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Immediate and long-term effects of anti-pronation insoles on spatiotemporal gait parameters in individuals with flat feet

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ABSTRACT

Purpose of the study: This study examined the immediate and long-term effects of anti-pronation insoles on gait characteristics in young adults with flexible flatfoot compared with healthy controls.

Methods: Twenty-four participants (12 flatfoot, 12 controls) underwent gait analysis under barefoot and shod conditions using a 3D motion system. The flatfoot group wore custom anti-pronation insoles during testing and continued daily use for six weeks. Spatiotemporal gait parameters were analyzed using repeated measures ANOVA and MANOVA.

Results: At baseline, the flatfoot group showed significant temporal differences, including prolonged opposite foot off and reduced single support duration ($p < 0.05$). Short-term insole use led to partial improvements, while post-intervention assessments demonstrated significant increases in step and stride length and normalization of stance-phase timing ($p < 0.05$). Cadence, walking speed, and step time remained unchanged.

Conclusion: Anti-pronation insoles produced both immediate and sustained improvements in gait timing and spatial characteristics in individuals with flexible flatfoot. Importantly, these benefits emerged not only after a single session but also following six weeks of use, underscoring the adaptive potential of long-term intervention. While gait velocity and cadence were unaffected, improvements in step and stride length and stance-phase dynamics suggest enhanced stability and efficiency. These findings support anti-pronation insoles as a conservative and clinically relevant strategy for restoring gait mechanics in individuals with flatfoot.

Keywords: Flatfoot, foot orthoses, gait analysis, biomechanical phenomena, postural balance

Conflict of interest: the authors declare no conflicts of interest.

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Немедленные и долгосрочные эффекты антипронационных стелек на пространственно-временные параметры ходьбы у людей с плоскостопием

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АННОТАЦИЯ

Цель исследования. В данном исследовании были изучены немедленные и долгосрочные эффекты антипронационных стелек на характеристики ходьбы у молодых взрослых с гибким плоскостопием по сравнению со здоровыми контрольными участниками.

Методы. Двадцать четыре участника (12 с плоскостопием, 12 в контрольной группе) прошли анализ походки босиком и в обуви с использованием 3D-системы регистрации движений. Группа с плоскостопием носила индивидуальные антипронационные стельки во время тестирования и продолжала их ежедневное использование в течение шести недель. Пространственно-временные параметры походки анализировались с применением дисперсионного анализа с повторными измерениями и многомерного дисперсионного анализа.

Результаты. На исходном этапе у группы с плоскостопием были выявлены значимые временные различия, включая удлинение момента отрыва противоположной стопы и сокращение продолжительности одноопорной фазы ($p < 0{,}05$). Краткосрочное использование стелек привело к частичным улучшениям, тогда как после завершения шестинедельного вмешательства наблюдалось значительное увеличение длины шага и длины двойного шага, а также нормализация временных характеристик фазы опоры ($p < 0{,}05$). Частота шагов, скорость ходьбы и время шага не изменились.

Заключение. Антипронационные стельки обеспечили как немедленные, так и устойчивые улучшения во временных и пространственных характеристиках ходьбы у людей с гибким плоскостопием. Важно отметить, что эти положительные эффекты проявлялись не только после одного сеанса, но и после шести недель использования, что подчёркивает адаптационный потенциал длительного вмешательства. Хотя скорость ходьбы и частота шагов не изменились, улучшения в длине шага, длине двойного шага и динамике фазы опоры указывают на повышение стабильности и эффективности.

Ключевые слова: Плоскостопие; ортопедические стельки; анализ походки; биомеханические явления; постуральный баланс

Ключевые слова: глюкозный гомеостаз, чувствительность к инсулину, здоровые взрослые, усвоение глюкозы

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1. Introduction

Human gait is a complex motor function and a key indicator of functional mobility and overall musculoskeletal health [1, 2]. Structural abnormalities in the foot can disrupt lower limb alignment and lead to altered gait biomechanics [3]. Flatfoot, or pes planus, is among the most prevalent skeletal deformities of the foot. It is characterized by a diminished or absent medial longitudinal arch and forefoot abduction [4]. This condition often results in excessive subtalar joint pronation and calcaneal eversion, which may impair normal lower extremity function [5]. Individuals with flatfoot frequently exhibit distinct gait patterns throughout the gait cycle. For example, a recent meta-analysis reported significantly reduced step length and walking speed in individuals with flatfoot compared to those with normal foot posture [6, 7]. Moreover, increased heel pronation angles and lateral foot displacement have been documented in this population, potentially contributing to abnormal force distribution across the lower limbs and increasing the risk of knee and hip discomfort [7].

Various conservative strategies—including strengthening exercises and foot orthoses—are commonly employed to manage flatfoot [8]. Among these, orthotic insoles are a widely used non-invasive intervention [9]. These devices aim to support the medial arch and restrict excessive pronation, thereby enhancing foot alignment and improving lower limb function [10, 11]. Previous research has shown that orthotic insoles can alter foot kinematics and redistribute plantar pressures. For instance, one study demonstrated that custom arch-supporting insoles increased navicular bone height and improved walking comfort [12, 13]. In a study, the immediate effect of insoles on the balance performance of adolescents with flat and concave feet was examined. Teenage boys and girls with flat and concave feet had better dynamic balance after using the insoles, but the medical insoles had little effect on their static balance [14]. The short-term effects of insoles and anti-pronation shoes on the center of pressure and ground reaction forces of flat-footed individuals during walking were evaluated in a study. The study showed that insoles lead to inefficient force transmission in the anterior direction. In addition, walking with and without insoles and Dye Low shoes had significant effects on the center of pressure shift at the end of the stance phase; however, these effects do not appear to increase the likelihood of gait-related injuries, as fewer loads and forces are applied to the joints at the end of the stance phase [15]. In a study, the immediate and long-term effects of Arch Support insoles on the electrical activity of muscles during landing in the three-step shot technique were compared in handball players with pronated feet. The results showed that immediate and long-term use of Arch Support insoles can improve the electrical activity of lower limb muscles during jumping and landing, as well as improve balance, shock absorption from landing, and ankle joint stability in handball players with pronated feet [16]. However, their effects on spatiotemporal gait parameters remain incompletely understood. Some studies suggest that while insoles may not significantly affect gait speed or cadence, they may enhance ankle stability and control [17]. Furthermore, limited evidence exists regarding the long-term biomechanical effects of continuous insole use on gait [18, 19]. A recent systematic review of foot orthoses in adults concluded that due to a lack of sufficiently controlled trials, the efficacy of orthoses in managing adult flatfoot remains inconclusive [20].

Given these gaps in the literature, the present study aimed to determine whether anti-pronation insoles can improve spatiotemporal gait parameters in individuals with flexible flatfoot and whether these effects are sustained or enhanced over time. Specifically, the study evaluated both the immediate (single-session) and long-term (six-week) effects of insole use on gait characteristics in individuals with flexible flatfoot, compared to those with normal foot posture. Additionally, the study sought to explore the potential biomechanical mechanisms underlying these effects, such as changes in support phase dynamics, and provide clinically relevant insights for professionals involved in flatfoot rehabilitation.

2. Methods

2.1. Participants

The study included young adults (male and female) aged 16 to 30 years. Twelve participants with clinically diagnosed flat feet were recruited from orthopedic clinics in [location] to form the experimental group (FFG), while 12 age-, height-, and weight-matched individuals with normal foot posture were selected through convenience sampling to serve as the control group (CG). Flexible flatfoot was diagnosed using the navicular drop test, with a drop greater than 10 mm—defined as the difference in navicular bone height between non-weight-bearing and weight-bearing conditions—serving as the inclusion criterion for the flatfoot group [21]. Exclusion criteria included a history of lower limb surgery or significant musculoskeletal injury, prior use of orthotic insoles or orthopedic footwear, and any diagnosed neuromuscular disorders or diabetes [21-23].

Using G*Power 3.1 software [21]. the required sample size for a repeated measures ANOVA was calculated based on an effect size of 0.40, an alpha level of 0.05, and a statistical power of 0.80. The analysis indicated that a minimum of 24 participants was necessary.

All participants provided written informed consent before data collection. The study was approved by the Ethics Committee of Islamic Azad University of Hamedan (Approval Code: IR.IAU.H.REC.1402.130) and was conducted in accordance with the ethical standards set forth in the Declaration of Helsinki.

2.2. Instrumentation and procedure

Anthropometric measurements, including height, weight, and lower limb dimensions (leg length, knee width, and ankle width) were recorded for each participant and entered into the motion analysis software for calibration. Gait assessments were conducted in the biomechanics laboratory using a 3D motion capture system (Vicon Peak, Oxford, UK) with six T20-series cameras operating at a sampling rate of 100 Hz. The system was used to capture gait kinematics along a 12-meter walkway, with two Kistler force plates embedded at the midpoint to detect gait events.

Reflective markers (14 mm diameter) were attached to specific anatomical landmarks on both lower limbs using double-sided adhesive tape, following the Plug-In Gait marker set protocol (Vicon Peak, Oxford, UK). Marker placement included the anterior and posterior superior iliac spines, lateral femoral epicondyles, distal one-third of the thighs and shanks, lateral malleoli, second metatarsal heads, and calcanei [24]. A calibrated capture volume of 3 × 1.5 × 2 meters allowed for the recording of at least two full gait strides within the calibrated space.

Participants began with a 10-minute familiarization session to become accustomed to the lab environment and equipment. They were then instructed to walk at a self-selected comfortable pace along the walkway, ensuring full foot contact with the force plates. Five trials were collected for each condition, and the three most successful trials were selected for analysis. Trials were considered valid if all lower limb markers were visible throughout the entire gait cycle. The testing protocol included two walking conditions: (1) barefoot walking, and (2) walking with sports shoes.

Participants in the CG wore standard athletic shoes without insoles, while those in the FFG used polyurethane anti-pronation insoles (Arc Support FO, Longxin Ltd.) inserted into their shoes. These insoles were designed with medial arch support and a raised lateral edge. To evaluate short-term effects, participants' gait under the barefoot condition was compared with the shod condition (with insoles for the FFG and without insoles for the CG) during the same session. Following this session, the FFG was instructed to use the insoles daily for a period of six weeks during regular physical activity. A minimum daily wear time was recommended, and weekly follow-ups were conducted to monitor adherence. After six weeks (to assess long-term effects), gait analysis was repeated in both barefoot and shod conditions (with insoles for the FFG). The CG received no intervention during this period and returned for follow-up testing after six weeks. Marker trajectories and force plate data were processed using Vicon Nexus (v1.8.2) and Polygon (v3.5.2) software. Kinematic data were filtered using a fourth-order Butterworth low-pass filter with a 6 Hz cutoff frequency [25]. For all variables, the mean of three valid trials was used for analysis.

Spatiotemporal gait parameters were classified into two categories: Variable parameters, including step length, stride length, step time, stride time, stance and swing durations, single and double support times, cadence, and walking speed. Fixed (event-based) parameters, including the relative timing (as a percentage of the gait cycle) of key events: opposite foot contact, opposite foot toe-off, and toe-off of the ipsilateral foot. Stance time for each limb was calculated using the following equation [25]:

$$\text{Stance time}_x = \text{double support time}_x + \text{single support time}_x,$$

Swing time was defined, based on the literature, as equal to the contralateral stance time. Since all participants were right-foot dominant and no significant differences were observed between right and left limbs in preliminary analyses, the dominant (right) leg was selected for subsequent calculations and statistical analyses [26]. All other parameters were directly extracted from the Polygon software.

2.3. Statistical analysis

The Shapiro-Wilk test was used to verify the normality of the data distribution. To examine the effects of the experimental factors on gait parameters, a three-way mixed repeated measures ANOVA was performed, with Time (pre vs. post) and Shoes (barefoot, shod) as within-subject factors, and Group (CG vs. FFG) as the between-subject factor. When significant main effects or interactions were observed, Bonferroni-adjusted pairwise comparisons were conducted to determine specific differences. All statistical analyses were performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA), and the level of significance was set at $p \leq 0.05$.

3. Results

Table 1 displays the demographic profiles of the participants and highlights the differences observed between the CG and FFG.

The factorial analysis for spatiotemporal outcomes is summarized in Table 2. Regarding the spatial parameters, both stride length and step length showed clear improvements with insole use. Although no group effects were observed ($p > 0.05$), significant main effects of shoes were found for stride length ($p < 0.001$, $\eta^2 = 0.492$) and step length ($p < 0.001$, $\eta^2 = 0.607$). Moreover, significant time × shoes interactions were detected for both variables (stride length: $p = 0.007$, $\eta^2 = 0.302$; step length: $p < 0.001$, $\eta^2 = 0.456$), indicating progressive spatial gains when participants used insoles over time. Walking speed also exhibited a significant time × shoes interaction ($p = 0.038$, $\eta^2 = 0.189$), suggesting that gait velocity increased progressively with insoles, particularly in the flat-foot group. Collectively, these findings highlight that anti-pronation insoles consistently improved spatial gait parameters (Fig. 1).

In terms of the temporal parameters, several notable effects were identified. For cadence, no main effects were significant (all $p > 0.05$), though a borderline shoes × group interaction ($p = 0.050$, $\eta^2 = 0.171$) suggested group-specific adaptations. Stride time demonstrated a significant shoes × group interaction ($p = 0.038$, $\eta^2 = 0.189$), pointing to differential modulation across groups. Strong effects were observed for opposite foot off (%), where both group ($p = 0.006$, $\eta^2 = 0.309$) and shoes ($p < 0.001$, $\eta^2 = 0.513$) were significant, and for foot off (%), with significant effects of group ($p = 0.016$, $\eta^2 = 0.248$) and shoes ($p < 0.001$, $\eta^2 = 0.768$). Single support was influenced by group ($p = 0.006$), time ($p = 0.038$), and shoes ($p = 0.003$), reflecting reduced single-support duration with insoles and over time. Conversely, double support increased significantly with insoles ($p < 0.001$, $\eta^2 = 0.546$),

Table 1

Demographic characteristics of the participants and comparison between the two groups

Таблица 1

Демографические характеристики участников и сравнение между двумя группами

	Groups		*p*-value
	FFG (*n* = 12)	**CG (*n* = 12)**	
Sex (male/female)	5/7	5/7	
Age (y)	20.81 (2.7)	21.41 (2.9)	0.888
Height (m)	1.6 (0.07)	1.7 (0.07)	0.992
Weight (kg)	68.90 (10.23)	69.58 (12.22)	0.316
BMI	24.97 (2.42)	23.68 (2.45)	0.942

Notes: Values are mean ± standard deviation. Abbreviations: FFG, experimental group; CG, control group; *n*, number of participants; BMI, body mass index; * Significance level $p < 0.05$.

Table 2

Results of factorial analysis (ANOVA) for spatiotemporal gait parameters in control group (CG) and flat-foot group (FFG) across conditions (NG: normal gait, PNG: post-normal gait, SH: shoes, PSH: post-shoes)

Таблица 2

Результаты факторного анализа (ANOVA) пространственно-временных параметров ходьбы в контрольной группе (CG) и группе с плоскостопием (FFG) в различных условиях (NG: нормальная ходьба, PNG: после нормальной ходьбы, SH: в обуви, PSH: после обуви)

		NG	PNG	SH	PSH	Group	Time	Time*Group	Shoes	Shoes*Group	Time*Shoes
Cadence (steps/min)	CG	106.59 ± 10.35	106.59 ±1 0.35	108.33 ± 6.45	108.33 ± 6.45	p = 0.339 F = 0.956 Eta = 0.04	p = 0.427 F = 0.657 Eta = 0.03	p = 0.427 F = 0.657 Eta = 0.03	p = 0.498 F = 0.475 Eta = 0.02	p = **0.05** F = 4.325 Eta = 0.171	p = 0.383 F = 0.796 Eta = 0.037
	FFG	109.7436 ± 5.61	113.74 ± 11.29	107.88 ± 40.77	107.78 ± 70.42						
Stride Time (s)	CG	1.1383 ± 0.11	1.13 ± 0.11	1.11 ± 0.06	1.11 ± 0.06	p = 0.38 F = 0.803 Eta = 0.037	p = 0.581 F = 0.315 Eta = 0.015	p = 0.581 F = 0.315 Eta = 0.015	p = 0.672 F = 0.185 Eta = 0.009	p = **0.038** F = 4.888 Eta = 0.189	p = 0.439 F = 0.622 Eta = 0.029
	FFG	1.10 ± 0.05	1.06 ± 0.11	1.26 ± 0.05	1.12 ± 0.08						
Opposite Foot Off (%)	CG	9.03 ± 1.23	9.03 ± 1.23	11.28 ± 1.18	11.28 ± 1.18	p = **0.006** F = 9.4 Eta = 0.309	p = 0.882 F = 0.023 Eta = 0.001	p = 0.882 F = 0.023 Eta = 0.001	p = **0.000** F = 22.083 Eta = 0.513	p = 0.13 F = 2.482 Eta = 0.106	p = 0.961 F = 0.002 Eta = 0.000
	FFG	12.34 ± 2.04	11.49 ± 1.83	12.13 ± 1.25	12.31 ± 4.68						
Opposite Foot Contact (%)	CG	50.14 ± 1.42	50.14 ± 1.42	49.83 ± 1.37	49.83 ± 1.37	p = 0.921 F = 0.01 Eta = 0.000	p = 0.411 F = 0.703 Eta = 0.032	p = 0.411 F = 0.703 Eta = 0.032	p = 0.664 F = 0.194 Eta = 0.009	p = 0.492 F = 0.489 Eta = 0.023	p = 0.154 F = 2.188 Eta = 0.094
	FFG	51.18 ± 2.50	49.18 ± 1.74	48.67 ± 1.53	49.01 ± 1.33						
Step Time (s)	CG	0.58 ± 0.05	0.58 ± 0.05	0.55 ± 0.04	0.55 ± 0.04	p = 0.391 F = 0.768 Eta = 0.035	p = 0.591 F = 0.298 Eta = 0.014	p = 0.591 F = 0.298 Eta = 0.014	p = 0.689 F = 0.164 Eta = 0.008	p = 0.052 F = 4.241 Eta = 0.168	p = 0.685 F = 0.169 Eta = 0.008
	FFG	0.55 ± 0.03	0.52 ± 0.06	0.56 ± 0.04	0.55 ± 0.06						
Single Support (s)	CG	0.46 ± 0.04	0.46 ± 0.04	0.43 ± 0.02	0.43 ± 0.02	p = **0.006** F = 9.262 Eta = 0.306	p = **0.038** F = 4.882 Eta = 0.189	p = **0.038** F = 4 .882 Eta = 0.189	p = **0.003** F = 11.245 Eta = 0.349	p = 0.22 F = 1.599 Eta = 0.071	p = 0.237 F = 1.483 Eta = 0.066
	FFG	0.42 ± 0.02	0.40 ± 0.03	0.41 ± 0.02	0.37 ± 0.09						
Double Support (s)	CG	0.21 ± 0.04	0.21 ± 0.04	0.25 ± 0.03	0.25 ± 0.03	p = 0.134 F = 2.428 Eta = 0.104	p = 0.881 F = 0.023 Eta = 0.001	p = 0.881 F = 0.023 Eta = 0.001	p = **0.000** F = 25.246 Eta = 0.546	p = 0.689 F = 0.165 Eta = 0.008	p = 0.748 F = 0.106 Eta = 0.005
	FFG	0.24 ± 0.03	0.24 ± 0.07	0.28 ± 0.03	0.26 ± 0.08						
Foot Off (%)	CG	59.55 ± 1.73	59.55 ± 1.73	61.75 ± 1.05	61.75 ± 1.05	p = **0.016** F = 6.907 Eta = 0.248	p = 0.361 F = 0.874 Eta = 0.04	p = 0.361 F = 0.874 Eta = 0.04	p = **0.000** F = 69.462 Eta = 0.768	p = 0.602 F = 0.281 Eta = 0.013	p = 0.667 F = 0.191 Eta = 0.009
	FFG	60.54 ± 1.44	61.45 ± 2.69	62.95 ± .98	63.79 ± 2.72						
Stride Length (m)	CG	1.29 ± 0.09	1.29 ± 0.09	1.38 ± 0.07	1.38 ± 0.07	p = 0.341 F = 0.948 Eta = 0.043	p = 0.095 F = 3.062 Eta = 0.127	p = 0.095 F = 3.062 Eta = 0.127	p = **0.000** F = 20.368 Eta = 0.492	p = 0.765 F = 0.091 Eta = 0.004	p = **0.007** F = 9.073 Eta = 0.302
	FFG	1.22 ± 0.04	1.31 ± 0.09	1.34 ± 0.09	1.32 ± 0.09						
Step Length (m)	CG	0.66 ± 0.04	0.66 ± 0.04	0.70 ± 0.04	0.70 ± 0.04	p = 0.227 F = 1.547 Eta = 0.069	p = 0.06 F = 3.955 Eta = 0.158	p = 0.06 F = 3.955 Eta = 0.158	p = **0.000** F = 32.458 Eta = 0.607	p = 0.46 F = 0.566 Eta = 0.026	p = **0.000** F = 17.569 Eta = 0.456
	FFG	0.61 ± 0.03	0.67 ± 0.05	0.67 ± 0.04	0.66 ± 0.06						
Walking Speed (m/s)	CG	1.14 ± 0.16	1.14 ± 0.16	1.22 ± 0.10	1.22 ± 0.10	p = 0.994 F = 0.000 Eta = 0.000	p = 0.137 F = 2.387 Eta = 0.102	p = 0.137 F = 2.387 Eta = 0.102	p = 0.069 F = 3.664 Eta = 0.149	p = 0.177 F = 1.952 Eta = 0.085	p = **0.038** F = 4.905 Eta = 0.189
	FFG	1.11 ± 0.09	1.24 ± 0.22	1.20 ± 0.11	1.19 ± 0.12						
Stance Time (s)	CG	0.68 ± 0.07	0.68 ± 0.07	0.67 ± 0.04	0.67 ± 0.04	p = 0.548 F = 0.374 Eta = 0.017	p = 0.295 F = 1.153 Eta = 0.052	p = 0.295 F = 1.153 Eta = 0.052	p = 0.404 F = 0.727 Eta = 0.033	p = 0.315 F = 1.058 Eta = 0.048	p = 0.458 F = 0.572 Eta = 0.027
	FFG	0.67 ± 0.04	0.64 ± 0.08	0.69 ± 0.04	0.60 ± 0.16						

Note: values are presented as mean ± SD. F: *F*-statistic; *p*: *p*-value; Eta: partial eta squared (effect size). Bold values indicate statistically significant effects ($p < 0.05$). CG: Control Group; FFG: Flat-Foot Group; NG: Normal Gait; PNG: Post-Normal Gait; SH: Shoes; PSH: Post-Shoes.

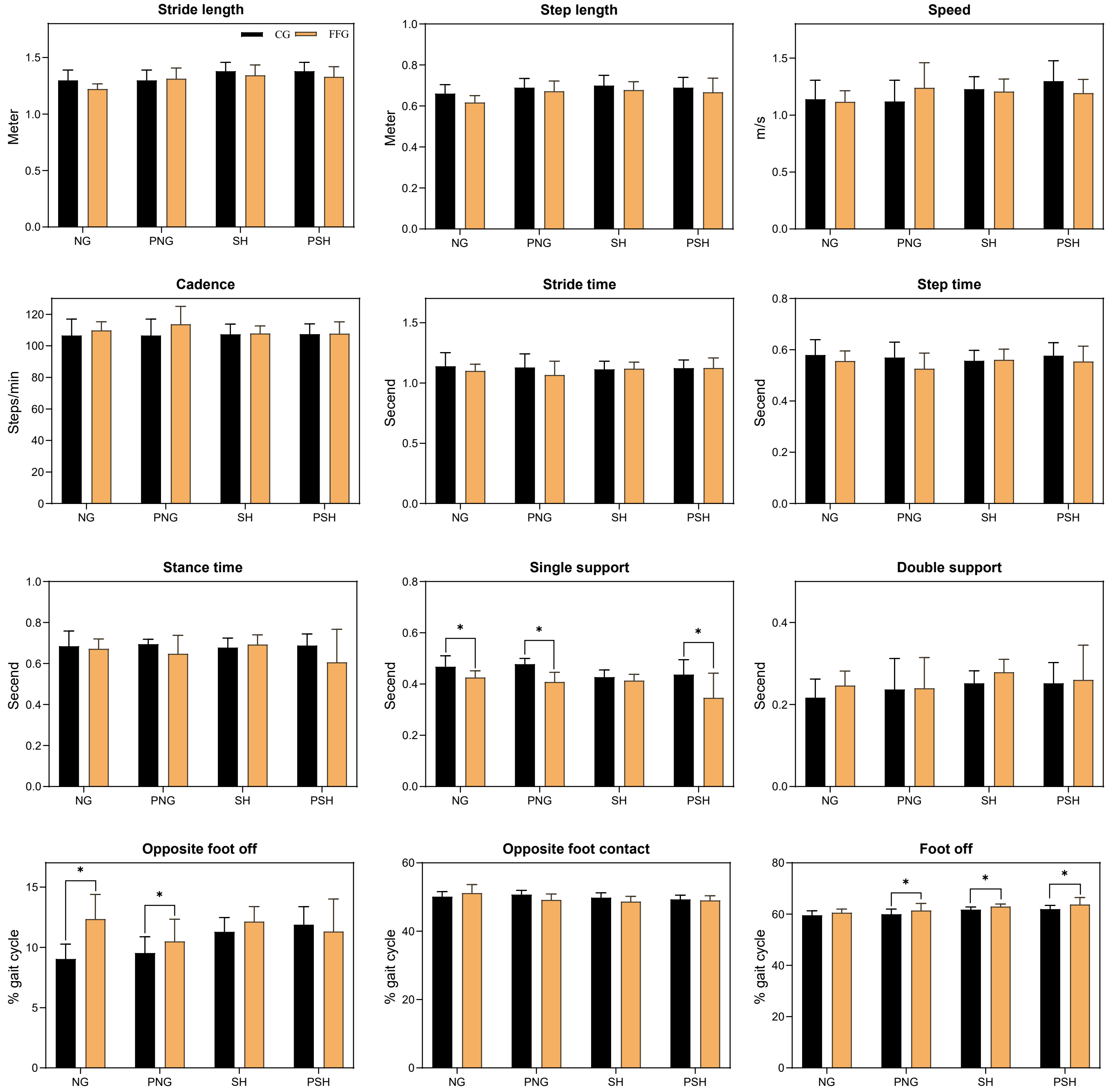

Fig. Comparison of spatiotemporal gait parameters between groups.

Values are presented as mean ± standard deviation for stride length, step length, speed, cadence, stride time, step time, stance time, single support, double support, opposite foot off, opposite foot contact, and foot off.

Note: * — significant differences between groups.

Рис. Сравнение пространственно-временных параметров ходьбы между группами.

Значения представлены как среднее ± стандартное отклонение для длины шага, длины полушага, скорости, каданса, времени шага, времени полушага, времени опоры, одноопорной и двуопорной фаз, момента отрыва противоположной стопы, момента контакта противоположной стопы и отрыва стопы.

Примечание: *— значимые различия между группами.

consistent across groups. In contrast, opposite foot contact, step time, and stance time revealed no significant changes (all $p > 0.05$), indicating their stability across conditions. Overall, these results suggest that anti-pronation insoles modify key temporal variables related to balance and phase timing (Fig.).

4. Discussion

This study aimed to evaluate the immediate and long-term effects of anti-pronation insoles on spatiotemporal gait parameters in individuals with flexible flatfoot [27]. The findings demonstrated that this non-invasive intervention improved specific aspects of gait, particularly stance phase timing and step length. Notably, individuals in the FFG demonstrated a reduction in single support duration and an increase in double support time when using insoles. Rather than indicating enhanced dynamic stability, these changes are more consistent with the adoption of a conservative stability strategy, whereby participants allocated more time to double support to ensure safe weight transfer and maintain balance. Such adaptations have been reported in previous studies, where orthotic interventions initially promote cautious gait adjustments before long-term neuromuscular adaptations emerge. These results are consistent with evidence suggesting that prolonged double support reflects a compensatory mechanism often observed in populations with balance impairments [27, 28]. At baseline, the FFG exhibited longer initial double support durations and shorter single support times compared to the CG. These gait abnormalities are likely related to medial arch collapse and excessive pronation, which can disrupt proprioceptive input and postural control [29, 30]. After insole use—particularly following the six-week intervention—although single support remained relatively reduced, the overall distribution of stance phases shifted toward values observed in the CG. This suggests that medial arch support plays a role in mitigating mechanical instability and gradually improving neuromuscular coordination.

Another key finding was the significant post-intervention increase in step and stride length in the FFG. While baseline values were only slightly lower than those of the CG, improvements after six weeks suggest enhanced push-off mechanics and greater confidence in forward weight transfer [31, 32]. Biomechanically, anti-pronation insoles may help normalize foot-ground contact by limiting excessive pronation and maintaining arch integrity. This mechanical support likely reduces stress on weakened soft tissue structures—such as the spring ligament—and allows key stabilizing muscles like the tibialis posterior to function more effectively [20]. Increases in single support time and step length in the FFG support this interpretation. These results are in line with those reported by Peng et al [33], who observed increased step length following arch support intervention, and Zifchock et al [34], who found that semi-rigid orthoses redistributed plantar pressure in individuals with collapsed arches. However, not all studies have reported significant benefits. For example, Chen et al [5], found no notable differences between walking with shoes alone versus shoes with orthoses, suggesting that a longer adaptation period may be required for biomechanical effects to become evident. The current findings support this perspective, as several improvements in the FFG reached significance only after the six-week intervention.

Another important finding was the significant increase in opposite foot off percentage with insole use. This indicates that the timing of contralateral toe-off was shifted forward, reflecting improved inter-limb coordination during the stance-to-swing transition. Previous studies have highlighted that altered contralateral toe-off timing is a marker of instability in flatfoot gait [7, 35]. The observed improvement in this variable suggests that anti-pronation insoles may help restore more physiologically normal timing of limb alternation, thereby enhancing gait symmetry. While this study adds to the growing body of evidence supporting corrective orthoses for flexible flatfoot, its findings should be interpreted in light of several limitations. The sample size was relatively small (n = 12 per group), and all participants were young adults. Results may not generalize to older populations or to dynamic tasks such as running. Furthermore, the study focused exclusively on spatiotemporal parameters; future research should incorporate joint kinematics and kinetics for a more comprehensive biomechanical assessment. Nonetheless, a key strength of this study lies in its longitudinal design, which enabled the observation of both immediate and adaptive changes over time. The findings suggest that anti-pronation insoles can enhance gait stability and mechanics in individuals with flexible flatfoot, even if speed and cadence remain unaffected. Clinically, these results underscore the value of orthoses in improving gait quality rather than performance, and practitioners should set realistic expectations when prescribing such interventions. Future studies may benefit from incorporating patient-reported outcomes, such as comfort and quality of life, to complement objective gait measures.

5. Conclusion

This study shows that anti-pronation insoles improve gait quality in young adults with flexible flatfoot, as reflected by reduced double support time and increased step length, without affecting walking speed or cadence. These short-term improvements were maintained after six weeks of use, with spatiotemporal gait patterns becoming more comparable to those of individuals with normal foot posture. Overall, the findings support anti-pronation insoles as an effective conservative intervention for enhancing gait stability in flexible flatfoot.

Authors contribution:

Negin Soltani — software, data curation, resources.

Mahdi Majlesi — writing — original draft, writing — review & editing, validation, supervision, methodology, conceptualization.

Ali Fatahi — methodology, project administration, writing– original draft, writing — review & editing.

Вклад авторов

Негин Солтани — программное обеспечение, сбор и обработка данных, ресурсы.

Махди Маджлеси — написание первоначальной рукописи, написание, обзор и редактирование, валидация, научное руководство, методология, концептуализация.

Али Фатахи — методология, администрирование проекта, написание — первоначальный вариант, написание — обзор и редактирование.

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