The relationship between non-elite sporting activity and calcaneal bone density in adolescents and young adults: a narrative systematic review

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Abstract

**Introduction**: Osteoporotic fracture represents a major public health burden. The risk of fragility fracture in late adulthood is strongly impacted by peak bone mass acquisition by the third decade. Weight bearing sporting activity may be beneficial to peak bone mass accrual, but previous studies have focused on elite sporting activity and used dual energy X-ray absorptiometry as a measure of bone density. The authors performed a narrative systematic review of individual sports performed non-competitively or at local level and calcaneal quantitative ultrasound (cQUS) bone measures in young people.

**Methods**: Multiple databases were systematically searched, up until 31st March 2019. The authors included studies of participants mean age 11 – 35 years reporting any level of recreational sporting activity and cQUS measures, excluding elite/professional sporting physical activity. Studies (title and abstract) were screened independently by two reviewers and a third reviewer resolved any discrepancies. STROBE guidelines were used to check the reporting of observational studies. The Newcastle – Ottawa Scale was used to assess the risk of bias of the studies included in the review. The systematic review was registered with the International Prospective Register of Systematic Reviews (PROSPERO).

**Results**: A search yielded 29,512 articles that considered relationships between bone density assessed by any technique and sporting activity. Duplicate and out of scope abstracts were removed. This left 424 papers which were screened by two reviewers, with six meeting inclusion criteria, including assessment by cQUS. The authors identified papers where sports considered included soccer (football), swimming, cycling, gymnastics, dancing, badminton, basketball, fencing, wrestling and judo. Although study heterogeneity prohibited meta-analysis, all six included studies reported significant benefits of weight bearing HRSA on cQUS outcomes.

**Conclusion**: Our study found beneficial effects of non-elite sports participation on cQUS in adolescence and young adulthood, although further work is now indicated.

# Introduction

Osteoporosis is a major international public health problem through its association with fragility fracture (1). Osteoporosis is often described as a disease which occurs when one becomes older, more often in females, and preventative methods often focus on older people (2). However, childhood and adolescence are critical periods of bone development; modifiable lifestyle behaviours have a major impact on the development of bones throughout life and peak bone mass (PBM) is a major determinant of later fracture risk (3). Previous studies have suggested that physical activity (PA) and dietary calcium intake during childhood and adolescence play a critical, synergistic role (4). There are, however, a limited number of studies looking at the impact of sporting activity rather than physical activity in the bone health of young people in the general population, with most studies focusing on the effect of elite level of sporting activity on bone health (2).

A number of previous systematic reviews have considered the relationship between sporting activity and bone health in this age group, and have studied associations between dual energy X-ray absorptiometry (DXA) and sporting activity. The effect of sporting activity varies according to sex, the skeletal sites and bone outcomes measured as assessed by DXA and peripheral quantitative computed tomography (pQCT) which gives an estimate of volumetric bone density and other assessment of bone strength at relevant sites, including the calcaneus (5). Tan et al’s 2014 systematic review assessed PA and bone strength: the findings indicated that bone strength modifications due to PA were related to maturity level, sex, and study quality (2). A review by Hind & Burrows in 2007 reported that weight-bearing exercise enhanced bone mineral accrual during early puberty, but it was unclear which form of exercise was the most beneficial (6) while Nikander et al’s 2010 systematic review of targeted exercise for optimising bone strength throughout life supported the use of exercise to develop bone strength in children at weight bearing sites (7).

Overall, previous studies that aimed to understand the relationship between sport in young people and bone health used ionising imaging tools, such as DXA (8-13). There has been an increasing interest in the use of heel ultrasound as an alternative assessment of bone density that also provides structural information of bone. Ultrasound technology is non-invasive, widely available, low-cost and portable tool that provides an assessment of bone density and quality at a readily accessible weight bearing site with a high trabecular bone content (14). Ultrasound technology has been shown to be associated with fragility fracture in older adults (15). The aim of this review was therefore to assess the relationship between non-elite sporting activity and bone density, as assessed by heel ultrasound in adolescents and young adults, through a systematic search and a narrative synthesis.

**Methods**

The systematic review study protocol is registered with the International Prospective Register of Systematic Reviews under the Registration number CRD42018080101 (16). The initial protocol described reviewing the association between non-elite sporting activity and bone density, with the latter being assessed using any bone measurement method. While the search and screening process adhered to this, for the current paper the authors only included studies that had assessed bone density through cQUS. This was a pragmatic decision based on the number of studies identified. The additional data retrieved will be used in a separate report on relationships between DXA and elite sporting activities.

An electronic search of PubMed/Medline, Proquest, AUSPORT, Ausport Med and Medline (Ovid) proceeded until 31st March 2019 to source the relevant articles under review (see Table 1 for a summary of search string used).

Observational studies were the main type of study for inclusion, however if baseline data could be extracted from trial/interventional studies, these were also included. Only full text, peer-reviewed journal articles published in English, unless they could be translated fully using Google Translate, were included (17). There were no limitations on sample size or country of origin.

*Participants, interventions and comparators*

The following search strategy was applied:

(1) Exposure: Non-elite participation in sporting activity performed at school or leisure time as an organised or regular activity – either self-reported or measured objectively. Participation in any type of sporting physical activity (quantitative studies).

(2) Outcome: Any bone heel ultrasound measures such as speed of sound (SOS)/velocity of sound (VOS), broadband ultrasonic attenuation (BUA), stiffness index (SI)/quantitative ultrasound index (QUI).

(2) Population:

Inclusions: The age of study participants was mean age 11 – 35 inclusive. Both sexes were included. Participation in named sporting activity at a local or regional level

Exclusions: Those with long-term disease or health issues such as physical/mental disability which directly affect bone health through treatment, supplementation or medication were excluded. Animal studies were excluded. Participation in competition(s) at an elite or national level was also an exclusion.

Two independent reviewers (HP and LS) screened the abstracts and titles of relevant reports and articles in duplicate to determine whether these met the given criteria for inclusion in the systematic review. Any discrepancies were resolved through discussion or with a third reviewer (ED). Then, the reviewers independently screened the articles identified from the title and abstract screening to determine whether they met the inclusion criteria for the review, and a third reviewer’s (ED) agreement was sought where appropriate. Where feasible, study authors were contacted by email for completeness and clarity. For those articles and reports meeting the inclusion criteria, their reference lists and bibliographies were screened for any additional relevant studies to be included in the systematic review.

*Methodological assessment: data extraction and presentation of study results*

The review is reported using the guidelines Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement (18).

*Risk of bias in the included studies*

The STROBE (Strengthening the Reporting of Observational studies in Epidemiology) guidelines were used to check the reporting of observational studies (19). The descriptive information of each study was extracted and summarised in Table 2. To assess the quality of the methods used in the selected studies, the Newcastle-Ottawa Scale (NOS) risk of bias assessment tool was used (20).

**Results**

*Study selection*

Figure 1 shows a flowchart of the literature search and the study selection process. The search yielded a reference list of a total of 37,042 articles. Duplicates were removed, leaving 29,512 articles to be screened by two independent reviewers. Based on title and abstract, 29,090 articles were excluded, primarily because they did not use cQUS as a measure of assessment of bone outcomes. This left 424 papers to be assessed in full where available; the reviewers were unable to obtain the full manuscript for the study performed by Coaccioli et al, despite attempts that included direct approach to the authors (21). In addition, the reviewers were unable to obtain a full translation from Chinese of a study by Qian (22). As such, those two studies were excluded. Following full text screening, a total of six studies remained as meeting the inclusion criteria for this systematic review. The sports identified from this process were soccer, swimming, cycling, gymnastics, dancing, badminton, basketball, fencing, wrestling and judo (see Table 2).

*Risk of bias assessment*

Using the NOS risk of bias assessment tool (20), the risk of bias of the six articles included in this systematic review was generally assessed as low to medium, with one of the studies assessed as having a high risk of bias (see Table 3). The main area of bias identified was in the recruitment process of the studies; most studies failed to clearly indicate how the sample size calculation of the study was approached and how and why participants were invited to participate in the study. Some articles failed to report how many participants were approached to participate in the studies, and why they were selected or not screened for the studies.

The bias assessment tool indicated that three of the included studies (Gomez-Bruton et al, Vlachopoulos et al and Nurmi-Lawton et al) had low bias with clear study designs, confounding factors such as diet and PA were acknowledged and detailed dietary assessment was available, and face to face interviews for PA (23-25). Of the studies with medium bias, Yung et al’s study had small sample numbers in each of the four groups (n = 15), with limited details of recruitment (26). Yung et al’s study performed a questionnaire that assessed PA and diet of participants, while Mentzel et al’s and Madic et al’s studies were also assessed as medium bias due the limitations of recruitment details and lack of dietary and PA assessment (26-28).

*Study designs and participant characteristics*

The studies extracted were too heterogeneous to allow for meta-analysis. A graphical display of the results and a summary of the key characteristics of the studies included in the review, along with a synthesis of the studies in a narrative form, is presented in Table 2. The sporting activity referred to in these studies included soccer, swimming, cycling, gymnastics, dancing and, to a limited degree, badminton, basketball, fencing, wrestling and judo.

Of note, the level of activity in the control groups was very different across the included studies. Vlachopoulos et al’s study compared 116 young Caucasian male adolescents that undertook regular swimming, soccer or cycling sports with active controls (including identifying participants that participated in other sports or swimming, soccer or cycling for less than three hours weekly) (24). Gomez-Bruton et al’s Spanish mixed gender cross-sectional study of 129 Caucasian children was part of a much larger controlled trial. The study compared the bone health of swimmers who competed at regional swimming tournaments at the start of the study with normally active control children who did other sports less than three hours a week and did not participate in other aquatic sports (23). In Madic et al’s Serbian study of 62 participants, male soccer players were compared to controls who participated in regular school based sporting activity only (28). Yung et al’s study of 55 Chinese male university students compared the bone effects of weight-bearing sports of swimmers, dancers, and soccer by contrasting players with a sedentary control group of students who did not exercise (26). Mentzel et al’s German study was a mixed study of 177 boys and girls from regional sports schools with various sports backgrounds whose bone health was compared against a reference population. The study presented limited details on how the levels of activity were assessed (27). Finally, Nurmi-Lawton et al’s English study compared 97 female gymnasts and normally active controls (the controls did not participate in high impact sports for the past year at a competitive level, although two of the controls were competitive swimmers) (25).

The six studies included in this review had a sample size that ranged from 55 to 177 participants. Five of the six studies included in this review studied school-aged children, with the study participants recruited from schools or sports clubs (23-25, 27, 28). The remaining study recruited students from their local university (26). The inclusion criteria varied amongst the six studies, with the main criteria being healthy children or adolescents with a reported sport history. General exclusion criteria in the studies included a history of chronic or musculoskeletal disease, and taking medication that affected bone metabolism. Gomez-Bruton et al, Mentzel et al, and Vlachopoulos et al specifically stated that participants with a known fracture history were excluded (23, 24, 27). Mentzel et al’s study also excluded children with a small shoe size as well as participants that missed appointments (drop-outs) or participants that could not be located (27).

The mean age of participants in the studies included in this systematic review were between 11 to 22 years. Pubertal status was considered in the studies by Gomez-Bruton et al, Madic et al and Vlachopoulos et al (23, 24, 28). None of the reviewed articles included the upper age range from 23 to 35. Collectively, 210 females and 426 males were included in this systematic review. One study included females only (25), three studies included males only (24, 26, 28), and two studies included both male and female participants (23, 27). The ethnicity of the study participants was clearly stated in four of the six studies. Two studies recruited those who were of white healthy Caucasian ethnicity only (23, 24). The third study declared all the participants were white except for one participant in their study (25), while the fourth study exclusively recruited Chinese university students (26). The Serbian and German studies do not state the study participants’ ethnicity but, for the purposes of this review, the authors assumed their ethnicity based on each study’s locality (27, 28).

Nutrition was acknowledged as a factor in bone health in all six studies: four of the six studies completed some form of dietary analysis (23-26). A trained researcher helped participants complete a calcium frequency questionnaire in Gomez-Bruton et al’s study (23). Yung’s university students completed a 7-day recall for the participant’s usual calcium intake (26). Similarly, Nurmi-Lawton et al’s longitudinal study used regular estimated food diaries for the duration of this study (25). Vlachoppoulos et al’s study stated that one of its limitations was the lack of nutrition-related covariates in the analysis despite the fact that data was collected for the study (24).

*Assessment tool*

The cQUS tools used include Lunar Achilles Insight (used in two studies), Sahara Hologic (used in two studies), Heel ultrasound densitometer Paris (Norland), Contact Ultrasound Bone Analyser, and Lunar Achilles Insight (TM Insight GE Healthcare, Milwaukee, WI, USA with OsteoReport PC (software version 5 GE Healthcare) (see Table 2). There was considerable variability in the bone measurements taken and the level of detail in the description of methods used to perform the measurements. All the papers employed statistical analysis using SPSS. The six study results were all presented *a priori* with *p*-values ​​of <0.05 being considered statistically significant but, due to the heterogeneity of the tools and methods employed, output values were not directly comparable.

*Sports participation – duration and intensity*

The sports measured in this review include soccer, swimming, cycling, dancing, badminton, basketball, gymnastics, fencing, wrestling and judoLack of comparability of intensity of sports training and duration of involvement in regular sport made it hard to draw comparisons between studies. For example, in Vlachopoulos et al’s study, athletic sports male participants at baseline had been engaged (≥3 hours/week) in osteogenic (soccer) and/or non-osteogenic (swimming and cycling) sports for the previous three years or more (24). Average years of training ranged from 3.9 to 5.9 years (24). By contrast, Gomez-Bruton et al’s study assessed swimming training in both girls and boys who had a previous history of swimming and competing in regional tournaments for more than three years and training for a minimum of six hours per week (23). The inclusion criteria for this study was that participants had to have been training on a regular basis in a sport (cycling was not included) for more than three hours per week for at least three years prior to the study. The swimmers were divided into those who were considered as pure swimmers as they had only participated in other sports for one or two years and other swimmers who were classified as participants in other sports for more than two hours per week and/or other sports for a period of more than two years prior to the study (23). Madic et al’s study on boys’ soccer activity required that participants had a sport history of a minimum one year of active sports occupation in soccer with weekly training sessions of typically lasting up to 10 to 15 hours (28). Yung et al’s male university students were categorised by main sporting activity from high to low impact weight bearing and non-weight bearing exercises (soccer, dancing, swimming and no exercise) (26). This exercise group of participants had to be engaged in supervised training in either soccer or dancing or swimming for at least two years, at twice a week, for at least two hour sessions (26). Mentzel et al’s study with both boys and girls included eight sporting activities: soccer, badminton, basketball, gymnastics, fencing, wrestling and judo (as only one child each represented tennis, triathlon and weight-training and, therefore, those sporting activities were not included in the analysis) (27). Sport participants had two or more 90-minute training sessions weekly at the start of the study; past and current sporting activity details of participants were not stated (27). Finally, Nurmi-Lawton et al studied female artistic gymnasts who had trained two or more years with more than 10 hours weekly training and had competed at club or regional level (25).

Hence the studies were not comparable for many reasons, including the duration and intensity of sporting activity of participants. For example, the athletes in Mentzel et al’s study potential activity levels of the sporting participants could potentially be equated to Vlachopoulos et al’s and Gomez-Bruton et al’s control group (23, 24, 27).

*Comparator (control) groups activity level*

The details provided in the six studies for the comparator (controls) measurement for potential past sporting history and other physical activities (which may have impacted the bone measurements) was often lacking and was too heterogeneous to compare across the studies.

Vlachopoulos et al’s study of athletic sports compared osteogenic soccer against non-osteogenic sports (swimming and cycling) and with a small control group of 14 active boys who did not participate in any sports (soccer, swimming or cycling) for more than three hours per week or in the three years prior to study commencing (24). Gomez-Bruton et al’s study of swimmers were compared with a control group who had neither performed in any aquatic sports on a regular basis nor participated in any other sport activity for more than three hours a week (23). Madic et al’s study on boys’ soccer activity was compared to that of young boys not actively engaged in sport, aside from 90 minutes per week of PA at school (28). Yung et al’s university male athletes were compared to a sedentary group who did not participate in exercise (26). In the study by Mentzel et al (2005), athletes were compared to local reference data of 3,299 healthy Caucasian children and adolescents obtained from an earlier study by the same author (27). The two studies used the same conditions and same device, although details of the reference population’s past sports history or PA level was not reported (29). Nurmi-Lawton et al’s gymnasts were compared to controls who were involved in normal activities (including walking to school and physical education classes at school) for an average of 2.6 hours weekly and not engaged in sports that required all year training at competition level (25). The potential sporting activity levels of the control participants from Vlachopoulos et al’s and Gomez-Bruton et al’s studies, which reached a maximum of 3 hours per week, may potentially equate to the sporting activity of Mentzel et al’s participants, as this study included participants from a sports college that trained less than participants in other studies (23, 24, 27).

*Bone measurement results*

Overall, high impact weight bearing sports such as soccer playing and gymnastics or dancing were associated with the greatest benefits for bone health (Table 2). Swimmers and cyclists were not at any apparent bone advantage compared to controls. Hence Madic et al’s study of male soccer players reported significant differences in cQUS between soccer players and controls (28). Yung et al’s study found weight bearing and high impact exercise to be associated with higher QUS parameters. In particular, soccer players and dancers had significantly greater BUA, VOS and SI than swimmers and the sedentary control group (26). In Vlachopoulos et al’s study, soccer players had statistically greater cQUS ultrasound parameter SI compared to swimmers, cyclists and controls at baseline (24).

Similarly, Gomez-Bruton et al’s gender study compared swimmers with controls and found no significant differences in any cQUS parameters when measuring the non-dominant calcaneus between any of the groups (23). In the only study to compare a very wide range of sporting activities, and with attendant power considerations for that reason, Mentzel et al’s study showed significant differences between cQUS SOS and BUA between the sports students (a mixed gender study of 177 children aged 11 to 18) and the reference group but direct sporting comparisons were more challenging(27).

Some studies investigated the level (or impact) of weight bearing activity and bone health. While Mentzel et al’s study did not observe strong correlations between increased weight bearing activity in basketball (n = 7) and bone health, this may be reflective of the very small sample size and lower study power (27). As such, the authors consider that the results of Mentzel et al’s study should be interpreted with caution (27). In Mentzel et al’s study, judo players and wrestlers showed a significant positive correlation between heel BUA versus level of activity (27). Further, when considering SOS as an outcome, significant differences were shown between badminton players and gymnasts, between basketball players and fencers as well as between judo players and gymnasts (27). Finally, one study considered body build in more athletic young people; Numri-Lawton et al’s study of gymnasts revealed that the gymnasts were smaller and lighter than controls, but they still had significantly higher QUS (25).

**Discussion**

In contrast to many other reviews, this review focuses only on specific non-elite sporting activity performed at a non-competitive level in young people as assessed by calcaneal ultrasound. The quality of the six articles was generally assessed as moderate quality, though variability was present and methodological differences prevented a meta-analysis.

The overall aim of the six studies was to investigate the effects of different non-elite sporting activities, some of which were classified as weight-bearing and non-weight-bearing non-elite sporting activity of different intensities on bone mineral accrual in adolescence and early adulthood. The studies were heterogenous, but a consistent pattern emerged, Vlachopoulos et al showed that boys playing soccer produced had better bone heel ultrasound outcomes than those who participated in cycling or swimming (24). Similarly, Nurmi-Lawton et al showed that female gymnasts had significantly higher bone density than controls,(25). Gomez-Bruton et al’s study indicated there were no differences found in QUS parameters between swimmers and controls (both male and female) (23). Madic et al’s study of male soccer players reported significant higher QUS values compared to controls (28). Mentzel et al’s comparison of those children involved in sports found the QUS (SOS and BUA) parameters were significantly higher in sport participants engaged in weight bearing activity compared to the reference data (27). Yung et al’s study indicated a linear increase in all QUS measures as weight bearing activity increased (26). In general, the six studies suggested that weight bearing non-elite sporting activity was associated with higher QUS, and that some dose effect was reported with greater levels of sporting activity (frequency and duration).

Weight bearing physical activity is thought to stimulate bone formation and thus improve bone mineral density (BMD) by exposing the skeleton to mechanical strain, provided that it is performed at high enough frequency and high impact intensity (as evident in the studies that included swimmers or cyclists who had similar cQUS results to their comparative controls) (23, 24, 26). Importantly, there is little epidemiological evidence that walking improves BMD (30). Rather, mixed loading programmes that included jogging, walking, and stair climbing consistently improve hip BMD in older people, although far fewer data exist in young adults (31). The optimum type and level of PA for improving BMD remains unknown, and it is unclear whether a specific threshold strain needs to be exceeded. It is also unclear if different loading movement in different sport may have varying effects on BMD and whether the effects are identifiable at different sites. Lower limb impact during weight bearing reflects their ground reaction force. In a study of adolescents from the Avon Longitudinal Study of Parents and Children, using pQCT and DXA found that vigorous PA (equivalent to jogging) was positively related to cortical bone mass, but no independent relationship was seen for moderate PA after adjusting for vigorous PA: highlighting the importance of vigorous activity in this age group (32). This also highlights the importance of quantifying the intensity, frequency and duration of PA in comparators controls when assessing the changes in cQUS measures associated with non-elite sporting activity .

There are several limitations to this systematic review. The QUS tools used varied, with distinct model versions used in the measurements undertaken. As such, the output values are not directly comparable. There was considerable variability of the bone measurements taken and the level of detail provided of methods used to perform the measurements. These methods varied from measuring both feet separately to find the mean of the two, performing measurements in duplicate or triplicate, performing measurements either on the dominant foot or the non-dominant foot, and measuring both left and right feet but presenting the results of the left foot only. Overall, the reproducibility of the QUS measurements within the individual studies themselves were within an acceptable range and researchers followed manufacturer’s instructions validating the use of the QUS measurement. Unfortunately, two articles were not obtainable despite numerous attempts to search the English translations of the full article or to contact the authors (21, 22). Funding precluded the use of an official translation service and so we were reliant on Google Translate. This is a limited service; although the study by Mentzel et al was subject to translation bias, its inclusion was justified as it was within the scope of this review. Mentzel et al’s study was therefore translated from German to English using Google Translate, a freely available online tool. This translation may include inaccuracies as sentences could be translated out of context, especially when translating colloquial words or words with multiple meanings. Another limitation of this review is that the age of the study participants under review leaned towards the younger end of the 11 to 35 age group. The lack of detail regarding power of the studies made it difficult to assess whether and how the sample size recruited, if at all, affected the results. The ethnicity of the study participants was not always clearly stated in the study. Further, although nutrition was acknowledged as a factor in bone health in all six studies, only three of the six studies completed any dietary analysis. Details for sports measurement for sporting history, duration and other physical activities included was heterogeneous and sometimes the methods of recording and confirming the details were ambiguous. For example, the duration of participation in regular sporting activity prior to enrolment in each study was often not provided. The mean weekly sport training regimes ranged from a minimum of three hours to up to 27 hours, and the level of participation in non-elite sporting activity between studies were not directly comparable. Inter-study comparisons of results may not be made as in the six selected studies the selection criteria for participants and the controls were inconsistent between the studies. For example, some study participants selected for controls in one study would be sufficiently active to be participants in another study in this group of six studies. Finally, resource limitations meant we were unable to include SPORTDiscus and Web of Science in our search.

In comparison, a number of other systematic reviews have assessed bone health at other bone sites using various imaging tools, and this review complements those data. Our results are complementary, and support the findings of those studies. Specifically, weight bearing sporting activity, and particularly high impact weight bearing activity, appears beneficial while swimming does not enhance bone mineral accrual. Previous studies compared differing age ranges or assessed bone outcomes in relation to pubertal status, while some reviews have been undertaken in groups of young people participating in exercise regimes or individual sports such as swimming, soccer, gymnastics, ballet which may be at a combination of recreation or elite or competitive level. For example, in a systematic review undertaken by Nikander et al in 2010, the authors found, using various imaging techniques, such as DXA, pQCT, MRI (Magnetic Resonance Imaging) and HSA (Hip Structural Analysis), that in children, an exercise regime lasting more than six months enhanced bone strength at loaded sites but this effect was not seen in adults (7). Gomez-Bruton et al suggests that swimmers may not be reaching PBM potential: Gomez-Bruton et al’s systematic review in 2016 found higher DXA-derived BMD values in young Causasian children and adolescents engaged in osteogenic sports relative to swimmers and controls (33). Gomez-Bruton et al’s recent systematic review in 2018 focused on young adult swimmers aged 18 to 30 and found that in these young adults, limited osteogenic effects of swimming during adolescence persisted through early adulthood (34). The systematic review by Lozano-Berges et al in 2018 also used various imaging tools and found children aged 6 to 18 playing soccer had positive bone mass outcomes compared to the controls (35). Burt et al in 2013systematically reviewed participation in gymnastics during the pre-pubertal growth period and found there was skeletal health benefits mostly for the upper body regions (36). Similarly, a systematic review by Wewege & Ward in 2018 in pre-professional female ballet dancers found site-specific osteogenic effects compared to the controls (37). A systematic review by Krahenbuhl et al in 2018 addressed the effects of weight bearing sports such as soccer and gymnastics on bone geometry in children and adolescents, and found that the benefit was dependent on the frequency and intensity of the PA measured (38). The systematic review by Koedijk et al in 2017assessed bone health in children up to the age of 24 and measured PA subjectively through questionnaires or objectively using an accelerometer, with a focus on sedentary behaviour rather than a specific HRSA (39). Three of the studies identified by Koedijk et al’s review that were of higher quality indicated that there was no association between sedentary behaviour and total body bone outcomes as measured by DXA; although twelve of the studies included in the same review assessed the lower peripheral bone outcomes with DXA or QUS found a negative association with sedentary behaviours (39).

The authors chose to undertake this systematic review of non-elite sporting activity with bone health using cQUS as the outcome measure in order to capture studies that may not have been included in previous systematic reviews. The authors used heel ultrasound as the outcome measure in this study to assess the effects of HRSA. Many studies indicated that heel ultrasound is used to assess bone structure and strength and is used worldwide for osteoporotic fracture risk assessment when DXA the gold standard tool in diagnosis is not available, although it is not to be used as a diagnostic tool (40, 41). The positive attributes of the heel ultrasound test are that it involves no risks or harm, and is a cost-effective, comfortable, pain-free, radiation-free test that is easy to use and only takes a few minutes to perform (42, 43). Studies have shown the quantitative ultrasound densitometry technique to be useful assessing skeletal health status changes due to exercise in all age groups and as a research tool (14, 44, 45). Jaworski et al’s study in 1995, Baroncelli’s study in 2008 and Daly et al’s study in 1997 found the use of ultrasound in normal healthy children a safe and non-invasive method when comparing the skeletal status of exercising children (46-48). Different studies have used either the dominant heel, the non-dominant heel or a mean of the two as the reported outcome. While it is possible that this might impact findings, the consistency of our results suggest this was not a major consideration here, particularly given the sports studied. Perhaps this plays a lesser role compared to the effect on the dominant limb in racquet sports such as tennis (49).

**Conclusion**

Although study heterogeneity prohibited meta-analysis, all six studies reviewed reported significant benefits of weight bearing non-elite sporting activity in children and young adults. While both sexes were studied in several of these individual reports, small sample sizes made it difficult to dissect differences in outcomes between the two sexes. The studies revealed habitual levels of high impact sports such as soccer, produced better bone outcomes (particularly in males) compared to non-weight bearing sports such as swimming and cycling. Sporting behaviours commencing in the early years is an opportunity to improve PBM potential and set in place other healthy long-term lifestyle behaviours. More studies, especially in young adults in their twenties and thirties, are now urgently required to examine this issue in greater detail with more clearly defined control groups.

## Figures

## Tables

# Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. Elaine Dennison has received consulting fees from Pfizer and UCB.

# Author Contributions

HP performed the searches, HP, LS and ED reviewed the search results and extracted the data, HD provided advice and guidance regarding the systematic review methods, and HP, ED, HD, PTS and LS edited the manuscript. All authors contributed to manuscript revision, and read and approved the submitted version.

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Table 1: Summary of search string used

|  |
| --- |
| (sport OR sport\* OR exercise OR exercis\* OR physical OR soccer OR football OR rugby OR athlet\* OR swimming OR tennis OR gym\* OR basketball OR “martial art” OR boxing OR cycling OR recreation OR cricket OR hockey OR Ball or golf OR badminton OR cycling OR wrestling) |
| AND |
| (bone AND health) OR (bone AND mass AND density) OR DXA OR DEXA OR BMD OR BMC OR SOS OR BUA OR SI OR (hip OR spine OR heel) AND ultrasound |
| AND |
| (adolescent OR child OR girl OR boy OR juvenile OR teen\* OR young OR people OR student OR youth OR minor OR college OR school OR paed\* OR pedia\*) |
| Include: Synonyms, related terms, opposites, international terms, alternative spellings, plurals, truncations and wildcards ( \* or $ or # to substitute for one character within a word), and proximity operators NEAR, NEXT, ADJ. |

Table 2: Key study characteristics

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Author/**  **Country**  **Setting** | **Type of study** | **Study size**  **Population**  **Sport** | **Sports Activity** | **Comparator/**  **Controls** | **Bone Measure & Site** | **cQUS Imaging Tool** | **Key findings** |
| Vlachopoulos et al/ 2018  England  sport clubs and schools | Longitudinal (PRO-BONE study) | Total n = 116 Caucasian males | Sport (swimming, soccer, cycling) duration > 3 years | Controls: no sport like soccer, swimming or cycling for more 3 hours/week nor 3 years prior | QUS heel mean of both feet, measured twice | Lunar Achilles Insight (TM Insight GE Healthcare, Milwaukee, WI, USA). | 12 months football participation associated better SI than for cycling or swimming |
|  |  | Aged 13.1.+/- 0.1 | Actual average years of training ranged from 3.9 to 5.9 years |  | SI only |  |  |
|  |  | n = 37 footballers | Actual average hours of training per week ranged from 5.2 to 9.4 hours |  |  |  |  |
|  |  | n = 37 swimmers | Actual average MVPA(min/day) ranged from 85.0 to 119.8 | Actual average MVPA(min/day) ~83.2 |  |  |  |
|  |  | n = 28 cyclists |  |  |  |  |  |
|  |  | n = 14 active controls |  |  |  |  |  |
| Gomez-Bruton Spain  Cclubs and high schools | Cross-sectional study within a larger randomised controlled trial | Total n = 129 Caucasian males & females | Sport (swimming) duration > 3 years, minimum of 6 hours/ week | Controls: normo-active with no participation in sports like swimming or aquatics regularly and no sporting activities more 3 hours/week | QUS heel (non-dominant ) | Lunar Achilles Insight (Achilles Insight, GE Health- care, Diegem, Belgium | cQUS results showed no significant differences between swimmers and controls; |
|  |  | Aged 11 to 18 | Competing in regional tournaments |  | SI, SOS, BUA |  |  |
|  |  | n = 77 swimmers (34 females/ 43 males) |  |  |  |  |  |
|  |  | n = 52 normoactive controls (23 females/ 29 males) |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
| Madic et al  Serbia  Schools | Observational | Total n = 62 male soccer players | Sport duration > 1 year | Control 90 minutes of PA/week at school | Both heels QUS | Sahara (Hologic, Inc., MA, USA) sonometer | BUA and SOS Soccer players than controls |
|  |  | Aged 10 to 12 |  |  | SOS Left and right |  |  |
|  |  | n = 32 soccer | Actual average hours of training per week ranged from 10 to 15 hours |  | BUA Left and right |  |  |
|  |  | n = 30 control regular school PA |  |  |  |  |  |
| Yung et a  China  Local university students | Cross sectional study | Total n = 55 Chinese male university students | Sport (swimming, dancing, soccer) duration > 2 years ; at least twice week for at least 2 hours | Control no exercise (sedentary control) | QUS heel dominant and non-dominant heel measured, analysis on dominant heel | Paris, Norland Medical System, Fort Atkinson, WI, USA | All QUS parameters showed a significant linear increasing with the weight bearing and high impact exercise |
|  |  | Aged 18 to 22 |  |  | VOS, BUA, SI |  | BUA, VOS, SI Soccer players > dancers > swimmers > sedentary control group |
|  |  | n = 15 soccer |  |  |  |  |  |
|  |  | n = 10 dancing |  |  |  |  |  |
|  |  | n = 15 swimming |  |  |  |  |  |
|  |  | n = 15 no exercise/sedentary control group |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
| Mentzel et al  Germany  Regional sports schools | Cross-sectional study | Total n = 177 sportspeople | Sport duration undetermined; 2 training sessions/week of at least 90 minutes | Reference population used (age, size, and gender related) | Both heel (mean) QUS | Sahara (Hologic, Inc., Waltham, MA, USA) sonar |  |
|  |  | Aged 11 to 18 (n = 121 boys; n = 56 girls) |  |  | SOS (SDS) and BUA (SDS) |  |  |
|  |  | n = 43 athletes |  |  |  |  | For the level of activity: significant correlation to BUA only judokas and wrestlers |
|  |  | n = 38 soccer players |  |  |  |  | For training sessions: SOS low negative correlation and BUA positive correlation |
|  |  | n = 12 badminton players |  |  |  |  |  |
|  |  | n = 7 basketball players |  |  |  |  |  |
|  |  | n = 8 gymnastics |  |  |  |  |  |
|  |  | n = 18 fencers |  |  |  |  |  |
|  |  | n = 16 wrestlers |  |  |  |  |  |
|  |  | n = 29 Judo players |  |  |  |  |  |
|  |  | n = 1 each tennis, triathlon, weight training |  |  |  |  |  |
| Nurmi-Lawton  England  Clubs | Mixed longitudinal 3 years/cross-sectional for mothers | Total n = 97 females | Sport duration average for 6 years, 2 or more 90 minute training sessions weekly; trained greater than 10 hours/week; competed at club or regional level | Normo-active sedentary controls including walking to school and attended school PE classes | QUS heel | Contact Ultra- Sound Bone Analyser (CUBA; McCue Ultrasonic Ltd., Winchester, UK) | Gymnasts had up to 24 –51% higher BMC and 13–28% higher BMD, depending on skeletal site. than controls. |
|  |  | Age Baseline 8-17 years of age |  | Included walking to school and attended school PE classes | Mean of both feet, measured twice |  |  |
|  |  | n = 45 gymnasts |  | No sports training requiring year around training; included two competitive swimmers as they were engaged in an activity the authors considered non-weight-bearing |  |  |  |
|  |  | n = 52 controls |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |

Table 3: Risk of bias (NOS)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| NOS Tool | Yung et al | Nurmi-Lawton et al | Gomez-Bruton et al | Mentzel et al | Madic et al | Vlachopulos et al |
| How well described is recruitment of the exposed group? | Chinese University students – numbers approached not stated | Gymnasts recruited from 5 clubs – numbers approached not stated | Source of recruits was local swimming clubs and numbers approached/ recruited provided | Recruited from College of Physical education – numbers approached not stated | Unclear – numbers approached not stated | Provided in separate referenced article; sports recruited were swimming/ football/cycling. Recruits came from sports club and schools |
| How were the exposed group selected? | At least 4 hours sport each week for at least 2 years; different sports described | At least 10 hours per week, and competing in competitions. | Swimmers training for at least 3 years, training for a minimum of 6 hours per week. Group subdivided according to whether participants were also training in another sport | At least 90 minutes per week | Soccer training for 10-15 hours weekly for at least one year | Training for over 3 hours per week for 3 or more years. Level of training provided for cases |
| How well described is recruitment of the control group? | Chinese University students | Local schools; taking part in PE lessons only though 2 were competitive swimmers | Source of recruits was local schools and numbers approached/ recruited provided. Could not be doing any sport for more than 3 hours per week | Used local reference data – so exposure to sport in this group was unclear | ‘Not engaged in active sport’. Other details not provided | Provided in separate referenced article |
| Length of exposure to sporting activity | Variable between duration and time/ week in different sports. Typically 2-3 years, range 7-15 hours per week | Training for range of 2-12 years; average 6.5 years | At least 3 years | Unclear | At least one year | Range 4-6 years |
| Information on important confounders | Provided | Provided | Provided | Unclear | Unclear | Provided |
| Overall risk of bias | Moderate | Low | Low | High | Moderate | Low |