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Objective Assessment of Cardiopostural Control and its Improvement after Yoga Training using Wii Balance Board and Heart Rate Variability in Young Girls with Flat Foot

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ABSTRACT

Objective: Bipedalism in humans demanded robust postural control systems to maintain balance and equilibrium during variety of volitional activities. Adaptive learning is a key characteristic of these control systems. Postural control and balance are associated with autonomic changes trying to maintain cardiovascular homeostasis during postural imbalances, which are specifically important in conditions like flat foot. Yoga training could help such cases to achieve better postural balance and autonomic state. Young adolescent girls with flat foot were studied in comparison to normal girls and flat foot boys.

Materials and Methods: Sixteen girls and 11 boys with flat foot were subjected to posturography on Wii Balance Board connected wirelessly to PowerLab 15T. Wireless heart rate belt was used to acquire RR intervals. Vrikshasana was chosen as the suitable asana for 4-week training. Displacement of center of pressure (COP) and heart rate variability was analyzed using LabChart pro software before and after yoga training.

Results: COP displacement in flat foot subjects is away from the center during erect stance and sway toward sides. Flat foot girls showed significant greater displacements and lesser correction after yoga compared to flat foot boys ($P < 0.05$). Flat foot girls also showed lesser recovery in LF% and RMSSD after 4-week yoga training.

Conclusion: Studying the autonomic changes during voluntary postural imbalance on balance board provide real-time picture of internal state in flat foot individuals. The sympathetic dominance would account for preparedness and adaptation in postural control systems. This state improved with yoga training toward better cardiac vagal tone.

Keywords: Flat foot, Yoga, Balance board, Heart rate variability

INTRODUCTION

Bipedalism in humans is an evolutionary breakthrough. It not only led to the development of complex sensory-motor circuits but also demanded robust control systems for posture and equilibrium. Posture is the disposition of the body parts on each other and with their environment at any given time. The postural control system must address challenges such as maintaining a steady stance with balance in the gravitational field; anticipating the volitional goal-directed movements and possible threats they might make to postural stability; and adapting and learning better control mechanisms for posture and balance.[1] Especially when the newer forces like centrifugal force are introduced, the control systems must work more efficiently without disturbing the visceral states. This could happen only when postural control systems incorporate autonomic control. Cardiovascular homeostasis, respiratory movements, skin conductance, glomerular filtration, and the release of adrenal medullary hormones, to name a few, change with postural fluctuations. For example, baroreceptor reflexes play a key role in cardiopostural control pathways. Furthermore, the plasma-free norepinephrine levels increase from 300 pg/ml in the supine position to about 500–600 pg/ml immediately on standing! The natural anatomical differences such as the pelvis and long bone anatomy, bone strength, and ligament density in females and males could also lead to differential postural adaptations as well as cardiovascular state. This could be the reason behind gender-specific interests in sports, fine arts, and skilled movements. May it be a long-standing disease in the postural control system or musculoskeletal system, or an acute change in posture during rapid volitional movements, they will have reflections on cardiorespiratory homeostasis. For example, anxiety and hypertension are associated with vertigo. If the disease is inborn, like flat foot, it could be expected that the effect on cardiovascular status will also be chronic and mostly hidden, making certain adjustments in the basal cardiovascular state itself. Usually, a flat foot goes unnoticed until there are symptoms of joint and muscle pain particularly calf muscles or a change in the gait of the individual.[2] Hence, it would be a good comparison to study the autonomic states and postural control abilities in both sexes with flat feet (FF).

Yoga is recognized as an ancient health and wellness practice that originated in India. It involves movement, meditation, and breathing techniques to promote physical and mental well-being. There are several types of yoga and many disciplines within its practice. Yoga exercises are believed to improve postural stability and balance and lower the risk of falls. Several yoga asanas help to give proper alignment of the body to maintain correct posture and balance. The most widely practiced asanas to improve stability and balance of an individual are the Mountain pose (Tadasana), Tree Pose (Vrksasana), Side Plank Pose (Vasisthasana), Dancer Pose (Natarajasana), Eagle Pose (Garudasana), One Leg Pose (Eka padasana), and the Chair Pose (Utkatasana). Intervention with yoga training would likely bring back good postural stability in individuals with the above-mentioned disease or inborn anatomical traits.[3] Hence, whether yoga training in individuals with expected problematic cardiopostural control systems as in the case of the flat foot will improve that the autonomic status is a question. Objective assessment of postural balance by measuring the displacement of center of pressure (COP) and relative weight distribution on the board coupled with simultaneous assessment of autonomic state proves worthy in studying the complex cardiopostural control systems.[4] Posturography or test of balance is one such non-invasive specialized clinical assessment technique used to quantify the central nervous system adaptive mechanisms such as sensory and motor inputs involved in the control of posture and balance.[5] Adequate balance during the Yogasanas will, hence, reflect in the autonomic balance which can be estimated through heart rate variability (HRV). HRV is the physiological phenomenon of the variation in the time interval between each heartbeat calculated in milliseconds. Time-domain indices of HRV are used to quantify the amount of variability in measurements of the interbeat interval, which is the period between successive heartbeats.[6]

The psychophysiological aspects of stress response arising from the brain functions reflect on the functions of the hypothalamic-pituitary-adrenal (HPA) axis. The HPA axis is the central stress response system. Since most of the motor commands are routed through the HPA axis and along with other endocrine functions, the motor commands are propagated through the brain stem and reticular activating system to the HPA axis. Thus, the stress-related effects of HPA are by modulating the neuroendocrine axis that, in turn, affects the immune system. HPA hyperactivity predisposes to increased cellular oxidative stress. Yoga leads to an inhibition of the posterior hypothalamus, thus, optimizing the body's sympathetic responses to stressful stimuli, and restoring autonomic regulatory reflex mechanisms associated with stress.[7]

The present study tries to answer this question: What is the benefit of yoga training in subjects with FF who are otherwise healthy in general, in regulating the postural balance and autonomic balance during a posturography assessment.

Yogasanas like Vrikshasana primarily improve physical and emotional balance. Just as a tree is able to balance, staying firmly rooted. People with flat foot tend to have postural instability and improper distribution of center of gravity. On adequate practice of yoga by flat foot individuals, there would be better autonomic balance which is quantified using time-domain indices of HRV.

MATERIALS AND METHODS

The study received permission from the Institutional Ethical Committee. Informed written consent was taken from each participant before the study. The study sample consisted of 30 medical students from ESIC Medical College, Sanathnagar, Hyderabad, with and without FF between the age group of 19 and 23. The exclusion criteria for this study are the individuals with disorders in balance and equilibrium, motor, visual, musculoskeletal impairment, history of head-and-neck trauma, lower extremity joint disorders, regular attacks of syncope, and seizures on medication affecting the central nervous system.[8] The study group consisted of medical students belonging to various socioeconomic statuses and those who were interested in practicing yoga for physical and mental well-being and individuals who can stand for 20 min independently. The participants are requested to come to the digital physiology laboratory. After signing the consent form, they were assessed through an interview whether they could perform the posturography study and comply with the yoga training for 4 weeks. After successful assessment, the subjects were given a schedule for the posturography study and yoga training. A trained teacher made visits to the medical college campus to train the students. The study comprised two parts, data acquisition before the yoga training and after the training. The equipment used for the study includes Wii Balance Board (WBB) and wireless heart rate belt both connected to the PowerLab 15T supplied by AD Instruments. The LabChart Pro v8.1.9 software was used for analysis.

Brief description of WBB: It is a rectangular board with four corners labeled as top right, top left, bottom right, and bottom left, which lie in front of and behind the right and left sides of the individual who stands on the board. A central space is present for the placement of feet [Figure 1]. The WBB is connected through Bluetooth to the main hardware unit. Wii Board instrument contains sensitive detectors connected through Bluetooth to the LabChart computer software.[9] Any minor oscillations of the body are detected and transmitted in real time to a computer shown on the LabChart software giving instant feedback on the posture and stability of the body.[10] The rectangular board measures 433 mm in breadth and 228 mm in width. These measures will be important in applying the formula to calculate the COP. The COP will have its two components on the X-axis and Y-axis.[11] The subjects were asked to stand on the WBB with their hands by the side and look straight. A wireless heart rate belt connected to the hardware through a Bluetooth port and attachable to the chest was used to acquire RR intervals. For girl subjects, exclusive privacy and security were ensured for connecting the wireless belt with the help of senior female members in the department.

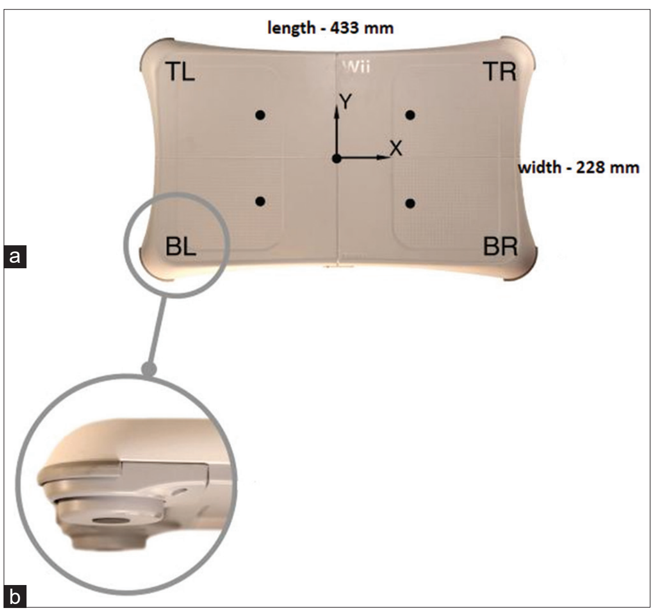

Figure 1: Wii Balance Board. (a) The top surface of the board is shown with the coordinates used for computing the center of pressure, sensor locations and the abbreviated protocol testing locations. (b) Foot-pegs housing force sensors are found under each of the four corners of the board (5).

The subjects were asked to remove their footwear and to stand on the WBB. The subjects were instructed to stand with their hand by their sides and with their head straight. The recording is started, and it is done for 1 min while standing straight and then the person is instructed to bend forward and backward for 30 s each. The person must come back to the straight erect position to allow his/her center of gravity to attain its actual position. Then, the person is made to stand on one leg, first right and then left with the opposite leg at about 90° to the hip joint. The total test took approximately 5 min for each participant. At the end of the recording, the participants were sent. The HRV module in the software is used to calculate, after eliminating the ectopic beats, various time-domain, frequency-domain, and non-linear measures, of which only a few measures are obtained for this study.[12]

After the initial recording, the subject is made to practice yoga under expert supervision. The specific asana chosen for this study is the tree pose or Vrikshasana which is one the most beneficial and easy Yogasana to perform. The Vrikshasana helps improve neuromuscular coordination, balance, endurance, enhance alertness, and concentration and overall body stability. First, the subject is made to stand erect and one feet distance is maintained between the feet. Then slowly, the arms are raised over the head as the forearms touch the ears while the head and neck are fixed. Slowly, the right leg is raised and placed on the left thigh such that the complete sole is in contact with the thigh. This position is maintained for 3 min. Breathing should be normal and under control. Then, the right leg is slowly placed on the floor and the same step is repeated with the left leg. In the end, the left leg is also placed on the floor and hands are slowly lowered to the side of the hips. Following 4 weeks of this yoga training session, the postural sway and balance were recorded on the WBB by the same above procedure.

RESULTS

A total of 60 medical students, 30 boys and 30 girls, were recruited for the study. The 30 girls included 14 girls with normal feet (NF) and 16 with FF. Similarly, the 30 boys included 19 with NF and 11 with FF. The mean age of girls and boys was 21 years. All the students were right handed. All the students were subjected to posturography study before and after 4 weeks of yoga training. The average heart rate and other HRV parameters were also collected while they were standing and performing balance postures on board. The results are detailed below.

For the posturography study, the parameters recorded were in order, the COP in both X-axis and Y-axis (COPx and COPy, respectively) recorded during onboard (OB) usual erect standing posture OB-COPx and OB-COPy, as well as during the right leg lift or right leg sway (RS-COPx and RS-COPy) and left leg lift or sway in the air (LS-COPx and LS-COPy). Percentage of total body weight applied on the bottom of the Wii board while bending forward and that applied on the top of the Wii board while bending backward was calculated. All values are expressed as mean±SD values. Along with the posturography study, the wireless heart rate kit was used to obtain the RR intervals during the total 5 min duration of the stay of the subject on the Wii board to calculate the average heart rate and the HRV.

Observations from the posturography in girls and boys:

While onboard in an erect posture, the OB-COPx and OB-COPy values were almost similar in both NF boys and girls and these values did not also differ much before and after yoga training. In FF girls and boys, however, during the erect stance, the OB-COPx and OB-COPy values were in a positive direction compared to the negative values in NF subjects [Table 1]. When one of the legs was raised and kept in air for 30 s resembling a sway to one side, the COPx and COPy values were obtained again and compared between sexes and yoga training. All the values were on the positive side. Girls with FF showed significantly greater values for RS-COPx compared to girls with NF and boys [Table 2]. Furthermore, after the yoga training, the values were significantly different in all the groups. They reduced from the original COP values suggesting better postural control by the body. This betterment was more evident in NF subjects than FF subjects [Table 2]. Multiple ANOVA performed for this test was significant ($P < 0.05$).

Table 1: Distribution of mean±SD values of OB-COPx and OB-COPy calculated at the beginning of the posturography study in usual erect posture at rest for 30 s and its variation before and after yoga training.

	OB-COPx		OB-COPy	
	Before	After	Before	After
Girls-NF (*n*=14)	−3.03±1.1	−3.12±1.3	−1.59±1	−1.72±1.2
Girls-FF (*n*=16)	3.73±1.7	3.68±1.8	1.96±1.9	1.84±2.0
Boys-NF (*n*=19)	−3.86±1.1	−3.94±1	−1.98±1.2	−1.87±1.1
Boys-FF (*n*=11)	4.03±2.3	3.99±1.4	2.05±1.1	2.10±1

OB-COPx: Onboard-center of pressure X-axis, OB-COPy: Onboard-center of pressure Y-axis, NF: Normal feet, FF: Flat feet

During the left leg lift for about 30 s, the values of LS-COPx and LS-COPy were obtained. The values in all the groups were on the negative side. The COPx values did not differ significantly in NF and FF girls before yoga training. The values showed a good improvement after the yoga training in both NF and FF groups but were not significantly different from during RS [Table 3]. Multiple ANOVA performed for this test was significant ($P < 0.05$).

After the calculation of COPx and COPy values in the erect, right sway and left sway postures, the RR intervals obtained through wireless heart rate belts were analyzed for HRV. The description of the various time-domain and frequency-domain measures of HRV is presented in [Table 4].[13] Among the time-domain measures, average heart rate and root mean square of successive RR interval differences (RMSSD) showed a good improvement after yoga training. The average heart rate throughout the 5 min posturography study was high in FF boys and girls compared to NF ones. This difference was even more in FF boys compared to FF girls

Table 2: Distribution of mean±SD values of RS-COPx and RS-COPy calculated during posturography study during right leg lift for 30 s and its variation before and after yoga training.

	RS-COPx		RS-COPy	
	Before	After	Before	After
Girls-NF (*n*=14)	121.5±3.4	87.69±2.3	63.98±1.8	46.17±1.2
Girls-FF (*n*=16)	130.7±1.4	98.23±3.6	68.82±1.8	56.17±4.2
Boys-NF (*n*=19)	100.05±4.4	87.69±2.3	52.68±1.8	46.17±1.2
Boys-FF (*n*=11)	124.16±2.8	89.45±2.3	65.38±2.1	53.97±2.7

RS-COPx: Right leg sway center of pressure X-axis, RS-COPy: Right leg sway center of pressure Y-axis, NF: Normal feet, FF: Flat feet

Table 3: Distribution of mean±SD values of LS-COPx and LS-COPy calculated during posturography study during left leg lift for 30 seconds and its variation before and after yoga training.

	LS-COPx		LS-COPy	
	Before	After	Before	After
Girls-NF (*n*=14)	−129.66±4.1	−136.7±1.8	−68.28±1.3	−71.91±1.9
Girls-FF (*n*=16)	−128.20±3.9	−130.8±1.2	−67.53±3.0	−69.25±1.5
Boys-NF (*n*=19)	−126.35±3.3	−137.2±1.4	−66.53±1.3	−70.82±1.4
Boys-FF (*n*=11)	−101.78±2.1	−128.8±3.8	−53.59±1.3	−68.54±4.6

LS-COPx: Left leg sway center of pressure X-axis, LS-COPy: Left leg sway center of pressure Y-axis, NF: Normal feet, FF: Flat feet

[Table 5]. The average heart rates were controlled after yoga training in both the groups and this reduction in heart rate was strikingly more in FF boys compared to FF girls. The RMSSD values also showed a reduction after yoga training in all the groups [Table 5]. The difference in the average heart rate and RMSSD before and after yoga training in FF girls and FF boys was separately estimated using paired t-test and was found to be significant with $P < 0.05$.

Among the frequency-domain measures, the LF power (LF%) and the HF power (HF%) were observed to be different after yoga intervention, particularly in FF boys and girls. The LF% declined after yoga training in all groups but particularly in FF boys and girls. The rise in HF% after yoga training was more obvious in FF boys compared to FF girls [Table 6]. The paired *t*-test was significant with $P < 0.05$.

Table 4: Various time-domain and frequency-domain measures calculated in this study and their description.

Parameter	Unit	Description
Avg HR	bpm	Average of the difference between the highest and lowest heart rates
SDRR	ms	Standard deviation of RR intervals (after ectopics are eliminated)
RMSSD	ms	Root mean square of successive RR interval differences (after ectopics are eliminated)
pRR50	%	Percentage of successive RR intervals that differ by more than 50ms (after elimination of ectopics)
VLF	%	Relative power of very low frequency band (0 – 0.04 Hz)
LF	%	Relative power of low frequency band (0.04 – 0.15 Hz)
HF	%	Relative power of high frequency band (0.15 – 0.45 Hz)
LF/HF	%	Ratio of LF to HF power

Table 5: Distribution of Mean±SD values across various time-domain measures of HRV before and after yoga training.

Group	Average Heart Rate (bpm)		RMSSD (ms)	
	Before	After	Before	After
Girls-*NF* (*n*=14)	74.31±6.1	72.82±6.0	20.49±13.93	22.58±11.05
Girls-FF (*n*=16)	84.15±5.6	73.25±3.8	37.15±16.3	31.25±10.9
Boys-*NF* (*n*=19)	78.24±4.6	77.14±4.2	26.47±15.81	24.12±11.43
Boys-FF (*n*=11)	91.36±2.7	76.28±2.2	40.28±13.26	30.54±12.41

NF: Normal feet, FF: Flat feet, HRV: Heart rate variability, RMSSD: Root mean square of successive RR interval differences

DISCUSSION

Postural control systems are closely associated with autonomic changes, especially when the postural balance is required during volitional movements. The autonomic imbalance may become more evident when the individual has any musculoskeletal disorders or simple anatomical differences in body structure. Furthermore, the postural balance may also be dependent on the natural anatomical constraints such as pelvis and long bone alignment in line with gravitational force. In the present study, young adults, both girls and boys with FF, were tested for their posture control and balance along with autonomic functional status. The posturography and the HRV were compared before and after the intervention using yoga training.

During the erect stance on the balance board, the displacement of the COP in both axes X and Y was in a positive direction, meaning, away from the center of the body toward the edge of the board in all flat foot students compared to normal foot counterparts. The COP is that point in the body where all the bodyweight is applied. In normal foot girls and boys, the value of COP and its displacement in the X and Y axes was negative [Table 1] which means that the point is well within the base formed by both feet. In flat foot girls and boys, the displacement of COP in X and Y directions is positive toward outside the body. Contrary to our logical understanding that FF could give the body more stability in simple standing posture, the flat foot students were distributing their body weight outside the base. Probably, the anatomical configuration of their feet poses additional work on their postural muscle groups to maintain an erect posture and this had reflected in terms of displacement of COP away from the center. This tendency did not differ much even after yoga training, meaning, their postural control system is tuned to such COP displacement which has been learnt from their childhood. The muscle tone and joint stiffness patterns

Table 6: Distribution of Mean±SD values across two frequency-domain measures of HRV before and after yoga training.

Group	LF power (%)		HF power (%)	
	Before	After	Before	After
Girls-*NF* (*n*=14)	25.26±12.3	21.67±17.7	51.58±17.7	53.98±11.9
Girls-FF (*n*=16)	32.39±6.8	18.98±17.7	45.18±11.4	58.35±14.2
Boys-*NF* (*n*=19)	26.61±10.4	24.28±11.2	49.68±4.1	51.23±3.9
Boys-FF (*n*=11)	36.19±9.4	20.49±3.8	39.08±7.2	65.13±3.2

NF: Normal feet, FF: Flat feet, HRV: Heart rate variability, LF: Low frequency, HF: High frequency which were gained through a long-standing adaptation are not easily changed with yoga training. Hence, to understand the abnormalities in postural balance mechanisms and their improvement with yoga training, the subjects were asked to perform right and left sway movements while onboard supporting their body with another leg.

The right leg or left leg sway involved raising the entire lower limb at the hip joint to approximately 90° for 30 s. Physiologically, for example, when the right leg will be raised in the air, even before the actual movement, the left hip and shoulder joints move toward the left to distribute weight on the left side. This is the anticipatory reaction. When the right ankle takes off the ground, COP first displaces to right and later moves toward the left leg, the supporting leg, and finally settles under the left leg. The target of the present study is to calculate this displacement and the degree of correction after the training. During right sway, the COPx and COPy displacement were more in FF girls compared to FF boys [Table 2].[14,15] Furthermore, after the yoga training, the degree of correction in COP displacement was better in boys compared to girls with FF. All the students were right handed. Hence, it becomes clear that their ability to support the bodyweight on the right leg (during left sway) would be better compared to supporting the weight on the left leg. Similar to this assumption, it was observed that the displacement of COP during the left sway was not as much as the right sway condition and the degree of correction after yoga training is also better in the left sway condition [Table 3]. During both sway conditions as well as the erect stance, it is clear that FF boys were better at correcting the COP displacements compared to FF girls. This could be probably related to one – anatomical differences in pelvis and long bones on girls; two – relative lack of active movements since childhood in FF girls as compared to FF boys (as such the girls in our culture restrict to household activities and take less part in sports or outdoor activities involving more movements); and three – lack of robust adaptability in postural control systems of FF girls compared to FF boys and NF girls and boys. As much as routine activities are concerned, this could not be a major constraint in the life of FF girls because they are usually not involved in severe sports or outdoor activities and such special circumstances like sways are not expected in their routine. However, what about their internal state during a threat to postural balance situation? That means when the FF girls and boys were asked to perform unusual postures on the balance board, how did their subconscious mind process the internal state? How did their autonomic system respond? The answer to these questions had brought a few interesting differences between FF girls and boys.

The autonomic state was assessed during the 5 min stay on the balance board in all students, from the wireless heart rate signal.[16] The average heart rate was high in FF girls and boys compared to their NF counterparts. The difference in average heart rate was higher in FF boys compared to FF girls. The increased heart rate could be understood as a sympathetic function due to the anticipated risk to the posture. After yoga training, these FF girls and boys reverted to normal average heart rates. Yoga had not had much impact on the average rate in NF students. As the students practiced Vrikshasana primarily for the postural balance which is better in NF students, the heart rate probably did not differ much after yoga. RMSSD is one of the time-domain measures which denote cardiac vagal tones, especially when recorded in shorter periods. The values of RMSSD were higher in FF girls and boys and recovered after yoga training indicating the return of cardiac vagal tone. This recovery of vagal tone is better in FF boys compared to FF girls, corresponding with greater correction in average heart rate in FF boys [Table 5]. When the frequency-domain measures were calculated, it was found that the FF girls and FF boys had greater LF% and lower HF%. After the yoga training, the degree of correction was better in FF boys compared to girls. All the above findings suggest that the adaptability of postural control systems and the balance in the autonomic state was better in FF boys compared to FF girls. It could be possible that the FF girls need a longer period of yoga training or a combination of yoga sessions compared to boys to achieve good recovery.

In the present study, Vrikshasana was chosen as means of yoga training for 4 weeks, administered as twice-daily sessions, each lasting for about 60 min. This helps to improve neuromuscular coordination, balance, endurance, and enhance alertness and concentration giving overall body stability.

The advantages of the present study are as follows:

a. Postural control systems are estimated using a standard balance board in FF girls and boys in contrast to NF subjects.
b. An autonomic state was obtained during the postural changes using wireless transducers.
c. The benefit of Vrikshasana on postural control and the autonomic state has been proven. This benefit is more in FF boys compared to FF girls.

The limitations of the present study are as follows:

a. The duration of yoga training could be increased to see a better improvement in FF girls. FF boys showed earlier correction of COP values and HRV parameters.
b. Along with COP displacement, COP path length could have been calculated in addition.
c. The way of action of yoga training should be studied in detail using other physiological parameters such as galvanic skin response and EMG studies.

CONCLUSION

Studying the autonomic changes during voluntary postural imbalance on balance board provide real-time picture of internal state in flat foot individuals. The sympathetic dominance would account for preparedness and adaptation in postural control systems. This state improved with yoga training toward better cardiac vagal tone.

Declaration of patient consent

Patient's consent not required as there are no patients in this study.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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