Title: Growth, maturation and overuse injuries in dance and aesthetic sports: A Systematic Review

Kolokythas N, Metsios G, Dinas P, Allen N, Galloway S, Wyon M

Research in Dance Education

Abstract

Overuse injuries are the most prevalent injuries in aesthetic sports, due to the repetitive nature of the training. Evidence of their relationship with growth, maturation, and training load is equivocal. The objective of this study was to investigate the effects of these factors on overuse injuries in dance and aesthetic sports. A database search was conducted using standard methods for article identification, selection, and risk of bias appraisal. The eligibility criteria for inclusion in the study consisted of peer-reviewed articles using any type of study design. Twenty-three studies met the criteria. These studies were cross-sectional in design, focusing on dance, gymnastics and diving. Nineteen studies indicated a positive association between growth, maturation, and overuse injuries and a further 6 reported a positive association with training load. There were inconsistencies in how the included studies accounted for important confounding associations of growth and maturation, in addition to showing high or unclear risk of bias. In conclusion, both the quantity and quality of research available on growth, maturation, and training load in association with overuse injuries in dance and aesthetic sports is lacking. The methodological approaches used, combined with the heterogeneity of the investigated populations, lead to equivocal and thus inconclusive results.

Key Words: sports; dance; ballet;

gymnastics; diving; ice-skating; synchronised swimming; adolescent

Introduction

Aesthetic sports are disciplines where performance is partly or mainly evaluated on the basis of criteria like "artistry" and "style"[1] with recent studies accepting these are: dance (e.g. ballet, modern), figure-skating, gymnastics, rhythmic-gymnastics, diving and synchronised swimming.[2] Training for these sports or activities may start as early as five or eight years old in ballet, gymnastics and synchronized-swimming, respectively.[3] It is accepted that elite performance in these disciplines relies on early-specialisation training,[4] defined as sport or disciplines based on the following three criteria: a) participation in intensive training and/or competition greater than eight months per year, b) exclusion from participation in other sports, and c) involving children around the age of 12.[5]

Early specialisation training is intensified during adolescence, i.e. ages between 10 and 19 years old.[4] During this period adolescents go through accelerated growth and maturation.[6] Growth refers to changes that can be quantified, either in the size of the body or the size of specific body regions, while maturation, refers to both functional and structural qualitative changes in the system of the body's progress towards a mature state.[7] Epidemiological studies,[8] systematic[9] and narrative reviews[10-12] indicate that during this period of accelerated growth, adolescent athletes are more susceptible to overuse injuries.

An overuse injury is microtraumatic damage to tissues (e.g. bone, muscle, tendon) due to repetitive submaximal loading without sufficient time to heal or undergo the natural reparative process.[13] Associated risk factors for an overuse injury have been identified as growth factors (e.g. growth-spurt) intrinsic factors (e.g. previous injury, menstrual dysfunction) and extrinsic factors (e.g. training load or technique).[14] Training or external load is any sport related work completed by the athlete over varying periods (from seconds to years) with varying magnitude (duration, frequency and intensity) and is measured independently of their individual characteristics (i.e. level of fitness).[10] However, the lack of uniform definitions on injury and illness prevalence in all aesthetic sports,[15] or training load, together with the fact that literature reporting overuse injuries depends on recall, self-reported data and are retrospectively collected, can make their reliability and comparability questionable. Moreover, the lack of data on children and adolescents makes it difficult to determine the causal relationship between overuse injuries growth and maturation.[16]

Despite the high incidence of overuse injuries in adolescents in sport,[9,17] such injuries are underestimated (45.9% to 54%) over acute injuries mainly because most epidemiological studies define injury as time loss from participation.[17] In aesthetic sports/activities, overuse injuries have higher prevalence than acute injuries. More specifically, these are 64.4% in gymnastics,[8] 44.1% in figure skating,[18] and 72% in pre-professional dancers.[19] A number of mechanisms are hypothesised on the reason behind the increased injury occurrence in adolescents. During this period of accelerated growth, there are changes to limb length, limb mass and moments of inertia.[20,21] These changes may cause delays or regressions in specific motor control aspects such as neuromuscular control, postural stability and intersegmental/interlimb coordination.[22] In addition, maturity timing or status, or the combination of both may affect interlimb asymmetry and neuromuscular control that could potentially lead to increased likelihood of injury.[23] Evidence of the relationship of injuries with growth and maturation in aesthetic sport or activities is either equivocal or not well-established.[24] This complex biological process varies vastly in adolescents, therefore, a better understanding is warranted in order to be able to minimise the risk of injuries at a young age as they increase the risk of reinjury at a later stage.[8,16] The aim of this systematic review, therefore, was to investigate the association between growth and maturation with overuse injuries. The review focused on one indicator of growth, stature and on two indicators of maturation, skeletal and chronological age, and menarche. The secondary aim was to explore whether training load was associated with growth, maturation in the prevalence of overuse injuries in aesthetic sports or activities.

METHODS

Search methods for identification of articles

Using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines[25] four electronic databases, EMBASE, PubMed, CINAHL, and Sport Discus were searched up until 19 August 2018 to identify potentially relevant articles. Table 1 depicts the combination of Medical Subject Headings (MeSHs) and text words used in our search. Two investigators (NK and PCD) independently conducted two identical searching actions in the aforementioned databases. The search strategy was adapted from the American Medical Society for Sports Medicine position statement on overuse injuries and burnout in youth sports.[17] The concepts around sports/athletics were, therefore, adapted in order for the search algorithm to be appropriate for aesthetic sports (see TABLE 1).

TABLE 1. Databases search algorithms

EMBASE strategy:
(sport* or dance* or ballet or gymnast* or rhythmic w2 gymnast* or artistic w2 gymnast* or vault or still w2 rings or horizontal w2 bar or balance w2 beam or pommel w2 horse or uneven w2 bars or ice w2 skat* or figure w2 skat* or synchronized w2 swim* or aesthetic w2 sport* or aesthetic w2 athlete).ab. AND (cumulative w3 trauma disorder* or athletic w2 injur* or injur* or trauma or adverse w2 effect* or adverse w2 event* or overuse).ab. AND (youth or adolescent or adolescence).ab. AND (matur* or maturity w2 status or maturity w2 timing or skeletal w2 age or peak w3 height velocity or growth w2 spurt or growth w2 tempo or growth w2 velocity or menarche).ab.
PubMed strategy:
((((((((((((((((((((((((sports[MeSH Terms]) OR sport*[Text Word]) OR dance[Text Word]) OR ballet[Text Word]) OR gymnastics[MeSH Terms]) OR gymnast*[Text Word]) OR artistic w2 gymnast*[Text Word]) OR rhythmic w2 gymnast*[Text Word]) OR vault[Text Word]) OR still w2 rings[Text Word]) OR horizontal w2 bar[Text Word]) OR balance w2 beam[Text Word]) OR pommel w2 horse[Text Word]) OR uneven w2 bars[Text Word]) OR ice skating[MeSH Terms]) OR ice w2 skat*[Text Word]) OR figure w2 skat*[Text Word]) OR synchronized w2 swim*[Text Word]) OR aesthetic w2 sport*[Text Word]) OR aesthetic w2 athlete*[Text Word])) AND (((((((((cumulative trauma disorders[MeSH Terms]) OR athletic injuries[MeSH Terms]) OR injur*[Text Word]) OR trauma[Text Word]) OR adverse effects[MeSH Terms]) OR adverse w2 effect*[Text Word]) OR adverse w2 event*[Text Word]) OR overuse injuries[MeSH Terms]) OR overuse[Text Word])) AND (((((youth[MeSH Terms]) OR youth[Text Word]) OR adolescent[MeSH Terms]) OR adolescence[MeSH Terms]) OR adolescen*[Text Word])) AND ((((((((((matur*[Text Word]) OR maturity w2 status[Text Word]) OR maturity w2 timing[Text Word]) OR skeletal w2 age[Text Word]) OR peak w3 height velocity[Text Word]) OR growth w2 spurt[Text Word]) OR growth w2 tempo[Text Word]) OR growth w2 velocity[Text Word]) OR menarche[MeSH Terms]) NOT ((animal[MeSH Terms] NOT human[MeSH Terms])))
SPORTDiscus strategy:
(((Sport*) OR (danc*) OR (ballet) OR (gymnastic*) OR ((artistic w2 gymnastic* OR rhythmic w2 gymnastic* OR vault OR still w2 rings OR horizontal w2 bar OR balance w2 beam "or" "or" pommel w2 horse OR uneven w2 bars)) OR ((ice w2 skat* OR figure w2 skat*)) OR (synchronised w2 swim*) OR (aesthetic w2 sport*)) AND ((cumulative trauma disorders) OR (injur*) OR (trauma) OR (adverse w2 effect* OR adverse w2 event*) OR (overuse injuries) OR (overuse)) AND ((youth) OR (adolescent*) OR (adolescence)) AND ((matur*) OR (skeletal w2 age) OR (peak w3 height velocity) OR (growth w2 spurt) OR (growth w2 tempo) OR (growth w2 velocity) OR (menarche)))
CINHAL strategy:
Sport* OR danc* OR ballet OR gymnastic* OR ((artistic w2 gymnastic* or rhythmic w2 gymnastic* or vault or still w2 rings or horizontal w2 bar or balance w2 beam or pommel w2 horse or uneven w2 bars)) OR ((ice w2 skat* or figure w2 skat*)) OR synchronised w2 swim* OR aesthetic w2 sport* AND cumulative trauma disorders OR injur* OR trauma OR (adverse w2 effect* OR adverse w2 event*) OR overuse injuries OR overuse AND youth OR adolescent* OR adolescence AND matur* OR skeletal w2 age OR peak w3 height velocity OR growth w2 spurt OR growth w2 tempo OR growth w2 velocity OR menarche

Eligibility criteria for considering articles for the review

Studies that measured and/or investigated the relationship/effects between growth, maturation and injuries were included. Participants had to be involved in aesthetic sports/activities, either recreationally or professionally. In addition, we included studies where the effects and/or associations of growth and maturation with overuse injuries could be separated for the target population. Studies that just reported the prevalence of injuries without investigating associations or effects between growth, maturation and injuries in adolescents were excluded. The search strategy was not limited by language.

Selection of studies

Two authors (NK and PCD) independently screened and assessed the identified articles for eligibility. Potentially relevant studies were merged from each database and duplicates were removed. The articles were screened by title and by abstract and 196 articles were retrieved and screened for eligibility. Disagreements on study eligibility were resolved through consensus between NK and PCD or, when necessary, there was a meeting with a third author not involved in the assessment (MW). Full-text copies of all potentially relevant studies were retrieved and reviewed.

Data extraction

Two authors (NK and PCD) independently extracted data using a pre-agreed data extraction form (**TABLE 2**). Characteristics of studies extracted included study design, sport/activity, method of assessment, primary and secondary outcomes. Disagreement was resolved by discussion, followed if necessary, by scrutiny from a third author (MW). The primary outcomes were extracted according to the relationship between growth, biological maturation, maturity status and timing, with overuse injuries including stress fractures but excluding acute injuries. Two biological maturation markers that are commonly assessed are the skeletal age (SA) and the secondary sex characteristics.[26] Both represent the chronological age (CA) of an individual when a specific level of maturity (status) of the hand-wrist bones, or the genitals was reached. Skeletal age is always relative to CA as it has limited utility as an individual value. The CA when specific maturation events take place correspond to maturity timing, which is commonly assessed by age at peak height velocity (PHV) and age at menarche.[26] The secondary outcomes were extracted based on the relationship between training load (hours per week, months per year) and overuse injuries.

Risk of bias assessment

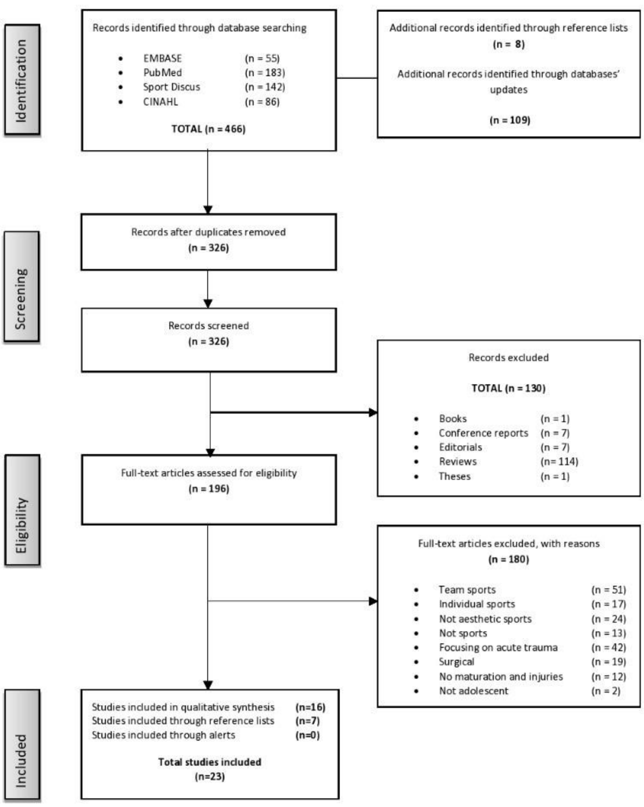
Two researchers (NK and PCD) both independently and in duplicate assessed the risk of bias of the included publications. Disagreement was resolved by discussion followed if necessary, by scrutiny from a third author experienced in conducting systematic reviews (GSM). The assessment of the quality of reporting was not implemented, as there is no evidence for such appraisals so they can create a misleading score and results. The use of quality scales and summarised scores can be problematic, as a biased but well reported study can receive credit, whereas, a well conducted study but poorly reported will be misclassified.[27] For this assessment the Research Triangle Institute item bank (RTI-IB) was utilised. This recently revised tool covers observational study designs and comes with guidelines for the appropriate use and scoring.[28] As recently reported a study with one or more of the key items being rated negative or unclear was rated as of high risk of bias. The risk of bias assessment was then based on the creation of a threshold in relation to the context of this review, as per RTI-IB guidelines.[28] Given that odds ratio and relative risk should be reported in observational studies in order to minimise outcome reporting bias, we completed the assessment having taken the latter into consideration.

RESULTS

Included studies

A total of 466 potentially relevant articles were identified from the primary search. The articles were screened based on the title and abstract. After the duplicates were removed, 326 articles were screened for eligibility, leaving 16 eligible studies. The references of these 16 articles were checked in order to identify any more relevant publications; seven new articles were identified (total articles included, n=23). We requested unreported data from one author but there was no response.[29] The searching outcome and process is presented in the PRISMA flow diagram in **FIGURE 1**.

Figure 1. PRISMA flow diagram of the searching outcome process



Design

The design of the included studies along with sample size, mean age and assessments appear in **TABLE 2**. All studies were published between 1986 and 2014 and study locations included USA, Europe, China and Australia. No randomised controlled trials addressing the effect of growth and maturation on overuse injuries in aesthetic sports were available. This review (n=23) therefore was based on observational studies. Seven of the studies (7/23) were cohort,[8,30-35] five case-series (5/23),[36-40] two case-control (2/23),[41,42] and nine cross-sectional studies (9/23).[29,43-50]

TABLE 2. Summary of included studies

First Author, Year of publication, Country	Level of performance	Sport or Discipline	Gender, Sample Size	Mean Age	Study Design/Length	Assessment	Primary Outcome	Secondary Outcome
Amaral et al. [43] 2012; Portugal	National-International	Gymnastics	Female n=33	11.1±2.1	Cross-sectional	X-Rays, Skeletal maturation: Tanner Whitehouse TW3 method, Training data: interviews	Association between Ulnar Variance and skeletal age was noted (r=0.38; p<0.05)	n/a
Caine, Cochrane et al. [8] 1989; USA;	Elite	Gymnastics	Female n=50	12.6	Cohort-prospective/ 1 year	Musculoskeletal screening, maturity assessment: Tanner's stages, injury surveillance	Association of competitive level (P<0.05) and maturation rate (P<0.06) in determining high or low injury risk.	n/a
Carter and Aldridge [38] 1988; United Kingdom	Mixed level	Gymnastics	Female n=4 Male n=17	13.8	Case series/ 4 years	Skeletal maturation: X-Rays	Association of injuries with skeletal age	n/a
Carter et al. [33] 1988; USA;	Competitive	Gymnastics	Male n=8	14.1	Cohort/ 27 months	Injury prevalence: questionnaire and X-rays	Association of chronological age and overuse injuries	n/a
Chang et al. [34] 1995; China	Elite	Gymnastics	*Study group:* Females (n=143), Males (n=118); *Control group:* Females (n=44), Males (n=19)	*Study group:* 14.4±2.4 *Control Group*: 13.9±1.4	Case control	Injury prevalence: questionnaire and X-rays	Association of repetitive stress in the wrists of adolescent gymnasts and localized growth disturbance of the distal-radius.	n/a
Goldstein et al. [49] 1991; USA	Pre-elite, Elite, National	Gymnastics Swimming	n=52	*Pre-elite* 11.8±1.1, *Elite* 16.6±1.6, *National* 25.7±3.5-: *AA/AAA* 14.6±2, *National* 18.6±1.6	Cross sectional-epidemiologic investigation	Demographic and training load data: interview, Injury prevalence: MRI	n/a	Association of chronological age and training hours per week with higher % of positive MRI results. Predictive value of 83.3% for MRI+ gymnasts and 73.3% for MRI- gymnasts
Kolt [35] 1999; Australia	Elite, sub-elite	Gymnastics	Female n=64	12.6±1.7	Cohort/18 months	Injury prevalence & training load: self- reported log.	n/a	Growth plate injuries associated with loading (hours per week).

TABLE 2. (cont.) Summary of included studies

First Author, Year of publication, Country	**Level of performance,**	**Sport or Discipline**	**Gender, Sample Size**	**Mean Age**	**Study Design/Length**	**Assessment**	**Primary Outcome**	**Secondary Outcome**
Lindholm et al. [41] 1994; Sweden	Elite, sub-elite	Gymnastics	*Study group:* Female (n=22) *Control group*: Female (n=22)	*Study group:* Mean age= 15±0.8 *Control group:* Mean age=15±0.7	Case Control-prospective/ 5 years	Anthropometric data, hormonal analysis: immune-metric methods, maturation stage: Tanner's stages	Association of injury occurrence with hard training combined with late menarche compared with the control group (p<0.05)	n/a
Maffulli et al. [40] 1992; England	Club to international gymnasts	Gymnastics	Females (n=6), Males (n=6)	13.5	Case Series-prospective/ 11 years	Injury prevalence through X-rays	Association of chronic stress and skeletal immaturity with high incidence of osteochondritic lesions, intraarticular loose bodies	n/a
Purnell et al. [45] 2010; Australia	Mixed level	Gymnastics	Females (n=69) Males (n=4)		Cross-sectional-retrospective	Survey	A moderate correlation between increased chronological age and occurrence of chronic injury (r=0.561)	Chronological age and loading (hours per week) were a risk factor for injuries.
De Smet et al. [44] 1994; Unspecified-	Elite	Gymnastics	n=201	15.9	Cross-sectional	Anthropometric survey and X-rays	No association of ulnar variance and carpal angle with chronological age (p value not reported)	The impact load and compression may be more important than repetition (estimated by hours of training and years of gymnast activity).
Bowerman et al. [31] 2014; Australia	Elite	Dance	Females (n=30), Males (n=16)	16±1.58	Cohort- prospective/ 6 months	Maturation assessment: Tanner stages, Skeletal maturation assessment: foot length, Alignment assessment: 2D video analysis	Growth is associated with a small to moderate increase in risk of lumbar and lower extremity overuse injury (RR= 1.41, CI= 0.93-2.13).	n/a
Steinberg, Siev-Ner [50] 2011; Israel	Recreational	Dance	Female (n=1336)	13.3	Cross-sectional	Injury prevalence: interviews, X-rays, MRI	Association of injury, re-injury and chronological age and growth spurt (P<0.001). The prevalence of injured girls increased significantly (P<0.001) from the age 8 to age 16	n/a

TABLE 2. (cont.) Summary of included studies

First Author, Year of publication, Country	Level of performance,	Sport or Discipline	Gender, Sample Size	Mean Age	Study Design/ Length	Assessment	Primary Outcome	Secondary Outcome
Steinberg et al. [46] 2013; Israel	Recreational	Dance	Female (n=569)	Mean Range age=8-16	Cross-sectional (Descriptive epidemiology study)	Questionnaires for participation, Self-reported injuries, interview for females, anthropometric data	Chronological age and age at menarche associated with injuries (p value not reported)	n/a
Warren et al. [42] 1991; USA;	Professional	Dance	Female (n=98) Control group: (n=47)	21.87±4.5 (range 13-29)	Case Control	Interviews, anthropometric, venous sample, bone density scans	Association between age at menarche and stress fractures (r=0.28, P<0.004).	n/a
Warren et al.[48] 1986; USA	Professional	Dance	Female (n=75)	24.3	Cross-sectional	Survey	Correlation between stress fracture and age at menarche r= 0.4, p<0.01	n/a
Kadel [29] 1992; USA	Professional	Dance	Female (n=54)	20.2±4.4	Cross-sectional	Injury prevalence & age at menarche: Survey	No correlation between chronological age and incidence of stress fracture, no association between age at menarche and stress fracture (P value not reported).	Dancers who had prolonged amenorrhoeic intervals (>6months), (F5.3,1644=93, P= 0.002) and danced >5 hrs per day (F1.7, 150= 16, P= 0.015) were significantly more likely to have a stress fracture than those dancing <5 hrs per week.

TABLE 2. (cont.) Summary of included studies

First Author, Year of publication, Country	Level of performance	Sport or Discipline	Gender, Sample Size	Mean Age	Study Design	Assessment	Primary Outcome	Secondary Outcome
Steinberg et al. [32] 2014; United Kingdom;	Recreational	Dance	Female (n=588) Males (n=218)	13.5±2.3	Cohort	Questionnaires for participation, Injury prevalence: Self-reported, interview: menarche, anthropometric data	No significant association in the rate of injuries and chronological age (p=0.59)	Total months in the Centres for Advanced Training (OR= 1.044, 95% CI= 1.014-1.075) and hours per week in creative style practice (OR= 1.282, 95% CI= 1.068-1.539) - significantly associated with injuries for all dancers.
Steinberg, Hershkovitz et al. [37] 2011; Israel	Recreational	Dance	Female (n=1082)	Range age 8-16	Case Series-retrospective	Interview, clinical assessment, anthropometric data, ROM, Dance technique	No association of injury was found with age of onset of menarche (P=0.34). No significant association of chronological age and overuse injuries.	Hours of practice per week associated with increased rate of injury (11.5 hours per week for the injured dancers vs 7.9 hours per week for the uninjured (P<0.001)).
Baranto et al. [30] 2006; Sweden	Not specified	Divers	Females (n=14) Males (n=6)	16.4±3.1	Cohort	MRI, injury data: questionnaires, self-assessment, Oswestry questionnaire	Association of back pain and chronological age.	n/a
Loud et al. [36] 2005; USA;	Not specified	Mixed sport	Female (n=5461)	13.9±1.6	Cross-sectional-retrospective/ 4 years	Review of self-reported data of a National Study	Chronological age was strongly associated with a history of stress fracture.	Girls participating in ≥16 hours per week had a significantly higher risk of stress fracture (1.88; 95% CI:1.18-3.03).

TABLE 2. (cont.) Summary of included studies

First Author, Year of publication, Country	**Level of performance**	**Sport or Discipline**	**Gender, Sample Size**	**Mean Age**	**Study Design**	**Assessment**	**Primary Outcome**	**Secondary Outcome**
Micheli and Fehlandt [39] 1992; USA;	Not specified	Mixed sport	Females (n=253) Males (n=193)	Range age 8-19	Case Series-retrospective	Review of cases	Association of growth and maturation with higher risk of injury occurrence.	n/a
Thein-Nissenbaum et al. [47] 2012; USA;	Recreational	Mixed sport	Female (n=249)	15.3±1.1	Cross-sectional-retrospective	Injury prevalence & menstrual irregularity: Survey	Non-significant association of menstrual irregularity and overuse injuries (Odds ratio=2.7, 95% CI=0.8, 8.8)	n/a

Participants and setting

The total number of participants involved in all 23 studies was 10,146. Eight studies (8/23) included female (n=1151) and male participants (n=597).[30-32,34,38-40,45] Fifteen studies included single gender (n=8398); 14 out of these 15 studies included solely female 100% (n=8390) participants,[8,29,35-37,41-44,46-50] whereas one out of these 15 studies included solely male <1% (n=8) participants.[33] It was noted that from one big study cohort, the authors have published two reports;[37,50] we have included in this review only the Steinberg *et al.*[50] study (n=1336) and excluded the other report Steinberg *et al.*[37] (n=1082). There were three studies that included control groups in the study design.[34,41,42] Eleven studies (11/23) were in gymnastics.[8,33-35,38,40,41,43-45,49] Two studies (2/23) were in ballet,[29,31] and six studies (6/23) in dance (ballet, modern, jazz).[32,37,42,46,48,50] One study (1/23) was in diving,[30] and three studies (3/23) were in a mixture of sports but included aesthetic sports athletes in their cohorts where sport-specific results could be extracted.[36,39,47]

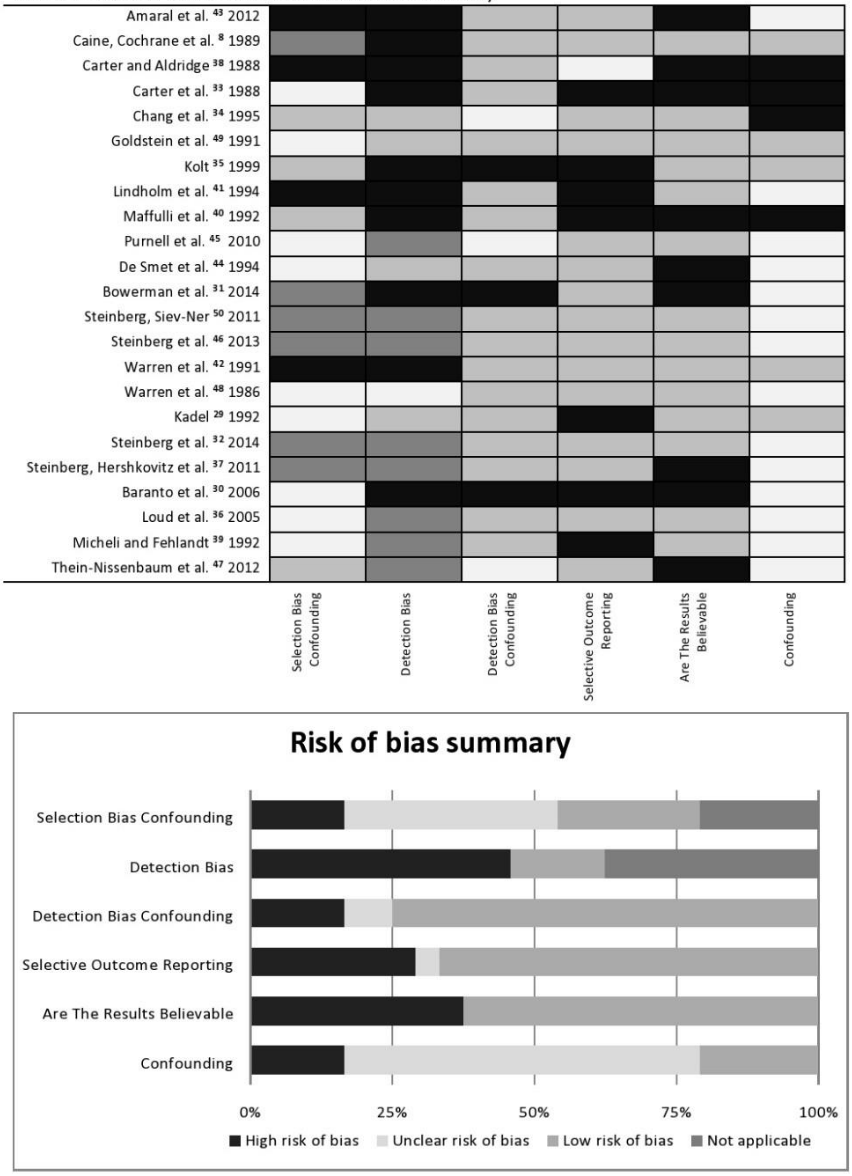
Level of performance

The level of performance (elite, pre-elite, sub-elite, professional, competitive, recreational) is reported according to the authors' classification. Thirteen studies (13/23) focused on elite/pre-elite/sub-elite/professional athletes,[8,29-31,34,35,40-44,48,49] and one study (1/23) was on competitive athletes.[33] Five studies (5/23) were on recreational athletes,[32,37,46,47,50] and two (2/23) were conducted on mixed populations of athletes;[38,45] finally, two studies (2/23) did not specify the level of performance.[36,39]

Risk of bias

The risk of bias assessment results and summary are displayed in **FIGURE 2**.

FIGURE 2. Risk of bias assessment results and Summary



Overall, the selected studies either showed high or unclear risk of bias in the selected quality areas as all 23 (23/23) scored on one or more key items either negative or unclear. In particular, confounding (i.e. retrospective data collection, length of study) was found to be the biggest risk of bias indicator as only five studies (5/23) took relevant confounders into consideration.[8,29,35,42,49] This together with the lack of blinding, either because it was not possible (9/23) due to the nature of the study (i.e. retrospective survey) or simply not included (11/23) increased bias due to not taking into account potential confounders that may have affected the reported results. Additionally, only three studies (3/23) reported a control group.[34,41,42] This made the selection bias confounding the second highest risk of bias indicator. Detection bias confounding showed low risk of bias (18/23), however, methodologically more robust studies failed to report serious methodological flaws and, therefore, were considered as high risk of detection bias. Specifically, Baranto et al.[30] used a higher specification magnetic resonance imaging scanner in the follow up compared to baseline. Bowerman et al.[31] utilised inappropriate maturation monitoring protocols; namely the size of the foot. Sixteen studies (16/23) showed low risk of bias on selective outcome reporting, however, seven studies (7/23) showed high risk of bias by missing out important statistical analysis or values,[29,30,33,35,39-41] while for one study (1/23) there was unclear risk of bias as authors did not statistically analyse their observed data.[38] Finally, 14 studies (14/23) showed low risk of bias in the believability of the results, however, the lack of confounding consideration and the nature of data collection through surveys and retrospective medical records decreased the validity of the reported results.[8,29,32,34-36,39,41,42,45,46,48-50]

Data Synthesis

Results of studies that were relevant to the primary and secondary objectives are summarised in **TABLE 2**. Due to the fact the studies were all cross-sectional, the reporting of outcomes in this section is broken down into relevant aesthetics sports/activities, rather than study design.

Gymnastics

Primary Outcome: Out of the 11 studies, two prospective studies reported a positive association of maturation[8] and age at menarche[8,41] with overuse injuries. Maturation rate was determined according to Tanner & Whitehouse.[51] Six studies[33-35,38,40,43] reported a positive association of skeletal age, and overuse injuries. Two studies,[45,49] indicated a positive association of chronological age and overuse injuries. One study[44] reported no association of chronological age and overuse injuries.

Secondary Outcomes: Three studies[44,45,49] reported a positive association of training load and overuse injuries.

Dance

Primary outcomes: Out of the nine studies that focused on dance (ballet, classical-ballet, modern and jazz), three[42,46,48] reported a positive association of age at menarche and overuse injuries. whereas two[29,37] reported no such association. Two studies[31,50] showed a positive association of growth and overuse injuries. Three studies[42,46,50] reported a positive association of chronological age with overuse injuries whereas three studies[29,32,37] reported no such association.

Secondary outcomes: Three studies[29,32,37] reported a positive association of training load and overuse injuries.

Diving

Primary outcomes: One study[30] reported a positive association of back pain and chronological age, and speculated that this could be due to overuse injuries to the spine during the growth-spurt.

Secondary outcomes: None reported

Mixed Sports

Primary outcomes: Out of the three studies that focused on mixed sports but included aesthetic sports, one[39] reported a positive association of maturation and growth with higher risk of overuse injuries whereas one[47] reported a non-significant association. One study[36] reported that chronological age was strongly associated with overuse injuries.

Secondary outcomes: One study[36] reported a positive association of training load and overuse injuries.

DISCUSSION

To the best of our knowledge, this is the first systematic review to primarily investigate the association between growth, maturation and overuse injuries in aesthetic sports/activities. The secondary aim was to explore whether training load was associated with our primary objective. The review used a systematic manner to identify articles according to established guidelines.[25]

Due to the heterogeneity of the included studies, 20 studies were pooled into three sports or activities (gymnastics, dance and diving) whereas three studies were on mixed sport populations where specific results from aesthetic sports or activities could be separated and studied. Most participants were female and only three studies included a control group. There is a lack of current studies reporting the female and male participation ratio in aesthetic sports or the numbers of participants according to level of performance nationally and internationally. Moreover, the timing of growth and maturation differs between genders,[26] therefore, our results cannot be generalised for all levels of performance or all genders.

A positive association between growth, maturation, skeletal and chronological age with overuse injuries was found in 19 studies. In gymnastics, the three studies that reported a lower risk of bias showed an association of skeletal age,[43] chronological age,[34,49] and training load[49] with overuse injuries; only one study took into account the effects of maturation confounders, such as age at menarche.[43] The two studies that focused on chronological age and training load, did not give clear indication of the maturation status of the participants.[34,49] In dance, diving and mixed sports studies, due to the cross-sectional design of the studies and their high risk of bias, no robust conclusion can be drawn about these associations. However, it is worth reporting that in dance, the studies led by Steinberg [32,37,46,50] utilised large cohorts of participants with contradictory results in terms of the associations between growth, maturation and overuse injuries. This contradiction could mainly be accounted due to the different hypothesis the two studies had as they referred to the same sample of participants.[37,50] Moreover, in Steinberg *et al.*[37] the inclusion of probing questions during the screening of the participants, may have introduced detection bias. Interestingly, in their study they reported no association of chronological age and paratenonitis, which is an overuse injury, whereas they reported an association of chronological age and injuries, both overuse and acute, in their study with the same cohort.[50] In mixed sports, the study of Loud and colleagues[36] included a very large national cohort (n=5461 female athletes) and concluded that chronological age was strongly associated with stress fractures in all multivariate models.

Furthermore, six of the studies reported an association of training load and overuse injuries; interestingly half of the studies did not report an association of growth, maturation and chronological age with overuse injuries, however, their findings are inconclusive due to the large variance of training loads which ranges between 8-16 hours per week for gymnastics,[44,45,49] >11.5-25 hours per week in dance,[29,32,37] and >16 hours per week in a mixed sport study.[36]

When interpreting the outcomes of this review, one should not only be aware of the variation in the participants' level of performance, but also the setting, duration of follow up, focus, terminology and assessment methods each study used. This systematic review showed inconsistency in how the included studies accounted for the important confounding associations of growth, maturation with overuse injuries in aesthetic sports/activities. Of the six studies that reported an association of skeletal age with overuse injuries,[33-35,38,40,43] only two studies[33,43] reported skeletal age in relation to chronological age. Inconsistencies also existed in the methods used for the assessment of skeletal maturation. The Tanner-Whitehouse 3, utilised by Amaral and colleagues,[43] a radiographic skeletal maturation assessment method that is used prospectively may not be cost effective or easily applicable for large cohorts.[52] On the other hand, older studies utilised different radiographic assessment methods,[33,38] a factor that makes the comparison of their results very challenging. Moreover, two studies[31,50] in dance that reported a positive association of growth and overuse injuries, differ in their methodological approach. Steinberg *et al.*[50] hypothesise the association from retrospective data of chronological age and injury history of a large group of recreational dancers (n=1336). Bowerman *et al.,*[31] on the other hand, prospectively observed a small group (n=46) of dancers for six months, however, the period was very short for any observations on the effect/association of growth and maturation on/with overuse injuries and the methodology of growth and maturation monitoring was flawed. The foot measurement protocol was not developed to monitor growth in adolescents and the Tanner stages, i.e. breast development and pubic hair, cannot be grouped between genders, as they correspond to different maturity timing and status. Also, the methods utilised by the available studies to assess overuse injuries and/or the confounding factors that may affect the prevalence of overuse injury in aesthetic sports, are characterised by different strengths and limitations. Furthermore, given the fact that overuse injuries are always reported after the event, recall bias is a major limitation both for prospective and retrospective studies.

Growth and maturation monitoring ideally need to be investigated through longitudinal research.[53] Even though, it has been argued that there is no “gold standard" method of maturation assessment,[53] this review has indicated fundamental flaws in the methodology of the included studies. This increased the risk of bias as none of the 23 studies were assessed as low risk of bias in all domains (**FIGURE 2)**.

Even though blinding of both participants and researchers can rarely be achieved in observational studies, steps can and should be taken to ensure blinding of outcomes assessors in order to minimise detection bias. Only four studies[29,34,44,49] did so, however, three of these four studies included blinding of outcomes,[34,44,49] whereas Kadel *et al*.,[29] included blinding but only in the selection of participants. In addition, none of the selected studies reported measurement errors for their measurements.

These identified methodological concerns may account for some of the observed equivocal and inconclusive evidence. For example, ulnar variance (UV) was the main primary outcome in three gymnastics studies[34,43,44] given that overuse injury is common in this sport. Their results however, were contradictory. The cross-sectional designs and the different assessments utilised in two of the studies,[43,44] may have accounted for these disparate results. However, even though in Chang *et. al.,*[34] the researchers included a control group and found significant difference ($p < 0.05$) between the two groups in UV prevalence, the question of whether the variance is associated to restricted growth of the radius and not to ulnar overgrowth needs to be considered. Other disciplines, like dance, are also characterised by contradictory outcomes. Specifically, in a cross-sectional study (n=54; mean age=20.2±4.4yrs) in professional dancers, no association was reported between age at menarche with stress fractures,[29] but such an association was reported in a cross-sectional study (n=75; mean age=24.3±4.1yrs)[48] and in a case control study (n=98; mean age=21.87±4.5yrs).[42] All three studies, however, relied on retrospective data on injury history from interviews and questionnaires, therefore, recall bias may have decreased the validity of these results.[54]

A recent systematic review on self-reported data states that there is no established athlete-reported outcome measure of the effects of injury/illness on performance in sport.[54] Included studies in this review reported outcomes from self-reported data collected via tools where the validity and reliability had not been tested or reported.[34,45,47] Even though 'one-size does not fit all' in surveillance methods,[54] the need for consensus-based practice in injury prevalence for aesthetic sports is paramount.

Research investigations in adolescents need to control for the effects of growth and maturation, in order to minimise its confounding effects.[55] Monitoring should not only include growth and maturation in relation to chronological age, but also training load, which based on the results of this systematic review also seems to be associated with overuse injuries. However, none of the reported studies clearly define training load. Recent studies in sports suggest that higher loads,[56] large increases in load too soon,[56] and imbalanced stress and recovery ratio[57] are all associated with greater injury rates. However, simply reporting hours/years of training is a limited indicator of training intensity.[53] A clearer understanding is needed of what the individuals are doing in the training of aesthetic sports/activities, and how this training affects them both physiologically and psychologically. Monitoring and understanding the association of growth, maturation, training load and overuse injuries may have a significant impact on health associated costs. The cost of dance related injuries in a professional company has been compared with that of a college athletic department or a professional sport team.[58] In addition, reducing the incidence as well as the risk of overuse injuries minimises the risk for future injuries[8,16] and, therefore, promotes better athlete's health and maximisation of performance potential.

Limitations

The results of this review have some significant limitations. One limitation is that the nature of the investigated field does not allow for randomised controlled trial studies to be conducted. This means that the current knowledge relies on evidence from observational studies, therefore, the discussion is about associations and not effects. Even though we investigated overuse injuries in aesthetic disciplines, the different disciplines are characterised by different injuries (i.e. body region, or body part), and therefore, both the comparison and the assessment of their association with growth and maturation is challenging. In addition, the gender and the level of performance differences together with the non-standardised reporting of training load of the included studies make the interpretation and comparison of their results difficult. Lastly, the included studies were characterised by increased risk of bias; therefore, the results cannot be generalised.

CONCLUSION

The findings of this systematic review cannot provide us with clear outcomes on whether the growth and maturation process or/and the training load are associated with overuse injuries in aesthetic sports/activities. This is mainly due to major methodological limitations of the included studies, such as the variation in the participants' level of performance, sample size, duration of follow up, focus, terminology and assessment methods each study used, together with the increased levels of risk bias due to either methodological constraints or negligence.

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