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Exposure of Undergraduate Nursing Students to Standing Environments - A longitudinal study on plantar force and pressure distribution

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The authors declare no conflicts of interest.

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ABSTRACT

Background: Understanding the link between plantar force, pressure, and foot discomfort is important for nursing students' well-being, given the prevalence of foot and ankle musculoskeletal disorders among nurses. Assessing these factors can inform tailored self-care interventions, supporting holistic nursing education.

Purpose: To assess the plantar force and pressure distribution of third-year nursing students at baseline and after 5 months of exposure to a clinical setting.

Methods: A prospective cohort study in a Portuguese nursing school measured changes in podiatric profile at 5 months, including peak pressure, maximum force, and contact area.

Results: Elevated mean peak pressure in the heel correlated positively with maximum force and contact area. Negative correlations were found between the contact area and edema. Peak pressure correlated positively with thigh pain, indicating pressure transfer to metatarsal heads.

Conclusions: The findings underscore the importance of integrating ergonomic education into nursing curricula and raising awareness of self-care interventions.

Keywords: ergonomic education, foot disorders, health-related quality of life, musculoskeletal disorders, standing position

Exposure of Undergraduate Nursing Students to Standing Environments - A longitudinal study on plantar force and pressure distribution

Nursing students are regularly exposed to demanding activities such as prolonged standing, lifting, and extensive ambulation within their educational curriculum.¹ These activities have been identified as potential contributors to musculoskeletal disorder (MSD) development, which can adversely impact student satisfaction and overall quality of life.²⁻⁴ Moreover, studies have linked musculoskeletal symptoms to an average dropout rate of 12% at the onset of nurses' careers. Recent investigations have revealed a high prevalence of foot and ankle MSDs among nurses, frequently leading to compromised physical activity levels and absenteeism due to sick leave and prolonged periods of work absence.^{5,6} Given the significance of the physical well-being of undergraduate nursing students, particularly in lower limb health, understanding the biomechanical determinants, including plantar force and pressure distribution, becomes critical for both their future professional trajectories and overall quality of life.⁷

Plantar force and pressure are integral parameters for dynamically assessing the interaction between the foot and the supporting surface during various activities. Anomalies in pressure distribution and excessive force have been associated with discomfort, pain, and, in some instances, direct correlations with foot and ankle disorders.⁸ A comprehensive evaluation of these parameters among nursing students offers valuable insights into potential risk factors, informing preventive interventions to promote enduring foot health, mainly through self-care interventions. Previous studies have underscored the utility of analyzing plantar pressure distribution in identifying functional manifestations of foot disorders.⁹

Foot problems also may arise from improper footwear choices and work conditions.¹⁰ In normal walking, the heel has the highest pressure, whereas the medial midfoot experiences the lowest pressure.¹¹ No cut points or thresholds have been defined regarding pressure and force on the normal foot, as many factors are at interplay, like gender, body mass index (BMI), contextual determinants, physical activity habits, and others. An adequate description of risk factors and relevant predictors of foot health deterioration, like abnormal pressure values under the foot caused by unadjusted foot or ergonomic behaviors, is important to tailor effective self-care interventions. Moreover, such evidence-based data are valuable for nurse educators to raise awareness of their students' MSD risk before starting their clinical rotations.

Despite the relevance of plantar force and pressure to the well-being of undergraduate nursing students, there is a notable research gap. Systematically profiling the baropodometric (diagnostic analysis of plantar pressure distribution) characteristics of nursing students can contribute to evidence-based strategies for enhancing their physical comfort and overall foot health throughout their academic and professional journey.

This study aimed to quantitatively assess plantar force and pressure distribution patterns in undergraduate nursing students over a 5-month period in which students engage in their first clinical experience requiring standing, lifting, and prolonged ambulation. This can provide a foundation for a comprehensive understanding of the biomechanical factors influencing lower limb health in this population. The insights gained can inform future interventions and educational programs designed to optimize the foot health of aspiring nursing professionals.

Methods

Design and Sample

A prospective observational cohort study was undertaken with third-year students, adhering to a preestablished protocol.¹⁰ The investigation was developed at a Portuguese public nursing school, spanning January to July 2022.

Regarding inclusion and exclusion criteria, eligible participants were limited to students actively enrolled in an undergraduate nursing degree program and not engaged in a clinical learning setting at the recruitment phase. Exclusion criteria were individuals with diagnosed chronic systematic diseases or metabolic disorders, visible lower limb swelling, contraindications for baro- podometric-related measurements, a history of orthopedic, neurological, or musculoskeletal issues likely to impact gait, and students concurrently committed to professional work or engaged in high-impact sports activities with potential implications for foot health.

Recruitment and participant retention were considered a challenge because the study was performed right after the COVID-19 pandemic. Initially, given the annual enrolment of approximately 300 third-year nursing students and employing a confidence interval of 95% with a margin of error of 5%, the calculated sample size required for the study was 169 participants. An additional 15% of the total sample size was incorporated to mitigate potential losses during the study, resulting in a targeted recruitment of 194 students. The significance level was predetermined at .05. Nevertheless, no randomization was performed, and recruitment was based on a presentation made by the project leader to a total of 4 classes. All third-year students from 4 separate classrooms were mobilized by their designated group representatives, who were tasked with organizing and coordinating the voluntary participation of their peers throughout the research.

Instruments and Outcomes

The investigation focused on a specific setting characterized by biomechanical risks affecting the foot/ankle region, which involves extended periods of standing and walking, defined as dedicating at least 5% of work time to these activities.¹¹ The primary outcome under examination centred on changes in the podiatric profile over 5 months, providing an objective and quantifiable measure. The assessment includes recording specific foot-related variables during walking, offering insights into the actual behavior of the foot during activity. Key kinetic variables examined encompass peak plantar pressure (measured in kilopascal, kPa), which delineates force distribution between the foot sole and the ground, maximum force (measured in newton, N), and contact area (measured in cm.²)

Data collection utilized a platform called EMED: Pressure Distribution Under the Foot, produced by novel.de, a pedography platform with calibrated capacitive sensors that accurately measure foot pressure in static and dynamic positions. The sensor platform features dimensions of 475 × 320 mm, housing 6080 sensors with 4 sensors/cm² resolution. The recording frequency is 50 Hz, with a pressure range of 10– 1270 kPa, a threshold set at 10 kPa, and a maximum total force capped at 193,000 N. The analysis subdivided the foot into 9 distinct areas: heel, midfoot, first metatarsal head (MH), second MH, third MH, fourth MH, fifth MH, hallux, and second to fifth toes.

The secondary outcome was foot health at 5 months, measured with the Portuguese version (Instrumento de Auto-Avaliação da Saúde do Pé) of the Self-Administered Foot Health

Assessment Instrument.¹² It is a self-reported instrument measuring current foot health, with 4 dimensions and 22 items: Skin Health (11 items), Nail Health (4 items), Foot Structure (5 items), and Foot Pain (2 items). All answers are dichotomous (yes or no) except for item 22, which has a Likert-type scale measuring pain intensity in different regions. It generates a general score (Foot Health Index) ranging from 22 to 44, with higher scores indicating better foot health. The internal consistency of the translated European Portuguese version, measured with Cronbach alpha, was .653, and the goodness-of-fit index of the hypothesized theoretical structure of the adjusted model was 0.913.

Study Layout

All outcomes were assessed and compared at baseline (T0) and 5 months (T1), before and after exposure. In both periods—T0 and T1—participants were weighted and heightened to acquire BMI values.

Regarding the pedography platform, a previously tested gait assessment protocol was used,^{13, 14} where an initial familiarization period was granted, after which the students walked barefoot at a self-selected pace along an 8.0 (26.24 ft) walkway where the platform was placed in the middle. They started from a preestablished initial position to ensure the feet hit the platform alternately and avoid gait alterations. Participants conducted 3 trials per foot, as recommended by previous research, to ensure the reliability of force and pressure data.^{15,16,17}

Statistical Analysis

Statistical analysis was performed using SPSS Statistics v25 (IBM Corp, Armonk, NY, USA), incorporating descriptive statistics such as averages, standard deviations (SDs), and medians, with a predetermined a priori significance level of $P < .05$. After assessing the sample distribution type through the Kolmogorov-Smirnov test with Lilliefors correction, the Mann-Whitney U test (for non-normal distribution) was employed to compare outcome changes pre- and postexposure. A stepwise multiple regression analysis assessed the variables' predictive capability.

Ethics

Written informed consent was obtained before participation. The local ethical committee approved the study (code no. P799_07_2021). The protocol is recorded on ClinicalTrials.gov under the number NCT05197166. The study findings were reported considering the strengthening the Reporting of Observational Studies in Epidemiology statement.¹⁸

Results

Macro Analysis of the Change in Podiatric Profile at 5 Months

A total of 54 participants were included in the study (Supplemental Content, Table 1). Elevated mean peak pressure values were discerned in specific anatomical regions of the foot, notably, the heel ($M = 305.05$; $SD = 73.00$), the fourth MH ($M = 430.58$; $SD = 150.90$), and the hallux ($M = 387.10$; $SD = 192.49$). The lowest peak pressure values were observed at the first MH ($M = 66.55$; $SD = 31.08$). Furthermore, a general equilibrium of values was noted between the left and right feet, albeit with a slight predilection for increased values in the left foot.

In terms of contact area, the regions with higher values included the heel ($M = 26.21$; $SD = 10.14$), the second MH ($M = 17.02$; $SD = 5.63$), and the fourth MH ($M = 15.48$; $SD = 1.79$). Conversely, the lowest contact area values were found in the midfoot ($M = 9.71$; $SD = 3.07$) and the first MH ($M = 5.86$; $SD = 5.87$). These values displayed a symmetrical distribution between the left and right feet. Concerning maximum force, the heel ($M = 54.66$; $SD = 8.3$) and the fourth MH ($M = 43.49$; $SD = 6.34$) exhibited higher values, with a tendency toward greater values in the left foot. A noteworthy reduction in peak pressure was observed in the left foot ($Z = -2.081$; $P = .04$).

Furthermore, an examination of the ranked data demonstrated that concerning maximum force, nearly half of the participants, both on the left and right feet, displayed increased maximum force values after the exposure period. A similar trend was observed for the contact area (Table 1).

The analysis of the data revealed several significant correlations among the measured variables. Notably, peak pressure exhibited positive correlations with both maximum force (0.44 ; $P < .01$) and contact area (0.53 ; $P < .01$). In addition, maximum force and contact area displayed a positive correlation (0.47 ; $P < .01$).

Moreover, BMI was found to be positively correlated with peak pressure values (0.51 ; $P < .01$) and contact area values (0.53 ; $P < .01$). These findings underscore the interrelationships between the variables, suggesting that variations in peak pressure, maximum force, contact area, and BMI are interdependent and statistically significant.

Microanalysis of the Change in Podiatric Profile at 5 Months

The study revealed notable correlations between foot metrics and various foot and ankle conditions. In the heel, significant negative correlations were found between the contact area and the presence of blisters (-0.50 ; $P < .01$), edema (-0.45 ; $P < .01$), and burning feet (-0.67 ; $P < .01$). Foot pain in the sole and knee pain showed a significant reduction in contact area in the midfoot (-0.87 , $P < .05$; -0.86 , $P < .05$; respectively). Thigh pain was linked to an increase in the contact area in the heel region.

Supplemental Content, Figure 1, illustrates that the heel experiences higher peak pressures, leading to a transfer to the MHs. Thigh pain exhibited a robust positive correlation with peak pressure, causing pressure transfer to the MHs. Ankle pain similarly led to increased pressure on the MHs.

Significant correlations were identified between peak pressure, maximum force, and contact area (Supplemental Content, Table 2). An elevation in peak pressure values at baseline demonstrated a significant association with an increase in these values after exposure (0.82 ; $P < .01$). In addition, maximum force values exhibited a highly pronounced positive correlation with contact area (0.88 ; $P < .01$).

In regression analyses (Supplemental Content, Table 3), peak pressure consistently emerged as the most robust predictor of the podiatric profile. In contrast, maximum force and contact area did not significantly contribute to the models. These findings underscore the crucial role of peak pressure in predicting foot metrics and understanding foot and ankle conditions.

Discussion

This study analyzed peak pressure, maximum force, and contact area in nursing students under prolonged standing conditions. The scarcity of existing studies on this topic, particularly among nursing students, poses a challenge for a comprehensive discussion. Although relevant literature from other populations was used, establishing normal values for nursing students remains unexplored due to limited research.

Studies by Putti and colleagues¹⁹ indicated that, in a standard foot, peak pressure under the MHs can range between 330 and 360 kPa, and for the heel, it is approximately 300 kPa. In our study, peak pressure under the MHs was 430.58 kPa; for the heel region, it was 305.05 kPa. This heightened load on the MHs seems partially attributed to adopting protective postures, where students rebalance weight in their feet to avoid pain or discomfort. Due to midfoot and heel discomfort, the observed force and pressure transfer to the MHs align with biomechanical patterns reported in previous studies.²⁰ This finding concurs with other studies identifying metatarsalgia (pain and inflammation in the area of the metatarsophalangeal joints) as a common and significant disorder among nurses in standing environments.²¹

Earlier investigations in professional nurses²² revealed statistically significant relationships between various body areas and load on specific foot arches, highlighting a consistent asymmetry with the left foot bearing more load. Our study similarly noted a trend toward increased load on the left foot. High foot arches have been associated with heightened pressure in both the heel and forefoot, consistent with findings from other studies²³. This suggests a need for caution regarding excessively supportive arch adaptations in professional footwear in those regions.

In summary, our findings indicate that even a relatively short exposure (5 months) to prolonged standing and walking conditions leads to increased maximum force and contact area outputs, with a notable decrease in pressure. Foot structure and function proved crucial predictors of peak pressure in the heel and hallux, with foot posture, especially in planus feet, associated with increased pressure at the heel and forefoot.

Moreover, the decrease in pressure may be influenced by students adapting their load distribution in response to localized discomfort, particularly in the forefoot and rearfoot, associated with common pain syndromes. Medium-to-strong negative correlations were observed between contact area and foot disorders like blisters, edema, and burning feet, conditions frequently developed by nurses in standing environments.²¹

Variables such as notable increases in peak pressure during prolonged clinical activities and a positive correlation with BMI also were observed, aligning with previous research.²⁴ However, caution is warranted regarding the limitations of macro-level analyses in detecting subtle foot or ankle disorders within shorter follow-up periods.

The presented results offer significant insights into the intricate interplay between foot characteristics, pressure distribution, and various foot-related disorders, underscoring the importance of scrutinizing the repercussions of prolonged standing and walking in acute clinical settings on the podiatric profile of nursing students. The scarcity of literature on this topic and the complexity of analyzing these data emphasize the need for further studies and highlight the novelty of this research.

Implications for practice include developing a multifaceted approach to promote better foot health among nursing students. This approach encompasses various strategies, including educational initiatives aimed at raising awareness about foot self-care practices, regular foot assessments to monitor for any signs of discomfort or conditions, recommendations for appropriate footwear choices, integration of foot-strengthening exercises into curricula, and access to foot care resources such as clinics or podiatrists.¹² Educating students about ergonomic principles and fostering peer support networks can mitigate foot-related issues. While systemic changes in the clinical setting may not be immediately feasible, empowering individual students with the knowledge and tools to prioritize foot health can improve their overall well-being and quality of life.

These findings contribute valuable insights into the effects of prolonged standing and walking on the podiatric profile of nursing students. They stress the importance of considering various factors in assessing foot health, including pressure distribution, force exertion, and contact area. The study also underscores the significance of a comprehensive approach to foot care, considering external factors, such as clinical environments, and internal factors, such as foot conditions and pain. Ultimately, these insights aid in developing strategies promoting better foot health among students earlier in their academic path.

The limitations of this study include the small sample size and the short follow-up period. The inability to control extracurricular activities introduced potential bias in the results. Future studies should take measures to address and mitigate these limitations.

Conclusions

The musculoskeletal health of nursing students is significantly impacted by their clinical rotations, particularly foot health, especially in the absence of adequate self-care interventions. Research indicates that even a relatively short period of 5 months within clinical settings is sufficient to increase foot pressure and force. These changes are associated with the emergence of foot disorders such as blisters or pain, which, if left untreated, can exacerbate and lead to a decline in students' quality of life and satisfaction during clinical practice.

Considering these findings, it is relevant to emphasize integrating ergonomic education into nursing curricula and promoting self-care interventions, mainly through guidance provided by faculty and clinical educators. Further research is warranted to explore the effectiveness of educational strategies in preventing such disorders and fostering a safe and comfortable learning environment for nursing students.

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Table 1. *Podiatric Profile at T0 and T1*

	<i>M</i>	<i>SD</i>	<i>m</i>	<i>Max</i>	<i>Z</i>	<i>p</i>	N		Ties	Total
							Negative Ranks	Positive Ranks		
PEAK_LF_T0	270.72	47.72	196.11	406,11	-					
PEAK_LF_T1	262.26	50.66	166.11	391,67	2.081	.04	34	19	1	54
FORCE_LF_T0	21.23	2.36	15.42	30,49						
FORCE_LF_T1	22.79	8.54	15.27	63,61	-.831	.41	31	23^a	0	54
AREA_LF_T0	13.24	1.91	8.25	17,55	-					
AREA_LF_T1	13.61	4.16	8.46	39,83	1.106	.27	29	25^b	0	54
PEAK_RF_T0	268.14	42.64	189.44	368,33	-					
PEAK_RF_T1	261.66	48.64	187.78	420,00	1.452	.15	33	20	1	54
FORCE_RF_T0	21.18	1.89	15.22	26,59	-					
FORCE_RF_T1	25.10	30.67	15.49	245.92	1.382	.17	33	21^a	0	54
AREA_RF_T0	13.52	2.26	7.96	20.91						
AREA_RF_T1	13.23	2.04	8.41	18.43	-1.49	.14	30	24^b	0	54

PEAK: peak pressure; FORCE: maximum force; AREA: contact area; LF: left foot; RF: right foot; M: mean; SD: standard deviation; m: minimum; Max: maximum; Z: Wilcoxon's Ranked test; a. FORCE T1 > FORCE T0; b. AREA T1 > AREA T0

Supplemental Content, Figure 1. Increase contact area in the heel with progressively increased peak pressure at the MHs in two pairs of the same feet (AB, CD)

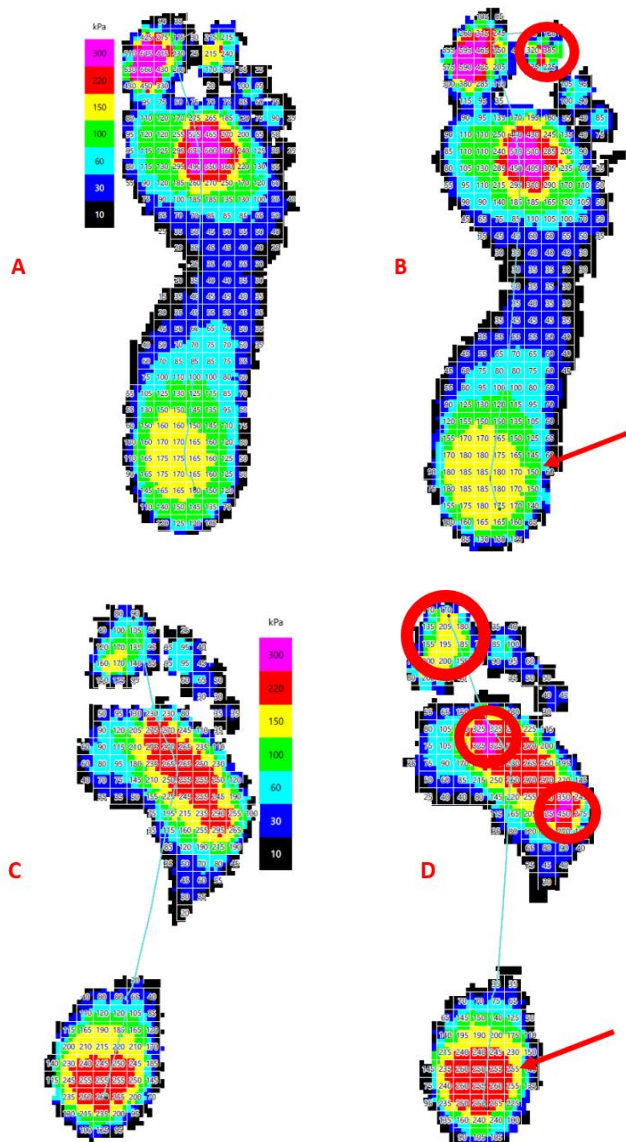


Figure 1A and Figure 1B: right foot of student AB at baseline and at 5 months, respectively; Figure 1C and Figure 1 D: right foot of student CD at baseline and at 5 months respectively; MHs: metatarsal heads.

Supplemental Table 2. Correlations coefficients (r) between peak pressure, maximum force and contact area (n=54)

	PEAK_L F_T0	FORCE_L F_T0	AREA_L F_T0	PEAK_R F_T0	FORCE_R F_T0	AREA_R F_T0	PEAK_L F_T1	FORCE_L F_T1	AREA_L F_T1	PEAK_R F_T1	FORCE_R F_T1	AREA_R F_T1
PEAK_LF _T0	1											
FORCE_L F_T0	,075	1										
AREA_LF _T0	,313*	,208	1									
PEAK_RF _T0	,777**	,003	,164	1								
FORCE_R F_T0	,091	,493**	,348**	,069	1							
AREA_RF _T0	,461**	,209	,823**	,248	,244	1						
PEAK_LF _T1	,817**	,144	,350**	,685**	,136	,446**	1					
FORCE_L F_T1	,293*	,082	,241	,118	,333*	,204	,309*	1				
AREA_LF _T1	,374**	,054	,410**	,370**	,092	,294*	,411**	,089	1			
PEAK_RF _T1	,766**	,194	,269*	,766**	,133	,377**	,838**	,214	,529**	1		
FORCE_R F_T1	,262	,027	-,033	,329*	-,019	-,086	,290*	-,007	,883**	,465**	1	
AREA_RF _T1	,459**	,202	,864**	,306*	,363**	,836**	,548**	,259	,402**	,420**	,001	1

T0: baseline; T1: 5 months; PEAK: peak pressure; FORCE: maximum force; AREA: contact area; LF: left foot; RF: right foot; r: Pearson correlations; * $p < .05$; **; $p < .01$

Supplemental Table 3. Significant predictors and their standardized regression coefficients for the podiatric profile measures

Peak Pressure		Maximum Force		Contact Area	
Predictors	Beta	Predictors	Beta	Predictors	Beta
Peak Pressure	0.841***	Peak Pressure	0.361***	Peak Pressure	0.466***
F(1,52)=125,86, $p<.01$ R ² =0.708***		F(1,52)=7,771, $p=0.007$ R ² =0.130***		F(1,52)=14,445, $p<.01$ R ² =0.217***	

(* $p<0.05$; ** $p<0.01$; *** $p<0.001$) F=degrees of freedom; R²=coefficients of determination;

F=degrees of freedom; R²=coefficients of determination