BAU HEALTH AND INNOVATION

Doi: 10.14744/bauh.2025.05706
BAU Health Innov 2025;3(1):1–8

Original Article

# Investigation of the Effect of Increased Subtalar Joint Pronation on Static Plantar Pressure Distribution

**Pelin Pişirici,[1] İrem Sena Erken,[1] Özlem Feyzioğlu[2]**

[1]Department of Physiotherapy and Rehabilitation, Bahçeşehir University Faculty of Health Sciences, İstanbul, Türkiye
[2]Department of Physiotherapy and Rehabilitation, Acıbadem Mehmet Ali Aydınlar University Faculty of Health Sciences, İstanbul, Türkiye

## Abstract

**Objectives:** This study aims to identify variations in mean and maximum plantar pressure parameters across different regions of the foot among individuals with neutral, pronated, and hyperpronated foot postures during static standing.

**Methods:** This cross-sectional study included 65 healthy participants categorized into three groups based on their Foot Posture Index: neutral (n=22), pronated (n=22), and hyperpronated (n=21). Navicular mobility and static plantar pressure were assessed using the Navicular Drop Test and the Footwork device, respectively. One-way analysis of variance (ANOVA) with post hoc Bonferroni corrections was used to compare numerical descriptive characteristics between groups.

**Results:** The average age and height of participants were 23.77±2.77 years and 172±8.86 cm, respectively. Demographic values were similar among groups, except for weight ($p=0.020$; $p<0.05$), body mass index (BMI) ($p=0.025$; $p<0.05$), and the Navicular Drop Test ($p=0.000$; $p<0.01$). No significant differences were found among groups in mean or maximum plantar pressure across different regions of the foot ($p>0.05$).

**Conclusion:** Plantar pressure distribution did not vary across different plantar regions based on foot posture. Further research is needed to compare plantar loads based on contact areas.

**Keywords:** Foot posture index, foot type, navicular drop test, obesity, pedobarography.

***Cite This Article:*** *Pişirici P, Erken İS, Feyzioğlu Ö. Investigation of the Effect of Increased Subtalar Joint Pronation on Static Plantar Pressure Distribution. Bau Health Innov 2025;3(1):1–8.*

The normal biomechanics of the subtalar joint allow the foot to adapt to uneven surfaces while also enhancing force transmission.[1] Subtalar joint pronation, which occurs due to its oblique axis,[2] consists of calcaneal eversion, talar adduction, and plantar flexion during weight-bearing.[3]

Subtalar joint pronation is essential for foot adaptation to the ground;[2] however, excessive pronation, or hyperpronation, is a common foot misalignment that can lead to subtalar joint dysfunction.[4] Hyperpronation, an abnormal foot alignment, has traditionally been associated with changes in kinematic variables and force distribution.[5] It is known to contribute to lower extremity overuse injuries,[6–8] tibial stress syndrome,[9] Achilles tendinopathy,[10] lumbopelvic dysfunction,[11] and lower extremity alignment issues.[12,13] Additionally, studies have shown that individuals with hyperpronation exhibit increased anterior pelvic tilt in the sagittal plane to maintain postural balance.[14]

Individuals with abnormal foot postures may exhibit altered plantar pressure distribution compared to those with normal foot postures.[15] In the assessment of plantar pressure distribution, peak pressure is considered an important indicator of lower extremity function and

**Address for correspondence:** Pelin Pişirici, MD. Bahçeşehir Üniversitesi, Sağlık Bilimleri Fakültesi, Fizyoterapi ve Rehabilitasyon Anabilim Dalı, İstanbul, Türkiye
**Phone:** +90 212 381 91 98 **E-mail:** pelin.pisirici@bau.edu.tr

**Submitted:** January 24, 2025 **Revised:** January 27, 2025 **Accepted:** February 07, 2025 **Available Online:** April 16, 2025
BAU Health and Innovation - Available online at www.bauhealth.org

biomechanics. The analysis of these parameters is frequently addressed in the clinical evaluation of lower extremity issues.[16] Additionally, changes in plantar load distribution in different foot postures have generally been evaluated dynamically,[17–21] while the number of studies examining pressure changes and surface areas through static assessment is limited.[22–24] Kırmızı et al.[22] demonstrated that foot posture assessments are related to peak pressure values in the first (M1), second (M2), and fifth metatarsals (M5), as well as the hallux (H) regions, in the context of static plantar pressure analysis. However, to our knowledge, no study has compared peak pressure values among individuals with neutral, pronated, and hyperpronated foot postures.

In this study, we aimed to determine the differences in plantar pressure variables, such as mean and maximum peak pressure, among individuals with neutral, pronated, and hyperpronated foot postures during static standing. We hypothesized that as the degree of pronation increases, peak pressure would increase in the hallux, the first three metatarsals, and the medial heel regions.

## Materials and Methods

### General Design

This study is a cross-sectional, prospective, single-center study investigating the plantar load distribution of healthy individuals with different degrees of pronation. The study population consists of healthy individuals aged 18–30 in Istanbul, Türkiye. Participant assessments will be conducted at the Physiotherapy and Rehabilitation Laboratories of Bahçeşehir University.

Foot posture classification will be based on the Foot Posture Index-6 (FPI-6), with participants categorized as follows:

- **Neutral Group (NG):** FPI-6 score of 0–5
- **Pronation Group (PG):** FPI-6 score of 6–9
- **Hyperpronation Group (HPG):** FPI-6 score of 10–12

Prior to study initiation, ethics committee approval was obtained from Istanbul Acıbadem University Research Ethics Committee (Approval No: ATADEK-2025/01, date: 09/01/2025). Data collection commenced following ethical approval.

All participants will receive a verbal explanation of the study details, including its potential benefits and risks. After the verbal explanation, a written informed consent form—prepared in accordance with the Declaration of Helsinki—will be provided to participants, and their consent will be obtained before participation.

### Participants

Sixty-five participants aged between 18 and 30 were included in the study. According to the FPI-6, those scoring between 0–5 were included in the neutral group (NG) (n=22), those scoring between 6–9 were included in the pronation group (PG) (n=22), and those scoring between 10–12 were included in the hyperpronation group (HPG) (n=21).

Inclusion criteria for the study were being between 18–30 years of age, not experiencing any pain, complaints, difficulty walking, or functional loss, having no history of lower extremity surgery, not having participated in any physical therapy program in the last six months, and not having any orthopedic/neurological conditions or visual and/or auditory impairments.

Exclusion criteria included having a congenital anomaly in the lower extremity, joint hypermobility, a history of foot or ankle surgery, an ankle injury in the last 12 months, or experiencing pain while resting or standing.

The sample size for the study was determined based on effect size values from the study conducted by Joneley et al.[23] According to this, the sample size was calculated considering an effect size of 0.41 with a power of 0.95 and an alpha of 0.05. It was determined that a total of 65 participants would be needed. The sample size was calculated using G*Power V.3.1.7 software (Kiel University, Kiel, Germany).

### Assessments

Foot posture assessment will be performed by a physiotherapist, while the pressure analysis evaluation will also be conducted by a physiotherapist.

### Foot Posture Evaluation

The navicular drop test (NDT) is a reliable clinical tool used to assess foot posture.[25] For the NDT, the individual sits on a chair with hips and knees at 90° flexion, and the foot is positioned in a neutral subtalar joint position.[26] The height of the navicular tuberosity from the ground is measured using a ruler. While seated, the ankle is first positioned in a neutral stance, and the navicular height is measured without any weight transfer. Then, the individual stands up, and after transferring body weight to the foot, the navicular height is measured again.[27] The navicular drop value is determined by calculating the difference between the height measured in the relaxed foot position and the height measured in the subtalar joint neutral position. Based on similar measurements in adult populations, normative data for the NDT range from 6 to 9 mm, and variations exceeding 10 mm are considered indicative of increased pronation.[28]

**Table 1.** Demographic variables of the groups

| | Group | | | Test (p) |
|---|---|---|---|---|
| | Neutral n=22 | Prone n=22 | Hyperprone n=21 | |
| Age, (year) | | | | |
| Mean±SD | 23.81±2.51 | 23.86±3.01 | 23.66±2.81 | F=0.029 |
| (Min-Max) | (20-30) | (20-30) | (20-30) | p=0.971 |
| Height, (cm) | | | | |
| Mean±SD | 170±8.76 | 175±8.77 | 172±9.05 | F=1.937 |
| (Min-Max) | (160-194) | (162-1.90) | (150-192) | p=0.153 |
| Weight, (kg) | | | | |
| Mean±SD | 66.4±12.78 | 77.68±12.54 | 64.8±11 | F=4.164 |
| (Min-Max) | (51-93) | (47-93) | (40-95) | **p=0.020** |
| BMI (kg/m$^2$) | | | | |
| Mean±SD | 22.64±2.96 | 24.97±2.85 | 23.31±2.68 | F=3.931 |
| (Min-Max) | (18.28-28.38) | (17.47-29,03) | (17.77-27.77) | **p=0.025** |
| NDT, (cm) | | | | |
| Mean±SD | 0.60±0.44 | 1.18±0.39 | 1.48±0.45 | F=23.15 |
| (Min-Max) | (0-1.5) | (0.5-2) | (0.5-2) | **p=0.000** |

pOne Way Anova; BMI: Body Mass Index; NDT: Navicular Drop Test; SD: Standart Deviation; Min: minimum; Max: maximum.

The Foot Posture Index-6 (FPI-6) is a reliable clinical diagnostic tool used to assess weight-bearing foot posture[25,27] and has demonstrated good inter-rater reliability (0.893–0.958).[29] The FPI-6 consists of six items: palpation of the talar head, curvature above and below the lateral malleolus, position of the calcaneus in the frontal plane, prominence at the talonavicular joint, alignment of the medial longitudinal arch, and abduction/adduction between the forefoot and hindfoot.[29] The FPI-6 includes a visual assessment based on six criteria, with each criterion scored on a 5-point Likert scale ranging from -2 to +2. Each criterion is scored between -2 (supination) and +2 (pronation), with 0 representing a neutral position, and the total score ranges from -12 (highly supinated) to +12 (highly pronated).[13] During the assessment, individuals' static standing posture is observed and scored while they stand comfortably. The reference value groupings for foot posture are 0 to +5 for the neutral position, +6 to +9 for the pronation position, and +10 to +12 for the hyperpronation position.[27]

Plantar Pressure Distribution Assessment in Static Standing

The static plantar pressure distribution data, recorded following a barefoot foot posture assessment in a stationary position, will be obtained using the Footwork (Footwork, AM3-Quart St. Anne, 84220 Goult, France) plantar pressure analysis device. The device features a 40 × 40 × 0.5 cm active surface plate and contains 2,704 calibrated pressure sensors made of polycarbonate-coated capacitors, which measure pressure in kilopascals (kPa).[30] The sensors are 7.6 × 7.6 mm in size, meaning there are 2 sensors per square centimeter on the pressure plate.[31]

Participants will be instructed to remain still for 30 seconds. All assessments will be repeated three times, and the average value will be recorded. Mean and maximum peak pressure values (kPa) will be collected from ten different foot regions: the medial, lateral, and total heel; the midfoot; metatarsals M1–M5; and the hallux (H).[32]

Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS) version 21.0 software package (IBM Corp., Armonk, NY, USA). The normality of the data was assessed using the Shapiro–Wilk test and Q-Q plots. Descriptive data were presented as mean±standard deviation (SD), minimum (min), and maximum (max) values. One-way analysis of variance (ANOVA) was used to compare the numerical descriptive characteristics of the participants between groups, with post-hoc Bonferroni corrections. In cases where the assumption of variance equivalence was violated, the Games–Howell method was applied. The Kruskal–Wallis test was used for non-parametric distributed data.

Eighty participants were evaluated; fifteen were excluded due to biomedical problems (n=7) and a history of orthopedic surgery (n=8). A total of 65 participants were divided into three groups according to their Foot Posture Index (FPI) scores: the neutral group (n=22), the pronation group (n=22), and the hyperpronation group (n=21). There were no missing data.

**Table 2.** Comparison of mean plantar pressure between groups

| | Group | | | Test (p) |
|---|---|---|---|---|
| | **Neutral n=22** | **Prone n=22** | **Hyperprone n=21** | |
| Hallux | | | | |
| Median | 11.41 | 10.53 | 12.32 | p*=0.649 |
| (IQR) | (2.32-15.51) | (0-20.31) | (10.03-17.05) | |
| M1 | | | | |
| Median | 21.16 | 24.34 | 24.23 | p*=0.526 |
| (IQR) | (18.04-24.83) | (16.76-29.89) | (17.96-28.56) | |
| M2 | | | | |
| Mean±SD | 38.40±10.16 | 38.81±11.46 | 37.24±9.22 | F=0.131 |
| (Min-Max) | (23.68-66.28) | (20.96-60.07) | (22.66-56.57) | p=0.877 |
| M3 | | | | |
| Mean±SD | 47.33±10.27 | 43.94±14.03 | 40.64±9.66 | F=1.815 |
| (Min-Max) | (24.21-63.50) | (22.47-73.72) | (25.02-61.74) | p=0.171 |
| M4 | | | | |
| Mean±SD | 38.60±8.13 | 35.62±9.49 | 32.65±8.60 | F=2.476 |
| (Min-Max) | (21.68-55.41) | (21.11-58.96) | (20.42-49.78) | p=0.092 |
| M5 | | | | |
| Mean±SD | 24.17±5.52 | 23.29±4.74 | 22.29±4.93 | F=0.645 |
| (Min-Max) | (15.26-34.48) | (16.84-34.93) | (16.88-33.04) | p=0.528 |
| MF | | | | |
| Mean±SD | 30.98±5.56 | 34.23±5.41 | 31.83±4.98 | F=2.190 |
| (Min-Max) | (22.93-42.86) | (25.06-43.24) | (22.41-38.59) | p=0.121 |
| Heel-Total | | | | |
| Mean±SD | 75.39±20.66 | 73.39±19.24 | 76.55±13.36 | F=0.168 |
| (Min-Max) | (39-123.5) | (30.26-101.42) | (55.65-101.90) | p=0.846 |
| Heel-Medial | | | | |
| Mean±SD | 80.25±21.54 | 81.65±19 | 84.76±14.69 | F=0.322 |
| (Min-Max) | (41.03-123.57) | (42.57-108.13) | (58.56-110.11) | p=0.726 |
| Heel- Lateral | | | | |
| Mean±SD | 61.20±15.47 | 61.16±15.83 | 63.20±14.75 | F=0.123 |
| (Min-Max) | (36.18-87.53) | (26.31-92.89) | (38.88-91.36) | p=0.884 |

p* Kruskal Wallis Test; p One Way Anova; M1: Metatarsal-1; M2: Metatarsal-2; M3: Metatarsal-3; M4: Metatarsal-4; M5: Metatarsal 5; MF: Midfoot; SD: Standard Deviation; IQR: IQR Interquartile Range.

The demographic and clinical characteristics of the participants were similar, except for weight, body mass index (BMI), and navicular drop test results between all groups (p<0.05). Additionally, the navicular drop test showed statistically significant differences between the neutral group and the pronation group, as well as between the neutral group and the hyperpronation group (p<0.05). The demographic variables of the participants are shown in Table 1.

There was no statistically significant difference between the groups in terms of mean pressure and maximum pressure in the plantar surface areas. The mean and maximum plantar pressure variables according to foot regions are shown in Table 2 and Table 3, respectively.

This study aims to compare the mean and maximum pressure distributions in different parts of the plantar surface of the foot during an eye-open static stance among individuals with neutral, pronated, and hyperpronated foot postures. Our results showed no differences between the groups in terms of mean and maximum pressure assessments. These findings do not support our hypothesis that as the degree of pronation increases, the mean and maximum pressure in the anterior and medial parts of the foot also increase.

Studies examining differences in foot posture through plantar pressure analysis have classified foot posture as neutral, pronated, and supinated.[11,18,33] To our knowledge,

**Table 3.** Comparison of maximum plantar pressure between groups

| | Group | | | Test (p) |
|---|---|---|---|---|
| | **Neutral n=22** | **Prone n=22** | **Hyperprone n=21** | |
| Hallux | | | | |
| Median | 16.34 | 15.44 | 18.26 | p*=0.506 |
| (IQR ) | (9.75-22.97) | (0-23.72) | (14.77-26.5) | |
| M1 | | | | |
| Median | 26.12 | 27.80 | 25.26 | p*=0.818 |
| (IQR) | (23.04-32.41) | (24.23-34.38) | (22.34-36.71) | |
| M2 | | | | |
| Mean±SD | 32.64±9.71 | 34.58±14.35 | 32.31±9.21 | F=0.253 |
| (Min-Max) | (11.82-57.38) | (6.52-69.03) | (14.91-53.66) | p=0.778 |
| M3 | | | | |
| Mean±SD | 41.30±9.19 | 38.08±13.27 | 35.98±10.15 | F=1.275 |
| (Min-Max) | (22.66-58.39) | (16.51-62.41) | (17.24-59.38) | p=0.287 |
| M4 | | | | |
| Mean±SD | 32.52±6.30 | 30.45±9.02 | 27.45±9.94 | F=1.911 |
| (Min-Max) | (17.62-47.56) | (18.50-54.05) | (12-46.25) | p=0.157 |
| M5 | | | | |
| Mean±SD | 18.04±7.08 | 17.86±5.70 | 13.52±9.51 | F=2.446 |
| (Min-Max) | (0.44-36.16) | (5.37-25.28) | (0-26.97) | p=0.095 |
| MF | | | | |
| Mean±SD | 25.85±6.70 | 28.99±5.79 | 28.07±8.33 | F=1.169 |
| (Min-Max) | (13.20-38.66) | (18.54-39.70) | (15.22-48.69) | p=0.318 |
| Heel-Total | | | | |
| Mean±SD | 62.67±21.17 | 56.97±17.27 | 62.73±13.08 | F=0.773 |
| (Min-Max) | (24.82-108.65) | (17.33-86.55) | (40.02-90.16) | p=0.466 |
| Heel-Medial | | | | |
| Mean±SD | 69.59±23.81 | 62.55±18.98 | 69.83±14.25 | F=0.983 |
| (Min-Max) | (26.75-121.38) | (17.93-89.34) | (46.09-99.48) | p=0.380 |
| Heel-Lateral | | | | |
| Mean±SD | 50.75±15.81 | 48.05±16.94 | 51.05±14.15 | F=0242 |
| (Min-Max) | (20.51-81.49) | (9.78-82.11) | (21.61-76.94) | p=0.786 |

p* Kruskal Wallis Test, p One Way Anova; M1: Metatarsal-1; M2: Metatarsal-2; M3: Metatarsal-3; M4: Metatarsal-4; M5: Metatarsal-5; MF: Midfoot; SD: Standart Deviation.

no study has examined the effect of neutral, pronated, and hyperpronated feet on plantar pressure distribution. There are a limited number of studies comparing neutral, pronated, and hyperpronated feet.[34,35] Bayıroğlu et al.[34] found no differences in static and dynamic postural stability, function, or dynamic knee valgus measurements among individuals with pronated and hyperpronated foot postures classified according to the FPI-6. Similarly, Pısırıcı et al.[35] compared individuals with neutral, pronated, and hyperpronated foot postures in terms of static and dynamic postural control, navicular mobility, foot dorsiflexion asymmetry, and jump performance. They found no differences between the groups except for navicular mobility. Both authors concluded that it may be more beneficial to focus on the pronated posture rather than the degree of pronation.[34,35] Since the measurement of foot pressure distribution is clinically useful for identifying anatomical foot deformities,[36] the changes in distribution across different plantar surfaces of the foot in a static stance as pronation increases have become a subject of interest.

According to the World Health Organization and the National Institutes of Health, a BMI value between 18.5 and 24.9 kg/m$^2$ is classified as normal, while a BMI between 25 and 29.9 falls into the overweight category.[37] Evidence indicates that obesity is strongly associated with a pronated foot posture,[38,39] and elevated body weight is significantly related to increased plantar pressure, especially in the forefoot and midfoot regions.[39] In our demographic data, due to the weight values of the participants in the pronation group, BMI values were not homogeneously distributed among the groups. The pronation group's BMI was found to be 24.97±2.85 kg/m$^2$. This value is at the threshold of overweight and is higher than that of the other groups. However, this did not result in a difference in plantar pressure distributions. We believe that the lack of difference in plantar pressure data, which is inconsistent with the literature, may be because the increase in BMI was not very high.

A foot with a normal posture should function as a rigid support point for propulsion while also facilitating shock absorption as it adapts to the ground.[40] A foot with a pronated posture has a reduced medial longitudinal arch (MLA) height,[41] resulting in a more flexible structure. Therefore, although the MLA allows the midtarsal joint to unlock during gait, enabling the foot to act as a shock absorber, it also decreases its stabilization ability.[6,42–44]

An individual with an abnormal foot posture may exhibit an altered pressure distribution compared to a normal foot during static pressure analysis.[22,23,24] There are conflicting results regarding the effect of decreased MLA height, or increased foot pronation,[11] on plantar pressure distributions.[44,45] In their study examining plantar pressure distribution in asymptomatic individuals, Syed et al.[44] demonstrated that individuals with a pronated foot posture had significantly lower maximum pressure compared to those with normal feet.[44] However, a study investigating the characteristics of foot posture and plantar pressure profiles among native Taiwanese using static assessment found that participants had low arches and higher plantar loads at the medial and lateral longitudinal arches as well as the medial metatarsals. Similarly, Khan et al.[24] found that flat feet identified through X-ray exhibited greater static and dynamic arch index values, higher midfoot pressure, and a larger midfoot surface area compared to FPI-positive flat feet and normal feet. However, our results found no statistically significant differences in plantar load distributions among individuals with neutral, pronated, and hyperpronated foot postures. Our study could not be directly compared with previous literature, as no research has examined plantar pressure distributions across different regions of the foot with varying degrees of pronation. In this regard, our study contributes to the literature.

Our study has limitations. We did not evaluate contact areas with plantar loads, and we only included the dominant side, without assessing compensations on the non-dominant side.

## Conclusion

This is the first study to compare plantar pressure distribution in a static standing position. Our findings indicate that plantar pressure distribution does not differ across different plantar regions. Further studies are needed to compare plantar loads based on contact areas.

### Disclosures

**Ethics Committee Approval:** The study was approved by the İstanbul Acıbadem University Research Ethics Committee (no: ATADEK-2025/01, date: 09/01/2025).

**Authorship Contributions:** Concept – P.P., İ.S.E., Ö.F.; Design – P.P., İ.S.E., Ö.F.; Supervision – P.P., Ö.F.; Resource – P.P.; Materials – P.P.; Data Collection and/or Processing – İ.S.E.; Analysis and/or Interpretation – Ö.F.; Literature Search – P.P., İ.S.E., Ö.F.; Writing – P.P., İ.S.E., Ö.F.; Critical Reviews – P.P., İ.S.E., Ö.F.

**Conflict of Interest:** All authors declared no conflict of interest.

**Use of AI for Writing Assistance:** AI support has been used for English language translation.

**Financial Disclosure:** The authors declared that this study has received no financial support.

**Peer-review:** Externally peer-reviewed.

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