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Influence of Athletic Experience on Plantar Load Distribution During Walking and Running Using an Instrumented Zebris Treadmill: A Pilot Case Study

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***Abstract*—This pilot case study investigates the influence of athletic experience on plantar load distribution during controlled walking and running using an instrumented Zebris treadmill. Five physically active volunteers were categorized into high- (n = 2), moderate- (n = 1), and low-experience (n = 2) groups according to self-reported track and field background. Each participant completed three locomotion stages: walking at 3 km/h, running at 8 km/h, and a second walk at 3 km/h. Average maximum load normalized to body weight was recorded across four plantar regions (left and right forefoot and rearfoot), and bilateral asymmetry indices were computed for the running stage. During running, high-experience athletes exhibited higher forefoot loading and markedly lower rearfoot loading than less experienced participants, consistent with forefoot-strike mechanics, whereas group differences during walking were small. A pronounced rearfoot asymmetry index of 40.9 percent was observed in one high-experience participant. Given the limited sample size, the findings are preliminary and descriptive; larger studies incorporating inferential statistics and motion capture are recommended to validate these observations and clarify the biomechanical adaptations associated with athletic training.**

***Keywords*—foot strike pattern, gait analysis, plantar pressure, running biomechanics, Zebris treadmill**

I. INTRODUCTION

Human locomotion is a complex biomechanical process involving coordinated interaction between the musculoskeletal and nervous systems. The analysis of gait patterns has become an important research topic in sports science, rehabilitation medicine, and biomechanics, as it provides valuable information about movement efficiency, performance optimization, and injury prevention [1], [4].

Plantar pressure analysis is one of the most widely used methods for investigating foot–ground interaction during locomotion. Modern pressure measurement systems, including pressure platforms and instrumented treadmills, enable researchers to collect high-resolution data on plantar load distribution across different regions of the foot. These systems allow detailed analysis of biomechanical parameters such as maximum pressure, load distribution, contact time, and center-of-pressure trajectory [22], [23].

Instrumented treadmill systems such as Zebris have become increasingly popular in biomechanical research because they allow continuous recording of gait data under controlled locomotion conditions. Unlike traditional force plates that capture only a limited number of steps, instrumented treadmills allow long-duration recordings and provide more representative measurements of walking and running mechanics [4], [8]. The reliability and validity of the Zebris instrumented treadmill system have been assessed in dedicated measurement studies. Reed et al. [27] demonstrated good to excellent interclass correlation coefficients (ICC ≥ 0.80) for spatiotemporal and kinetic gait parameters during treadmill walking, supporting the between-session repeatability of the system. Van Alsenoy et al. [28] further evaluated the Zebris FDM-THQ during running trials, reporting acceptable to excellent reliability for contact time and flight time (ICC ≥ 0.70–0.90), while noting a tendency for the system to underestimate maximal vertical force at higher running speeds. These findings support the use of the Zebris system for comparative plantar pressure analysis under controlled treadmill conditions such as those employed in the present study.

Running biomechanics have been extensively investigated in relation to athletic performance and injury risk. Previous studies have demonstrated that experienced runners often exhibit different biomechanical characteristics compared to novice runners, particularly with respect to foot strike patterns and load distribution across the foot [2], [9].

One of the most commonly reported differences involves the type of foot strike used during running. Highly trained runners frequently demonstrate forefoot or midfoot strike patterns, whereas recreational or less experienced runners often rely on rearfoot (heel-strike) running patterns [2], [10]. These differences influence how impact forces are absorbed and redistributed throughout the lower extremity during ground contact.

Forefoot striking has been associated with lower vertical loading rates and potentially reduced risk of certain running-related injuries. By shifting impact absorption toward the ankle joint and elastic structures of the foot, forefoot striking may reduce the magnitude of collision forces during initial contact [9], [20].

The redistribution of plantar loads toward the forefoot may also improve propulsion efficiency during the push-off phase of running. The forefoot plays a critical role in generating propulsive forces that contribute to forward movement and running economy [7], [12].

Although numerous studies have investigated plantar pressure distribution in runners, relatively few have directly compared plantar loading characteristics between individuals with different levels of athletic experience under controlled treadmill conditions. Research conducted at institutions in South-Eastern Europe, including biomechanical modeling studies from the Bulgarian Academy of Sciences examining gait parameters in the local population [29], underscores the relevance of expanding such investigations within this regional context.

Understanding how athletic experience influences plantar load distribution during both walking and running may provide valuable insights into the biomechanical adaptations associated with training. Such knowledge may be useful for coaches, sports scientists, physiotherapists, and clinicians working in performance optimization and injury prevention.

The aim of the present pilot case study is to investigate the influence of athletic experience on plantar load distribution during controlled walking and running conditions using a Zebris instrumented treadmill system. The analysis focuses on four plantar regions: left forefoot, right forefoot, left rearfoot, and right rearfoot. Participants were categorized into three experience levels based on their involvement in track and field activities: high experience, medium experience, and low experience.

It is tentatively hypothesized that athletes with higher levels of experience will demonstrate increased forefoot loading and reduced rearfoot loading during running compared to less experienced participants. Additionally, it is expected that differences between experience groups will be more pronounced during running than during walking.

II. Materials and Methods

A. Participants

Five physically active volunteers from Bulgarian universities (National Sports Academy “Vassil Levski”, Sofia) participated in this pilot case study. All participants were healthy adults without current lower-limb injuries or musculoskeletal disorders that could influence gait mechanics. Informed consent was obtained from all participants prior to participation.

The experiments were conducted with five healthy volunteers without physical problems, with the permission of the Ethics Committee. Participation was entirely voluntary, no invasive procedures were involved, and data were collected solely for academic research purposes. Participant demographic characteristics are presented in Table I.

TABLE I
PARTICIPANT DEMOGRAPHIC CHARACTERISTICS

ID	Experience Level	Sex	Age (years)	Body Weight (kg)	Shoe Size (EU)
ID1	High	Male	21	61.0	43
ID2	High	Male	19	67.8	44
ID3	Medium	Male	19	75.0	44.5
ID4	Low	Female	27	47.0	36
ID5	Low	Male	19	76.0	43

Participants were categorized according to self-reported level of experience in athletic training and track and field activities. Experience levels were not verified through objective performance records but were based on participants’ own accounts of their training history. The primary distinguishing factor between the high-experience and low-experience groups was approximately two to three years of additional structured athletic practice. The high-experience athletes were ID1 and ID2; the moderate-experience athlete was ID3; and the low-experience athletes were ID4 and ID5.

The moderate-experience participant (ID3) is presented in individual data tables as an illustrative reference point; formal group comparisons were conducted only between the high- and low-experience groups.

B. Instrumentation

Plantar pressure measurements were obtained using a Zebris instrumented treadmill system (model FDM-T, Zebris Medical GmbH). The system incorporates a high-density array of capacitance-based pressure sensors embedded within the treadmill surface, enabling continuous measurement of plantar pressure distribution. Four plantar regions were analyzed: left forefoot, right forefoot, left rearfoot, and right rearfoot.

C. Experimental Protocol

The experimental protocol consisted of three locomotion stages: (1) walking at 3 km/h for 90 seconds; (2) running at 8 km/h for 120 seconds; (3) a second walking stage at 3 km/h for 90 seconds. The order was fixed and not randomized across participants. Prior to testing, participants completed approximately two minutes of treadmill familiarization walking. All participants were barefoot. An example of the Zebris output for a single participant is shown in Fig. 1.

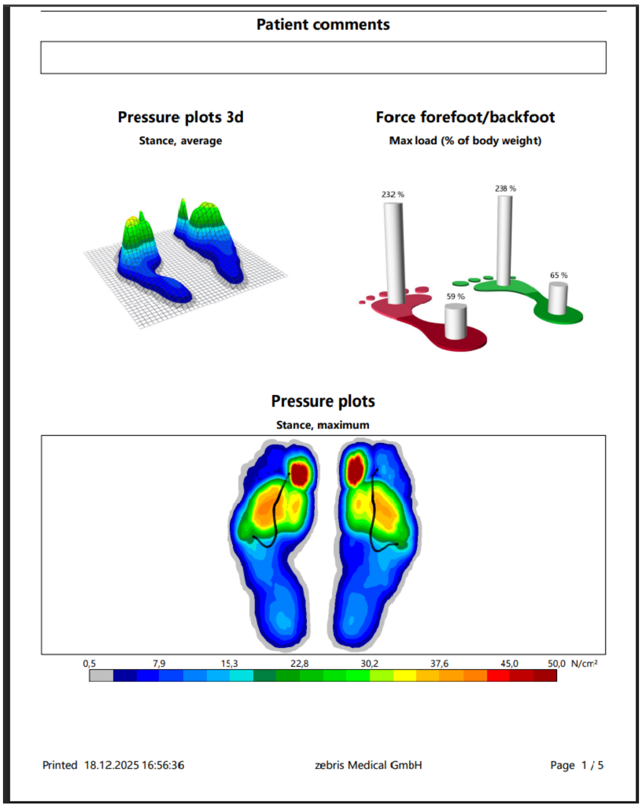

Fig. 1. Example pressure plots of participant ID1.

D. Data Analysis

The primary outcome variable was average maximum load expressed as %BW. Given the small sample size (n = 2 per group), formal inferential statistical tests were not applied. Descriptive statistics (mean ± SD) are reported for the high (H) and low (L) experience groups. A bilateral asymmetry index (AI) was computed for each participant during running, given by (1):

$$AI = |L - R| / [(L + R) / 2] \times 100 \qquad (1)$$

where L and R are the average maximum load values (%BW) for the left and right sides, respectively. An asymmetry index exceeding 10–15% is generally regarded in the literature as potentially biomechanically meaningful [28].

III. Results

All values are expressed as average maximum load (%BW). Descriptive statistics (mean ± SD) are reported for the H and L groups. ID3 (M) is included in individual tables as a reference. A comprehensive summary across all participants and stages is presented in Tables II–IV; bilateral asymmetry indices for the running stage are presented in Table V.

A. Summary Tables – All Participants and Stages

TABLE II
AVERAGE MAXIMUM PLANTAR LOAD (%BW) – WALKING STAGE 1

ID	Exp.	Forefoot L	Forefoot R	Rearfoot L	Rearfoot R
ID1	H	118.835	123.897	77.033	79.651
ID2	H	119.579	115.755	80.704	74.526
ID3	M	102.503	103.604	78.786	77.770
ID4	L	108.186	107.313	76.010	79.146
ID5	L	112.679	89.545	81.079	77.428
H mean±SD		119.21±0.53	119.83±5.76	78.87±2.60	77.09±3.62
L mean±SD		110.43±3.18	98.43±12.56	78.54±3.58	78.29±1.21

TABLE III
AVERAGE MAXIMUM PLANTAR LOAD (%BW) – RUNNING STAGE

ID	Exp.	Forefoot L	Forefoot R	Rearfoot L	Rearfoot R
ID1	H	231.726	237.988	58.700	64.926
ID2	H	231.443	204.035	57.564	87.137
ID3	M	224.519	228.476	91.424	100.360
ID4	L	185.339	195.117	87.398	77.434
ID5	L	195.742	183.595	74.986	68.161
H mean±SD		231.58±0.20	221.01±24.01	58.13±0.80	76.03±15.71
L mean±SD		190.54±7.36	189.36±8.15	81.19±8.78	72.80±6.56

TABLE IV
AVERAGE MAXIMUM PLANTAR LOAD (%BW) – WALKING STAGE 2

ID	Exp.	Forefoot L	Forefoot R	Rearfoot L	Rearfoot R
ID1	H	109.835	113.815	75.958	81.952
ID2	H	118.787	117.675	78.626	70.920
ID3	M	101.948	104.946	80.659	81.054
ID4	L	107.305	106.250	76.564	79.351
ID5	L	112.777	92.373	80.635	80.333
H mean±SD		114.31±6.33	115.75±2.73	77.29±1.89	76.44±7.80
L mean±SD		110.04±3.87	99.31±9.81	78.60±2.88	79.84±0.69

TABLE V
BILATERAL ASYMMETRY INDEX (AI) DURING THE RUNNING STAGE (CELLS SHADED RED INDICATE AI > 20%)

ID	Exp.	Forefoot L/R (%BW)	Forefoot AI (%)	Rearfoot L/R (%BW)	Rearfoot AI (%)
ID1	H	231.73 / 237.99	2.7	58.70 / 64.93	10.1
ID2	H	231.44 / 204.03	12.6	57.56 / 87.14	40.9
ID3	M	224.52 / 228.48	1.7	91.42 / 100.36	9.3
ID4	L	185.34 / 195.12	5.1	87.40 / 77.43	12.1
ID5	L	195.74 / 183.59	6.4	74.99 / 68.16	9.5

B. Average Maximum Load – Left Forefoot

TABLE VI
AVERAGE MAXIMUM LOAD – FOREFOOT L (%BW)

ID	EXP.	WALK STAGE 1 (%BW)	RUNNING STAGE (%BW)	WALK STAGE 2 (%BW)
ID1	H	118.835	231.726	109.835
ID2	H	119.579	231.443	118.787
ID3	M	102.503	224.519	101.948
ID4	L	108.186	185.339	107.305
ID5	L	112.679	195.742	112.777
H mean±SD	High	119.21±0.53	231.58±0.20	114.31±6.33
L mean±SD	Low	110.43±3.18	190.54±7.36	110.04±3.87

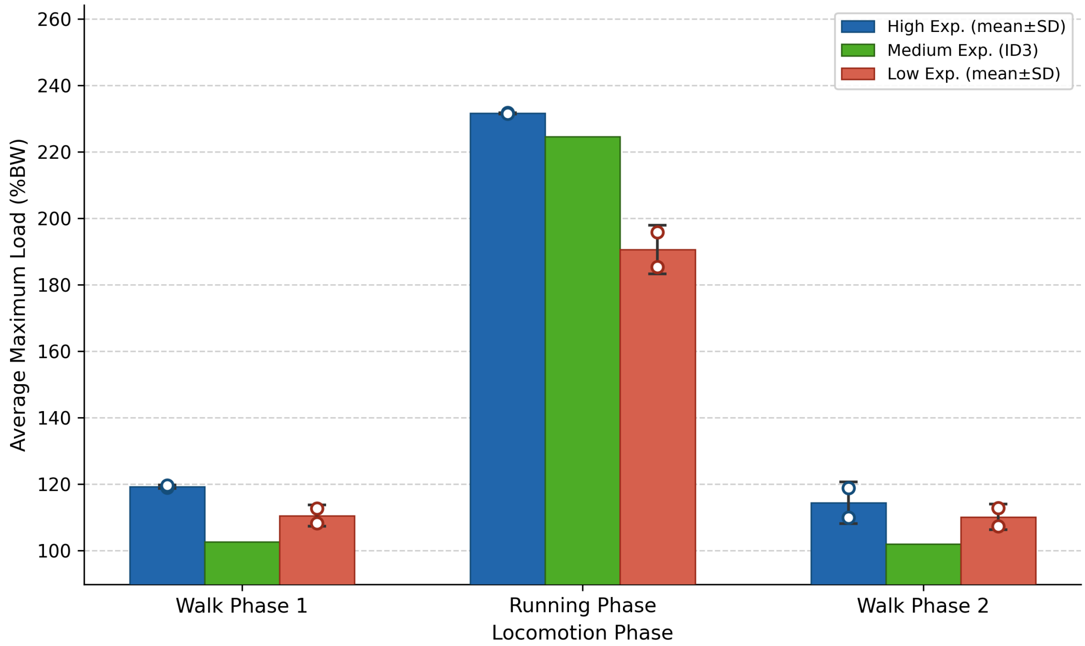

Fig. 2. Average maximum plantar load (%BW) in the left forefoot region across locomotion phases. Bars represent group means ± SD; white circles indicate individual participant values. H = high experience; M = medium experience; L = low experience.

During walk stage 1, the high-experience group demonstrated a mean of 119.21 ± 0.53 %BW vs. 110.43 ± 3.18 %BW for the low-experience group (difference: +8.77 %BW, +7.9%). During the running stage, the high-experience group produced 231.58 ± 0.20 %BW compared to 190.54 ± 7.36 %BW for the low-experience group (difference: +41.04 %BW, +21.5%), substantially exceeding the 10–15% practical significance threshold. During walk stage 2, the difference narrowed to +4.27 %BW (+3.9%). The notably low within-group SD for high-experience athletes during running (0.20 %BW) reflects near-identical values between ID1 and ID2, though this should be interpreted with caution given that it is based on only two observations.

C. Average Maximum Load – Right Forefoot

During walk stage 1, the high-experience group showed 119.83 ± 5.76 %BW vs. 98.43 ± 12.56 %BW for the low-experience group (+21.40 %BW, +21.7%). The high within-group SD for the low-experience group reflects the pronounced right-side loading difference between ID4 and ID5. During running, the high-experience group produced 221.01 ± 24.01 %BW vs. 189.36 ± 8.15 %BW (+31.66 %BW, +16.7%). The elevated SD in the high-experience group reflects the bilateral asymmetry in ID2, discussed in Section IV-C. During walk stage 2, the difference was +16.43 %BW (+16.5%).

TABLE VII
AVERAGE MAXIMUM LOAD – FOREFOOT R (%BW)

ID	EXP.	WALK STAGE 1 (%BW)	RUNNING STAGE (%BW)	WALK STAGE 2 (%BW)
ID1	H	123.897	237.988	113.815
ID2	H	115.755	204.035	117.675
ID3	M	103.604	228.476	104.946
ID4	L	107.313	195.117	106.250
ID5	L	89.545	183.595	92.373
H mean±SD	High	119.83±5.76	221.01±24.01	115.75±2.73
L mean±SD	Low	98.43±12.56	189.36±8.15	99.31±9.81

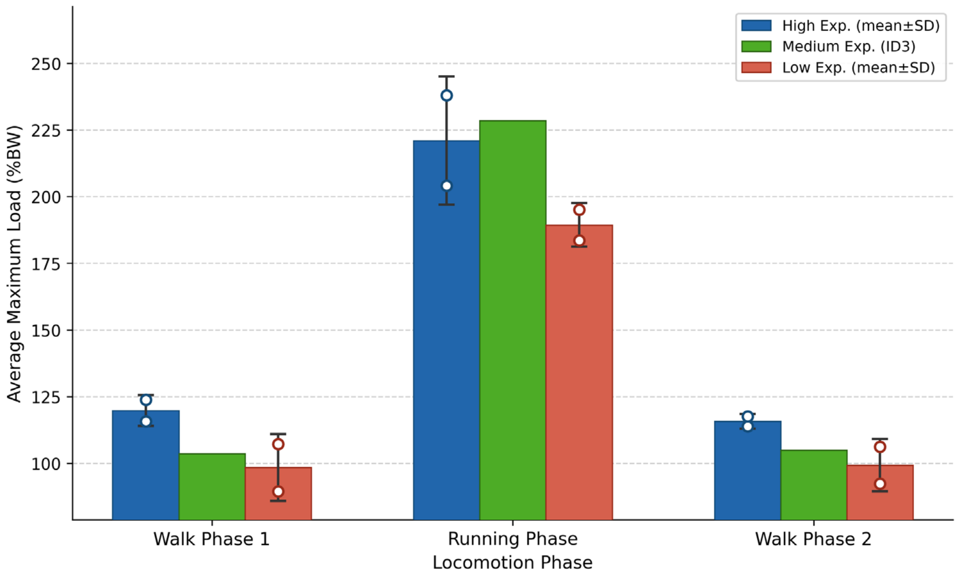

Fig. 3. Average maximum plantar load (%BW) in the right forefoot region across locomotion phases. Bars represent group means ± SD; white circles indicate individual participant values.

D. Average Maximum Load – Left Rearfoot

In contrast to the forefoot regions, the left rearfoot showed an inverse pattern. During walk stage 1, loading was virtually identical (H: 78.87 ± 2.60 %BW; L: 78.54 ± 3.58 %BW; diff: +0.32 %BW, +0.4%). During running, the high-experience group demonstrated markedly lower left rearfoot loading (58.13 ± 0.80 %BW) compared to the low-experience group (81.19 ± 8.78 %BW), a difference of −23.06 %BW (−28.4%). This is consistent with forefoot-dominant loading in trained runners. During walk stage 2, group differences remained negligible (−1.31 %BW, −1.7%).

TABLE VIII
AVERAGE MAXIMUM LOAD – REARFOOT L (%BW)

ID	EXP.	WALK STAGE 1 (%BW)	RUNNING STAGE (%BW)	WALK STAGE 2 (%BW)
ID1	H	77.033	58.700	75.958
ID2	H	80.704	57.564	78.626
ID3	M	78.786	91.424	80.659
ID4	L	76.010	87.398	76.564
ID5	L	81.079	74.986	80.635
H mean±SD	High	78.87±2.60	58.13±0.80	77.29±1.89
L mean±SD	Low	78.54±3.58	81.19±8.78	78.60±2.88

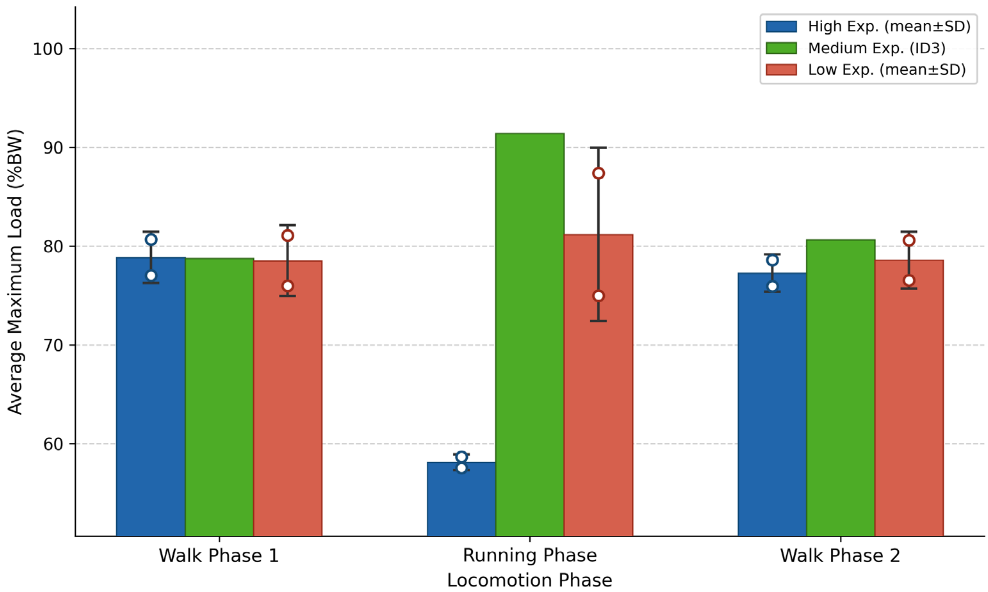

Fig. 4. Average maximum plantar load (%BW) in the left rearfoot region across locomotion phases. Bars represent group means ± SD; white circles indicate individual participant values.

E. Average Maximum Load – Right Rearfoot

TABLE IX
AVERAGE MAXIMUM LOAD – REARFOOT R (%BW)

ID	EXP.	WALK STAGE 1 (%BW)	RUNNING STAGE (%BW)	WALK STAGE 2 (%BW)
ID1	H	79.651	64.926	81.952
ID2	H	74.526	87.137	70.920
ID3	M	77.770	100.360	81.054
ID4	L	79.146	77.434	79.351
ID5	L	77.428	68.161	80.333
H mean±SD	High	77.09±3.62	76.03±15.71	76.44±7.80
L mean±SD	Low	78.29±1.21	72.80±6.56	79.84±0.69

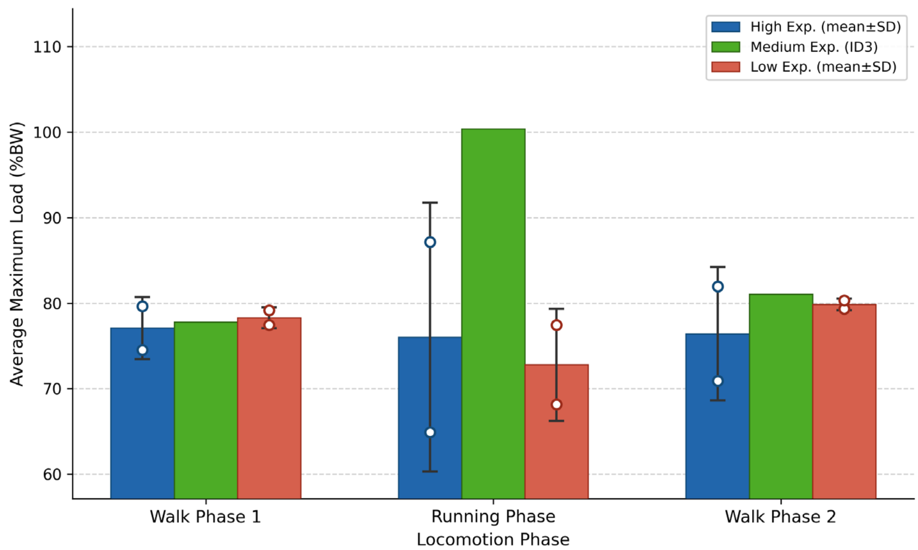

Fig. 5. Average maximum plantar load (%BW) in the right rearfoot region across locomotion phases. Bars represent group means ± SD; white circles indicate individual participant values.

The right rearfoot showed a notably different pattern from the left. During walk stage 1 and walk stage 2, group differences were negligible (−1.20 and −3.41 %BW, respectively). During running, the high-experience group produced 76.03 ± 15.71 %BW vs. 72.80 ± 6.56 %BW for the low-experience group (difference: +3.23 %BW, +4.4%). The high within-group SD for the high-experience group is driven by the pronounced bilateral rearfoot asymmetry in ID2 (left: 57.56 %BW; right: 87.14 %BW; AI = 40.9%), discussed in Section IV-C.

IV. DISCUSSION

The aim of this pilot case study was to investigate how athletic experience is associated with plantar load distribution during controlled walking and running. Preliminary trends indicate discernible differences between high- and low-experience groups, particularly during running. The following discussion interprets these observations in the context of existing literature, while explicitly acknowledging the exploratory nature of the findings.

A. Forefoot Loading and Running Experience

The most notable preliminary trend is the substantially greater forefoot loading among high-experience athletes during running. The left forefoot difference of approximately 41 %BW (+21.5%) substantially exceeds the 10–15% threshold tentatively associated with biomechanically meaningful differences [28]. These preliminary observations are consistent with the established finding that trained runners frequently adopt forefoot or midfoot strike patterns, whereas less experienced runners more commonly demonstrate rearfoot strike patterns [2], [10].

Forefoot strike running has been associated with lower vertical loading rates and altered impact mechanics [2], [9]. The higher forefoot loads among high-experience participants may tentatively reflect such a biomechanical adaptation, though this interpretation requires confirmation in larger samples with concurrent kinematic data.

The preliminary data also suggest that less experienced runners showed substantially greater left rearfoot loading during running (−23.06 %BW compared to high-experience athletes), consistent with reliance on heel-strike mechanics and associated higher impact forces [6], [21].

B. Walking vs. Running

Differences between experienced and less experienced groups were considerably smaller during walking stages. This observation suggests that walking biomechanics may be less sensitive to differences in athletic training level. Walking is a highly automated locomotion pattern, whereas running involves higher mechanical demands and more complex neuromuscular coordination, which may amplify experience-related biomechanical differences [1], [4].

The second walking stage did not reveal substantial fatigue-related changes in plantar loading, tentatively suggesting that the moderate running duration was insufficient to induce measurable gait alterations in this small sample.

C. Bilateral Asymmetry

A particularly noteworthy finding in this pilot dataset is the pronounced bilateral rearfoot asymmetry observed in ID2 during running (left: 57.56 %BW; right: 87.14 %BW; AI = 40.9%). This value substantially exceeds the >10% threshold considered potentially significant in the inter-limb asymmetry literature [30]. The other four participants showed rearfoot AIs ranging from 9.3% to 12.1%.

It is important to note that this asymmetry does not reflect a group-level pattern among high-experience athletes; ID1 demonstrated a rearfoot AI of only 10.1%. The divergence between these two high-experience participants highlights the importance of individual-level data reporting in pilot studies where group means can mask substantial within-group variability. The origin of this asymmetry in ID2 cannot be determined from the present data; possible explanations include limb dominance, prior injury history, or habitual training patterns. Future studies should assess whether such pronounced rearfoot asymmetries are associated with specific training histories or injury risk factors.

D. Practical Implications

From a practical perspective, the preliminary findings of this pilot study may have implications for sports training and injury prevention, pending confirmation in larger samples. Monitoring plantar pressure distribution may help coaches and sports scientists identify inefficient loading patterns and optimize running technique. Similarly, clinicians may use such analyses to assess rehabilitation progress and evaluate biomechanical risk factors [21], [23].

The relevance of plantar pressure measurement extends beyond athletic performance research. As highlighted by Qiu et al. [26], evaluation of locomotion efficiency including plantar load distribution is fundamental to the design and control of lower extremity robotic exoskeletons, illustrating the broader applicability of the biomechanical data reported here.

E. Limitations

The results of this pilot case study must be interpreted within the context of several methodological limitations. First and most significantly, the sample size of five participants (n = 2 per group) is insufficient for inferential statistical analysis; all observed differences are descriptive only. Second, experience levels were self-reported and not objectively verified. Third, the locomotion order was not randomized, precluding the exclusion of order effects. Fourth, no kinematic data were collected, limiting mechanistic interpretation. Fifth, the familiarization period (approximately two minutes) may not have been sufficient for complete treadmill acclimatization.

Future studies should address these limitations by recruiting larger samples, implementing objective experience verification, randomizing locomotion order, incorporating simultaneous motion capture, and extending familiarization protocols.

V. Conclusion

This pilot case study investigated the preliminary relationship between athletic experience and plantar load distribution during walking and running using an instrumented Zebris treadmill system. The scientific contribution lies in providing region-specific, individual-level plantar loading data that demonstrate the feasibility of instrumented treadmill-based comparative biomechanical assessment in athletic populations.

Preliminary descriptive trends suggest that high-experience athletes demonstrate greater forefoot loading during running (left forefoot: 231.58 ± 0.20 %BW vs. 190.54 ± 7.36 %BW for low-experience athletes; +21.5%), exceeding the 10–15% threshold tentatively associated with biomechanical meaningfulness. Conversely, less experienced runners showed elevated left rearfoot loading during running (−23.06 %BW). A notable bilateral rearfoot asymmetry was observed in one high-experience participant (ID2, AI = 40.9%), and differences between experience groups were considerably smaller during the walking stages.

All findings are preliminary and descriptive only given the small sample size (n = 5). Future research with larger samples, objective experience verification, randomized protocols, and concurrent motion capture is necessary to validate and extend these observations.

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