The Open Public Health Journal
DOI: 10.2174/0118749445356998241129112203, 2025, 18, e18749445356998
ISSN: 1874-9445

RESEARCH ARTICLE
OPEN ACCESS

The Interrelation of Clarke's Angle with Body Composition and Lower Extremity Explosive Muscle Strength in School-going Adolescents: A Cross-sectional Study

Dikshita Darphang[1], Kuldeep Deka[2,*], Shreekanth D. Karnad[2], Akshatha Nayak[2], Shalaka Baidya[1], Nirmali Gogoi[3] and Muskan Rastogi[2]

[1]Faculty of Physiotherapy, Assam Downtown University, Guwahati 781026, India
[2]Department of Physiotherapy, Kasturba Medical College, Mangalore, Manipal Academy of Higher Education, Karnataka, Manipal 576104, India
[3]Faculty of Nursing, Assam Downtown University, Guwahati 781026, India

Abstract:

Introduction: Adolescence is a distinct period with many important physiological and behavioural changes, including alterations in body composition, changes in fitness attitudes, physical activity, and sedentary behaviour.

Aim of the Study: The primary purpose of this study was to characterize foot posture in school-aged adolescents aged 11-17 years, and to investigate the relationships between foot posture and body composition and lower extremity muscular explosive strength.

Materials and Methods: This cross-sectional study involved 150 school-going adolescents (11-17 years) who regularly participated in physical education classes and were assessed for their body composition, degree of flexible pes planus, and performance on the standing long jump test. The Spearman correlation coefficient was used to demonstrate the relationship between the degree of flatfoot and the standing long jump test.

Results: The median Clarke's angle for the right foot for male and female participants was 42^0, whereas for the left side, it was measured as a median of 43^0 and 42^0 for females and males, respectively. The median standing long jump test distances for males and females were 154.0 and 116.5 centimetres, respectively. A clinically relevant correlation was not observed, as the ρ values were =0.03, R^2=0.001 and ρ=0.05, R^2=0.001 for the right and left Clarke's angles when associated with standing long jump test distance, and the same test had a weak correlation (ρ=0.145) with body composition.

Conclusion: This study has highlighted that flexible flat feet are not a challenging concern and do not interfere with performance in relation to lower extremity explosive muscle strength.

Keywords: Adolescent, Body composition, Flexible flatfoot, Horizontal jumping, Standing long jump test, Physical activity.

*Address correspondence to this author at the Department of Physiotherapy, Kasturba Medical College, Mangalore, Manipal Academy of Higher Education, Manipal 576104, India; Tel: +91-9954676301; E-mail: kuldeep.deka@manipal.edu

Cite as: Darphang D, Deka K, Karnad S, Nayak A, Baidya S, Gogoi N, Rastogi M. The Interrelation of Clarke's Angle with Body Composition and Lower Extremity Explosive Muscle Strength in School-going Adolescents: A Cross-sectional Study. Open Public Health J, 2025; 18: e18749445356998. http://dx.doi.org/10.2174/0118749445356998241129112203

Received: September 25, 2024
Revised: November 07, 2024
Accepted: November 12, 2024
Published: January 17, 2025

1. INTRODUCTION

Adolescence is a critical period with many important physiological and behavioral changes, including alterations in body composition, changes in fitness attitudes, physical activity, and sedentary behavior [1]. The foot posture of children varies from adolescence to adulthood due to periodical changes in growth and musculoskeletal maturation [2, 3].

However, with gradual growth and development, plantar fat gradually disappears, the valgus angle decreases, and the longitudinal and transverse arches of the foot become prominent [4]. The process of progressive development of the foot arch ends mostly between 10 and 13 years of age and is characterized by specificity in comparison to overall somatic development [5]. In the most common foot disorders, *i.e*., flat foot (pes planus, a biomechanical change), there are significant changes to the talocalcaneal and talonavicular joints, which increases the risk of foot pain, knee pain, and poor exercise performance [6, 7] and puts an individual at risk of injury [8].

It has been proposed that flatfoot is associated with body composition [9, 10]. More distinctively, the amount of muscle mass (appendicular lean mass index) [11] may be associated with the development of flatfoot. During any closed kinetic chain activity, the foot serves as a terminal part of the chain, and any deviation from normal foot posture may affect the motor abilities of the lower extremities, which may indirectly influence physical performance related to sports and leisure activities. Fundamentally, physical performance has been regarded as a useful and powerful marker of health in adolescence [12]. For that reason, it is important to investigate the degree of flatfoot and its connection with body composition and lower extremity physical performance in adolescence. Therefore, the primary purpose of this study was to characterize foot posture in school-going adolescents aged 11-17 years and investigate the relationship of foot posture with BMI and lower extremity muscular explosive strength.

2. MATERIALS AND METHODS

2.1. Study Participants, Design, and Procedure

In this cross-sectional study, we randomly selected 10 out of 161 schools in the city of Guwahati, India. Two of the 10 schools agreed to participate. Within each school, we randomly selected one class representing one age category (children between the ages of 11 and 17). This could yield a total of 12 classes from the two schools. School-going adolescent students (11-17 years) were included in the study according to the assent form and informed consent of the school's head and parents. The sample size was computed by adopting the estimated prevalence of flat feet of 16% among school-going adolescents in South India according to a study performed by Pranati *et al*. [13]. With a prevalence of 16% at the 95% confidence interval and a precision rate of 5%, the sample size was found to be 206, using the formula $4pq/I^2$, where p = prevalence, q = 1-p, and I= standard error. The students were selected in classes from fifth to tenth years by the school, which was proportionally and randomly chosen on the basis of the inclusion and exclusion criteria. The enrolment flowchart of the study participants is shown in Fig. (**1**). The criteria for inclusion in this study were physically active students who regularly participate in physical health education classes, while the exclusion criteria consisted of students with congenital abnormalities of the foot (*e.g*., vertical talus, rigid flat foot), any structural lower extremity deformities, recent musculoskeletal injury, and rheumatic pathology at the time of the study.

The research was conducted after obtaining approval from the ethical approval committees for scientific work and the ethics committee of the Faculty of Physiotherapy, Assam Downtown University, Assam, India (adtu/Ethics/stdnt-lett/2023/040). Instructions were given to the participants regarding the testing procedure, and screening assessments were conducted during their physical education classes.

2.2. Testing Protocol

All the measurements and tests were carried out in the morning hours during the physical education classes. The test protocol in all the schools was the same, and the measurements were carried out by the same group of researchers to avoid any measurement error. The test was carried out in random order to avoid the carryover effect of one testing method over the other. Before the test measurements were started, verbal instructions and demonstrations were given to all the participants regarding the testing procedures. The test procedure was subsequently conducted in a 3-part system.

2.2.1. Anthropometric Measurements

Weight: It was measured without shoes with an electronic weighing scale to the nearest 0.1 kg.

Height: Height was measured using a height meter, without shoes or arms hanging loosely by the side of the body, and the height meter was pulled on the top of the head with enough impact to feel bony resistance; the reading was then taken in centimeters.

Body Mass Index (BMI): BMI was calculated *via* the Quetelet index [14].

2.2.2. Measurement of pes Planus

2.2.2.1. Clarke Angle (CA)

For CA measurement, a static footprint was obtained. Each student was asked to step both feet onto a steel tray with water-soluble ink and ask them to press firmly over the ink pad; then, they were asked to step forward, placing their right foot onto a white sheet and, similarly, his/her left foot. They were asked to stand stable in a relaxed bipedal stance position with equal weight on both feet. If the footprint was not clear because of an inadequate amount of ink, the footprint was discarded, and the procedure was repeated to obtain a good footprint. The

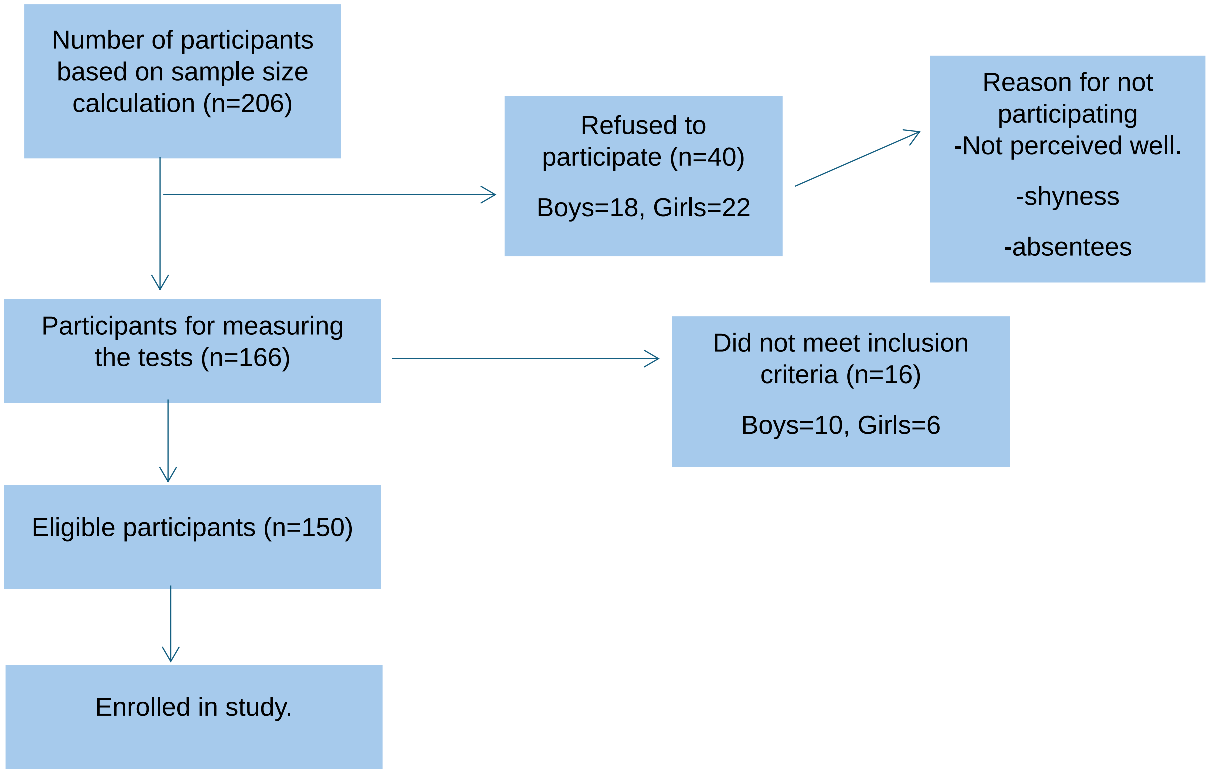

Fig. (1). Enrolment flowchart of the study participants.

footprints were then allowed to dry for some time. The CA was calculated *via* a marker pen, ruler, and protractor marked at one-degree intervals, and the angle between the medial tangential line that connects the medial edges of the first metatarsal head and the heel and the second line that connects the first metatarsal head and the medial longitudinal arch concavity was calculated [15].

2.2.3. Physical Performance Assessment

2.2.3.1. Standing Long Jump Test

A line was drawn on a ground hard surface that served as the starting line. The student had to stand behind the line marked on the ground with feet slightly apart. The student was asked to jump horizontally as far as possible, landing on both feet. Each student was given 3 trials, and the distance of the best jump was measured, to the nearest 1 cm, from the line to the point where the heel closest to the starting line landed. The length of the jump was determined *via* a tape measure. If the subject fell backward, the distance where the body part closest to the starting line touched the ground was measured as the jump length [16].

2.3. Statistical Analysis

The data were coded and entered into the statistical software Jamovi 2.4.11. Descriptive statistics was used to summarize the demographic variables. The data were evaluated for normality *via* the Shapiro-Wilk test; the data have been denoted as the median and interquartile range since the data did not follow the normality assumption. The chi-square test was employed to demonstrate the associations between the degree of flatfoot categorized as high-arched, normal, mild, moderate, or severe flatfoot and the standing long jump test results categorized as poor, average, or good. $p < 0.05$ was considered statistically significant. The Spearman correlation coefficient was used to demonstrate the relationship between the degree of flatfoot using Clarke's Angle (CA) and the Standing Long Jump Test (SLJT) (supplementary data).

3. RESULTS

3.1. Demographic Variables

The demographic variables are depicted in Table **1**. The study involved a total of 150 typically developing children from the school community. Among 150 adolescents, 80 were females and 70 were males. The median age of the included adolescents was 14 (11-16) years for females and 15 (12-17) years for males. Overall, the weights of the adolescents involved ranged from 38-43 Kg, with a maximum weight of 71 kg among female children and 65 kg among male children. There was no significant difference in the height of the included adolescents according to sex. The BMI range of the included female participants was 11.4-31.3 kg/m^2 and that of the male participants was 13.2-25.1 kg/m^2.

Table 1. Demographic characteristics of the study participants.

Descriptive	Gender	N	Median	IQR	Minimum	Maximum	Shapiro-Wilk	
							W	P
Age	Female	80	14.0	2.50	11	16	0.894	<.001
	Male	70	15.0	3.00	12	17	0.863	<.001
Weight	Female	80	38.0	9.42	23.0	71.0	0.946	0.002
	Male	70	43.0	16.75	25.0	65.0	0.974	0.163
Height	Female	80	148.0	9.25	135.0	167.5	0.981	0.292
	Male	70	158.0	14.75	136.0	177.0	0.977	0.231
BMI	Female	80	17.0	2.81	11.4	31.3	0.853	<.001
	Male	70	17.1	4.15	13.2	25.1	0.952	0.009
Standing long jump test	Female	80	116.5	28.00	60	166	0.991	0.874
	Male	70	154.0	46.00	90	210	0.972	0.125
Clarke's angle R	Female	80	42.0	10.00	27	57	0.984	0.432
	Male	70	42.0	9.75	12	60	0.919	<.001
Clarke's angle L	Female	80	43.0	8.25	26	55	0.982	0.312
	Male	70	42.0	9.00	10	55	0.886	<.001

Note: n, number; *p*, <0.05; body mass index, BMI; interquartile range, IQR; right, R; left, L.

Table 2. Correlation analysis between the standing long jump test score and the degree of flatfoot and BMI.

Type of Test	Correlation Test Parameter	Clarke's Angle R	Clarke's Angle L	BMI
BMI	Spearman's rho	-0.049	0.032	—
	Df	148	148	—
	p-value	0.551	0.695	—
SLJT	Spearman's rho	0.037	0.051	0.145
	Df	148	148	148
	p-value	0.655	0.537	0.076

Note: ρ, correlation coefficient of -1 to +1, with 0 indicating no correlation; *p* < .001; standing long jump test, SLJT; body mass index, BMI; right, R; left, L.

3.2. Outcome Variables

Clarke's angle was measured to identify the degree of flatfoot; it has been described for each side separately and considered for analysis. The median Clarke's angle for the right foot for females and males was 42^0. For the left side, a median of 43^0 and 42^0 angles was measured for females and males, respectively. The data were non-normally distributed among males for both feet.

The standing long jump test was used to identify the degree of power generation at the calf in adolescents. The median SLJT distance for females was 116.5 cm (60-166), and for males, it was 154 cm (90-210) (Table **1**).

3.2.1. Correlation between the Degree of Flatfoot and SLJT

Spearman's rho analysis was used to analyse the degree of correlation between the SLJT distance and variables, such as Clarke's angle of right and left and BMI. As depicted in Table **2**, there was no positive correlation between Clarke's angle for both the right and left feet and the SLJT distance. Although the correlation was positive, a clinically relevant correlation was not observed, as the ρ values were ρ=0.03, R^2=0.001 and ρ=0.05, R^2=0.001 for the right and left Clarke angles, respectively, when associated with the SLT distance. However, the data revealed a weak correlation (ρ=0.145) between the SLJT distance and BMI. Similar results were depicted *via* scatter plots (Figs. **2** and **3**).

4. DISCUSSION

There is no clear specific clinical or radiologically accepted universal definition of flatfoot, and in simpler terms, it is a condition in which the longitudinal arch of the foot collapses, and only 4% of cases persist after 10 years of age in children [17]. Flexible flatfoot is usually asymptomatic. However, if it is associated with a short Achilles tendon, it can give rise to pain and functional disability [18]. This impairment often goes unnoticed, and in the time ahead, it may affect sports and recreational activity performance among adolescents. Therefore, the present study aimed to determine which type of association may occur between flexible flatfoot and body composition and lower limb explosive muscular strength among school-going adolescents. The major outcome of the present study was that an insignificant statistical association existed between pes planus and the Standing Long Jump Test (SLJT), irrespective of body composition. These results have revealed that flat feet do not have any negative influence on horizontal jumping ability in this studied population and, second, counter parental clinical concerns regarding flat feet.

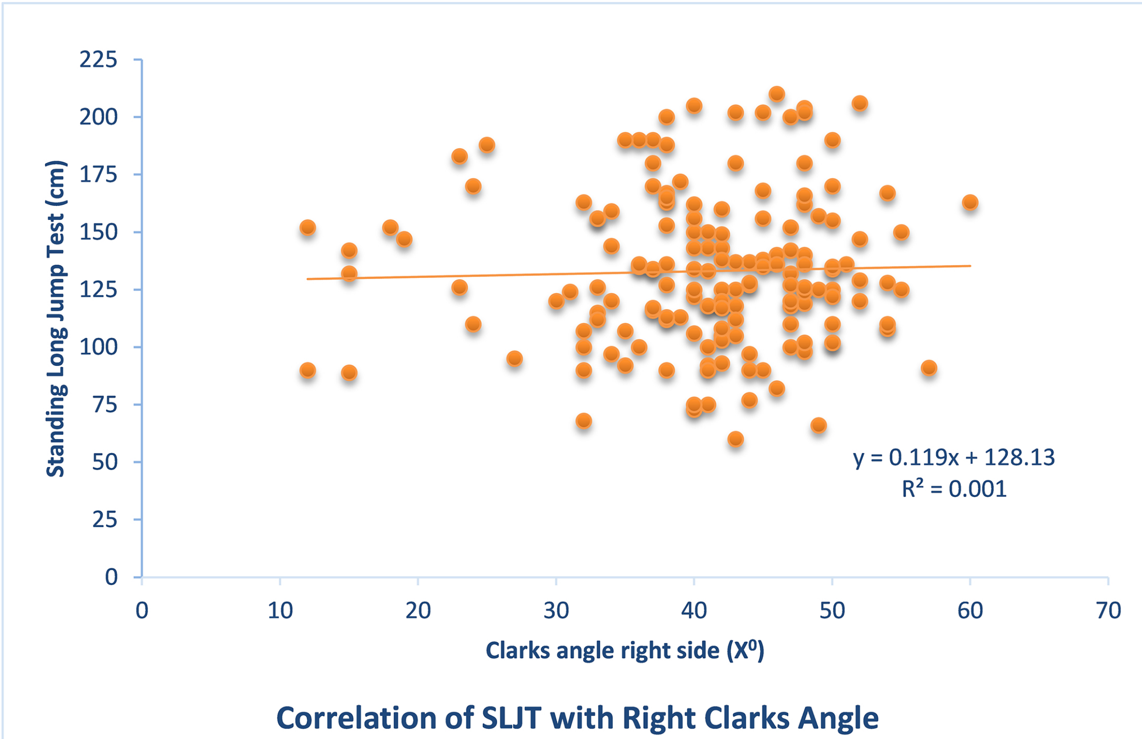

Fig. (2). Correlation between SLJT and the right clarke angle.

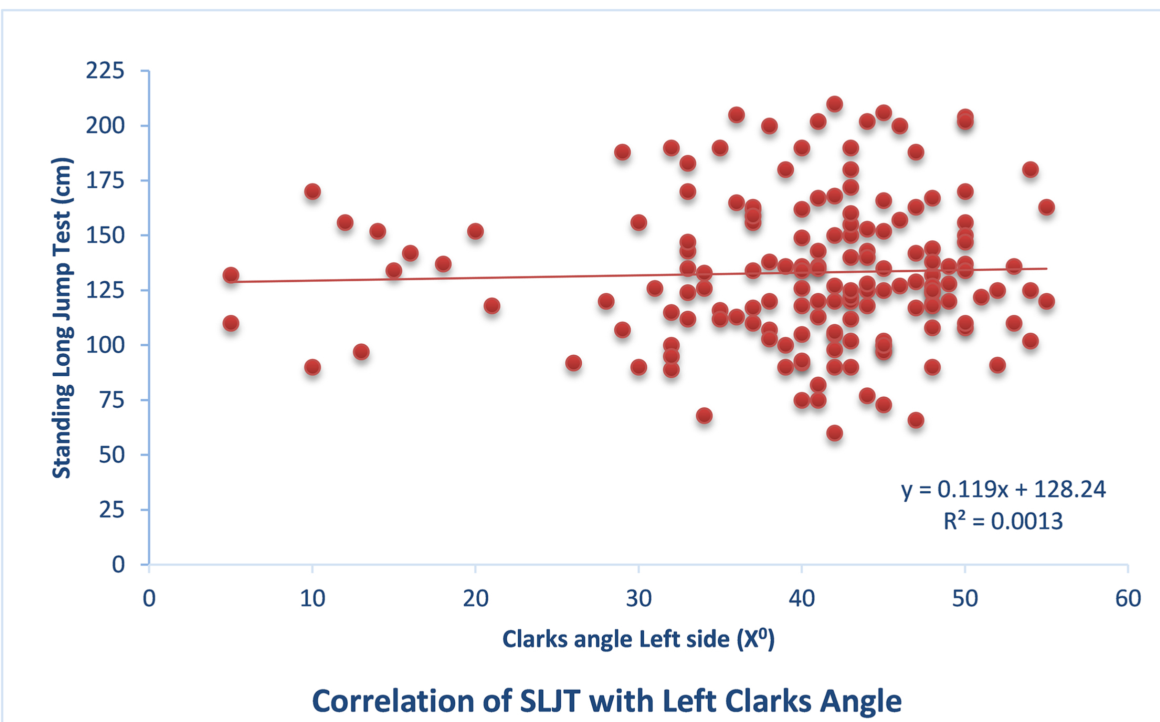

Fig. (3). Correlation between SLJT and the left clarke angle.

Barabas and Malina *et al.* specified that during the period of childhood, the average Standing Long Jump (SLJ) performance increases linearly with age in both sexes until the age of 12 in girls and 13 in boys [19, 20]. In the present study, we aimed to investigate the correlation of flatfoot with lower extremity explosive muscle strength in general. Biomechanically, the SLJ movement system has two main phases: preparation (arms swing and flexion of hips, knees, and ankles) and action (take-off, flight, landing, and standing recovery) [20, 21]. Electro-physiological assessments with electromyography, EMG, or motion capture technology to assess muscle activation during each phase of a long jump were not performed in the present study. Therefore, the distinct effect of Pes planus on horizontal jumping performance cannot be explained well in terms of biomechanical characteristics, which could have enhanced the depth of the analysis in the study.

Numerous authors have clearly described the gradual increase in jump height performance from childhood to adolescence [22-24]. The standing long jump test is commonly used in practice to assess the explosive power of the lower extremity, and the literature has shown varied results across different studies. Ho M *et al.* reported that flat-footed basketball players produced a lower horizontal ground reaction force and lower hip angular velocity than did normal-arched players in standing long jump test performance, and this characteristic lower extremity biomechanical variance suggests that flat-footed individuals must work hard to achieve the same performance [23]. In another study by Sagat *et al.*, test performance in children with flat feet was below the standard in a few physical performance tasks, and the same participants presented significantly poorer results in bilateral and unilateral SLJT [24]. The current study also revealed a non-significant statistical association between the standing long jump test and Clarke's angle measures. The occurrence of flat feet can be multifactorial and can be present from birth or develop later in life; most of these conditions are physiological or pathological causes associated with laxity of the ligament, midfoot laxity, posterior tibial tendon insufficiency, and tarsal coalitions. Most often, flatfoot remains asymptomatic, and clinicians consider it an essentially normal condition. Variability in clinical assessment techniques and consideration of physical and biomechanical factors in the evaluation of flat feet across various studies have revealed conflicting results regarding the associations of pes planus with lower extremity explosive muscle test performance. Therefore, a clearer explanation of the influence of flatfoot on horizontal jumping performance is difficult without a detailed analysis of the characterization of ankle and foot biomechanics.

With respect to vertical jumping ability, most studies have focused on determining the effect of the pes planus on vertical jump height across different age groups, *i.e.*, children to adulthood along with athletes to nonathlete participants, and the results have revealed a non-significant association between jump height and the existence of the pes planus. Alexandrovic *et al.*, in a pilot study in which the vertical jump height of adolescent individuals was related to the degree of pes planus, reported no significant differences [25]. Thus, the vertical jump ability is clearly unlinked with the degree of pes planus.

Another additional finding of a non-significant correlation between body composition and a flat foot stood as a cofounding result in our study, and the pattern appeared to be like that of the study by Daneshmandi *et al.*, in which the researchers reported no meaningful association between BMI and a flat foot [26]. In contrast, Chen *et al.* and Pourghasem *et al.* reported a strong positive correlation between increased BMI and flatfoot in children [27, 28]. Another study in South India by Reddy and Kishve investigated 300 medical students in the 17-23 year age group and reported a flat foot to be associated with BMI and weight and to have a weak relationship with foot length and height [29]. This variability in the association of BMI with flatfoot may be due to factors related to the developmental and biomechanical characteristics of the lower extremity, which may further affect the usual development of the foot structure. With the correlational analysis of BMI and horizontal jumping ability tested with SLJT, we found a non-significant relationship, and the results have been found to be in line with those of a study by Kwiecinski *et al.*, in which the association between BMI and performance ability tested with the standing long jump was not significantly linear in either sex [30].

The demographic characteristics of the 150 school-aged adolescents in our study included a median BMI of 17.1kg/m^2 for males and 17.0kg/m^2 for females, indicating the participants to have adequate nutrition and age-appropriate physical growth. This finding was consistent, although marginally like that reported by Khadilkar *et al.* [31]. Furthermore, genetic and environmental factors differ across geographical areas and ethnicities [32], and because of these factorial variations, it is difficult to generalize the anthropometric findings. The analysis of the minimum-maximum degree of flat foot measured with Clarke's Angle (CA) revealed the right and left angle ranges to be between 12-60° (IQR 9.75) and 10-55° (IQR 9.00) in male participants, whereas among females, they were 27-57° (IQR 10.00) and 26-55° (IOR 8.25), respectively, indicating considerable variability in the pes planus angle among the studied population. With respect to Clarke's angle, the literature suggests CA 42°–54° (normal), 35°-41° mild flatfoot, 30°–34.9° (moderate), < 30° (severe), and > 54° (high arched) to be the reference value criteria for adolescents [17, 33-35].

Jumping is an important motor skill, and its performance depends entirely on physical health-related fitness, body composition, muscular flexibility and strength, speed, agility, and many other factors. Any sort of jumping requires a definite explosive muscle strength of the lower extremity, and an individual's performance may vary depending on several factors in relation to anthropometry and physiological and biomechanical characteristics [36]. However, the findings of the present study have shown that the pes planus does not negatively influence horizontal jumping ability. Ultimately, these findings show that for physical educators and sports coaches to fully unlock the potential of those with flat feet, they must take a proactive approach to encourage all children and adolescents to participate in sports activities. Most importantly, the findings of the current study have supported the practical utility of Clarke's angle measurement to thoroughly screen and characterize pes planus during the developmental transition age period from childhood to adolescence. Early identification and evaluation of pes planus in school-going children by health care professionals, sports coaches, or physical educators are important to prevent the lower extremity biomechanical pattern from being negatively affected and lessen other secondary foot problems associated with flat feet. Furthermore, with the knowledge of foot posture, adolescent readiness for sport and leisure activity participation can be well planned in a more integrated and interdependent approach by physical educators and sports coaches.

There are many studies pertaining to flat feet in children and adolescents, with conflicting evidence indicating the associations of flat feet with sports- and recreational-specific physical performance. Previous studies have shown that flatfoot in children causes parental anxiety because of concerns that it may develop into a pathological flatfoot later in life [37]. With our study results, we can conclude that flexible flat feet are not a challenging concern related to the required explosive physical strength of the lower extremity in this specific adolescent population, which is essentially a major strength of the current study. However, there have been certain limitations in the present study. First, the study population was confined to two schools, and we considered children with flexible flat feet. Second, we examined the biomechanical activation of the selected muscles during each phase of the horizontal jump test and did not consider the physical, psychological, and environmental influences. Third, by drawing upon a cross-sectional study design, we could not determine the causal relationship between flat feet and the explosive muscle strength of the lower extremities. Given these limitations, the generalizability of the findings to other populations seems to be difficult in terms of a comprehensive understanding. Therefore, future research with a larger sample from a wider geographical region and with more comprehensive biomechanical assessments may help clarify the relationships among flat feet, body composition, and lower extremity physical performance ability. Further longitudinal studies are needed to establish the influence of ankle and foot biomechanical factors on jumping ability to provide greater evidence of their cause-effect relationships.

CONCLUSION

Our study results have indicated that flat feet do not influence horizontal jumping ability. These results counter the adverse effects of flat feet on participation in low- to high-impact sports and leisure activities, which require explosive muscular strength of the lower extremities. However, the study has involved several limitations, including a restricted population scope, a lack of biomechanical analysis, and a cross-sectional design limiting causal inference. Future research with larger, more diverse samples and thorough comprehensive biomechanical assessments could help clarify the relationships among flat feet, body composition, and lower extremity explosive muscular strength. Furthermore, early identification and evaluation of pes planus in school-going children and adolescents by health professionals, sports coaches, and physical educators will assist them in developing and planning a more integrated and interdependent approach toward their readiness for sport and leisure activity participation.

AUTHORS' CONTRIBUTION

D.D., K.D., S.B.: Study conception and design; D.D., N.G.: Data collection; K.D., A.N., S.K.: Analysis and interpretation of results; K.D., A.N., S.B., N.G., M.R., S.K.: Drafting of the manuscript. All authors have reviewed the results and approved the final version of the manuscript.

LIST OF ABBREVIATIONS

BMI	=	Body mass index
CA	=	Clarke Angle
SLJ	=	Standing long jump
SLJT	=	Standing long jump test
EMG	=	Electromyography

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The research study was conducted with the ethical approval from committees for scientific work and ethics committee of the Faculty of Physiotherapy, Assam Downtown University, Assam, India (adtu/ethics/stdnt-lett/2023/040).

HUMAN AND ANIMAL RIGHTS

All human research procedures followed were in accordance with the ethical standards of the committee responsible for human experimentation (institutional and national), and with the Helsinki Declaration of 1975, as revised in 2013.

CONSENT FOR PUBLICATION

School-going adolescent students (11-17 years) were included in the study according to the assent form and informed consent of the school's head and parents.

STANDARDS OF REPORTING

STROBE guidelines were followed.

AVAILABILITY OF DATA AND MATERIAL

All data generated or analyzed during this study are included in this published article.

FUNDING

None.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

ACKNOWLEDGEMENTS

Declared none.

SUPPLEMENTARY MATERIALS

Supplementary material is available on the Publisher's website.

REFERENCES

[1] Alberga AS, Sigal RJ, Goldfield G, Prud' homme D, Kenny GP. Overweight and obese teenagers: why is adolescence a critical period? Pediatr Obes 2012; 7(4): 261-73. http://dx.doi.org/10.1111/j.2047-6310.2011.00046.x PMID: 22461384

[2] Carvalho BKG, Penha PJ, Penha NLJ, Andrade RM, Ribeiro AP, João SMA. The influence of gender and body mass index on the FPI-6 evaluated foot posture of 10- to 14-year-old school children in São Paulo, Brazil: a cross-sectional study. J Foot Ankle Res 2017; 10(1): 1. http://dx.doi.org/10.1186/s13047-016-0183-0 PMID: 28670344

[3] Müller S, Carlsohn A, Müller J, Baur H, Mayer F. Static and dynamic foot characteristics in children aged 1–13 years: A cross-sectional study. Gait Posture 2012; 35(3): 389-94. http://dx.doi.org/10.1016/j.gaitpost.2011.10.357 PMID: 22118730

[4] Carr JB II, Yang S, Lather LA. Pediatric Pes planus: A state-of-the-art review. Pediatrics 2016; 137(3): e20151230. http://dx.doi.org/10.1542/peds.2015-1230 PMID: 26908688

[5] Klimczyk M, Stec M. The physical and motor development of 9-year-old children attending football classes in "football school for children". Pedagog Psychol Med Biol Probl Phys Train Sports 2014; 18(12): 65-9. http://dx.doi.org/10.15561/18189172.2014.1212

[6] Truszczyńska-Baszak A, Drzał-Grabiec J, Rachwał M, Chałubińska D, Janowska E. Correlation of physical activity and fitness with arches of the foot in children. Biomed Hum Kinet 2017; 9(1): 19-26. http://dx.doi.org/10.1515/bhk-2017-0004

[7] Omey ML, Micheli LJ. Foot and ankle problems in the young athlete. Med Sci Sports Exerc 1999; 31(7) (Suppl.): S470-86. http://dx.doi.org/10.1097/00005768-199907001-00008 PMID: 10416548

[8] Tong JWK, Kong PW. Association between foot type and lower extremity injuries: systematic literature review with meta-analysis. J Orthop Sports Phys Ther 2013; 43(10): 700-14. http://dx.doi.org/10.2519/jospt.2013.4225 PMID: 23756327

[9] Wyszyńska J, Leszczak J, Podgórska-Bednarz J, *et al.* Body fat and muscle mass in association with foot structure in adolescents: A cross-sectional study. Int J Environ Res Public Health 2020; 17(3): 811. http://dx.doi.org/10.3390/ijerph17030811 PMID: 32012971

[10] Mahaffey R, Morrison SC, Bassett P, Drechsler WI, Cramp MC. The impact of body fat on three dimensional motion of the paediatric foot during walking. Gait Posture 2016; 44: 155-60. http://dx.doi.org/10.1016/j.gaitpost.2015.12.009 PMID: 27004650

[11] Yam TTT, Fong SSM. Leg muscle activation patterns during walking and leg lean mass are different in children with and without developmental coordination disorder. Res Dev Disabil 2018; 73: 87-95. http://dx.doi.org/10.1016/j.ridd.2017.12.014 PMID: 29275080

[12] Ortega FB, Ruiz JR, Castillo MJ, Sjöström M. Physical fitness in childhood and adolescence: A powerful marker of health. Int J Obes 2008; 32(1): 1-11. http://dx.doi.org/10.1038/sj.ijo.0803774 PMID: 18043605

[13] Pranati T, Babu K. Assessment of plantar arch index and prevalence of flat feet among south indian adolescent. Population. JPharmSciRes 2017; 9(4): 490-2.

[14] National Health and Nutrition Examination Survey III : Body measurements (anthropometry). 1988. Available from:https://stacks.cdc.gov/view/cdc/53134(accessed on 18-11-2024).

[15] Hegazy F, Aboelnasr E, Abuzaid M, Kim IJ, Salem Y. Comparing validity and diagnostic accuracy of clarke's angle and foot posture index-6 to determine flexible flatfoot in adolescents: A cross-sectional investigation. J Multidiscip Healthc 2021; 14: 2705-17. http://dx.doi.org/10.2147/JMDH.S317439 PMID: 34611407

[16] Standing long jump test. 2008. Available from:www.topendsports.com/testing/tests/longjump.htm(accessed on 18-11-2024).

[17] Atik A, Ozyurek S. Flexible flatfootness. North Clin Istanb 2014; 1(1): 57-63. http://dx.doi.org/10.14744/nci.2014.29292 PMID: 28058304

[18] Aenumulapalli A, Kulkarni MM, Gandotra AR. Prevalence of flexible flat foot in adults: A cross-sectional study. J Clin Diagn Res 2017; 11(6): AC17-20. http://dx.doi.org/10.7860/JCDR/2017/26566.10059 PMID: 28764143

[19] Biomechanics of sport patterns and motor development. 1996. Available from:https://ojs.ub.uni-konstanz.de/cpa/article/view/2672/2504(accessed on 18-11-2024).

[20] Malina RM, Eisenmann JC, Cumming SP, Ribeiro B, Aroso J. Maturity-associated variation in the growth and functional capacities of youth football (soccer) players 13-15 years. Eur J Appl Physiol 2004; 91(5-6): 555-62. http://dx.doi.org/10.1007/s00421-003-0995-z PMID: 14648128

[21] James G, Reid J, Gavin . Anatomy, Mechanics, and Human Motion. United Kingdom: Prentice Hall 1988.

[22] Sokołowski B, Chrzanowska M. Development of selected motor skills in boys and girls in relation to their rate of maturation – A longitudinal study. Human Mov 2012; 13(2): 132-8. http://dx.doi.org/10.2478/v10038-012-0014-5

[23] Ho M, Kong PW, Chong LJY, Lam WK. Foot orthoses alter lower limb biomechanics but not jump performance in basketball players with and without flat feet. J Foot Ankle Res 2019; 12(1): 24. http://dx.doi.org/10.1186/s13047-019-0334-1 PMID: 31044012

[24] Sagat P, Bartik P, Štefan L, Chatzilelekas V. Are flat feet a disadvantage in performing unilateral and bilateral explosive power and dynamic balance tests in boys? A school-based study. BMC Musculoskelet Disord 2023; 24(1): 622. http://dx.doi.org/10.1186/s12891-023-06752-9 PMID: 37525236

[25] Aleksandrovic M, Kottaras S. Does pes planus precondition diminish explosive leg strength: A pilot study. FU Series Phys Ed Sport 2015; 13(2): 303-9.

[26] Daneshmandi H, Rahnema N, Mehdizadeh R. Relationship between obesity and flatfoot in high school boys and children. Int J Sports Sci Eng 2003; 3: 43-9.

[27] Chen JP, Chung MJ, Wang MJ. Flatfoot prevalence and foot dimensions of 5- to 13-year-old children in Taiwan. Foot Ankle Int 2009; 30(4): 326-32. http://dx.doi.org/10.3113/FAI.2009.0326 PMID: 19356357

[28] Pourghasem M, Kamali N, Farsi M, Soltanpour N. Prevalence of flatfoot among school students and its relationship with BMI. Acta Orthop Traumatol Turc 2016; 50(5): 554-7. http://dx.doi.org/10.1016/j.aott.2016.03.002 PMID: 27760696

[29] Reddy G, Kishve P. Prevalence of flat foot among medical students and its impact on quality of life and functionality. Int J Res Med Sci 2021; 9(4): 1082-9. http://dx.doi.org/10.18203/2320-6012.ijrms20211355

[30] Kwieciński J, Konarski JM, Strzelczyk R, *et al.* Non-linear

relationships between the BMI and physical fitness in Polish adolescents. Ann Hum Biol 2018; 45(5): 406-13.
http://dx.doi.org/10.1080/03014460.2018.1494306 PMID: 30328714

[31] Khadilkar VV, Khadilkar AV, Cole TJ, Sayyad MG. Crosssectional growth curves for height, weight and body mass index for affluent Indian children, 2007. Indian Pediatr 2009; 46(6): 477-89.
PMID: 19556658

[32] Sarna A, Porwal A, Acharya R, *et al*. Waist circumference, waist-to-height ratio and BMI percentiles in children aged 5 to 19 years in India: A population-based study. Obes Sci Pract 2021; 7(4): 392-404.
http://dx.doi.org/10.1002/osp4.493 PMID: 34401198

[33] Szczepanowska-Wolowiec B, Sztandera P, Kotela I, Zak M. Feet deformities and their close association with postural stability deficits in children aged 10–15 years. BMC Musculoskelet Disord 2019; 20(1): 537.
http://dx.doi.org/10.1186/s12891-019-2923-3 PMID: 31722701

[34] Chen KC, Yeh CJ, Kuo JF, Hsieh CL, Yang SF, Wang CH. Footprint analysis of flatfoot in preschool-aged children. Eur J Pediatr 2011; 170(5): 611-7.
http://dx.doi.org/10.1007/s00431-010-1330-4 PMID: 20972687

[35] Forriol F, Pascual J. Footprint analysis between three and seventeen years of age. Foot Ankle 1990; 11(2): 101-4.
http://dx.doi.org/10.1177/107110079001100208 PMID: 2265808

[36] Aouadi R, Jlid MC, Khalifa R, *et al*. Association of anthropometric qualities with vertical jump performance in elite male volleyball players. J Sports Med Phys Fitness 2012; 52(1): 11-7.
PMID: 22327081

[37] Evans AM, Rome K. A Cochrane review of the evidence for non-surgical interventions for flexible pediatric flat feet. Eur J Phys Rehabil Med 2011; 47(1): 69-89.
PMID: 21448121