfield et al. [31] measured control of the trunk during single leg squat performance and reported no significant difference between specialised and non-specialised baseball and softball players. However, significantly greater control was indicated in athletes who trained for eight months or more of the year than those who did not.

4. DISCUSSION

4.1 Summary of evidence

This synthesis of the literature examined whether sport specialisation results in altered movement competency in youth. The results indicate that there is inconclusive evidence to support an association between movement competency and sport specialisation, with some studies showing improved movement competency in multi-sport athletes [3, 24-27, 29, 30, 32, 34], while others did not [7, 28, 31, 33]. These inconsistencies may be due to variations in methods and definitions used, as well as limited control for confounding factors. Most studies included assessments of jump landing mechanics, with fewer assessing balance, muscular endurance, strength and range of motion. These findings make comparisons between studies difficult, suggesting the need for consensus in definitions of both movement competence and sport specialisation.

Development of physical literacy is important to build a strong foundation of movement competence and physical activity behaviours through adolescence and into adulthood [35, 36]. Sport sampling (participating in more than one sport) has been suggested, which is important in youth athletes as it provides a base for sport specific skills [37]. It also has the potential to decrease risk of injury by ensuring that athletes develop the strength and coordination to perform movements required in a safe manner [25] and contributes to well-being through long term physical activity involvement, giving youth the skills and confidence to participate in a range of activities [36]. While the evidence remains inconclusive, coaches, parents and sporting organisations may wish to consider adjustments to youth athletes’ training and sport participation to ensure all youth are being exposed to sufficient opportunities to develop their overall movement competence, rather than just sport specific skills.

4.2 Jump landing mechanics

Seven studies assessed vertical drop jump landing mechanics using either the LESS [7, 25, 26, 28, 30] or 3D motion analysis [3, 24]. The results were inconsistent, which could in part be due to different methods used to assess landing mechanics (LESS vs 3D motion analysis), how specialisation was defined, and the range of different sports included. Analysis identified improved 3D landing mechanics in athletes participating in more than one sport [3, 24]. These findings were consistent with DiStefano et al. [25] and Herman et al. [26] during the LESS. Interestingly, of the studies that reported no difference in jump landing mechanics, only one controlled for maturation of participants [30]; however, the specialised athletes in their study were gymnasts, who would be expected to display a high level of movement control. All studies that reported a difference either controlled for maturation [3, 24, 25] or had participants who had reached physical maturity [26].

Of five studies classifying athletes based on the number of sports they play/played, four reported significantly poorer landing technique in athletes who participated in a single sport compared to multi-sport athletes [3, 24-26]. However, when athletes were classified using the 3-point scale, no significant difference in landing technique was shown based on specialisation status [28, 30]. Thus, it could be suggested that sport sampling, rather than specifically specialising in a sport is more favourable [25]. However, as mentioned earlier, there are other confounding factors (sport and maturation), making it difficult to determine whether the method of classification affected the results of these studies.

Athletes assessed participated in football (soccer) [3, 7, 24-26, 28], volleyball [3, 24, 26, 28], basketball [3, 24-26, 28], American football [28], tennis [28], lacrosse [26] and gymnastics [30]. This diversity precludes our ability to provide definitive conclusions and may confound the results as comparing jump landing mechanics in athletes who specialise in gymnastics or volleyball with those in football or tennis presents limitations. These sports have different demands and specific movement patterns and imbalances may occur as a result of increased and earlier exposure to these sports. Thus, further research is warranted to investigate specific sports. Interestingly, two studies included athletes from only one sport; football [7], and gymnastics [30]. Neither of these studies identified significant differences in LESS score based on level of specialisation. However, Beese et al. [7] did report a greater proportion of multi-sport athletes (21%) scored 'excellent' compared to specialised athletes (10%), and a lower proportion of 'poor' (37%) than specialised athletes (57%). There appears to be some association between jump landing mechanics and sport specialisation, however the strength of this relationship may be weak and dependent on the sport and methods used.

The results from these studies suggest that specialising in a single sport may lead to reduced neuromuscular control during jump landings [3, 24-26]. The observed decrements may lead to a reduced ability to effectively control ground reaction forces during landings and an increase in lower extremity injury risk [3]. While the evidence did not conclusively demonstrate reductions in neuromuscular control were present in all sport specialised athletes, the potential for increased risk of injury suggests that screening for deficits in jump landing mechanics is warranted, especially for those who specialise in a single sport. Integrative neuromuscular training may also be beneficial to improve motor skill development and decrease risk of injury [3, 24, 25].

4.3 Balance

Three studies included the lower body Y-Balance [27, 30, 33] and one of these also used the upper body variant of this test [30]. Conflicting results were shown, which may be due to the reporting of different outcome measures (absolute, relative, and composite reach distances and asymmetry). Inconsistencies were also present in sports played and the age of participants. One study included gymnasts aged 10.9 ±2.9 years [30], while participants from the other studies were older (15.4 ±1.2 to 15.9 ±1.2 years) and participated in a range of different sports including basketball, football, volleyball, and tennis [27]. Gymnastics requires a high level of flexibility, static and dynamic balance, so athletes who specialise in gymnastics might be expected to display better performance on the Y-Balance test as it is considered a measure of dynamic stability [38] and ROM [39]. Conversely, the balance requirements in team sports such as basketball and football are different and less frequent; thus, differences in the level of specialisation and performance on balance tests in these sports may vary. Nonetheless, a potential limitation of the Y-balance test is that it measures how far a person can reach in a specified direction, with no analysis of movement quality. Thus, it may be more accurately classified as a measure of flexibility and dynamic stability [38]. From these results it appears that the relationship between Y-balance tests and sport specialisation may be sport specific and depend on the demands of each sport. Reach asymmetries of greater than 4 cm have previously been linked to increased risk of lower extremity injury [40, 41]. Coaches and practitioners should be mindful of those who breach this threshold when interpreting results collected using this test with their athletes and implement targeted training programs to reduce these asymmetries.

4.4 Other movement components

Other components of movement competence investigated included range of motion [3, 24, 30, 32, 34], and muscular strength and endurance [30, 32, 34]. In some cases, the tests used were chosen based on the physical capacity requirements of the sport [30], whereas others selected tasks designed to identify athletes at greater risk of injury [3, 24, 31] or movements linked to gross motor skill development [34]. A broad jump was used in two studies [25, 34], both of which showed poorer performance in specialised athletes than multi-sport athletes. Similarly, cardiovascular fitness was lower in single sport athletes aged 10-12-year olds than those who participated in multi-sports [34]. One could speculate that improved performances in multi-sport athletes might be due to a varied exposure to a range of physical, cognitive, and psycho-social demands [3, 24, 34, 42] but this requires further investigation. Vertical jump [30, 32], agility [25, 30] and coordination [34] tests showed no significant difference. Due to the range of methods and/or measures used in these studies, it is difficult to compare the results and to determine if an association is present between these additional measures of movement competence and sport specialisation.

It should be noted that across all of the reviewed studies only athletes who specialised in gymnastics were reported to have improved performance in any of the reported measures [30]. Gymnastics and other sports where peak performance is attained prior to physical maturity, have been suggested to require early sport specialisation in order to reach elite performance levels [30]. In other sports, specialising in a single sport may lead to deficits in neuromuscular control and an increased risk of injury [3]. Coaches and practitioners should consider including periods of unstructured free play as well as exposure to a variety of movement tasks with differing demands during training when working with youth athletes, as well as regularly screening athletes for neuromuscular control deficits [3, 7, 24, 25].

4.5 Definitions of movement competency

Due to the broad range of approaches used to measure movement competency across the included studies, no standardised definition was present. It should also be noted that some measures included could be better classified as performance indicators, rather than measures of movement competency. Distance or height jumped do not give any indication of how the jump is performed. Similarly, agility tests which are measured purely as time taken to complete a set task give a better idea of speed, rather than an indication of movement quality. Using purely performance measures for these tests may not be sensitive enough to identify differences in movement mechanics or between limb differences [43, 44]. Additionally, studies have shown that although no difference is seen in performance, differences could exist in movement strategy, which could be potential indicators of increased risk of injury [43, 44]. There is a need for more comprehensive assessment of movement strategy as well as more well-defined definitions that can be applied to specific sport settings. This will enable researchers and coaches to objectively compare results and more accurately determine if there is an association between sport specialisation in different sports and movement competency development.

4.6 Definition of sport specialisation

The most widely accepted definition of sport specialisation is 'intense, year-round participation in a single sport to the exclusion of all other sports' [1]. All included studies used some or all parts of this definition; however, the method of implementation to classify athletes as specialised or not (or the level of specialisation), varied significantly between studies. Most (n=11) classified athletes dichotomously as either specialised or not, many based on the athlete self-reporting the number of sports they were currently participating in. In some cases, extra parameters were added to ensure single sport participants were specialised, including adding a lower limit (1-2 years) to the length of participation in a sport before one can be classified as being specialised [3, 7, 24]. Similarly, Barfield et al. [31] included a minimal time spent in training per year (8 months) as a requirement to be categorized as a specialised athlete. Three studies classified participants along a continuum, as low, moderate or highly specialised using the Jayanthi 3-point scale [27, 28, 30]. Two studies grouped participants based on the number of sports played during high school [26, 29], indicating a more standardised approach is warranted.

This argument is further illustrated by Miller et al. [27], who compared Y-balance results across specialisation groups using three different methods of classification; single vs multi-sport, the Jayanthi 3-point scale, and the Jayanthi 6-point scale. The Jayanthi scales were developed to cover the key aspects of specialisation; participating in a single sport, year-round, and exclusion of other sports [9]. The 3-point scale covers these in three questions, then classifies athletes as high, moderate, or low specialised. The 6-point scale includes an additional three questions around training volume and classifies athletes as specialised or not specialised. Miller et al. [27] reported the percentage of participants classified as specialised or highly specialised ranged from 28% to 55% depending on the method used. Furthermore, Y-balance results showed differences in asymmetry between groups using the 3-point and 6-point scales, but not when classified as single vs multi-sport. It is also important to note that while methods used to classify athletes as specialised incorporate some aspects of the most commonly accepted definition, none include all aspects. Specifically, none of the methods used to classify athletes incorporate a measure of intensity, despite defining sport specialisation as including 'intense participation'. This suggests that intensity is an aspect which should be included in the future development of a standardised classification system to determine the level of athletes' specialisation. To date there is no consensus in the literature around the definition of early specialisation, ranging from 12 years [45, 46] to 16 years [47]. The terms early specialisation and sport specialisation are often used interchangeably; however, there are subtle differences. Some level of sport specialisation is required to reach elite levels of sport performance [48]. However, evidence to support the importance of sport specialisation in youth athletes as a pre-requisite for future adult sporting success is lacking. A clearer consensus is required to more clearly differentiate between early specialisation and sport specialisation.

4.7 Quality analysis and risk of bias

Most studies were classified as having low risk of bias, with one classified as satisfactory [34] and high risk of bias [29] respectively. A criterion that consistently scored poorly was the control for confounding factors, which was only awarded to DiStefano et al. [25] and DiCesare et al. [3, 24]. It is expected that the risk of bias due to confounding is a domain that rates high in studies in this field of research, due to the nature and complexity of variables involved. Studies which scored a point for this item made some attempts to minimise or acknowledge the potential effects of confounders by controlling for maturation, gender, sport participation (type and/or volume) and injury history [3, 25, 30]. Clear links have been seen in previous research between movement strategies and maturation [49]. In the one prospective study included in this review, significant differences were shown in jump landing mechanics pre to post PHV [3]. Studies not fulfilling the criteria for control of confounding variables did not attempt to control for these [7, 24, 26-29, 31-34]. Inception/time lead bias is also a methodological issue present in all the reviewed studies due to participants not being followed before the onset of specialisation. This makes it difficult to accurately determine the length of time participants have specialised. In some cases, retrospective information was sought to find out how long participants had been specialised for [25, 30, 32]. However, this is problematic due to recall bias, and often players are simply classified based on their specialisation status at the time, with no attempt to determine how long they have been specialised. These limitations are further evident in the research of Herman et al. [26], who reported movement competency in adulthood in relation to high school sport participation. However, athletes who went on to become successful and play for regional or higher-level teams were excluded from the study. Arguably, this group may have been the high school sport athletes whose movement competence was most affected by their sport participation. Most of the studies reviewed were also cross-sectional or retrospective in nature, with only one study collecting prospective data [24]. To more clearly understand if a causal relationship is present between sport specialisation and the development of movement competency, prospective longitudinal studies are needed.

5. CONCLUSIONS

Available evidence to demonstrate a consistent association between the level of sport specialisation and movement competence is limited. Inconsistent methods and definitions used across studies makes comparison difficult. Tasks included to measure movement competence ranged from jump landing mechanics, Y-balance tests, muscular endurance, flexibility, movement control, and cardiovascular fitness. The results were inconsistent across studies; however, the data indicate that jump landing mechanics are often significantly different in multisport athletes, whereby greater movement competency is shown. This review highlights the need for sport specific research, as well as the development and use of consistent definitions and methods to assess both level of sport specialisation and movement competence in youth athletes.

ACKNOWLEDGEMENTS

The authors declare no conflicts of interest and no sources of funding were used to assist in the preparation of this review.

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Appendix 1: Search strategy

Early speciali?ation

AND

Movement competenc*

Movement ability

Movement control

Movement pattern

Physical performance

Coordination

Fitness

Motor skill

Motor development

Movement performance

Neuromuscular control

Balance

Asymmetr*

Sport Speciali?ation

AND

High school OR youth

AND

Movement competenc*

Movement ability

Movement control

Movement pattern

Physical performance

Coordination

Fitness

Motor skill

Motor development

Movement performance

Neuromuscular control

Balance

Asymmetr*

Early sport speciali?ation

AND

Movement competenc*

Movement ability

Movement control

Movement pattern

Physical performance

Coordination

Fitness

Motor skill

Motor development

Movement performance

Neuromuscular control

Balance

Asymmetr*

Single sport

AND

High school OR youth

AND

Movement competenc*

Movement ability

Movement control

Movement pattern

Physical performance

Coordination

Fitness

Motor skill

Motor development

Movement performance

Neuromuscular control

Balance

Asymmetr*

Appendix 2: Interpretations of quality analysis questions

1. Study design was clearly stated

Study design was stated either in the abstract or the methods section of the article.

2. Study objective/purpose is clearly stated

Study objective/purpose was outlined either in the abstract or introduction section of the article.

3. The study clearly states the inclusion criteria for participants

Inclusion and/or exclusion criteria was clearly outlined.

4. The characteristics of the population are detailed

Population characteristics including at least age, sex, and sport outlined.

5. The study population is representative of the intended population for which the research is aimed

Sample characteristics were clearly outlined including age, sex, and sport and matched those of the intended population. No additional exclusion criteria were applied to make the sample characteristics differ from the population of interest.

6. A justification for the selection of the sample/study population size is provided

Power calculation was used to inform the required sample size.

7. The methods used throughout testing are well detailed

Sufficient detail is provided to enable the reader to replicate the study.

8. The measurement tools used throughout the study are reliable and have been validated

As there is no validated measure of sport specialisation, this was applied only to the measurement of movement competence.

9. Detail on the statistical methods used was provided

Clear description of the statistical tests used, including significance levels.

10. The results of the study are well detailed

Results reported for all tests/measurements including raw data and outcomes of statistical tests.

11. The information provided in the paper is sufficient information was provided so to allow the reader to make unbiased assessment of the study findings

Raw data clearly reported allowing the reader to interpret these results, including information of statistical significance, variation, confidence intervals or effect sizes.

12. Confounding factors within the study are identified

Confounding factors were acknowledged, and some attempt was made to control for these.

13. Study funding/conflicts of interest were acknowledged

Funding/conflicts of interest clearly acknowledged.

14. Limitations to the study were identified

Main limitations of the study clearly outlined.

Appendix 3: Study quality and risk of bias assessment

INSERT TABLE A3 ABOUT HERE

Table 1: Summary of Study Characteristics

Study	N; Sport (%); sex (%); Methodology	Quality analysis (RoB)	Mean age, (SD)	Specialisation definition	Specialisation (%)	Movement measure description	Summary of differences
Barfield [31]	49; Softball (53%), Baseball (47%); Sex NR; Descriptive, cross-sectional	11 (Low)	12.96 (2.32)	≥8 months in season and quit another sport	High (32.7%); Low (67.3%)	Single leg squat (trunk lateral flexion, trunk axial rotation, trunk flexion)	No significant difference based on level of specialisation (p>0.05).
Beese [7]	40; Football (100%); Female (100%); Cross-sectional	12 (Low)	HS 15.05 (1.2); Low 15.32 (1.2)	Specialised competitively in 1 sport for ≥ 1 year	High (52.5%); Low (47.5%)	Jump landing (LESS)	No significant difference based on level of specialisation (p>0.05).
DiCesare [24]	158; Basketball, Football, Volleyball; Female (100%);	14 (Low)	13.4 (1.8)	≥2 years of participation in 1 sport and <2 years	High (50%); Low (50%)	Drop jump (knee flexion ROM, knee abduction ROM, knee internal rotation ROM, knee extensor moment, Knee	Significantly greater post-pubertal increase in HS for knee abduction ROM (p=0.005) and knee abduction moment

	Prospective, longitudinal			participation in any other sport		abduction moment, knee internal rotation moment)	(p=0.006). Significantly lower post-pubertal increase in knee extensor moment (p=0.032) in HS.
DiCesare [3]	732; Basketball (47%), Football (42%), Volleyball (11%); Female (100%); Cross-sectional	15 (Low)	13.8 (2.0)	≥2 years of participation in 1 sport and <2 years participation in any other sport	High (50%); Low (50%)	Drop jump (coupling angle variability in: hip flexion-knee flexion, knee flexion-ankle flexion, hip flexion-knee abduction, knee flexion/ abduction, knee flexion/ internal rotation, knee abduction/ internal rotation)	Dominant leg coupling angle variability was significantly greater for the HS in hip flexion-knee flexion (p=0.015), knee flexion-knee abduction (p=0.014), and knee flexion-knee internal rotation (p=0.048)
DiStefano [25]	355; Football (77%), Basketball (21%); Male (34%),	15 (Low)	11 (2)	Only played soccer or basketball in the previous year	High (25.6%); Low (74.4%)	Jump landing (LESS: scored as a continuous variable and dichotomous as good vs poor); jump (distance;	Significantly greater chance of poor performance in LESS (good/poor) (p<0.01) in HS.

	Female (66%); Cross-sectional					football players only); t-test (time; basketball players only)	Significantly lower performance in broad jump (p<0.01) in HS.
Fransen [34]	735; Sport NR; Male (100%); Cross-sectional	10 (Satisfactory)	6-8 (n=161) 8-10 (n=310) 10-12 (n=264)	Participation in only 1 sport during the year in which testing took place	6-8 years - High (36.6%); Low (63.4%) 8-10 years - High (48.7%); Low (51.3%) 10-12 years - High (42.8%); Low (57.2%)	Sit up test (# reps); Push up test (# reps); Hand grip strength; Broad jump (distance); Sit-and-reach test (distance); 10x5m shuttle run (time); Endurance shuttle run (time); Motor quotient (points based on performance of walking backwards, moving sideways, hopping for height, jumping sideways)	6-8yrs: Significantly lower hand grip strength (p<0.05) in HS. 8-10yrs: no significant difference between groups. 10-12yrs: significantly lower performance in Endurance shuttle run test (p<0.05), push up test (p<0.01), broad jump (p<0.01), sit-and-reach test (p<0.01) and motor quotient (p<0.01) in HS.

Gorman [33]	184; Sport NR; Male (74%), Female (26%); Cross-sectional	11 (Low)	15.9 (1.2) (SS); 15.4 (1.2) (MS)	Participate in only 1 high school sport	High (50%); Low (50%)	LYBT (absolute reach, relative reach, composite reach, reach asymmetry)	No significant difference between specialisation groups ($p>0.05$).
Herman [26]	Basketball (38%) 50; Volleyball (18%), Football (46%), Lacrosse (22%); Male (56%), Female (44%); Retrospective, cross-sectional	13 (Low)	No sport 23.4 (3.1); SS 23.8 (2.5); MS 24.1 (2.2)	Participated in 1 sport at varsity level in high school	SS (42%); MS (36%); No sport (22%)	Jump landing (LESS)	Significantly poorer performance in no sport ($p=0.002$) and SS ($p=0.004$) groups than MS. Significantly fewer errors ($p=0.004$) with each additional sport played.
Miller [27]	295; Basketball, Football, Volleyball (only female),	12 (Low)	15.6 (1.2)	Self-classified SS 3-point scale 6-point scale	SS/MS (28.4%/71.6%); 3-point	LYBT (absolute anterior reach, anterior reach asymmetry)	No significant difference in absolute anterior reach distance between specialisation groups.

	Tennis, Male (40%) Female (60%); Cross-sectional				High/Low (36.2%/NR); 6-point High/Low (54.9%/45.1%)		Anterior reach asymmetry significantly greater in mod specialised group (p=0.009).
Peckham [28]	574; Football (34%), Volleyball (17%), American Football (6%), Basketball (36%), Tennis (8%); Male (43%) Female (57%); Cross-sectional	13 (Low)	Male 16 (1); Female 15 (1), 16 (1)	3-point scale	High (31.1%) Mod (30.5%) Low (38.4%)	Jump landing (LESS)	No significant differences in LESS score between groups (p>0.05).

Root [30]	131; Gymnastics (100%); Male (36%) Female (64%); Retrospective cross-sectional	13 (Low)	10.9 (2.9)	3-point scale	High (14.5%) Mod (50.4%) Low (35.1%)	Vertical jump (height); Hanging pike test (# reps); Normalised shoulder flexibility test (ROM); Agility test (time); Pull-up test (# reps); Push-up test (# reps); Handstand test (time); Plank (time); Double leg lower (Controlled ROM); Hollow hold (time); Bridge (time); Single-leg hop (distance); UYBT (relative reach distance); LYBT (relative reach distance); Jump landing (LESS)	Significantly greater normalised shoulder flexibility in high and mod compared to low specialised (p=0.035). Significantly greater hop distance (right leg) in high specialised compared to low (p=0.039). Significantly greater Left UYBT reach distance in high and mod specialised compared to low (p=0.033). Significantly greater LYBT right (p=0.004) and left (p=0.055) in high and mod specialised compared to low.

Sugimoto [32]	236; Sport NR; Female (100%); Cross-sectional	11 (Low)	SS 15.3 (1.6); MS 14.3 (1.7)	Participate in 1 sport	High (25.4%) Low (74.6%)	ROM (knee extension, knee flexion, ankle plantarflexion); Strength (knee extensor, knee flexors, hip abductors, hip adductors); Vertical jump (height); Front plank (time)	Significantly greater right (p=0.003) and left (p=0.011) ankle plantarflexion ROM in HS. Significantly lower right knee extensor strength (p=0.05) in HS.
Triplett [29]	100; Football (21%), Volleyball (24%), Basketball (39%), Track (40%), NR sports (9%); Male (43%) Female (57%); Retrospective, cross-sectional	5 (High)	19.5 (1.7)	Number of sports participated in during high school	NR	FMS	Significant, positive correlation, FMS score improved as number of sports in high school increased. Significant, positive correlation, FMS score improved as number of sports seasons increased

Abbreviations used in table: NR=Not reported, SS=Single sport, HS=High specialised, MS=Multi-sport, Mod=Moderate, LESS=Landing error scoring system, ROM=Range of motion, LYBT=Lower body Y-Balance test, UYBT=Upper body Y-Balance test, FMS=Functional movement screen, # reps=Number of repetitions, RoB=Risk of bias

Table A3: Study Quality and Risk of Bias Assessment

Study	Barfield [31]	Beese [7]	DiCesare [24]	DiCesare [3]	DiStefano [25]	Fransen [34]	Gorman [33]	Herman [26]	Miller [27]	Peckham [28]	Root [30]	Sugimoto [32]	Triplett [29]
Study design was clearly stated	0	1	1	1	1	1	0	1	1	1	1	1	1
Study objective/ purpose is clearly stated	1	1	1	1	1	1	1	1	1	1	1	1	1
The study has a clearly testable hypothesis	1	1	1	1	1	1	0	1	1	1	1	1	1
The study clearly states the inclusion criteria for participants	0	1	1	1	0	0	1	1	1	1	1	0	0

The characteristics of the population are well detailed	0	0	1	1	1	0	0	1	0	0	1	1	0
The study population is representative of the intended population for which the research is aimed	1	0	1	1	1	0	0	0	0	0	1	0	0
A justification for the selection of the sample/study population size was provided	1	1	0	0	1	0	1	0	0	1	0	0	0

The methods used throughout testing are well detailed	1	1	1	1	1	0	1	1	1	1	0	0	0
The measurement tools used throughout the study are reliable and have been validated	1	1	1	1	1	1	1	1	1	1	1	1	1
Detail on the statistical methods used was provided	1	1	1	1	1	1	1	1	1	1	1	1	0
The statistical methods used to analyse the data were appropriate	1	1	1	1	1	1	1	1	1	1	1	1	0

The results of the study are well detailed	1	1	1	1	1	1	1	1	1	1	1	1	0
The information provided in the paper is sufficient information was provided so to allow the reader to make an unbiased assessment of the study findings	1	1	1	1	1	1	1	1	1	1	1	1	0
Confounding factors within the study are identified	0	0	1	1	1	0	0	0	0	0	1	0	0

Study funding/ conflicts of interest were acknowledged	0	0	1	1	1	1	1	1	1	1	0	1	0
Limitations to the study were identified	1	1	1	1	1	1	1	1	1	1	1	1	1
Total (/16)	11	12	15	15	15	10	11	13	12	13	13	11	5
RoB	Low	Low	Low	Low	Low	Satisfactory	Low	Low	Low	Low	Low	Low	High

Risk of bias (RoB) classified as high (0-5), satisfactory (6-10), or low (11-16).

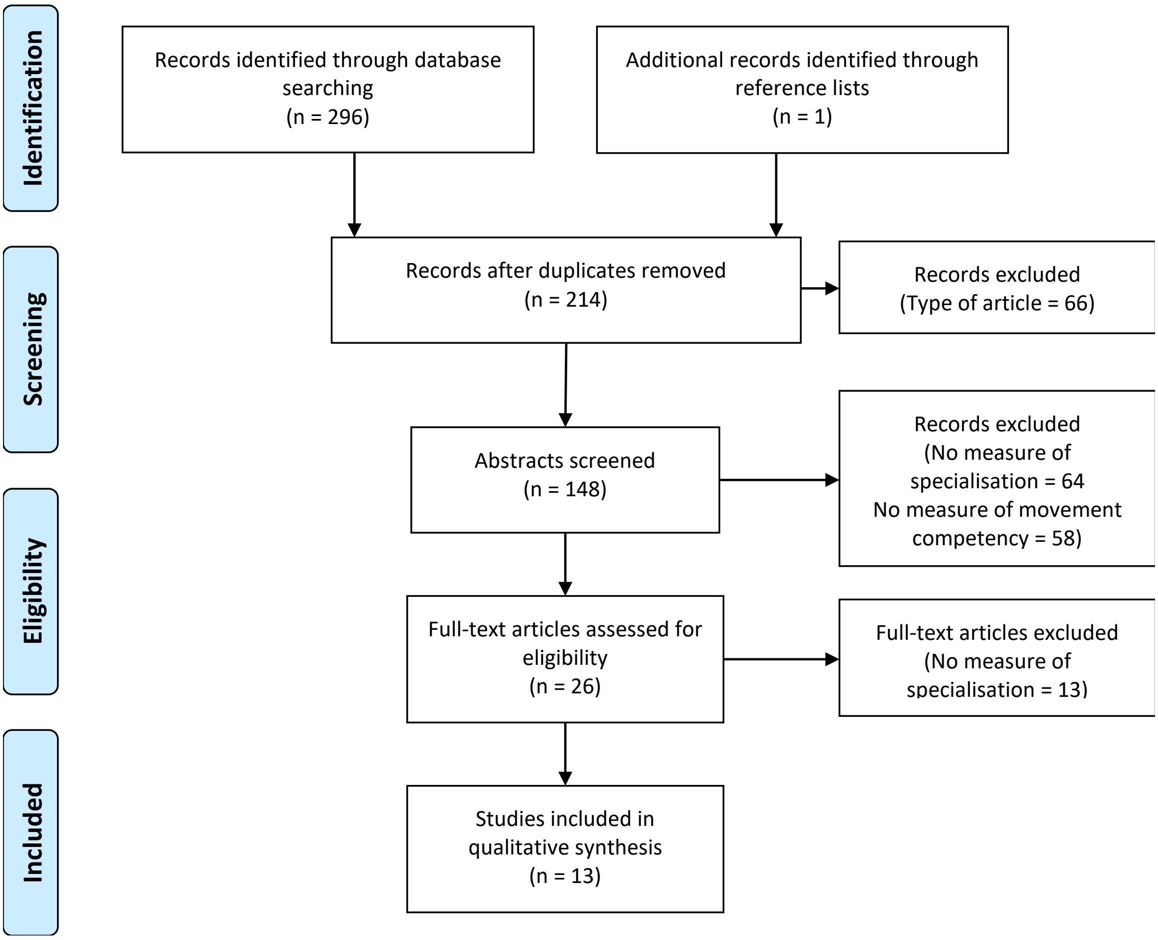

Figure 1: PRISMA Flow Diagram Showing the Selection Process