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Original Article

Analysis of chippaux smirak index on dynamic balance scores

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Abstract

Aim: The aim of this study is to examine whether Chippaux Smirak Index (CSI) calculated from footprint and measurements taken from foot have an effect on balance scores.

Materials and Methods: 61volunteers (25 males, 36 females) between the ages of 18 and 24 were included in our study and 122 feet were measured. Footprints of the participants were taken by using Harris imprint. Footprints were scanned, the parameters were measured with Digimizer program and CSI was calculated. Metatarsal foot width (MFW), maximum metatarsal foot width (MMFW), length of the foot (LoFA), heel width (HW) and foot length (FL) taken from footprints were measured. Individuals with CSI >62.70% were considered as flatfooted and excluded from the study. Dynamic balance measurements were made with Biodex Balance System (BBS) (Biodex Medical Systems, Shirley, 2000, New York). Overall (OA), anterior-posterior (AP) and medial-lateral (ML) dynamic balance assessments of the participants were made with eyes open.

Results: According to Mann Whitney U analysis results, statistically significant difference was found between MFW, MMFW, LoFA, HW and FL parameters of men and women in both feet ($p<0.05$). It was found that OA, AP and ML balance scores had a statistically significant difference between men and women for dynamic balance ($p<0.05$). According to Sperman Rho correlation analysis, a positive correlation was found between weight and body mass index (BMI) and balance scores in men and women. It was found that there was no significant correlation between CSI and balance scores.

Conclusion: As a conclusion, while no association was found between weight and BMI and CSI, a positive correlation was found between weight and balance scores. We believe the fact that women have lower BMI gives them an advantage in terms of balance scores. In addition, it was found as a result of this study that there was no association between CSI and balance scores. We believe that our study will have an important place in literature and be a guide since we compared both genders.

Keywords: Chippaux smirak index; dynamic balance; foot; pes planus

INTRODUCTION

The sole of the foot provides a support surface by direct contact with the ground and also plays a role in load distribution during body movements. It has the duty to absorb shocks caused by heel strike while walking (1). In addition, the feet provide a connection between the body and the floor, providing a somatosensorial input to the body through tactile and proprioceptive system and these inputs have a significant place in postural control. Sensory feedback from subcutaneous receptors on the plantar face of the foot plays an important role in maintaining postural control. They ensure the continuity of static and dynamic posture by being aware of proprioceptive senses, positions and movements. In addition to these, the ankle joint, muscle, tendon and arches provide afferent information (2). Pes planus is defined as valgus that occurs in the posterior foot while walking, decrease or loss of medial longitudinal arch (MLA) height in the midfoot and supination of the forefoot relative to the posterior foot. Heel eversion or pronation accompanies forefoot supination. The main problem is in the subtalar joint (3).

Many different methods are used in the assessment of foot structure. Although it has limitations, footprint method is an indirect technique used frequently in clinic. Various footprint classification techniques have been generated to assess footprint parameters and the structure of the foot. Numerical parameters such as footprint index, valgus index, arch index, Staheli index and CSI are some of these (4-6).

Balance is the ability of the body's visual, vestibular and somatosensorial systems to integrate. Somatosensory system consists of a series of superficial and deep

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mechanoreceptors. The continuity of balance is ensured by the proper functioning of neuromuscular system and biomechanical harmony of the lower extremity (7). Balance is basically developed in two stages as static and dynamic. Providing postural control on a moving floor or while moving is defined as dynamic balance, while static balance is the control of body balance while maintaining a fixed posture (8). The postural control strategy that we use while standing or walking is sensitive to mechanical changes in support surface and muscles strategies (9). Our feet provide static and dynamic stability by creating a support surface. They send spatial and temporal feedback to postural control system. Thus, it is thought that even a small biomechanical change on support surface will create an effect on postural control and thus balance (10,11).

The aim of this study is to analyse whether Chippaux Simirak Index (CSI) has an effect on dynamic balance scores in healthy men and women whose footprints were taken based on information in literature.

MATERIALS and METHODS

Study Group

This study was carried out with 2020/197 coded permission of İnönü University Ethical Board. 61 volunteers (25 men, 36 women) were included in the study. Inclusion criteria were determined as being physically healthy, having no medical impairment to participate in the study such as vision or hearing, not having a chronic disease related to the musculoskeletal system and not having a surgical intervention history. The participants were informed about the study and they signed informed consent form. The study was conducted in accordance with the principles of Helsinki Declaration.

Dynamic balance measurements

In the study, Biodex Balance System (Biodex, Inc, Shirley, New York) was used for balance measurement. Biodex balance device consists of a movable platform that allows the participant to move forward, backward and sideways besides standing still. Overall (OA), anterior-posterior (AP) and medial-lateral (ML) dynamic balance indices of the measured individuals were tested with eyes open. The participants were asked to stand on the platform with eyes open, bare feet, feet as wide as the shoulder, knees bent 15º, arms crossed over the chest and looking opposite. The test started at level 8 for 60 seconds and ended at level 3. OA index is accepted as the best indicator for balance skill among the balance indices taken. A high OA index indicates that the loss of balance is high (12,13).

Measurements of foot

Metatarsal Foot Width (A-B): Foot breadth was measured between the most medial points on the head of the first metatarsal to the most laterally placed point on the head of the fifth metatarsal (14,17).

Maximum Metatarsal Foot Width (B-C): Foot width was measured between the outermost point of the first metatarsal in the medial and the outermost point of the fifth metatarsal in the lateral (15,16).

Length of the Foot Arc (D-E): The narrowest length was measured on the footprint in the middle of the foot (16).

Heel Width (H-J): The distance between the lateral portion and anterior portion of heel region or arches of heel (16,17).

Foot Length (G-K): It was measured from an imaginary vertical line drawn from the posterior prominence of the heel, to the tip of the longest toe, on the plantar aspect of the foot. In some people, the first toe is the longest; in other people, the second toe is the longest (17,18).

Calculation of CSI: Two physical therapists were responsible for collecting the footprints of the participants. The participants were asked to stand on one foot on the Harris-Beath mat to make ink footprints (19). The collected footprints were scanned into image files, and computer software was used for the measurement and calculation of the length of the images in pixels. In this study, the CSI was used as the judgment criterion for flatfoot. The CSI is defined as the ratio of line E-F, a parallel line to B-C at the narrowest point on the foot arch, to line E-F, the maximum width at the metatarsals ((E-F/B-C)x100%) in the footprint (Figure 1). The ratio was used for judging whether the participants suffered from flatfoot. In previous studies using the CSI as a judgment criterion, preschool-aged children with CSI>62.70% were deemed flatfooted, and those with CSI≤62.70% were deemed normal (20).

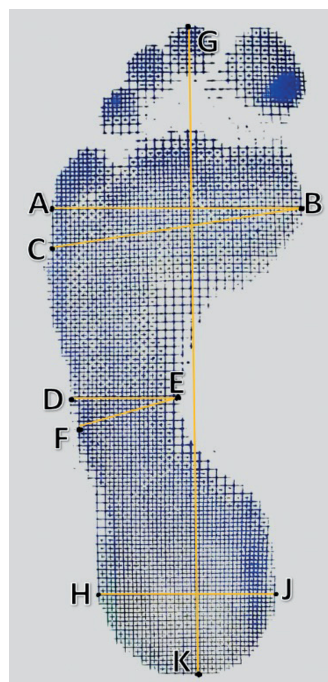

Figure 1. Measurements taken from footprint. A-B: Metatarsal Foot Width, B-C: Maximum Metatarsal Foot Width, D-E: Length of the Foot Arc, H-J: Heel Width, G-K: Foot Length

Statistical Analysis

Normality distribution of the data was tested with Kolmogorov Smirnov test. Median, minimum (min) and maximum (max) values of the data that were not normally distributed were given. Mann Whitney U test was conducted on the data to compare the samples' demographic features and the measurements taken from feet in terms of gender. Spearman Rho correlation was conducted for correlation analysis. p<0.05 value was considered as statistically significant. IBM SPSS Statistics 22.0 program was used in analyses.

RESULTS

Table 1 shows median (min-max) values of age, height, weight and body mass index (BMI) of men and women who participated in the study. Mann Whitney U analysis was conducted on the data to compare age, height, weight and BMI variables between men and women. According to analysis results, heights and weights of men and women were found to have statistically significant difference (p<0.05), (Table 1). It was determined that the height and weight of men are more than women.

Table 1. Median (min-max) values and Mann Whitney U analysis results of age, height, weight and BMI of men and women

Sex	Age	Height (cm)	Weight (kg)	BMI (kg/m²)
Male	20 (18-24)	179 (171-185)	73 (55-90)	23.1 (17.5-27.8)
Female	20 (18-23)	166 (150-178)	59 (41-78)	21 (15.2-27.4)
Mann Whitney U	.800	<0.001	<0.001	.160

Table 2. Median (min-max) values and Mann Whitney U analysis results of the parameters taken from the right and left feet of men and womenn

Right/Left	Sex	MFW	MMFW	LoFA	HW	FL	CSI
Right	Male	8.8 (7.6-9.6)	9.8 (8.5-10.5)	3.9 (2.5-5.5)	5.6 (4.8-6.4)	25.1 (23-26,8)	40.4 (24.5-52.4)
	Female	7.8 (6.1-9)	8.7 (6.6-9.6)	3.3 (2.3-6.5)	4.8 (3.5-5.6)	22.4 (17.2-24.9)	39.4 (24-61.3)
Mann Whitney U	p value	**<0.001**	**<0.001**	**.048**	**<0.001**	**<0.001**	.926
Left	Male	9 (7-9.8)	9.5 (8.5-10.3)	3.9 (2.1-5.8)	5.5 (4.8-6.4)	25.2 (22.9-26.9)	36.2 (20.4-59.2)
	Female	7.7 (6.1-9.4)	8.5 (6.2-9.9)	3.2 (2.1-6)	5 (3.9-5.9)	22.2 (16.7-24.8)	38.7 (25.3-60.6)
Mann Whitney U	p value	**<0.001**	**<0.001**	**.045**	**.001**	**<0.001**	.570

MFM: Metatarsal Foot Width, MMFW: Maximum Metatarsal Foot Width, LoFA: Length of the Foot Arc, HW: Heel Width, FL: Foot Length, CSI: Chippaux Smirak Index

Table 2 shows Median (min-max) values and Mann Whitney U analysis results of MFW, MMFW, LoFA, HW and FL and CSI taken from the right and left feet of men and women who participated in the study. According to analysis results, MFW, MMFW, LoFA, HW and FL taken from both right and left feet of men and women were found to have statistically significant difference (p<0.05). It was determined that MFW, MMFW, LoFA, HW and FL values were higher in males than females. According to analysis results, it was found that CSI calculated from the right and left feet of men and women did not show statistically significant difference (p>0.05), (Table 2).

Table 3. Median (min-max) values and Mann Whitney U analysis results of dynamic balance scores of men and women

Sex	OA	AP	ML
Male	6.2 (2.4-14.3)	5.1 (1.4-11.6)	4.2 (1.9-8.9)
Female	4 (2.7-8.2)	2.7 (1.4-6.2)	2.9 (2.1-5.6)
Mann Whitney U	.030	.018	.046

OA: Overall, AP: Anterior-posterior, ML: Medial-lateral

Table 4. Correlation analysis results of age, height, weight and BMI variables of men and women with CSI, OA, AP and ML scores

Variables	Spearman Rho	Male					Female				
		CSI-R	CSI-L	OA	AP	ML	CSI-R	CSI-L	OA	AP	ML
Age	r	.601	.468	.482	.484	.462	.002	.057	-.145	.012	-.154
	p	.058	.079	.069	.068	.083	.989	.742	.399	.947	.371
Height	r	-.500	-.302	**.536**	**.604**	**.417**	-.057	.050	.035	.206	-.132
	p	.058	.274	**.039**	**.017**	.122	.741	.771	.837	.228	.443
Weight	r	.079	.138	**.831**	**.856**	**.729**	-.282	-.199	**.497**	**.599**	**.233**
	p	.780	.624	**.000**	**.000**	**.002**	.096	.246	**.002**	**.000**	**.012**
BMI	r	.268	.314	**.786**	**.814**	**.704**	-.291	-.201	**.545**	**.577**	**.325**
	p	.334	.254	**.001**	**.000**	**.003**	.085	.240	**.001**	**.000**	**.033**

CSI-R: Chippaux Smirak Index-Right, CSI-L: Chippaux Smirak Index-Left, OA: Overall, AP: Anterior-posterior, ML: Medial-lateral

Table 3 shows median (min-max) values and Mann Whitney U analysis results of dynamic balance scores of men and women in the study. According to analysis results, OA, AP and ML balance scores of men and women calculated at dynamic balance were found to have statistically significant difference (p<0.05), (Table 3). It was determined that women's balance scores were better than men.

Spearman Rho correlation analysis was conducted on the data to find out how age, height, weight and body mass index (BMI) variables of men and women in the study correlated with CSI, OA, AP and ML scores. According to analysis results, a positive correlation was found between height and OA, AP, weight and BMI and OA, AP and ML dynamic balance scores in men. In women, weight and BMI scores were found to have a positive correlation with OA, AP and ML dynamic balance scores (Table 4).

Spearman Rho correlation analysis was conducted on the data to find out how MFW, MMFW, LoFA, HW and FL variables of men and women in the study correlated with CSI-R, CSI-L OA, AP and ML scores. According to correlation analysis results, a positive correlation was found between MFW, MMFW and FL taken from right feet of men and OA, AP and ML balance scores, between LoFA and CSI-R and between HW and OA, ML balance scores. A positive correlation was found between MMFW taken from the left feet of men and ML balance scores, between LoFA and CSI-L, between HW and OA, ML balance scores, between FL and OA, AP and ML balance scores (Table 5). According to correlation analysis results, a positive correlation was found between MFW and MMFW taken from right feet of women and OA, AP and ML, and between LoFA and CSI- R. A positive correlation was found between LoFA taken from the left feet of women and CSI-L (Table 5).

Table 5. Correlation analysis results of MFW, MMFW, LoFA, HW and FL variables taken from right and left feet of men and women with CSI OA, AP and ML scores

Sex	Variables	Spearman Rho	Right				Left			
			CSI-R	OA	AP	ML	CSI-L	OA	AP	ML
Male	MFW	r	.162	**.635**	**.592**	**.645**	-.080	.134	.076	.188
		p	.565	**.011**	**.020**	**.009**	.777	.634	.786	.501
	MMFW	r	.094	**.639**	**.554**	**.682**	-.107	.494	.424	**.522**
		p	.740	**.010**	**.032**	**.005**	.705	.061	.115	**.046**
	LoFA	r	**.953**	.456	.324	.552	**.973**	.304	.157	.434
		p	**<0.001**	.087	.238	.053	**<0.001**	.271	.575	.106
	HW	r	.074	**.514**	.493	**.508**	.316	**.572**	.462	**.641**
		p	.794	**.049**	.062	**.043**	.250	**.026**	.083	**.010**
	FL	r	.035	**.651**	**.597**	**.670**	-.155	**.607**	.566	**.603**
		p	.911	**.016**	**.031**	**.012**	.580	**.016**	.028	**.017**
Female	MFW	r	-.093	**.325**	**.425**	**.097**	-.325	.167	.185	.028
		p	.591	**.043**	**.010**	**.045**	.053	.329	.280	.869
	MMFW	r	.054	**.140**	**.272**	**.159**	-.234	.106	.125	-.005
		p	.755	**.016**	**.018**	**.031**	.170	.538	.468	.976
	LoFA	r	**.878**	-.133	-.063	-.167	**.801**	.011	.074	-.900
		p	**<0.001**	.439	.717	.330	**<0.001**	.950	.669	.601
	HW	r	.176	.117	.281	-.042	-.181	.126	.110	.089
		p	.305	.497	.097	.809	.292	.464	.525	.608
	FL	r	.125	.056	.138	-.056	-.188	.135	.141	.080
		p	.468	.746	.423	.745	.273	.431	.411	.642

Maximum Metatarsal Foot Width, LoFA: Length of the Foot Arc, HW: Heel Width, FL: Foot Length, CSI-R: Chippaux Smirak Index-Right, CSI-L: Chippaux Smirak Index-Left, OA: Overall, AP: Anterior-posterior, ML: Medial-lateral

Spearman Rho correlation analysis was conducted on the data to find out how CSI and OA, AP and Med-Lat dynamic balance scores differed. According to analysis results, significant correlation was not found between CSI and OA, AP and Med-Lat dynamic balance scores (Table 6).

Mann Whitney U analysis was conducted to compare MFW, MMFW, LoFA, HW, FL and CSI taken from the right and left feet of men and women. According to analysis results, no statistically significant difference was found between MFW, MMFW, LoFA, HW, FL and CSI taken from the right and left feet of both men and women (p>0.05), (Table 7).

Table 6. Correlation analysis results between CSI and OA, AP and Med-Lat dynamic balance scores

Sex	Variables	Spearman Rho	OA	AP	ML
Male	CSI-R	r	.186	.154	.271
		p	.508	.585	.328
	CSI-L	r	.139	.114	.250
		p	.621	.685	.369
Female	CSI-R	r	-.126	-.072	-.103
		p	.466	.678	.548
	CSI-L	r	-.119	-.053	-.114
		p	.491	.758	.510

CSI-R: Chippaux Smirak Index-Right,
CSI-L: Chippaux Smirak Index-Left

Table 7. Mann Whitney U analysis results of the comparison of right and left MFW, MMFW, LoFA, HW, FL and CSI of men and women

Sex	MFW	MMFW	LoFA	HW	FL	CSI
Male	.899	.327	.771	.819	.963	.983
Female	.778	.302	.672	.436	.835	.978

MFM: Metatarsal Foot Width, MMFW: Maximum Metatarsal Foot Width, LoFA: Length of the Foot Arc, HW: Heel Width, FL: Foot Length, CSI: Chippaux Smirak Index

DISCUSSION

As a conclusion, it was found in the present study that there were differences between right and left feet of men and women in terms of the variables of MFW, MMFW, LoFA, HW, FL, while no differences were found in terms of CSI. When dynamic balance scores were examined, women were found to have statistically better scores when compared with men. A positive strong correlation was found between LoFA and CSI in men and women. In addition, a positive correlation was found between MFW and MMFW and dynamic balance scores. Since dynamic balance is important in each moment of daily life activities, our study will have an important place in literature.

Foot, which consists of muscle, tendon and ligaments, is an organ which is under high physical effect because of its contact with the ground while walking, running and carrying body weight. The foot is relieved of this physical effect through the ability of elastic and flexible arcus to absorb impacts that may occur during steps by adapting to the shape of the ground. Literature review showed that the rate of flatfoot was r=1.982 (p=0.013) in children with delayed motor development, while the rate of flatfoot was r=1.365 (p=0.108) in children with normal development (p<0.05), (21). Mickle et al. (22) argued that this phenomenon may be related with the fact that medial longitudinal arch develops later in men when compared with women and the fat layer on plantar surface is thicker in men than women.

Pes planus occurs according to the degree of the collapse of the arcus formed so that the foot does not wear physically in contact with the ground. The high arch is called "pes cavus". In studies conducted with electromyography (EMG), it has been concluded that the cause of function losses in musculus (m.) tibialis posterior, which is one of the deep group plantar flexors of the leg, is pes planus. While the deformity can cause pain, loss of stability and severe functional limitations, it may also not cause any complaints. Since it is mostly caused by the damage of posterior tibial tendon, it is mostly defined as "tibialis posterior tendon deficiency" or "adult acquired pes planus" in literature (23). In their study, Lee et al. (24) reported that pes planus increased support surface but this biomechanic change had negative effects on balance and walking. Yucel (25) concluded that flexible pes planus did not have an effect on Achilles tendon length, age, height, leg and foot length, while flexible pes planus was more likely to occur in overweight individuals. In our study, a positive correlation was found between weight and BMI and dynamic balance scores in both men and women. According to Forriol and Pascual (26), CSI value being 0% indicates foot with high arch, a value between 0.1% and 29.9% indicates normal arch, a value between 30 and 39.9% indicates moderate arch, a value between 40 and 44.9% indicates low arch and 45% indicates morphological flat arch.

In this study, it was found that CSI of men varied between 20.4% and 59.2%, while CSI of women varied between 24% and 61.3%. According to analysis results, it was found that CSI of men and women calculated from right and left feet did not show statistically significant difference (p>0.05). In a study conducted by Aras et al. (27) on preschool children, flatfoot was more frequent in boys when compared with girls and in a study comparing normal weight children and overweight children, overweight children were found to have higher risk in terms of flat feet. Riddi ford-Harland et al. (28) analysed the foot structure of 62 obese (BMI>95%) and 62 non-obese (10%<BMI<90%) children and found that footprint angles were increased in obese children. It was found that increased footprint angles changed the structure of foot, flattened the longitudinal arch and enlarged the middle foot area. Samples with a CSI≤62.70% were included in the present study and foot measurements of healthy individuals were made. As a result of our analyses, it was concluded that there was no correlation between weight and BMI and CSI and that weight and BMI were not associated with pes planus.

Balance is a system that adjusts our stance in a way that will prevent falling by adjusting to the environment where there is a perception of width, height and depth (29). Balance is grouped in two as static and dynamic. Static balance is the ability to maintain the position the individual is in with minimum movement, while dynamic balance is defined as the ability to maintain the center of gravity against pull of gravity while continuing a movable position (30). Marencakova et al. found a correlation between body weight distribution and postural stability related pes planus and postural control. In the study, it was concluded that poor medial arch caused poor positioning in the foot and deteriorated postural control (31).

Biodex balance system is a multi-axis device which objectively measures the balance of an individual under dynamic stress and records the measurement results. On this system, balance is measured in three ways as OA, AP, ML. The difficulty level of this device is rated from 1 (most mobile) to 8 (most immobile). As a result of measurement, high balance score is an indicator of weak balance. According to the results of balance studies conducted with girls and boys by Cuğ et al. (32), girls were found to get lower scores, in other words more balanced results, in OA and AP balance index when compared with boys.

In our study conducted with Biodex balance system, dynamic balance scores were found to be better in women when compared with men. In their study conducted on the relationship between shoe use and balance and functional performance by Güçhan et al., it was found that maneuvers with left feet were difficult and even if the shoes used were suitable, the values recorded without shoes were better (33). In this study, the subjects were taken on the platform without shoes. Another negative effect of high BMI on balance is that as BMI increases, the body's weight point shifts down. The downward approach of the centre of gravity puts an extra burden on the ankle to achieve the required balance. In this case, balance is negatively affected (32).

The reason why the results of the present study contradict with the literature is the fact that individuals who have completely healthy feet are included in the study. Volunteers who could be considered as flatfooted according to CSI were not included in the study. In addition, individuals who were obese according to BMI were not included in the study. For this reason, a correlation was found between BMI and balance. BMI of the subjects in the study was found as 27.8 kg/m2 the most. CSI of the subjects in the present study was ≤62.70%. It was found that there was no association between CSI and balance scores of the subjects in the study.

Our study had some limitations. To prevent the cases from being influenced by external factors, exercise training was conducted before they were taken on the Biodex balance system. Radiological measurements could have been made for more objective results. We believe that adding higher number of participants in the study and repeating the study by including anthropometric measurements will provide stronger comments.

CONCLUSION

As a conclusion, while no association was found between weight and BMI and CSI in the present study, a positive correlation was found between weight and balance scores. There are sensors sending information such as position, shape and movement to the brain in specific areas of the body. Some of these sensors are mechanical sensors under feet. It has been shown that mechanical sensors' being exposed to high intensity and continuous stimulant will decrease the sensitivity of their sensing features. One of the important factors that will decrease this sensitivity is high BMI. When the BMI scores between men and women are examined, it can be said that the lower body mass index of women when compared with men can be an indicator that the severity of these mechanical sensors is lower. This may have caused balance scores to be better. Smaller foot size of women when compared with men is a disadvantage in balance. In this case, smaller BMI of women may have balanced the advantage while their small foot size may have balanced the disadvantage. In other words, it can be said that women's smaller BMI will cause a less pressure on their feet and their small feet size can increase the pressure applied on unit point. We believe that the present study will have an important place and be a guide in literature since we compared both genders.

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