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Research Article

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Walking Asymmetry in Parkinson's Disease Requires Multi-Layered Interpretation: A Longitudinal Single-Subject Analysis Using Apple Health Data

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Abstract

Background: *Consumer-device gait metrics offer a promising means of continuously monitoring Parkinsonian gait in daily life. However, interpretation of algorithm-derived parameters such as walking asymmetry remains difficult because the absence of a recorded value may reflect either the absence of measurable asymmetry or failure of the walking episode to satisfy algorithmic recording conditions. In addition, our recent work has shown that Apple HealthKit-based digital phenotyping can detect pharmacological interference in Parkinsonian gait, demonstrating that this platform is useful not only for long-term monitoring but also for objective assessment of treatment-related motor deterioration. Objective: To re-evaluate the meaning of walking asymmetry data in Parkinson's disease (PD) by separating the signal into three components: non-zero asymmetry values, days without measurable asymmetry, and zero-valued asymmetry events. Methods: A 77-year-old man with PD was monitored longitudinally using Apple Health data collected by iPhone during daily life. Raw XML files were examined directly to extract walking asymmetry, walking speed, step count, double-support percentage, and walking steadiness. Because asymmetry values of 0 were not retained in standard Auto Export output, XML-level analysis was required. Detailed analyses focused on October-December 2024 and October-December 2025, spanning the period before and after recurrent falls in November-December 2025.*

Results: *Walking asymmetry could not be interpreted as a single continuous variable. Instead, three distinct signals emerged. First, non-zero asymmetry values were observed, but their frequency markedly decreased in 2025 compared with 2024. Second, days without measurable asymmetry became more common during the fall-prone period, particularly in November 2025. Third, zero-valued asymmetry events, which were frequent in 2024, markedly decreased in 2025. Step count analysis showed that lack of asymmetry data was not explained solely by absence of walking; rather, in the more impaired state, greater walking volume was often required for asymmetry to be recorded. Walking steadiness showed only limited change during the fall-prone months, likely because this composite metric incorporates walking speed, step length, double-support percentage, and asymmetry, thereby attenuating the specific contribution of instability-related asymmetry changes.*

Conclusion: *In PD, Apple Health walking asymmetry should not be treated as a single metric. Its interpretation requires simultaneous consideration of non-zero asymmetry values, days without recorded asymmetry, and the frequency of zero-valued events. This multi-layered approach may provide a more informative framework for evaluating unstable gait and emerging fall risk in daily life than conventional averaging of asymmetry values alone.*

Keywords: Parkinson's Disease, Gait Asymmetry, Digital Phenotyping, Apple Health kit, Fall Risk, Walking Steadiness

1. Introduction

Gait disturbance is one of the most disabling manifestations of Parkinson's disease (PD), contributing to reduced mobility, loss of independence, and increased fall risk. Yet clinical evaluation of gait remains largely dependent on brief observation and semi-quantitative rating scales, which cannot adequately capture daily fluctuation or gradual deterioration in real-world walking [1-3]. Smartphone-based passive monitoring offers an attractive alternative because gait-related variables can be collected continuously during ordinary daily activity. Apple Health provides several such measures, including walking speed, step length, step count, double-support time, walking asymmetry, and walking steadiness [4,5]. In our previous longitudinal analysis using Apple HealthKit data, walking speed, step length, and walking steadiness worsened from 2024 to 2025, consistent with clinical progression of PD [6]. We also showed in a separate report that the same Apple HealthKit-based framework could objectively identify short-term pharmacological interference in Parkinsonian gait, demonstrating marked deterioration in gait variability, asymmetry, and step length during rotigotine exposure and recovery after discontinuation [7]. These observations indicate that consumer-device digital phenotyping can detect both long-term disease progression and medication-related motor deterioration.

However, walking asymmetry behaved differently from the other gait parameters. During October-December 2025, when recurrent falls occurred, asymmetry values did not simply increase in parallel with worsening clinical instability. Instead, asymmetry values often became unavailable despite ongoing walking activity. This discrepancy suggested that conventional averaging of asymmetry values might be insufficient for interpreting Parkinsonian gait.

Re-examination of raw XML export files revealed that the asymmetry dataset contains at least three distinct types of information. The first is the familiar non-zero asymmetry value. The second is the absence of measurable asymmetry on a given day. The third is the presence of asymmetry records with a value of zero, which are not retained in standard Auto Export output and therefore may be overlooked unless XML files are examined directly. This observation fundamentally changed our interpretation of the metric. The present study therefore aimed to reinterpret walking asymmetry in PD not as a single value, but as a composite signal consisting of measurable asymmetry, non-recorded days, and zero-valued events. We further examined step count in parallel because days without asymmetry data could otherwise be attributed simply to lack of walking. Finally, we evaluated these observations together with double-support percentage and walking steadiness in order to better understand gait instability during the months surrounding recurrent falls.

2. Methods

2.1. Participant and Study Design

A 77-year-old man with PD was monitored longitudinally using Apple Health data collected during daily life. The broader observation period spanned January 2024 through December 2025, but the present analysis focused on October-December 2024 and October-December 2025 because these intervals allowed direct comparison across years and captured the period surrounding recurrent falls in November-December 2025. Falls occurred on November 3, 17, and 29 and December 8, 2025.

2.2. Data Sources and Preprocessing

Raw Apple Health XML export files were used as the primary data source. This choice was essential because standard Auto Export output did not retain walking asymmetry events with a value of 0, whereas XML-level data preserved these records. XML files were manually converted into Excel tables by separating fields and retaining the relevant columns, including startDate, endDate, and value. During the period analyzed here, the data used were derived from the iPhone source [8].

2.3. Gait Metrics

The primary metric of interest was walking asymmetry percentage. In XML export, this variable is stored as a decimal fraction rather than as a percentage display value, and 0 indicates a recorded event with no measurable asymmetry rather than missing data. On the basis of XML review, asymmetry data were separated into three components: (1) non-zero asymmetry values, (2) days without recorded asymmetry data, and (3) events with asymmetry value = 0. Step count was analyzed in parallel to determine whether lack of asymmetry data could be explained simply by insufficient walking activity. Double-support percentage and walking steadiness were also examined as related markers of gait stability [9].

2.4. Analytical Approach

The analysis proceeded in three steps. First, asymmetry values greater than 0 were tabulated and compared between 2024 and 2025. Second, days without asymmetry data were counted with simultaneous inspection of daily step count. Third, asymmetry events with a value of 0 were counted and compared across years. For October-December 2025, special attention was paid to temporal changes across the three months. October was examined as the pre-fall phase with increased measurable asymmetry, November as the peak fall month with more frequent non-recorded days, and December as the post-fall phase in which measurable asymmetry partially reappeared but zero-valued events remained reduced [10]. Because this study represents exploratory within-subject digital phenotyping, results were interpreted descriptively rather than as definitive threshold-based diagnostic claims.

3. Results

3.1. Overall Gait Changes

Walking speed and step length were lower in 2025 than in 2024, consistent with progressive deterioration in gait function. However, these parameters appeared to reflect quantitative slowing and shortening of gait more directly than the qualitative instability associated with falls. Double-support percentage showed only modest differences between 2024 and 2025 and did not exhibit a striking change across October-December 2025.

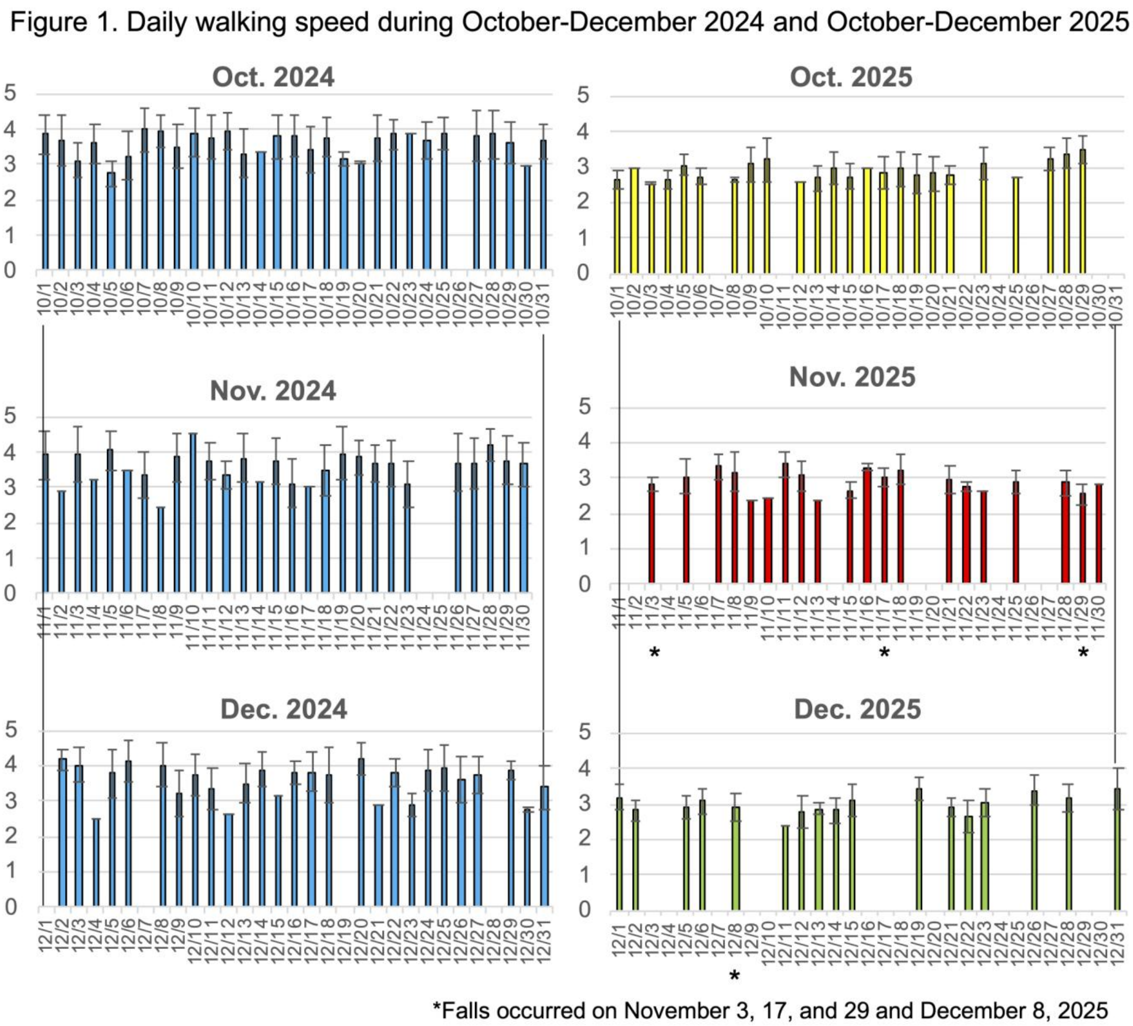


Figure 1: Daily Walking Speed During October-December 2024 and October-December 2025.

Walking Speed was Lower in 2025 than in 2024, Indicating Overall Slowing of Gait. However, the Monthly Pattern did not Clearly Predict Recurrent Falls in November-December 2025.

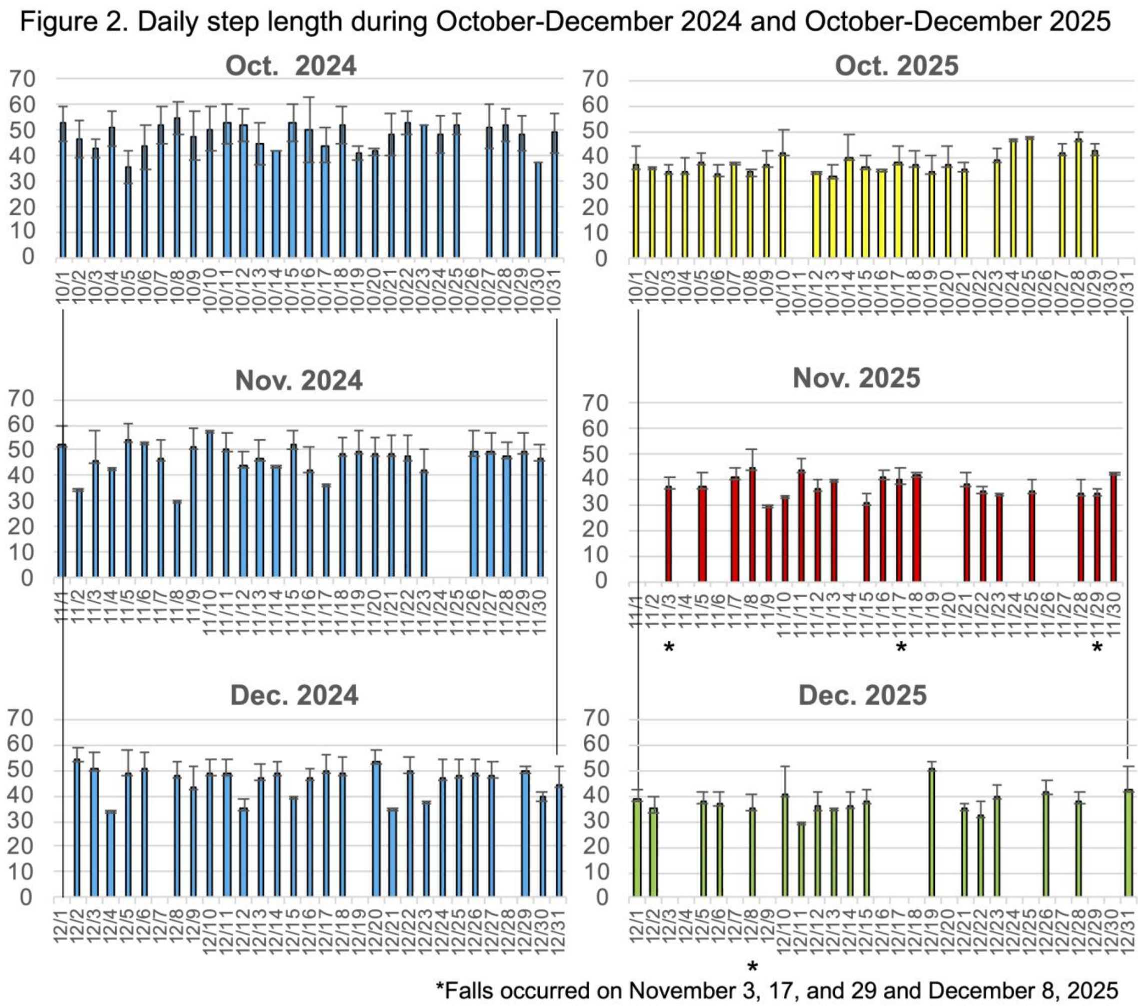


Figure 2: Daily Step Length During October-December 2024 and October-December 2025.

Step Length was Reduced in 2025 Compared with 2024, Consistent with Worsening Gait Function, but the Pattern was not Sufficient by itself to Explain Fall-Related Instability.

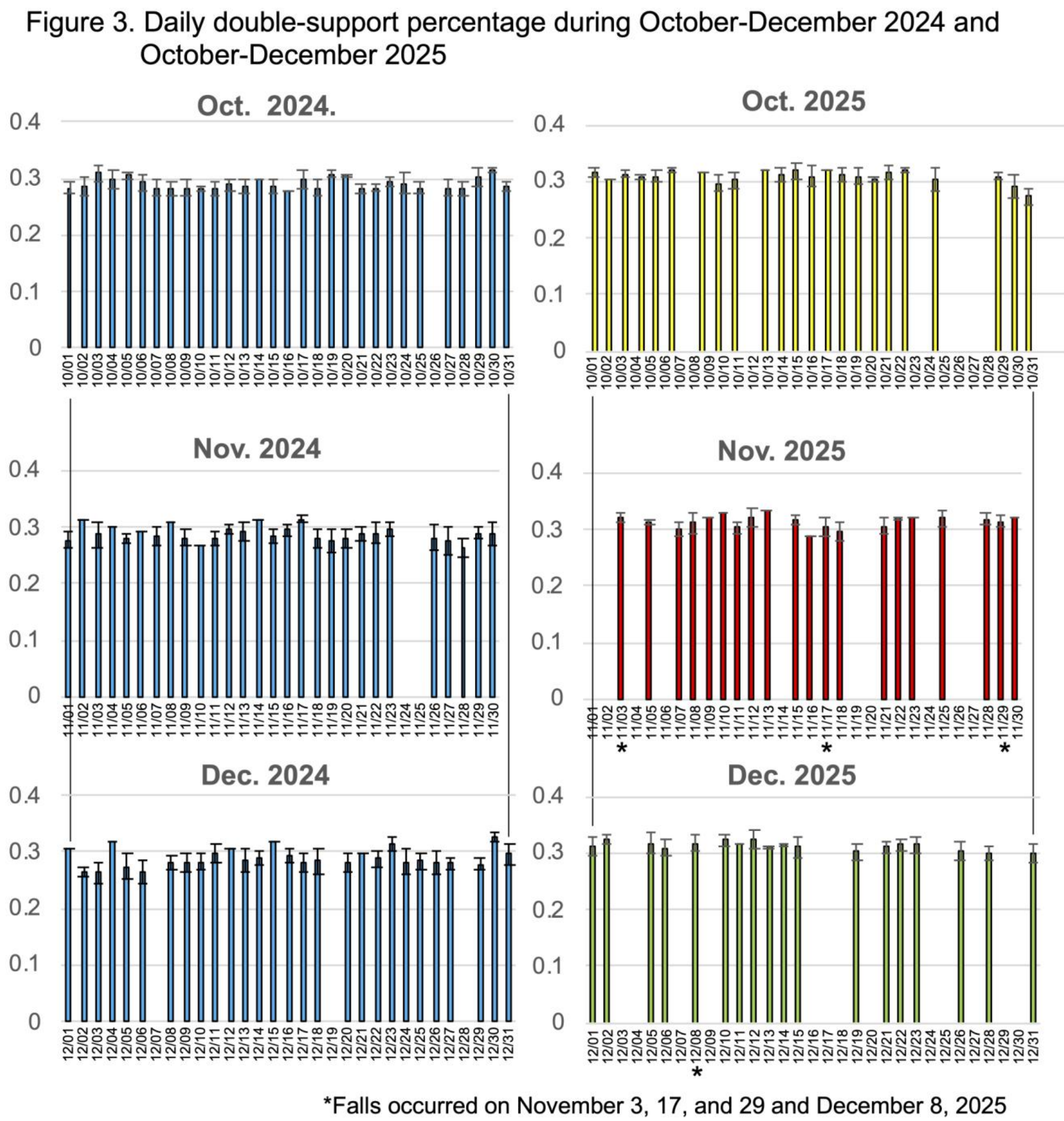


Figure 3: Daily Double-Support Percentage during October-December 2024 and October-December 2025.

Double-Support Percentage Tended to be Higher in 2025 than in 2024, Indicating Reduced Gait Stability. However, month-to-month Differences During the Fall-Prone Period were Modest, Suggesting Limited Sensitivity of this Parameter to Short-Term Fall-Related Changes in this Case.

3.2. Walking Asymmetry Contained Three Distinct Signals

Detailed XML-based inspection showed that walking asymmetry was not a single interpretable variable. Instead, it consisted of three separable signals: measurable non-zero asymmetry values, days without recorded asymmetry, and zero-valued asymmetry events [11]. This decomposition became necessary because the apparent reduction of asymmetry during the fall-prone period did not represent improvement. Rather, it reflected a shift in the recording pattern itself.

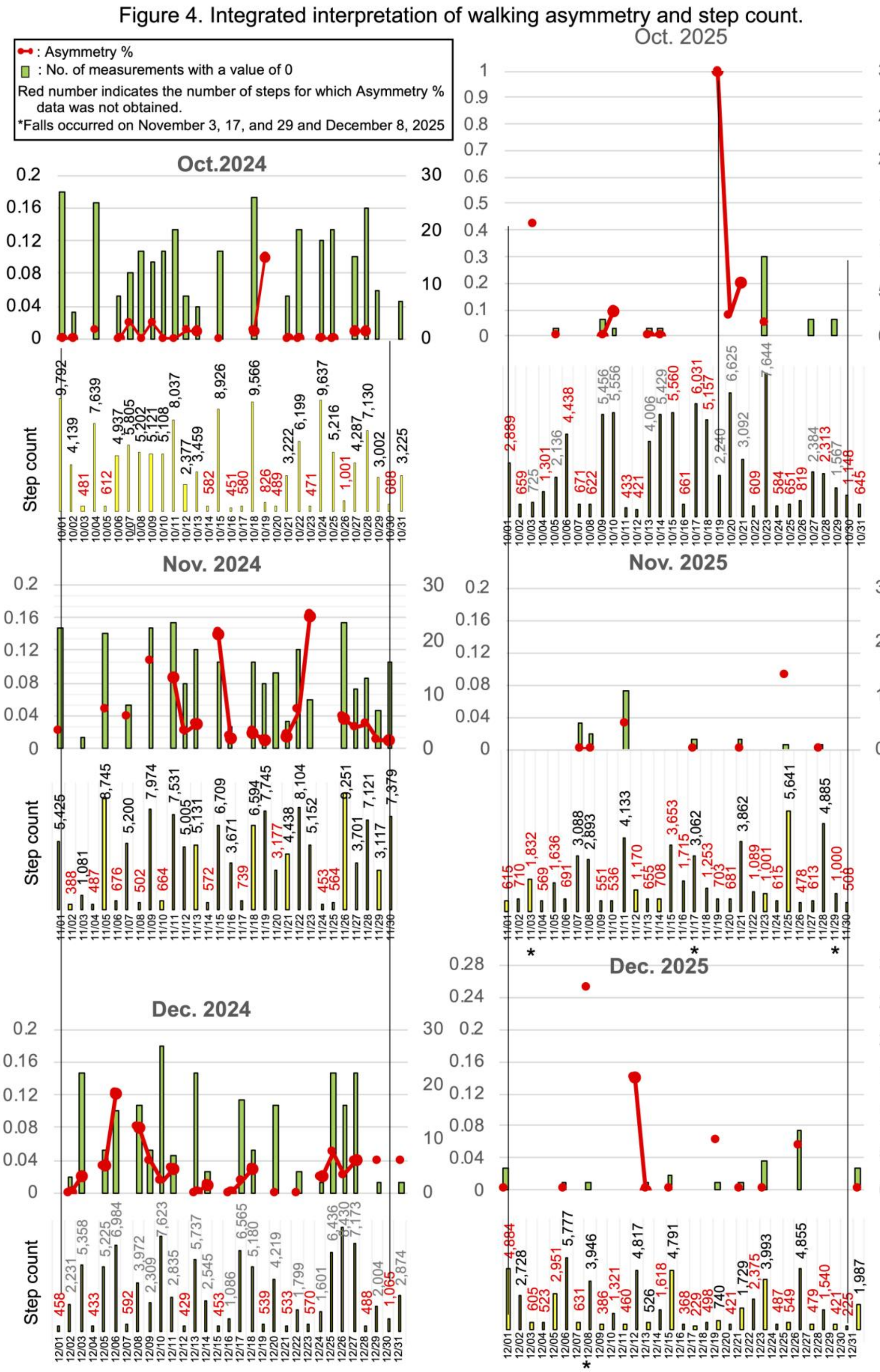


Figure 4. Integrated Interpretation of Walking Asymmetry and Step Count.

Daily step count is shown together with measurable walking asymmetry values and the number of asymmetry events with value = 0. Red numbers indicate the number of steps on days for which asymmetry data were not obtained. These plots illustrate that walking asymmetry in PD contains at least three distinct signals: non-zero asymmetry values, non-recorded days, and zero-valued events.

3.3. Non-Zero Asymmetry Values

When non-zero asymmetry values were tabulated, their frequency was markedly lower in 2025 than in 2024. This finding was initially unexpected because worsening PD might be expected to increase gait asymmetry. Instead, measurable asymmetry became less frequent during the more unstable state. Within 2025, October showed increased measurable asymmetry and reduction of zero-valued events. In November, during the month with repeated falls, measurable asymmetry did not continue to rise, rather, days without asymmetry data increased. In December, asymmetry values again appeared on more days, but zero-valued events remained reduced.

3.4. Days Without Asymmetry Data and their Relation to Step Count

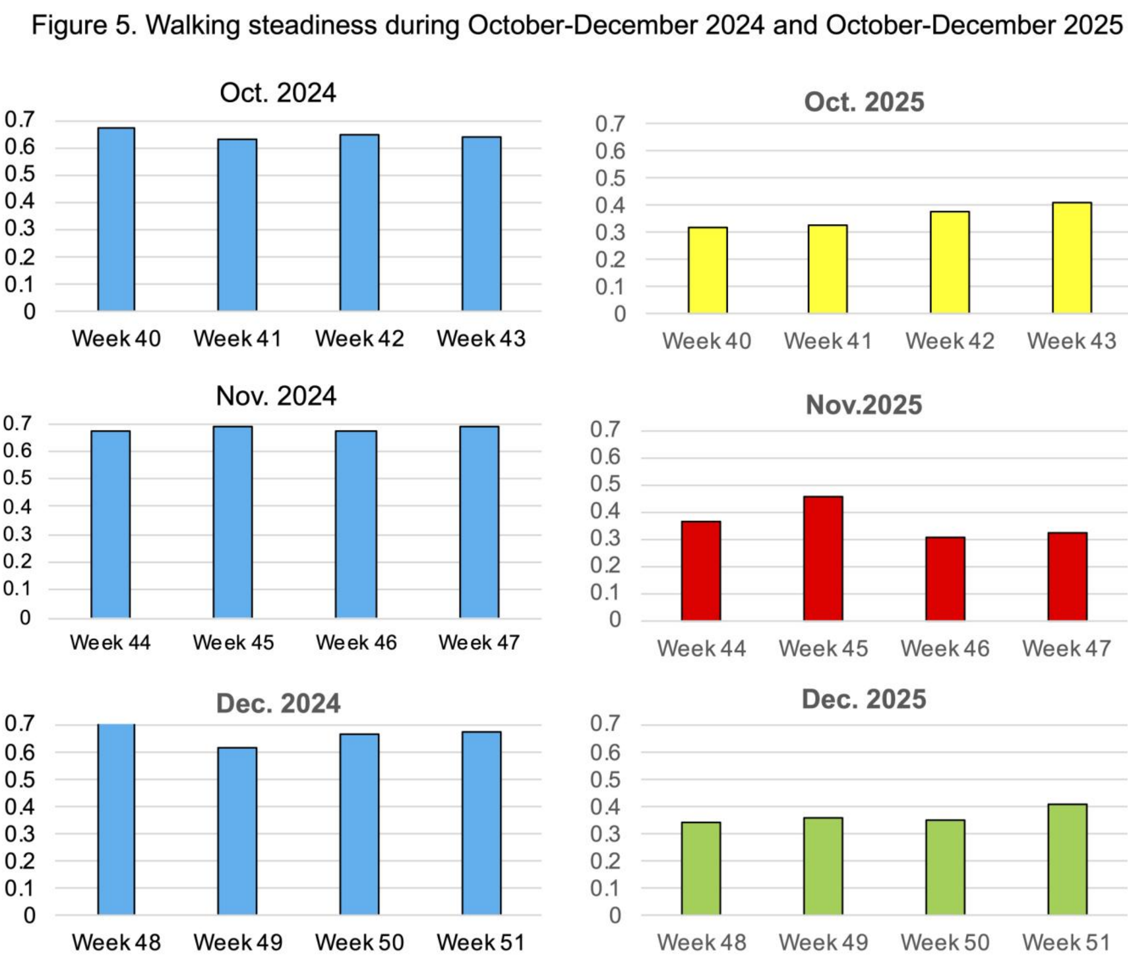
The number of days without measurable asymmetry was somewhat higher in 2025 than in 2024, especially in November 2025. Step count analysis showed that the absence of asymmetry data could not be explained solely by failure to walk. In November 2025, asymmetry data were missing on many low-step days, but there were also days with more than 3000 steps and no measurable asymmetry. Comparison with 2024 suggested that when gait was more impaired, more walking was often required before the algorithm identified a sufficiently stable pattern for asymmetry measurement.

3.5. Zero-Valued Asymmetry Events

The most striking difference between years was the frequency of asymmetry events with value = 0. These zero-valued events were abundant in 2024 but became markedly less frequent in 2025. This reduction was more pronounced than the change in non-zero asymmetry values or the change in days without data.

3.6. Walking Steadiness

Walking steadiness showed clear overall deterioration from 2024 to 2025, consistent with our previous longitudinal report. However, during the fall-prone months examined here, its month-to-month changes were less informative than those observed for the decomposed asymmetry signals. This limited sensitivity likely reflects the fact that walking steadiness is a composite measure derived from multiple parameters, including walking speed, step length, double-support percentage, and asymmetry. Because walking speed and step length mainly reflected quantitative changes, and double-support percentage changed only modestly, the specific contribution of instability-related asymmetry changes may have been diluted in the composite score.



	2024	2025		2024	2025		2024	2025
Week 40	10/06-10/13	10/05-10/12	Week 44	11/03-11/10	11/02-11/09	Week 48	12/01-12/08	11/30-12/07
Week 41	10/13-10/20	10/12-10/19	Week 45	11/10-11/17	11/09-11/16	Week 49	12/08-12/15	12/07-12/14
Week 42	10/20-10/27	10/19-10/26	Week 46	11/17-11/24	11/16-11/23	Week 50	12/15-12/22	12/14-12/21
Week 43	10/27-11/03	10/26-11/02	Week 47	11/24-12/01	11/23-11/30	Week 51	12/22-12/29	12/21-12/28

*Falls occurred on November 3, 17, and 29 and December 8, 2025

Figure 5. Longitudinal Changes in Walking Steadiness During October–December 2024 and 2025.

Weekly walking steadiness values derived from Apple Health data are shown for October–December 2024 and October–December 2025. Compared with 2024, walking steadiness was generally lower in 2025, indicating overall deterioration in gait stability. However, temporal fluctuations around the fall period were modest, and no distinct change specifically corresponding to the timing of falls was observed. Because walking steadiness is a composite metric derived from multiple gait parameters, including walking speed, step length, double-support percentage, and walking asymmetry, its sensitivity to qualitative gait disorganization may be attenuated. Falls occurred on November 3, 17, and 29 and December 8, 2025.

4. Discussion

This study shows that walking asymmetry in Apple Health cannot be interpreted in PD as a single continuous variable. Instead, its meaning emerges only when the dataset is decomposed into at least three components: measurable non-zero asymmetry, days without recorded asymmetry, and zero-valued asymmetry events. This reinterpretation arose directly from XML-level analysis and would not have been possible using simplified exported summaries alone. The first important finding is that worsening gait did not produce a simple increase in measurable asymmetry. On the contrary, non-zero asymmetry values became less frequent in 2025. This initially paradoxical result can be understood if Apple's algorithm records asymmetry only when walking contains a sufficiently sustained and internally consistent pattern. In PD, progression toward instability may produce fragmented, disorganized, or highly variable walking rather than a stable asymmetrical pattern. In that situation, the measured asymmetry value may decrease not because gait improves, but because the walking episode no longer satisfies the recording conditions.

The second important finding is that days without asymmetry data carry information of their own. Such days should not automatically be classified as missing values in the usual statistical sense. Some may reflect low walking volume, but others occurred despite substantial step counts. Therefore, in at least part of the dataset, absence of asymmetry appears to indicate walking episodes that failed to meet algorithmic conditions, possibly because of irregular or unstable gait organization. This makes non-recorded days potentially meaningful as a marker of instability, provided that step count is shown in parallel. The third and most novel finding is the marked reduction of zero-valued asymmetry events in 2025. These value-0 events are easily overlooked because they are absent from standard Auto Export output. Yet in this analysis they emerged as a highly sensitive signal distinguishing the more stable 2024 state from the more impaired 2025 state. We interpret them cautiously as episodes of relatively preserved or less asymmetric gait rather than as proof of fully normal walking. Even with that caution, their sharp reduction suggests loss of gait regularity and may provide information not captured by non-zero asymmetry values alone.

Walking steadiness warrants separate comment. Although it clearly distinguished 2024 from 2025 overall, it was less useful for assessing fall-related dynamics during October-December 2025. A plausible explanation is that walking steadiness is a composite metric that incorporates walking speed, step length, double-support percentage, and asymmetry. In the present study, walking speed and step length mainly reflected quantitative slowing rather than qualitative instability, while double-support percentage showed relatively modest changes. Consequently, the instability-related signal captured by walking asymmetry may have been diluted in the composite score, limiting the utility of walking steadiness as a predictor of falls in this setting. These findings also extend the scope of Apple HealthKit-based digital phenotyping. Our recent report demonstrated that the same platform can objectively identify pharmacological interference in Parkinsonian gait [7]. Taken together, the present results and the pharmacological study suggest that continuous digital phenotyping can detect both treatment-related and disease-related changes, but that interpretation of each parameter must take account of the algorithmic structure underlying data acquisition. This study has limitations. It is a single-subject analysis, and Apple's proprietary algorithms are not specifically designed for Parkinsonian gait. Interpretation of zero-valued events and non-recorded days remains inferential. Environmental context, phone carriage, and daily activity patterns may also influence measurement. Nevertheless, the observations were internally consistent and were grounded in direct inspection of raw XML data rather than post-processed summaries. This strengthens the methodological significance of the findings.

5. Conclusion

Walking asymmetry data from Apple Health should not be treated in PD as a single metric. At least three distinct signals must be considered simultaneously: non-zero asymmetry values, days without recorded asymmetry, and zero-valued asymmetry events. In this single-subject longitudinal analysis, worsening gait and recurrent falls were associated not simply with increased asymmetry, but with reorganization of the entire asymmetry recording pattern, including loss of value-0 events and increased non-recorded days. These findings suggest that XML-level, multi-layered interpretation of walking asymmetry may provide a more informative framework for monitoring unstable gait in daily life than conventional averaging of asymmetry values alone.

Declarations

Author Contributions: K.Y. conceived the study, interpreted the data, and wrote the manuscript. Z.L. curated the data and contributed to formal analysis. Both authors reviewed and approved the final manuscript.

Funding: This research received no external funding.

Competing Interests: The authors declare no competing interests.

Ethics Approval and Consent to Participate: This study analyzed anonymized self-collected gait data from a single individual. The participant provided informed consent for the use and publication of these data. According to institutional guidelines, analysis of de-identified self-tracked data did not require IRB approval.

Consent for Publication: The participant provided consent for publication.

Data Availability: Data are available from the corresponding author upon reasonable request.

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