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Diurnal variations in gait parameters among older adults with early-stage knee osteoarthritis: insights from wearable sensor technology

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Knee osteoarthritis (KOA) significantly impairs mobility in older adults. Understanding its impact on gait dynamics throughout the day is crucial for optimizing management strategies. This study aimed to explore diurnal variations in gait parameters among older adults with KOA using an in-shoe motion sensor (IMS) system equipped with accelerometers and gyroscopes. In this cross-sectional observational study, 19 older adults clinically diagnosed with early-stage KOA (Kellgren–Lawrence grades 1 or 2) participated. Key gait parameters were measured using an IMS system during morning (6:00 AM–11:59 AM) and afternoon (12:00 PM–5:00 PM) sessions. The IMS, placed bilaterally in the participants' shoes, continuously collected gait data during normal daily activities over a 24-hour period. Participants were instructed to walk for at least 10 min in each session. Data were analyzed using descriptive statistics, and paired t-tests or Wilcoxon signed-rank tests were applied to identify significant differences between sessions. Statistical significance was set at $p < 0.05$. The study included 19 participants (11 females, 8 males) with an average age of 71.4 ± 4.2 years. Walking speed decreased significantly from 1.06 ± 0.14 m/s in the morning to 0.99 ± 0.16 m/s in the afternoon ($p = 0.028$). Similarly, the maximum dorsiflexion angle decreased from 20.34° ± 2.98° to 18.80° ± 3.01° ($p = 0.024$), and the maximum plantar flexion angle decreased from 63.40° ± 5.84° to 60.79° ± 5.77° ($p = 0.017$) in the afternoon. Other parameters such as foot height, peak swing angular velocity, and maximum speed during the swing phase also showed significant reductions in the afternoon. Conversely, the roll angle of heel contact increased from 4.60° ± 2.62° to 5.53° ± 3.12° ($p = 0.026$), and stance time and pushing time increased significantly in the afternoon. Significant diurnal variations in gait parameters among older adults with KOA highlight the importance of considering time of day when evaluating gait and planning interventions. Wearable sensor technology enables continuous, objective gait monitoring in real-world settings, facilitating personalized and time-sensitive approaches for managing KOA.

Keywords Knee osteoarthritis, Older adults, In-shoe motion sensor, Wearable sensor technology, Gait parameters, Diurnal variations

Osteoarthritis (OA) is a prevalent multifactorial chronic condition that affects joints and its tissues[1]. OA affects approximately 7% (over 500 million individuals) of the global population[2,3]. Among the susceptible joints, the knee, hand, and hip joints are particularly prone to developing OA[4]. The disease is particularly disabling when the knees are affected. Knee OA (KOA) accounts for almost four-fifths of the global burden of OA[5]. Global estimates suggest that 9.6% of men and 18.0% of women aged 60 years and older experience symptomatic OA[6]. Various factors, such as advanced age, prior knee injuries, high body mass index (BMI), female sex, genetic predisposition, sedentary lifestyle, repetitive movements, participation in high-impact sports, joint misalignment, and instability significantly increase the risk of KOA development[7,8]. Clinical manifestations of OA encompass joint functional limitations, stiffness, pain, swelling, joint deformity, and difficulties in walking or running, and probably other symptoms[1,9,10].

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Walking ability serves as a crucial indicator of overall health and reflects an individual's functional capacity for daily activities. It has also been proposed to be a 'vital sign'[11,12]. Recent research has established significant correlations between various walking parameters such as gait speed and sedentary time and important health outcomes including mortality, morbidity, and quality of life[13,14]. Parameters, such as speed and other spatiotemporal aspects, are pivotal for characterizing gait under a wide range of pathological conditions. In patients with KOA, pain often leads to compensatory mechanisms aimed at minimizing joint loading and resultant discomfort[15]. KOA can limit walking tolerance, leading to subsequent health consequences[16,17]. Compared to individuals without KOA, those with KOA exhibit distinct gait characteristics, including smaller knee extension excursion and moment, larger knee flexion excursion and moment, and larger knee adduction excursion and moment when walking at self-selected gait speeds[15,18,19]. Furthermore, temporal- and distance-related gait factors, including velocity, cadence, and stride length, are frequently diminished in KOA[20,21]. Additionally, parameters such as stance phase flexion–extension, peak vertical ground-reaction forces, and loading rates are notably reduced in patients with KOA[22–24]. Meanwhile, stride and double support times were increased in patients with OA[21].

A deeper understanding of gait is important to quantify the pathomechanics of patients with KOA. In general, noninvasive gait data on KOA in the literature have been obtained from specialized gait laboratories equipped with camera-based motion capture systems and force plates integrated into the floor[25]. However, this conventional gait analysis method requires specialized locomotion facilities as well as expensive equipment, setup, and post-processing. Furthermore, the moving area and gait cycles of the observed patients have limitations[26,27]. Recent technological advancements have ushered in the development of reliable and cost-effective wearable sensors for gait analysis, facilitating their application beyond laboratory confines and during routine activities, thereby offering objective insights into individual gait patterns[28]. A real-world gait analysis can enhance clinical assessments and influence associated interventions regardless of laboratory environmental constraints.

When assessing gait parameters across individuals, researchers and clinicians need to consider the reliability and influence of diurnal variation, which refers to changes that occur throughout the day, on the outcomes being assessed. Circadian rhythms influence physical, mental, and behavioral changes, including the regulation of alertness and fatigue[29]. Moreover, they affect various physiological processes and cognitive and motor functioning[30–33]. In addition to circadian rhythms, extrinsic factors that interact with the time of day, such as fatigue, exercise, mood, sleep, and food intake, also influence cognitive and motor function[33], collectively contributing to diurnal rhythm. As cognitive and motor functions are integral to postural control and gait[33–36], time of day may also affect gait. Evidence supports diurnal variations in lower limb muscle contractility and fatigability[37], postural control[38], and gait parameters such as walking speed and stride length during short-duration treadmill walking near the walk–run transition speed in healthy young adults[39]. Conversely, another study observed that healthy young adults did not exhibit diurnal variations in stride time variability outcomes during continuous, over ground walking[40]. Additionally, analysis of the spatial and temporal variables of footstep patterns revealed that patients with multiple sclerosis (MS) exhibited a symmetric, short-stepped, slow gait with minimal variability in performance from the morning to afternoon. The finding that self-rated fatigue significantly increased from the morning to afternoon, while walking patterns remained consistent, suggests that the mechanisms governing locomotion differ from those that regulate perceived fatigue[41].

Analyzing gait offers crucial insights into the impact of ambulatory biomechanics on OA progression and aids in crafting effective therapeutic strategies. The aim of this study is to explore diurnal variations in daily life gait patterns of individuals with early KOA using an in-shoe motion sensor system (IMS), focusing on how gait characteristics vary between morning and afternoon sessions.

Materials and methods

Study design

This was a cross-sectional observational study designed to investigate diurnal variations in gait parameters among older adults with early-stage KOA.

Participants

A total of 30 older Japanese adults were recruited for this study between September 1 and September 19, 2023. Participants were recruited through a recruiting firm that engaged with the local community in Kyoto, Japan. The inclusion criteria for the study were as follows: participants had to be aged 60 years or older and have a clinical diagnosis of early-stage KOA, defined as Kellgren–Lawrence (KL) grades 1 or 2, confirmed through weight-bearing bilateral knee radiographs in accordance with the European League Against Rheumatism (EULAR) criteria[42,43]. Additionally, participants needed to have the ability to walk outdoors independently without the use of assistive devices and to sustain continuous walking for at least 6 min without requiring rest. Furthermore, daily use of smartphones was required to facilitate data synchronization.

The exclusion criteria for the study were as follows: individuals with cognitive impairments or an inability to provide informed consent. Participants with a history of other musculoskeletal or neurological disorders that could affect gait, as well as those who had undergone prior lower limb surgery, were also excluded. Additionally, individuals with cardiac or respiratory conditions that limited physical activity or those reliant on walking aids were not eligible to participate in the study.

Out of 30 volunteers, 11 were excluded due to meeting exclusion criteria or inability to complete the study protocol, resulting in a final sample of 19 participants (11 females, 8 males). The majority of participants had bilateral KOA; unilateral involvement was present in two participants.

Ethics statement

Approval: This study was approved by the Medical Ethics Committee of Kyoto University, Japan (approval number: R3664-3).

Accordance: This study was conducted in accordance with ethical standards and guidelines.

Consent: Written informed consent was obtained from all participants prior to study initiation.

Equipment

Measurements were performed using the IMS (A-RROWG, NEC Corporation, Tokyo, Japan)[44]. The IMS is a device used for gait analysis and is powered by an ARM Cortex-M4F MCU (nRF52832) from Nordic Semiconductor, featuring a 64-MHz CPU, 64-KB RAM, and 512-KB ROM. The IMS consists of an inertial measurement unit (IMU) incorporating a triaxial accelerometer and gyroscope (Bosch BMI160) for precise motion tracking. The accelerometer has a full-scale measurement range of ±16 g with a sensitivity of approximately 0.488 mg/LSB, while the rate gyroscope has a full-scale range of ±2000°/s with a sensitivity of approximately 0.061°/s/LSB. The device is powered by an ARM Cortex-M4F microcontroller and includes data storage and real-time clock capabilities. The IMS was mounted bilaterally on custom insoles placed under the foot arch to minimize discomfort. The sampling rates were 3.125 and 100 Hz in the standby mode and during measurement, respectively. Measurements were conducted from 6:00 AM to 10:00 PM at 2-minute intervals, during which the IMS actively collected data for the first minute before entering the power-saving sleep mode. In the active phase, vibration detection and stable walking discrimination were performed to measure the walking parameters for three steps within the ensuing 9 s, and the average value was recorded if detection was successful. Stable-gait identification involves determining whether the detected motion is consistent with level walking. The device monitors repetitive walking patterns by counting the number of instances in which posterior acceleration exceeds 3.5 g, a threshold typically observed during foot contact in normal walking. If this threshold is reached three times within a 5-second window, the device confirms stable walking and proceeds to measure gait parameters over the subsequent 9 s. Activities such as ascending or descending stairs, walking on uneven terrain, or frequent directional changes generally do not produce these stable repetitive acceleration patterns and are therefore automatically filtered out by the system's algorithm[44]. If fewer than two steps were measured, then the attempt was considered a failure. Up to three measurement attempts were allowed per minute; if all attempts failed, no data were recorded for that interval. The device calculates 16 vital gait parameters as follows: walking speed, stride length, maximum (peak) dorsiflexion angle, maximum (peak) plantar flexion angle, foot height, Lateral foot displacement, toe-in/toe-out angle, roll angle of heel contact, roll angle of toe-off, cadence, stance time, swing time, pushing time, peak swing angular velocity, maximum speed during the swing phase, and foot clearance. These parameters have either been validated for accuracy in previous studies or have been calculated from validated parameters[44–46]. Table 1 presents the definition of each parameter disclosed by the NEC Corporation.

Procedure

The data collection took place from 1st September to 19th September 2023. On the first day, participants were visited at Kyoto University, Japan, where anthropometric measurements were conducted and they were introduced to the IMS-equipped insoles. Participants who donned their everyday attire and comfortable walking shoes had their demographic and physical measurements (height, weight, and foot size) taken before the insertion of the IMS-equipped insoles. To prevent discomfort while walking, the IMS was mounted on an insole placed under the foot arch. A 5-meter gait confirmed that the patient had no difficulty or pain during gait. The protocol required participants to engage in normal daily activities for a minimum of 24 h, exclusively

Parameters	Definition	Units
Walking speed	Stride length divided by stride time	m/s
Stride length	Distance between successive points of initial contact of the same foot	cm
Maximum dorsiflexion direction angle	peak foot-sole angle in the dorsiflexion direction	degrees (°)
Maximum plantar flexion angle	peak foot-sole angle in the plantarflexion direction	degrees (°)
Foot height	Maximum vertical height of the foot during the swing phase	cm
Lateral foot displacement	Displacement of the foot in the medial-lateral direction during the swing phase	cm
Toe-in/toe-out angle	Average foot adduction/abduction angle during the swing phase	degrees (°)
Roll angle of heel contact	Angle of the foot about the longitudinal axis at heel contact	degrees (°)
Roll angle of toe-off	Angle of the foot about the longitudinal axis at toe-off	degrees (°)
Cadence	Number of steps per minute	steps/min
Stance time	Duration the foot is in contact with the ground during the gait cycle	seconds (s)
Swing time	Duration the foot is not in contact with the ground during the gait cycle	seconds (s)
Pushing time	Time from heel-off to toe-off during stance phase	seconds (s)
Peak swing angular velocity	Peak angular velocity of the foot during the swing phase	degrees/second
Maximum speed during swing phase	Maximum forward speed of the foot during the swing phase	m/s
Foot clearance	Minimum vertical distance between the foot and ground during swing phase	cm

Table 1. Definition of the parameters.

wearing the IMS outdoors and carrying a smartphone for data collection. Participants were instructed to walk for more than 10 min in each of the morning and afternoon sessions. Specific care instructions were provided to prevent damage to the IMS from water exposure. Gait data were collected using IMS placed in both the left and right shoes. Data were collected in the morning (6:00 AM–11:59 AM) and afternoon (12:00 PM–5:00 PM) sessions to accurately reflect the variance in daily gait behaviors. This timeframe was selected to ensure consistency across participants and to account for practical considerations related to participant schedules and data quality. The number of attempts recorded varied across participants and between morning and afternoon sessions, reflecting natural differences in daily activity patterns. This variability is expected in real-world settings where daily routines differ among individuals, influencing the frequency of stable walking attempts captured by the IMS.

Data analysis

The analysis commenced with a rigorous data-cleaning phase in which outliers were identified and excluded using the interquartile range method, with particular emphasis on the walking speed parameter to maintain data fidelity. Subsequent segmentation delineated the data into morning (6:00 AM–11:59 AM) and afternoon (12:00 PM–5:00 PM) sessions, facilitating a temporal comparison of the gait metrics. Data from both limbs were used in analysis. Descriptive statistics, including mean, standard deviation (SD), and range, were computed for each time segment to encapsulate the variability and central tendency of the gait parameters. Statistical integrity was further ensured through normality assessments for each parameter, guiding the use of either t-tests or Wilcoxon signed-rank tests, based on distribution characteristics, to ascertain significant temporal variations in gait dynamics. All statistical analyses were conducted using SPSS version 27 with a significance threshold of $p < 0.05$. Given the exploratory nature of this study, corrections for multiple comparisons (e.g., Bonferroni correction) were not applied to avoid an increased risk of Type II errors, which could obscure potentially meaningful findings.

Results

Table 2 presents the details of participant demographics and KOA severity. This study included 19 participants with an average age of 71.42 years (SD = 4.15). The average weight and height of the participants were 58.89 kg (SD = 10.62) and 1.55 m (SD = 0.12), respectively, resulting in a mean BMI of 24.37 (SD = 1.34). The sex distribution was relatively balanced, with 57.89% of the participants being female ($n = 11$) and 42.11% being male ($n = 8$). The average NRS pain score among participants was 2.34 ± 1.42, with a range from 0 to 5. The median score was 2.0, indicating mild to moderate pain levels in this cohort. The severity of KOA was classified using the Kellgren–Lawrence grade, showing a distribution of 5.26% in grade 0 ($n = 2$), 52.63% in grade 1 ($n = 20$), 42.11% in grade 2 ($n = 16$).

In our study, we observed significant variations in gait parameters between the morning and afternoon sessions among older adults with KOA. Table 3 presents the comparison of gait parameters between morning and afternoon sessions. Walking speed decreased from an average of 1.06 (0.14) m/s in the morning to 0.99 (0.16) m/s in the afternoon ($p = 0.028$). The maximum dorsiflexion angle reduced from 20.34° ± 3.82° to 18.80° ± 4.35° ($p = 0.024$), and the maximum plantar flexion angle decreased from 63.40° ± 5.66° to 60.79° ± 6.98° ($p = 0.017$). Foot height slightly decreased from 12.99 ± 1.34 cm to 12.39 ± 1.63 cm ($p = 0.029$). The roll angle of heel contact increased from 4.60° ± 3.62° to 5.53° ± 3.41° ($p = 0.026$). Cadence decreased from 115.64 ± 10.2 steps/min to 112.40 ± 11.1 steps/min ($p = 0.018$). Stance time increased from 0.65 ± 0.05 s to 0.68 ± 0.06 s ($p = 0.003$). Pushing time increased from 0.211 ± 0.03 s to 0.229 ± 0.04 s ($p = 0.002$). The peak swing angular velocity and maximum speed during the swinging phase were reduced, with p-values of 0.006 and 0.023, respectively. Figure 1 shows the distribution of several key gait parameters that varied significantly between the time segments.

Characteristics		Mean (SD)
Age		71.42 (4.15)
Weight (kg)		58.89 (10.62)
Height (m)		1.55 (0.12)
BMI (Kg/m^3)		24.37 (1.34)
NRS Pain Score		2.34 (1.42)
		Count (%)
Sex	Female	11 (57.89%)
	Male	8 (42.11%)
KOA severity	KL grade 0	2.0 (5.26%)
	KL grade 1	20.0 (52.63%)
	KL grade 2	16.0 (42.11%)

Table 2. Summary of participant demographics and knee osteoarthritis severity. SD, standard deviation; BMI, body mass index; NRS, Numeric Rating Scale; KOA, knee osteoarthritis; KL, Kellgren–Lawrence grade. The KL grade 0 classification corresponds to the unaffected limbs of the two participants with unilateral KOA included in the final analysis.

Parameters	Morning mean (SD)	Afternoon mean (SD)	Significance (*p*-value)	Effect size (Cohen's d/effect size *r*)
Walking speed	1.06 (0.14) m/s	0.99 (0.16) m/s	0.028*	0.57
Stride length	109.69 (8.3) cm	104.76 (9.4) cm	0.064	0.45
Maximum dorsiflexion angle	20.34° (3.82)	18.80° (4.35)	0.024*	0.38
Maximum plantar flexion angle	63.40° (5.66)	60.79° (6.98)	0.017*	0.41
Foot height	12.99 (1.34) cm	12.39 (1.63) cm	0.029*	0.40
Lateral foot displacement	3.94 (1.33) cm	3.75 (0.98) cm	0.418	0.19
Toe-in/toe-out angle	15.51° (7.9)	15.97° (8.2)	0.398	-0.06
Roll angle of heel contact	4.60° (3.60)	5.53° (3.41)	0.026*	0.51
Roll angle of toe-off	−2.20° (5.49)	−1.92° (4.48)	0.461	-0.06
Cadence	115.64 (10.2) steps/min	112.40 (11.1) steps/min	0.018*	0.54
Stance time	0.65 (0.05) s	0.68 (0.06) s	< 0.01**	-0.45
Swing time	0.398 (0.02) s	0.400 (0.02) s	0.570	-0.01
Pushing time	0.211 (0.03) s	0.229 (0.04) s	< 0.01**	-0.53
Peak swing angular velocity	485.08°/s (57.79)	452.89°/s (48.87)	< 0.01**	0.63
Maximum speed during swinging phase	3.50 m/s (0.27)	3.32 m/s (0.33)	0.023*	0.57
Foot clearance	20.4 (1.66) cm	19.8 (2.24) cm	0.13	0.28

Table 3. Comparison of gait parameters between morning and afternoon sessions in participants with knee osteoarthritis. SD, standard deviation. *$p < 0.05$. **$p < 0.01$.

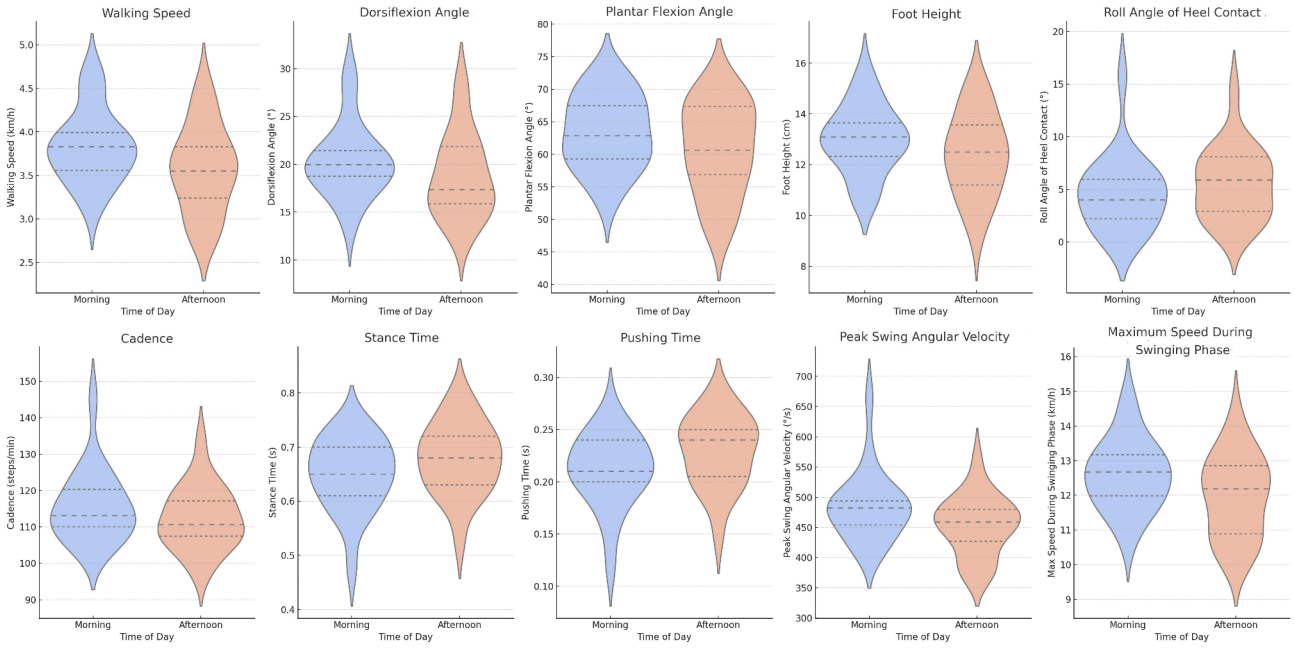

Fig. 1. The violin plots visualize the distribution of walking speeds, maximum dorsiflexion angle, maximum plantar flexion angle, foot height, roll angle of heel contact, cadence, stance time, pushing time, peak swing angular velocity and maximum speed during swinging phase of patients with knee osteoarthritis in the morning and afternoon sessions, providing insights into the data's distribution, mean values, variability, and comparison between different times of the day.

The other gait parameters examined did not indicate significant differences between the morning and afternoon sessions. Stride length changed from 109.69 ± 8.3 cm in the morning to 104.76 ± 9.4 cm in the afternoon ($p = 0.064$) . Lateral foot displacement slightly varied from 3.94 ± 1.33 cm to 3.75 ± 0.98 cm ($p = 0.418$) . Toe-in/toe-out angle experienced a minor adjustment from 15.51° ± 7.9° to 15.97° ± 8.2° ($p = 0.398$) . The roll angle of the toe-off shifted from − 2.20° ± 5.49° to − 1.92° ± 4.48° ($p = 0.461$) . Swing time changed from 0.39 ± 0.02 s to 0.40 ± 0.03 s ($p = 0.570$) . Lastly, foot clearance slightly changed from 20.4 ± 1.66 cm to 19.8 ± 2.24 cm ($p = 0.132$).

Discussion

This study investigated diurnal variations in gait parameters among older adults with early-stage KOA using wearable sensor technology during normal daily activities. Our findings revealed significant decreases in walking speed, maximum dorsiflexion and plantar flexion angles, foot height, peak swing angular velocity, and maximum speed during the swing phase from morning to afternoon. Additionally, increases in the roll angle of heel contact, stance time, and pushing time were observed in the afternoon. These results suggest that time of day influences gait patterns in individuals with KOA.

The observed decrease in walking speed of approximately 0.07 m/s from morning to afternoon, while statistically significant, represents a relatively small change. However, even modest reductions in walking speed can be clinically meaningful in older adults, as slower gait speed has been associated with increased risk of adverse health outcomes[13]. However, it is important to note that the observed changes in walking speed may also be partially attributed to differences in the types of activities performed during the morning and afternoon. For example, participants may have engaged in more physically demanding or rushed activities in the morning, while afternoon sessions could have been influenced by accumulated fatigue or more relaxed routines. Therefore, caution should be exercised in attributing these changes solely to diurnal effects, as both activity-related factors and environmental factors may have influenced the results. The decreases in maximum dorsiflexion and plantar flexion angles indicate reduced ankle range of motion in the afternoon, which may reflect fatigue or joint stiffness accumulating throughout the day[47].

The increase in stance time and pushing time suggests that participants spent more time in the stance phase and during push-off in the afternoon. Prolonged stance time may indicate a cautious gait pattern, possibly due to increased joint discomfort or fatigue[48]. The increased roll angle of heel contact could reflect alterations in foot placement strategies to compensate for knee discomfort.

These gait changes may be attributed to several factors. Diurnal fluctuations in pain and stiffness are common in KOA, with some patients experiencing worsening symptoms as the day progresses[49]. Fatigue accumulating from daily activities may also contribute to altered gait patterns in the afternoon[50]. Additionally, circadian rhythms can influence muscle strength and proprioception, potentially affecting gait[51].

Our findings align with previous research indicating that gait parameters can vary throughout the day in individuals with musculoskeletal conditions[41]. However, studies in healthy adults have shown inconsistent results regarding diurnal variations in gait, suggesting that such variations may be more pronounced in populations with underlying joint pathology[52].

It is important to consider whether the observed changes are clinically significant. While some changes, such as a 1.5° decrease in dorsiflexion angle, may seem small, they could cumulatively impact joint loading and mobility over time. Understanding these variations can inform the timing of gait assessments and interventions. For instance, while morning sessions, when gait is more stable, may enhance rehabilitation efficacy, training during symptom-prone periods can improve real-life functional capacity. A balanced approach, targeting both favorable and challenging times, may maximize therapeutic outcomes[53,54].

This study has several strengths that contribute to its scientific and clinical relevance. The use of wearable in-shoe motion sensors enabled continuous gait monitoring in real-world settings, enhancing ecological validity and providing insights into natural diurnal variations in gait parameters. By analyzing 16 distinct gait variables, including spatiotemporal and kinematic measures, the study offers a comprehensive assessment of gait dynamics in older adults with early-stage KOA. Additionally, the findings establish preliminary reference values for diurnal gait variations, which can serve as benchmarks for future research. As an exploratory investigation, this study lays the groundwork for future longitudinal studies and intervention trials aimed at understanding and optimizing gait performance in individuals with KOA. Several limitations should be acknowledged. The sample size was relatively small, which may limit the generalizability of the findings. The study population consisted of older adults with early-stage KOA; thus, results may not be applicable to those with advanced KOA. Additionally, we did not include a control group of age-matched individuals without KOA, which would help isolate the effects of KOA from age-related changes in gait. Furthermore, while BMI was not a controlled variable in this study, the BMI range of participants (21.5–26.5) suggests limited representation of individuals with higher BMI. Therefore, the potential influence of BMI on gait parameters should be considered when interpreting the results, particularly in relation to generalizability to populations with higher BMI. Another limitation is the grouping of unilateral and bilateral KOA participants, as these groups may exhibit distinct compensatory gait patterns that could introduce variability in the findings[55]. Finally, it is important to note that multiple comparisons were conducted across 16 dependent variables without applying corrections like the Bonferroni adjustment, which could increase the risk of Type I errors. Although we considered statistical corrections to control for familywise error rates, we chose not to apply them due to the exploratory nature of this study and the interrelatedness of gait parameters. Applying stringent corrections could increase the risk of Type II errors, potentially obscuring meaningful diurnal variations in gait characteristics. Nonetheless, we acknowledge this as a limitation, and future studies with larger sample sizes may benefit from implementing appropriate statistical adjustments to balance the risks of Type I and Type II errors.

Factors such as frailty and sarcopenia, common in older adults, could also influence gait parameters and diurnal variations[56,57]. While we collected data on KOA duration and pain levels, we did not assess muscle strength or fatigue objectively, which could provide further insights into the observed gait changes. Future studies with larger datasets should consider including a control group of age-matched individuals without KOA, distinguishing between unilateral and bilateral KOA participants, and adopting narrower time frames to provide more granular insights into diurnal gait variations.

Implications for KOA management

Understanding diurnal variations in gait parameters can inform the development of personalized management strategies for KOA. For example, interventions aimed at improving ankle mobility and strength may help mitigate the reductions in dorsiflexion and plantar flexion observed in the afternoon. Additionally, scheduling therapeutic exercises or activities during times of the day when gait patterns are more favorable could enhance intervention efficacy. While addressing functional limitations under less favorable conditions may improve the ability to function effectively during daily activities when they are most challenged. Wearable sensors provide valuable feedback that can guide these personalized approaches.

Conclusions

This study demonstrated significant diurnal variations in gait parameters among older adults with early-stage KOA, highlighting the influence of time of day on gait patterns in this population. The findings highlight the importance of considering diurnal variations when evaluating gait and planning interventions for individuals with KOA. Wearable sensor technology offers a valuable tool for capturing real-world gait data, facilitating personalized and time-sensitive approaches to KOA management.

Data availability

The data set used during the current study is available from the corresponding author upon reasonable request.

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Declarations

Competing interests

The authors declare no competing interests.

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