



## FOOT AND ANKLE DEFORMITY IN YOUNG ACROBATIC AND ARTISTIC GYMNASTS

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### ABSTRACT

**Purpose.** The aim of the paper was to determine the occurrence of feet and ankle deformities in trampoline and artistic gymnasts. **Methods.** Ten acrobatic gymnasts (trampolinists) and 10 artistic gymnasts aged 6–14 years were recruited. The calcaneal-tibial (rearfoot) angle was determined as the angle of the upper calcaneal tendon and the longitudinal heel axis while Clarke angles were determined by podoscopy. **Results.** The trampolinists showed significantly greater medial angulation (calcaneal valgus) than the group of gymnasts. Right and left foot Clark's angles in both the trampoline and artistic gymnasts were above 55°. **Conclusions.** Trampolinists exhibit significantly more pronounced calcaneal valgus than artistic gymnasts. The prevalence of foot and ankle deformities in both populations should be addressed by coaches in the gymnastics training of young children.

**Key words:** foot and ankle deformities, young gymnasts, acrobats-trampolinists

### Introduction

Abnormal foot anatomy and associated lower extremity joint disorders are extremely prevalent postural defects in children. Pfeiffer et al. [1] examined 835 Austrian children aged 3–6 years and ascertained that 44% presented flexible flatfoot while less than 1% pathological flatfoot. However, the prevalence of poor foot structure was found to decrease with age, leading them to conclude that intervention is unwarranted at this early age. Kasperczyk [2] determined that appearance of pes planus (flat feet) is natural below the age of 4 partly due to the presence of excess plantar adipose tissue that gradually disappears over time. Similarly, the prevalence of calcaneal valgus (abnormal medial angulation of the foot as viewed by the long axis of the tibia resulting in overpronation) or varus (abnormal lateral angulation of the foot leading to supination) in children aged 3–4 years is not indicative of lower extremity dysfunction. Only the propagation of such foot and ankle deformities in later childhood (from 6 years of age) ought to signify a pathologic etiology and require corrective action.

It is known that the normal development of the lower extremities in children is conditioned by numerous factors including physical activity level [3], the influence of footwear, sex, and body mass [1]. The former aspect is of particular importance as it directly stimulates musculoskeletal growth and motor development, although excessive or asymmetric training loads at this early stage in life may contribute to biomechanical faults. The gaining popularity of acrobatic sporting disciplines and the use of the trampoline for competitive and recreational

purposes among children is one example where an excellent source of physical activity can be associated with significant overuse and injury risk. Blajer and Czaplicki [4] calculated that the vertical ground reaction force of performing a back somersault by an adult weighing 70–80 kg on trampoline can reach 5000 N (approx. 500 kg), placing a six- to seven-fold load on the musculoskeletal system. Besides trampoline-induced stresses, the practice of acrobatic gymnastics also places significant loads on the upper extremities during tasks such as handstands, round-offs, handsprings, and vaults [5, 6]. A comparative investigation on the aetiology of injuries in trampoline, tumbling, and acrobatic gymnastics found a significant association between lower extremity injury and trampoline practice and concluded that acrobatic sports share a similar injury profile as artistic gymnastics [7]. Furthermore, study on the types of injuries in gymnastics finds that, for example, 41% of trampoline-related injuries involved lower extremity soft-tissue damage [8]. The prevalence of injury in gymnastics sports (acrobatic gymnastics, artistic gymnastics, trampoline) is of particular concern as ever younger athletes (aged 5–6 years) are recruited when still at very early stages of motor and musculoskeletal development. While initial training loads may be kept low, child athletes soon commence specialized training regimes and enter competition (even the Polish Gymnastics Association, for example, recommends that 7- to 9-year-olds begin competing).

Gymnastics (regardless of discipline) inherently requires demanding footwork on a variety of surfaces, from hardwood floors, gymnastics mats of varying densities, landing mats, and trampolines. Furthermore, the increased range of motion in various joints during gymnastics practice may increase mobility at the cost of weakened stability, thereby promoting locomotor dysfunction. Aydog et al. [9] reported that elite gymnastics

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athletes present higher longitudinal arch height than untrained cohorts, which suggests the possibility that the variety of loads experienced in gymnastics across a wide range of exercises may positively influence foot shape. Nonetheless, the relatively large stresses induced by gymnastics (in relation to age) only progress as expertise and competitive level rise over time. This is paralleled by a natural increase in training load, which is particularly magnified in competitive rebound sports such as trampolining. In this acrobatic discipline, it has been suggested that general training requires augmentation exercises in order to negate the adverse effects of the multiplied loads placed on the musculoskeletal system in trampoline jumping [4]. Furthermore, trampoline-based events are fundamentally different from artistic gymnastics in that while the latter also induces mechanical loading by both jumping (off of the vault or during floor exercise) it also involves combinations performed on the parallel and horizontal bars where the body is frequently extended and unloaded.

It is unknown whether there are substantial differences in the systematic loads induced by regular trampoline and artistic gymnastics practice and their effects on foot and ankle structure in child athlete populations. More specifically, there is a lack of information if the inherent training profile of these two gymnastics modalities are associated with the prevalence of such postural deformities as pes planus or talocrural deformity. Therefore, the aim of the study was to determine the relationship between training loads and the occurrence of foot and ankle deformities in young acrobatic gymnasts specializing in trampolining and artistic gymnasts.

### Material and methods

This study was performed in 2014 and involved 20 healthy female athletes (10 trampoline gymnasts and 10 artistic gymnasts) aged 6–14 years attending regular training. The general characteristics of the sample are presented in Table 1. Participation in the study was voluntary and consent was obtained from the parent/guardian as well as respective coach. Inclusion criteria required the participant have at least 6 months training experience in their given discipline preceded by 1 year of pre-training. The pre-training was similar in design in both gymnastics groups and meant to prepare the athletes for competition. It included strength training of all the major muscle groups and agility–acrobatic exercises (e.g., hand-

stands, bridges, cartwheels, splits). The artistic gymnasts performed a relatively larger share of bar-based exercises (wall bars, horizontal bar) than the trampolinists as well as spending more time on the balance beam although this apparatus was rarely used by either group.

After recruitment, the participants' training history and profile was reviewed. All attended training classes (2 h duration) three to five times per week. Among the trampolinists, one athlete (14-years-old with 5 years of experience) competed at the junior level and was a national medalist. Three other participants (aged 11 to 12 years) also had 5 years of junior-level experience and competed at the regional and national level. The remaining six participants included two 6-year-olds with 0.5 and 1 years of trampolining experience, three 9-, 10, and 11-year-olds with 1–3 years of experience, and one 12-year-old with 3.5 years of experience. Among the artistic gymnasts, one was 14-years-old and a national junior team member with 8 years of experience, one 12-year-old with 1 year of training experience but none competitive, four 7-year-olds with 2–3 years of experience and participation in regional youth competition, one 9-year-old with 1.5 years of experience including intramural and friendly competition, and three 8-year-olds with 2–3 years of experience with regional competitive success. The years of training experience provided above does not include the first year of pre-training and is based on the time length of regularly-held training.

The first phase of the study involved taking measurements of body height and mass using a stadiometer and digital scale (Radwag, Poland), respectively. Anthropometry was performed in afternoon hours before training. Body mass index (BMI) was calculated and compared with World Health Organization percentile thresholds for females aged 5–19 years. All of the participants were found to be normal for their age, with 75% falling within the 50<sup>th</sup> percentile and the remaining 25% in the 75<sup>th</sup> percentile.

Foot and ankle alignment were assessed by standardized photography in a neutral standing position with the legs hip-width apart and feet parallel to one another. Five megapixel photographs were taken from the posterior at a distance of 90 cm from the participant without additional artificial lightning on a 10-cm grid background. Line drawings were then marked on the photographs along the calf and heel lines [2]. The calf line was determined along the bisection of the upper calcaneal tendon and the heel line as the bisection of the calcaneus

Table 1. Characteristics of the study participants

Gymnasts	Body mass (kg) Min–Max	Body height (m) Min–Max	BMI Min–Max	Age (years) Min–Max	Training experience (years) Min–Max
Trampoline ( <i>n</i> = 10)	22.7–51.8	1.16–1.60	14.63–20.24	6–14	0.5–5
Artistic ( <i>n</i> = 10)	20.9–47.8	1.16–1.53	14.27–20.41	7–13	1–8



Figure 1. Calcaneal-tibial angle as determined by calf and heel lines drawn on the photographed lower extremities



Figure 2. Measuring longitudinal arch by the Clarke angle (left foot 70°, right foot 66°)

(center of calcaneal tendon at the talocrural region) (Figure 1) [1, 2]. A standard SFTR pocket goniometer (Sammons Preston, USA) was used to measure the axis of these two lines to express the calcaneal-tibial angle. In normal ankle anatomy, the heel line should extend along the calf line to create in effect an angle of 180°. Based on previous reports, a deviation of 5° in the calcaneal-tibial angle was treated to be within physiological norms [2]. Any further medial angulation relative to the tibia (positive angular value) was diagnosed as calcaneal valgus. Conversely, a lateral angulation relative to the tibia (negative angular value) was treated as calcaneal varus.

Foot pronation was assessed by the Clarke angle, a measure of the medial longitudinal arch [10]. A digital podoscope, as designed and modified by Demczuk-Włodarczyk, was used to obtain a foot imprint [11, 12]. The procedure involved the participant sitting in a stable chair with the tibia set perpendicular to the ground with the feet bare and resting on the podoscope. An image was obtained in this unloaded position in order to determine foot shape in non-weight bearing conditions [11, 12]. Another image was then captured during upright standing. Next, the digital photographs were examined using computer software to determine the Clarke angle for the right and left foot, which was treated as the angle between the tangent of the medial edge of the foot (running from the peak of the first metatarsal head to the most internal point of the calcaneus) and the tangential line connecting the acme of arch concavity with the most medial point on the forefoot (Figure 2) [2]. Based on the obtained angle, the foot was defined as collapsed arch or pes planus (0–30°), reduced arch (31–41°), neutral arch (42–54°), and high arch or pes cavus (> 55°) [2].

Statistical analysis was performed using the Statistica 10.0 software package (StatSoft, USA). The Shapiro–Wilk test was used to check for data normality, confirming a normal distribution for the calcaneal-tibial angle and Clarke angle in both groups (trampoline and artistic gymnasts) for the right and left foot. Parametric statistics were then applied, with pairwise comparisons made using Student's *t* test. Pearson product-moment correlation coefficients between age, body mass, body height, BMI, and training experience with the calcaneal-tibial angle and Clarke angle were computed. A normal distribution was rejected for data on training experience in the artistic gymnasts, therefore Spearman's rank correlation coefficients were used to compare this variable with the calcaneal-tibial angle and Clarke angle. Statistical significance for all tests was defined at  $p < 0.05$ .

## Results

Mean calcaneal-tibial angles in both groups were positive and exceeded the adopted 5° norm. None of the trampoline gymnasts presented a normal calcaneal-tibial angle, and six were found to show a deviation greater than 10°. Significantly lower mean calcaneal-tibial angle was found

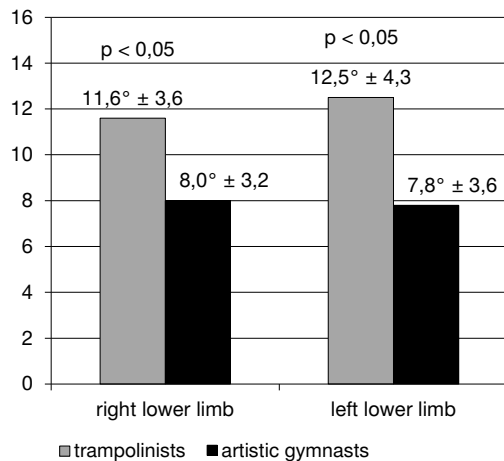


Figure 3. Calcaneal-tibial angle (°) in the trampolinists and artistic gymnasts

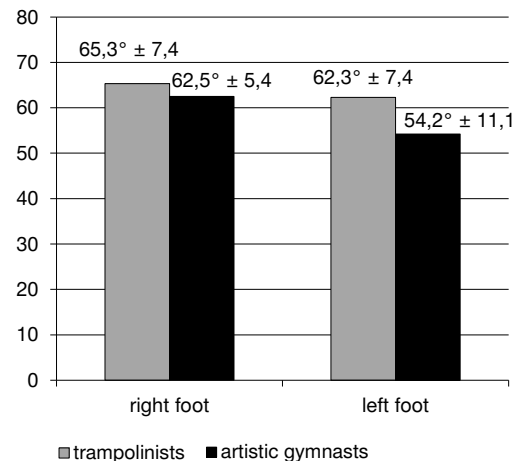


Figure 4. Mean Clarke angles (°) in the trampolinists and artistic gymnasts

in the artistic gymnasts for both the right and left foot (Figure 3). Negative calcaneal-tibial angles were not observed in either group.

Mean Clarke angles in the trampolinists for the right and left feet exceeded 55°. Inter-individual analysis revealed that only one gymnast displayed a neutral longitudinal arch, the remaining participants all showed a tendency for pes cavus. Among the artistic gymnasts, the obtained values were slightly lower although, again, only one of the gymnasts presented neutral arch structure with Clarke angles between 42° and 54°. Mean Clarke angles for this group were 55° and 54° for the right and left foot, respectively, falling within the accepted range but at the upper limit. Inter-group comparisons revealed no statistically significant differences for either the right or left foot (Figure 4).

Pearson correlation coefficients between the anthropometric variables and right and left calcaneal-tibial angles were low and not significant in either group. Analysis of the dependencies with the Clarke angle revealed significant correlations between the Clarke angle and body mass for the right foot ( $r = 0.67$ ) and the Clarke angle and body height for the right and left feet ( $r = 0.65$  and  $r = 0.67$ , respectively) in the trampoline gymnasts. A significant correlation was also observed between the Clarke angle and age in this group ( $r = 0.7$ ). In the artistic gymnastics group, no significant correlations were found between the calcaneal-tibial angle and Clarke angle and any of the anthropometric or demographic variables.

Noteworthy is the fact that the oldest trampoline gymnast (14-years-old with 5 years of training experience) was found to present the largest Clarke angle and calcaneal-tibial angle (9°) in both feet, whereas the oldest artistic gymnast (13-years-old with 8 years of training experience) had a high arch but a calcaneal-tibial angle falling within the accepted norm (4° and 2° for the right and left foot, respectively).

## Discussion

The results of the present study attest to significant differences in ankle structure between acrobatic gymnasts that systematically train trampolining and artistic gymnasts who do not. This was most evident in the fact that the trampolinists presented significantly larger rear-foot angles than the acrobatic gymnasts. While trampoline and artistic gymnastics may share a number of similarities, the former involves a greater jumping component in which the vertical load forces on the musculoskeletal system may be several times greater than that experienced by artistic gymnasts, whose training profile is mostly centered on hanging and stand exercises. For this reason does the present study focalize on the effects of trampolining as a significant contributor to abnormal foot and ankle anatomy. It is highly probable that the forces induced by rebounding and landing on a trampoline [4] are of such magnitude that even the relatively strong tibialis posterior muscles are unable to effectively stabilize the ankle, leading to lower extremity deformity as a result of overuse. Analysis of the effects of trampoline jumping on countermovement jump performance revealed significantly diminished vertical jump height after 60-s of trampolining [13]. However, no significant differences in lower extremity muscle activation were observed before and after this trampolining task, leading the authors to attribute reduced jump height to changes in the temporal and sequential patterns of motor unit recruitment and not reduced muscle activation. Therefore, it can be inferred that while jumping on a trampoline involves similar amplitudes of muscle activation throughout the movement, modifications in the temporal sequence of calf muscle activation may be the cause of insufficient stabilization of the ankle during rebound. This may ultimately lead to overpronation and introduce calcaneal valgus particular among acrobatic gymnasts who compete in trampolining and tumbling

events due to the very large instantaneous vertical forces they experience [4]. Another variable influencing unnatural lower extremity joint loading is the relatively narrow stance (generally the width of the hips) used during rebound. This is a natural technique resulting from better balance control at the moment of impact with the trampoline net. The above publications have suggested that this position nevertheless promotes overpronation and medial stress during trampoline jumping in what has been called “inward shear” and may contribute to the prevalence of chronic lower extremity injury.

Our examination revealed that artistic gymnasts present only slightly increased calcaneal-tibial angles (outside of the accepted  $5^\circ$  norm as adopted by Kasperczyk [2]) with an approximate  $8^\circ$  deviation (Figure 3). It is possible that the more diverse training structure of artistic gymnastics, although also responsible for excessive load [14], is less detrimental to the foot and ankle joints than trampoline gymnastics. As previously mentioned, the initial phase of artistic gymnastics development involves a significant share of hanging and stand exercises on the horizontal and uneven bars. Boraczyński et al. studied the effects of a 1-year artistic gymnastics training program on physical fitness in 7-year-old girls to find the most dynamic increases to be in the areas of upper limb strength (via the bent-arm hang test) and only slight improvements in lower limb strength (via the standing broad jump) [6]. This finding implies that artistic gymnastics training may be less stressful than training that involves a significant trampolining component. Furthermore, artistic gymnasts complete jumps (vault landings or balance beam and parallel bar dismounts) and floor exercise on landing mats and spring floors, respectively, which can significantly reduce vertical ground reaction force [15]. Also of relevance is gymnastics landing technique in that requires the feet to be joined (stuck landing), which may reduce the probability of ankle and knee overpronation.

The findings of the present study demonstrate that the majority of trampoline and artistic gymnasts have a pes cavus deformity, as indicated by Clarke angles above  $55^\circ$  (approximately  $65^\circ$  for the right foot in both groups and approximately  $55^\circ$  for the left foot among artistic gymnasts, Figure 4). This can be explained by frequent plantar flexion and dorsiflexion during gymnastics training, which may have strengthened the intrinsic muscles that support the foot arches while also weakening the deep posterior antagonist muscles of the leg. An investigation on young female dancers, whose movement structure is similar to that in gymnasts, found reduced dorsiflexion compared with non-dancers possibly due to muscle contracture of these deep posterior muscles [16]. Firak et al. performed a targeted analysis of arch structure in 110 acrobatic gymnasts with the Clarke angle measure, finding the majority presented neutral pronation and concluded that acrobatic gymnasts training is conducive to foot anatomy [17].

Noteworthy is that the greatest Clarke angles were observed in tumbling gymnasts. This finding was confirmed in another study on elite female acrobatic gymnasts where their training was positively associated with longitudinal arch structure but negatively with transversal arch structure [18]. While these findings are of particular interest, it needs to be mentioned that neither of the aforementioned studies involved trampolinists outright.

Aydog et al. [9] reported that elite gymnastics athletes present enlarged longitudinal arch compared with untrained individuals. These researchers found a significant positive correlation between arch indexes and foot eversion strength in gymnasts but not among controls. While lower extremity strength is undoubtedly enhanced by the numerous jump-related exercises that quantify acrobatic and artistic gymnastics practice, the gymnasts recruited in the present study presented deformity by way of a high-arched foot although the prevalence of this defect and its magnitude was greater in the trampoline group. However, epidemiological data collected on 80 untrained children aged 6–10 years discovered that only 48% of children had normal foot structure whereas 25% presented pes planus and 28% pes cavus [10]. It is therefore possible that the etiology of this foot deformity in the present sample of gymnasts may have occurred at some earlier time point (before entering gymnastics training), but this aspect was not investigated. Notable is the positive correlative relationship between the Clarke angle and both age and body height ( $r = 0.7$ ) in the trampoline gymnastics group, which may support the notion that their may be other causes responsible for pes cavus as the magnitude of this angle did not correlate with years of experience. Pauk et al. also found a positive correlation between longitudinal arch height and age-standardized BMI [19]. It is nonetheless difficult to exclude the effects of long-term trampolining on the prevalence of foot deformity in the present sample of trampoline and artistic gymnasts. One other point of interest is that all of the trampolinists (besides one with 1-year of experience) were characterized by pes cavus in both feet and that, in some extreme cases, podoscope imaging revealed an imprint showing only the forefoot and heel imprint with no connection between the two. Such a case was not observed among the artistic gymnasts (even in the gymnast with 8-years of experience) although pes cavus was also determined to occur in this group.

It is quite possible that the performance of multiple jump-based exercises, a core component of trampoline and artistic gymnastics training (particularly in the floor exercise and vault events), can strengthen the lower extremity muscles such as the calf and plantar flexor muscles. Kochanowicz et al. found numerous positive and significant correlations between maturity status and standing broad jump performance and dynamometer-assessed handgrip strength in gymnasts aged 6–12 years when demonstrating the effects of jump-

based exercises as well as hanging and stand exercises, the latter of which require considerable grip strength during cast handstands [20]. In view of the aforementioned findings, the high longitudinal arch height we observed in our sample is likely the result of the multitude of jump-based exercises they perform. In addition, the aesthetic nature in both gymnastics modalities frequently requires plantar flexion in lower extremity movements, activating the foot and calf muscles in a range outside of normal daily functioning. Nonetheless, the lack of direct correlative evidence confirming the association between gymnastics activity and excessive longitudinal arch warrants additional investigation.

The lack of associations between the calcaneal-tibial and Clarke angles with body mass, body height, BMI, or training experience in the artistic gymnast group suggests that these variables are not influencing factors in the prevalence of calcaneal valgus and pes cavus. Instead, as evidenced by the previously described dependencies in the group of trampolinists, the pathophysiology of these foot deformities may lie in the unilateral construct of gymnastics training and also the anthropometric characteristics of its participants, particularly at this early life stage.

The present study has some limitations due to the small sample size and the narrow range of gymnasts in terms of age and skill level. For this reason it does not allow for any conclusive diagnosis if gymnastics training is suspect in the etiology of lower extremity deformities. Additional research ought to continue exploring this issue in light of the fact that competitive gymnastics involves ever younger age groups and that any additional findings may help coaches in designing training strategies that circumvent biomechanical faults in such young athletes. Furthermore, the negative impact of habitual trampoline use on the lower extremities suggests that even its recreational application among children ought to be reconsidered for individuals that may present contraindication. The present findings also place doubt on the application of trampoline training to correct pes planus in children due to the possible introduction of pes cavus.

## Conclusions

The majority of the trampoline and artistic gymnasts presented pes cavus, whereas the former showed significantly more pronounced calcaneal valgus than the latter. The prevalence of foot and ankle deformities in both populations should be addressed by coaches in order to reverse the biomechanical changes underlying abnormal medial angulation of the foot or abnormally high medial longitudinal arch.

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