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Research Article

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Measurement Inconsistencies in Consumer Smartwatch-Based Outdoor Gait Assessment: Implications for Real-World Monitoring in Parkinson's Disease

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Abstract

Background: *We have sought to make objective gait assessment in Parkinson's disease (PD) accessible in daily life using widely available consumer devices, rather than requiring specialized facilities or brief clinic-based tests. During repeated outdoor walking assessments, we encountered inconsistencies in distance and time records.*

Objective: *To characterize these inconsistencies and consider their implications for practical real-world assessment while recognizing genuine day-to-day motor fluctuations.*

Methods: *From August 16 to September 30, 2026, one participant with PD completed 22 distinct outdoor walking sessions in Harbin, China; one healthy adult completed two additional walks. An Apple Watch Ultra 2 and WorkOutDoors were used for recording; data were reviewed in HealthFit. Distance recorded by the device (recorded distance: RD) was compared with route distance measured using Google Maps (map distance: MD). The signed measurement error rate (MER) was defined as 100 × (RD − MD)/MD. Total time (TT), moving time (MT), and repeated imports were examined.*

Results: *Thirteen PD sessions were categorized as routine Tests and nine as Cases with conspicuous recording inconsistencies. One of two healthy-control walks also displayed a distance discrepancy, yielding 10 flagged sessions among 24 distinct walks (41.7%). Mean MER was +38.45 ± 19.92% for Tests and +28.28 ± 33.04% for Cases. Three stick-assisted walks showed negative MER (−21.2%, −15.7%, and −9.1%); the faster healthy-control walk showed −10.0%. In some records MT was nearly equal to TT, whereas in Case 4 MT exceeded TT by 1 min 44 s. Re-importing the same activity also altered displayed values.*

Conclusion: *Consumer-device gait assessment enables repeated real-world quantification without specialized facilities, but recorded distance and time require careful interpretation. Technical inconsistencies should be distinguished from genuine daily changes in PD walking ability. Simple review of route and time records can help preserve the accessibility of this approach.*

Keywords: Parkinson's Disease, Real-World Gait, Apple Watch, Workoutdoors, Healthfit, GPS, Distance Discrepancy, Freezing Of Gait, Day-To-Day Variability

1. Introduction

Assessing walking impairment in Parkinson's disease (PD) remains difficult because symptoms fluctuate within and across days and may change gradually over months or years. Conventional clinical examinations and short-distance walking tests are useful for targeted assessments, but their limited observation windows cannot fully represent performance during ordinary daily life. The presence of an examiner and a short test distance may also influence how a participant chooses to walk. Specialized instrumented gait analysis can offer detailed measurements, yet access to such facilities is

limited. These constraints motivate complementary methods that patients can use repeatedly in familiar environments [1–3]. Our research objective has been to establish a practical system for quantitative and objective evaluation of walking function in the real world: an approach usable by patients at different times and places and over walking routes of varying lengths. We have therefore investigated commonly available smartphones, smartwatches, and software including Apple Health, WorkOutDoors, HealthFit, Health Auto Export, and Google Maps. The central advantage is not laboratory-grade control of every variable but the ability to collect repeated observations of walking performance in ordinary life.

In our previous publications, we reported longitudinal changes in Apple Health-derived gait metrics over two years, pharmacological interference detected by within-person digital phenotyping, the distinct interpretation of recorded, zero-valued, and missing walking-asymmetry data, limitations of AI-based numerical aggregation compared with manually checked source data, quantitative estimation of freezing of gait (FOG) using smartwatch telemetry, and a proposed classification of akinetic freezing and inefficient tremulous gait using temporal and distance indices [4-9]. Together, these studies illustrate the potential of repeated self-measurement while emphasizing the need to understand how recorded variables are produced. During additional field walking tests in Harbin, we noticed substantial disagreements between recorded distance and mapped route distance, as well as inconsistent time values and changed outputs after a record was re-imported. Similar problems were subsequently noticed in Fukuoka, so the observations were not restricted to Harbin. This study examines the Harbin series to document the discrepancies, distinguish technical inconsistencies from clinical day-to-day variation, and identify practical issues that matter when consumer-device measurements are used for PD assessment.

2. Materials and Methods

2.1. Participants and Walking Sessions

Between August 16 and September 30, 2026, one participant with PD performed 22 distinct outdoor walking assessments. Thirteen were designated Tests (routine walking records), and nine were designated Cases because the stored records contained conspicuous inconsistencies requiring examination. A healthy adult performed two additional control walks, one at an ordinary pace and one at a faster pace. Thus 24 distinct walks were assessed. Re-imports or alternate displays of the same recorded activity were not counted as new walks. The study analyzed repeated sessions within individuals rather than treating each session as an independent participant.

2.2. Outdoor Setting and Data Collection

The assessments took place on a pedestrian/jogging road within an elongated park of more than 5 km in Harbin, China. The road had no traffic lights and relatively few other users. The starting location was constant, destinations differed but were specified by recognizable landmarks, including flower beds, toilets, or path junctions. For each session, map distance (MD) was determined from the corresponding route using Google Maps. The participant wore an Apple Watch Ultra 2 on the left wrist and recorded walking with WorkOutDoors. The activity records and time displays were examined using HealthFit, tabulated values were maintained in Excel. Scheduled rest breaks were manually paused and resumed after the rest. The approach used commercially available hardware and software without special laboratory infrastructure.

2.3. Recorded Variables and Practical Classification

Recorded distance (RD, m) was the distance displayed in the activity record. Map distance (MD, m) was the length obtained for the intended route with Google Maps. We calculated the signed measurement error rate (MER, %) as MER = [(RD − MD)/MD] × 100. MER > 0 indicates that RD exceeds MD, and MER < 0 indicates that RD is shorter than MD. Total time (TT) and moving time (MT) were read from the displayed workout records. We inspected substantial RD–MD disagreement, TT and MT relationships, and discrepancies between displays of the same re-imported activity. These are observable record-level features, the specific internal mechanism of each discrepancy was not measured.

For consistency with our preceding FOG publications, we also retain the operational FOG ratio, calculated as (TT − MT)/TT for recordings where the time values are coherent [8,9]. This is a calculation-based index of time not classified as moving by the application, used to investigate FOG in our earlier work, it is not asserted to equal independently observed seconds of freezing in every activity. The present study focuses on circumstances in which the underlying TT or MT data are inconsistent and, accordingly, the index cannot be interpreted without checking the source record.

2.4. Statistical Analysis

We summarized the number of distinct walks in each record category, the number with identified inconsistencies, and MER as mean ± sample standard deviation and range. We retained the original and re-imported displays of a given walk for comparison but did not duplicate the walking session in the statistical denominator. Because the PD data came from one individual and control data from one additional individual, comparisons are presented as within-series observations rather than between-patient inference. The descriptive analyses preserve the genuine day-to-day variation in PD symptoms.

3. Results

3.1. Walking-Session Counts and Distance Discrepancies

Of the 24 distinct sessions, 13 were routine PD Tests, nine were PD Cases with conspicuous record inconsistencies, and two were healthy-control assessments. Among the 22 PD sessions, nine were classified as Cases (40.9%). With one control walk showing a distance discrepancy, ten of 24 distinct walks (41.7%) were flagged in the current series. This proportion describes these recorded sessions and does not represent a general population incidence of GPS malfunction. Representative Test displays are shown in Figure 1. Cases can be classified into 5 types. First, like Case 1, equal total time is equal to Moving time (Figure 2). Similar

results occurred in Cases 2, 3 and 8. Second, like Case 4, moving time is longer than total time (Figure 3). Third, like Cas 5, moving time is longer than total time after reloading (Figure 4). Similar results occurred in Case 6. Forth, like Case 7, RD is shorter than map distance in stick-assisted walking (Figure 5). Similar results occurred in Case 8. Fifth, like control case 2, RD is shorter than map distance during faster walk (Figure 6).



Figure 1: Representative routine walking Test records. Test 4 and Test 9, showing WorkOutDoors tracks and HealthFit summaries. The displayed total and moving times differ, while the device-reported distance can exceed the distance estimated for the route using Google Maps

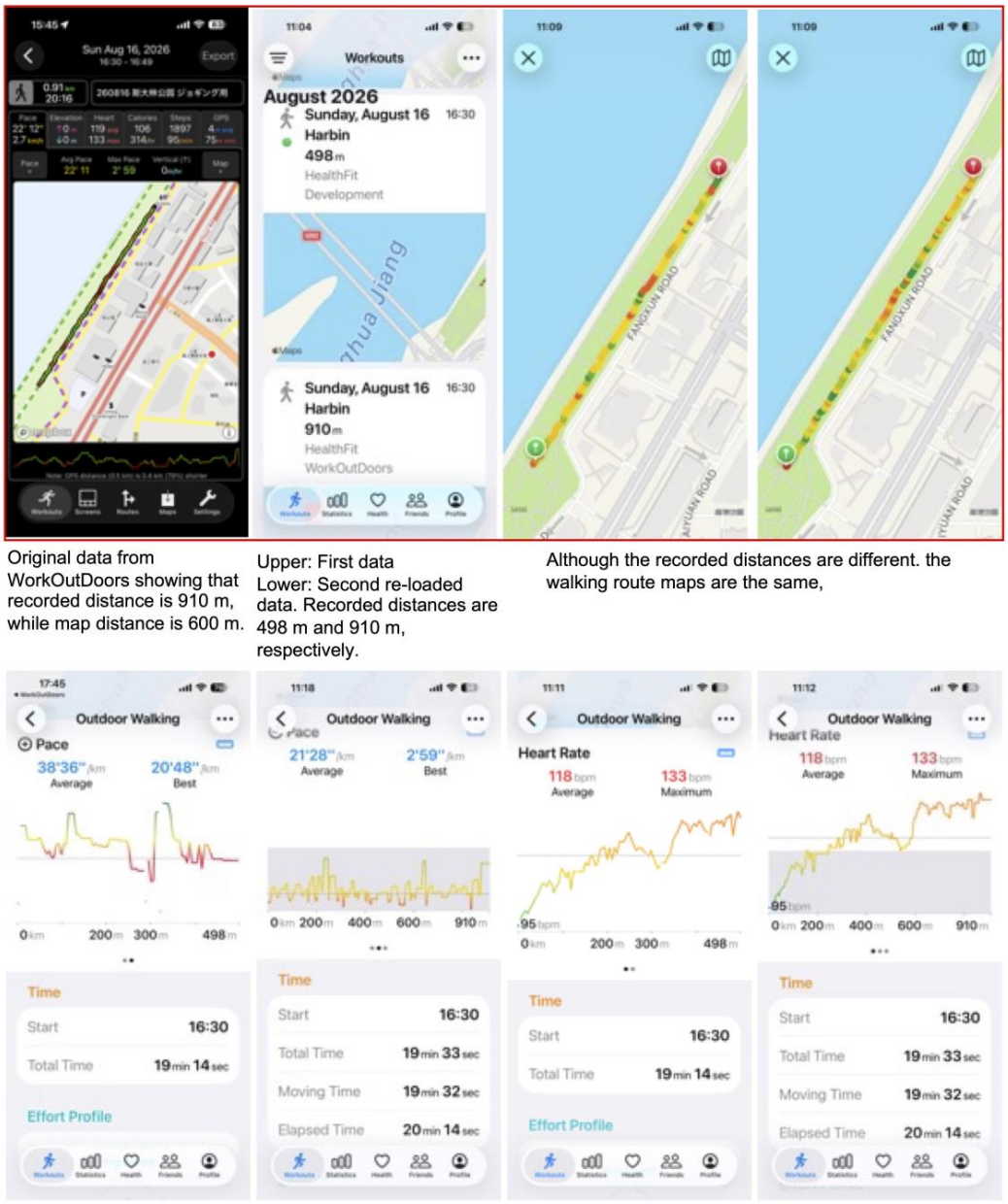
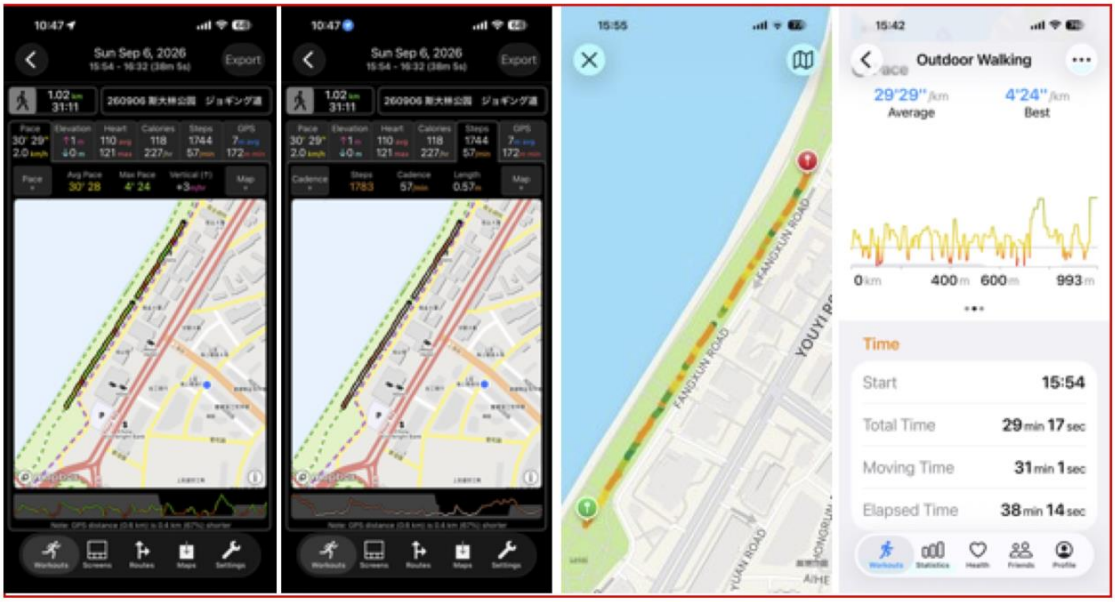


Figure 2. Example of case in which Total time is almost same to Moving time.

Figure 2: Case 1: equal total time to Moving time. Different displayed distances after processing the same activity is also noted. WorkOutDoors recorded approximately 910 m, one HealthFit record displayed approximately 498 m and another approximately 910 m. The tracks appear similar, while the displayed pace and time information differ between presentations of the same session. Screenshots are reproduced from the original applications. Similar results occurred in Cases 2, 3 and 8

Case 4. Sep. 6, 2026 14:54-16:32



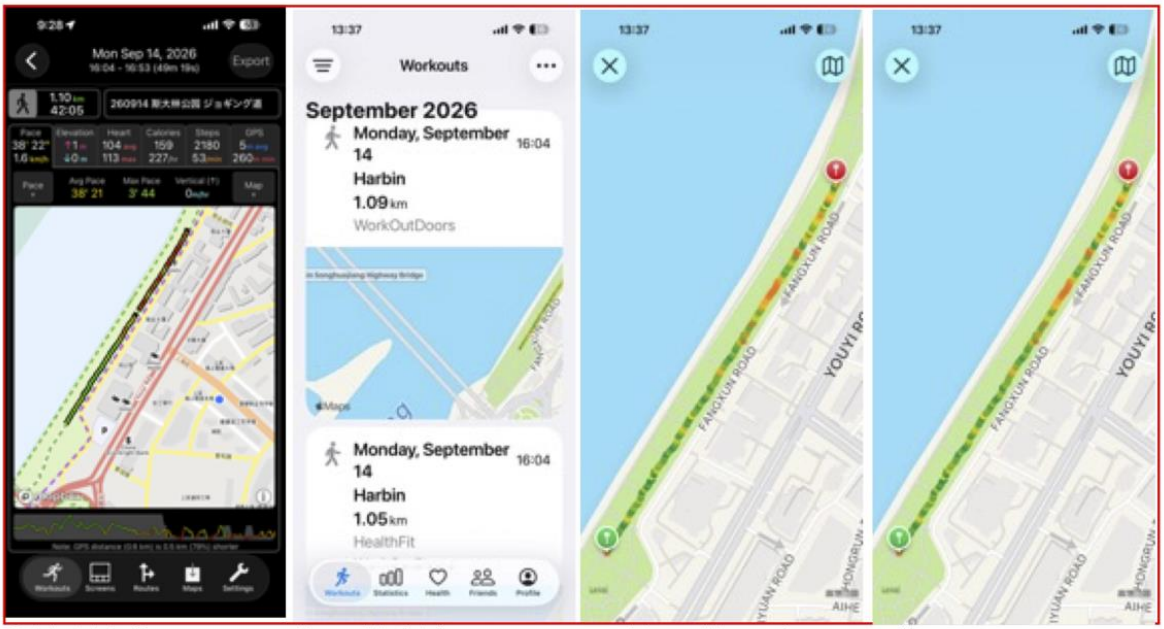
Original data (left) and re-loaded data (right) from WorkOutDoors. In both cases recorded distance is 1020 m, while map distance is 700 m.

In this case, Moving time is longer than Total time. Like in Case 4, brake was taken once along the way. Measurement was paused during brake and resumed after brake.

Figure 3. Example of case in which Moving time is longer than Total time.

Figure 3: Case 4: moving time exceeding total time. HealthFit displayed TT = 29 min 17 s and MT = 31 min 1 s. The walking record began at 15:54 local time. The figures reproduce the original application displays, deliberate rest was paused during measurement

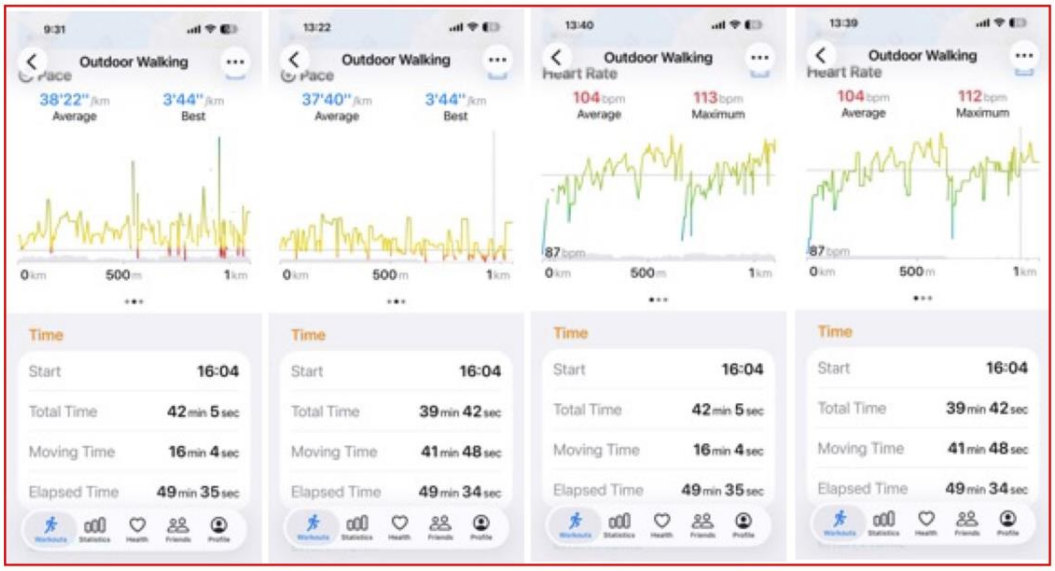
Case 5. Sep 14, 2026 16:04-16:53



Original data from WorkOutDoorsshowing that recorded distance is 1100 m, while map distance is 700(~~600~~) m.

Upper: First data
Lower: Second re-loaded data. Recorded distances are 1090 m and 1050 m, respectively.

The walking route maps are the same,



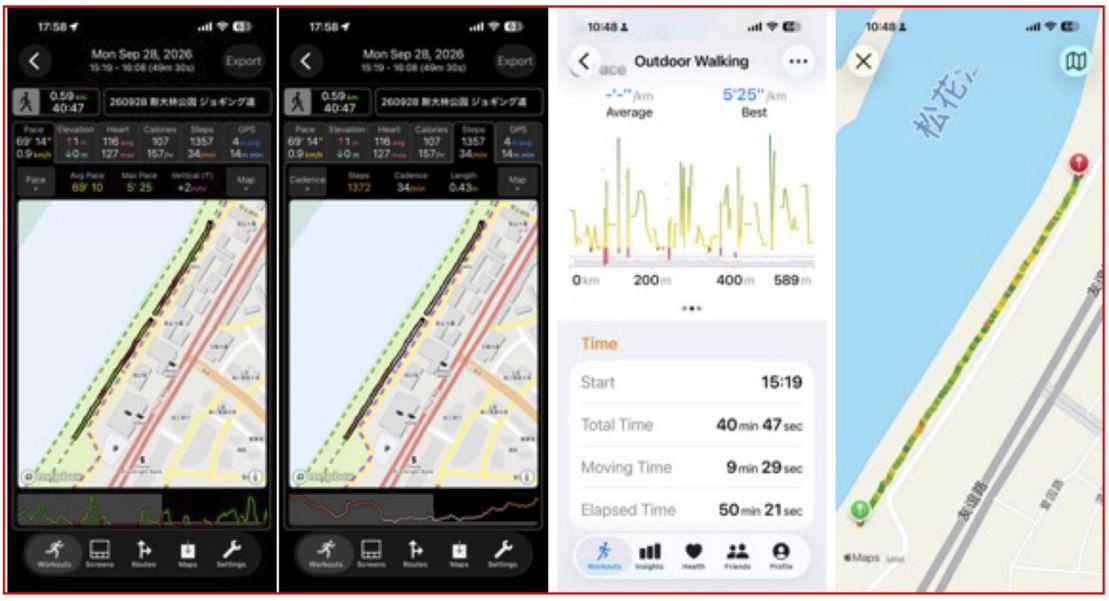
In the First data Toal time is longer than Moving time as usual. However, in second reloaded data Moving time is longer than total time. In this case, brake was taken once along the way. Measurement was paused during brake and resumed after brake.

Although the first and second reloaded data sets have different moving time, the heart rate data is the same.

Figure 4. Example of case in which Moving time is longer than Total time in second reloaded data.

Figure 4: Case 5: longer moving time than total time after reloading. Variation between original and re-imported activity data is also noted. WorkOutDoors and HealthFit presentations display different recorded distances and markedly different time fields for the same walking session. Google Maps route distance was 700 m. The respective images retain their original displayed values. Similar results occurred in Case 6

Case 7. Sep 28, 2026 15:19-16:08

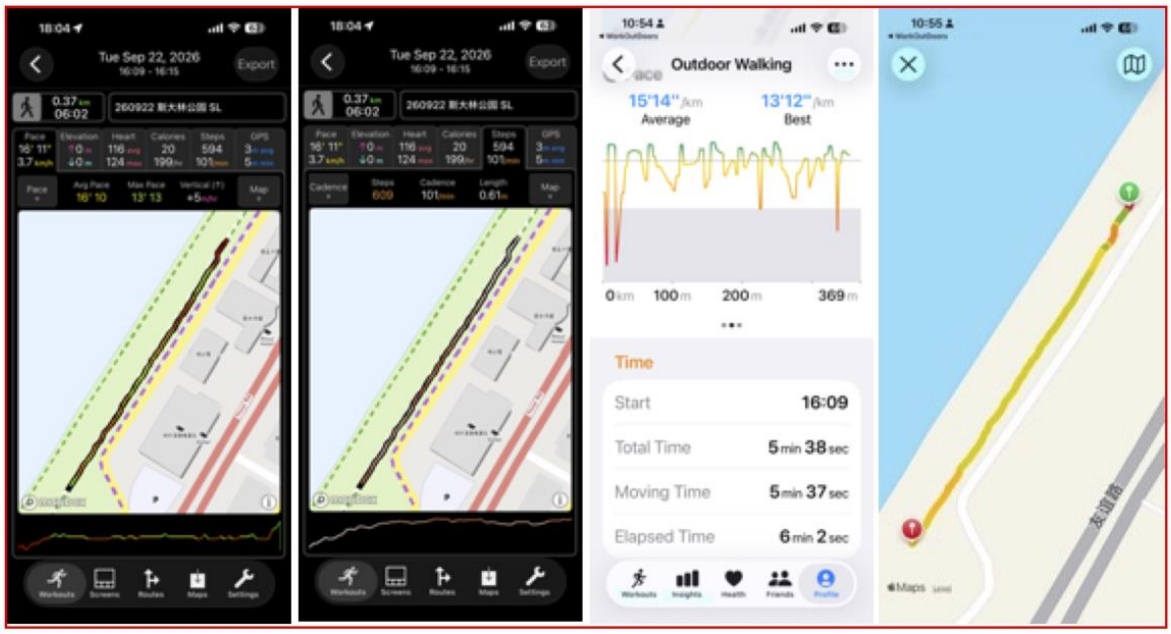


When walked with the help of the stick in my right hand. Under such situation, the recorded distance (590 m) is 110 m shorter than the map distance (700 m).

Figure 5. Example of case in which recorded distance is shorter than map distance.

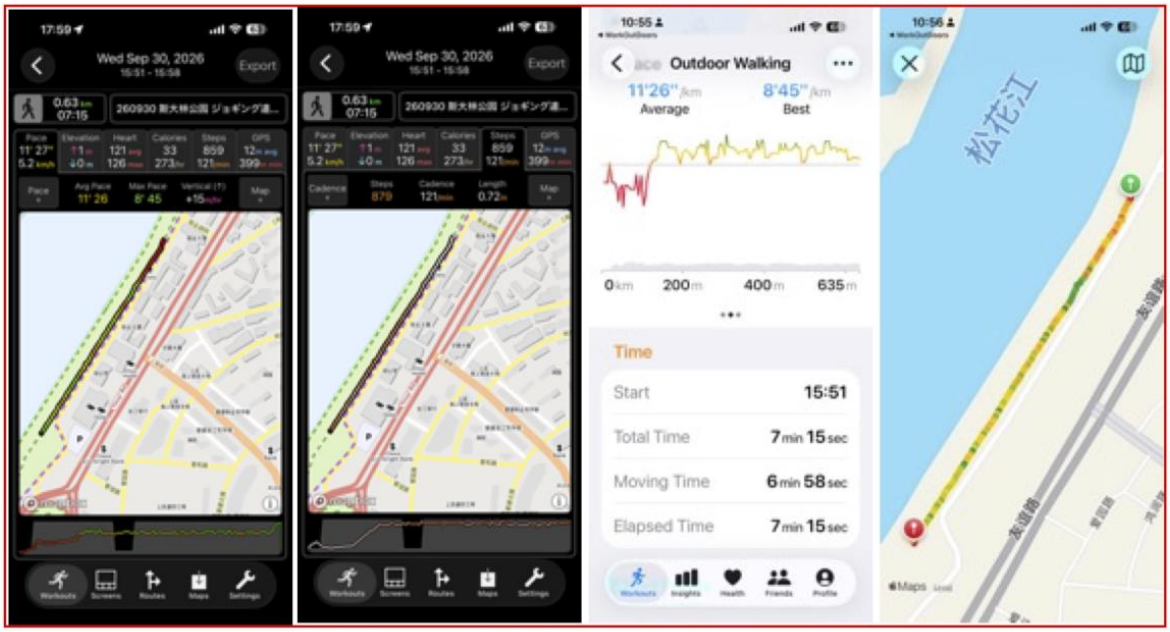
Figure 5: Case 7: shorter RD (590 m) than map distance (700 m) in stick-assisted walking. Similar distance under-recording occurred in Cases 6 and 8.

Cont. Case 1. Sep 22, 2026 16:09-16:015



When a healthy person walks at a speed of 3.7 km/h, the recorded distance (370 m) is the same as the map distance (370 m).

Cont. Case 2. Sep 30, 2026 15:51-15:58



When a healthy person walked at a speed of 5.3 km/h, the recorded distance (630 m) was 70 m shorter than the map distance (700 m).

Figure 6. Example of case in which recorded distance is shorter than map distance in a healthy control.

Figure 6: Healthy-control records. At ordinary pace (approximately 3.7 km/h), RD and MD were both 370 m. During a faster walk (approximately 5.2–5.3 km/h), RD was approximately 630 m versus MD = 700 m (MER −10.0%)

Gait performance across all cases is summarized in Table 1 and 2. Signed measurement error rate (MER) by walking-session category is shown in Table 3. Across the 13 Test sessions, the mean signed MER was +38.45 ± 19.92% (range +14.29% to +81.08%). Among the nine PD Cases (Table 2 and 3), MER averaged +28.28 ± 33.04% (range −21.21% to +57.14%). The routine Tests therefore also showed substantial RD–MD differences, notwithstanding their coherent time displays. Table 3. Signed measurement error rate (MER) by walking-session category. Values are descriptive summaries of distinct walks, positive values indicate RD > MD and negative values RD < MD. The healthy control performed two walks, rather than representing two independent control individuals.

Group	Sessions (n)	MER, mean ± SD (%)	Range (%)	MER > 0 / < 0 / = 0
PD Tests	13	+38.45 ± 19.92	+14.29 to +81.08	13 / 0 / 0
PD Cases	9	+28.28 ± 33.04	−21.21 to +57.14	6 / 3 / 0
Healthy control	2	−5.00 ± 7.07	−10.00 to 0	0 / 1 / 1

	Date Time	Map distance (MD) (m)	Recorded distance (RD) (m)	Measurment error (MD-RD) (m)	Measurement error ratio (MER) [(MD-RD)/MD] x100 (%)	Total time (TT)	TT (min)	Moving time (MT)	MT (min)	Freezing time (FT) =TT-MT	FOG ratio (FT/TT)
Case 1	260816 16:30-16:49	600	910	310	51.7	0:19:33	19.6	0:19:32	19.5	0:00:01	0.001
Case 2	260826 15:41-16:02	600	910	310	51.7	0:21:03	21.1	0:21:03	21.1	0:00:00	0.000
Case 3	260828 15:57-16:25	700	1020	320	45.7	0:27:53	27.9	0:27:52	27.9	0:00:01	0.001
Case 4	260906 15:54-16:32	700	1020	320	45.7	0:29:17	29.3	0:31:01	31.0	-0:01:44	—
Case 5	260914 16:04-16:53	700	1100	400	57.1	0:42:05	42.1	0:16:04	16.1	0:26:01	0.618
Case 5 Reloaded	260914 16:04-16:53	700	1050	350	50.0	0:39:42	39.7	0:41:48	41.8	-0:02:07	—
Case 6	260921 17:44-18:09	330	260	-70	-21.2	0:25:16	25.3	0:25:15	25.3	0:00:01	0.001
Case 7	260928 15:19-16:08	700	590	-110	-15.7	0:40:47	40.8	0:09:29	9.5	0:31:18	0.767
Case 8	260930 15:03-15:20	370	550	180	48.6	0:16:41	16.7	0:16:41	16.7	0:00:00	0.000
Case 9	260930 15:31-15:49	330	300	-30	-9.1	0:19:24	19.4	0:05:23	5.4	0:14:01	0.723
Cont. Case 1	260922 16:09-16:15	370	370	0	0.0	0:05:38	5.6	0:05:37	5.6	0:00:01	0.003
Cont. Case 2	260930 15:51-15:58	700	630	-70	-10.0	0:07:15	7.3	0:06:58	7.0	0:00:17	0.039

Table 1: Gait Performance Across all Tests

	Date Time	Walking speed (km/h) WorkOutDoors =D4/H4*60/1000	Step count	Cadence (steps/min)	Step length (cm)
Case 1	260816 16:30-16:49	2.7	1897	95	48
Case 2	260826 15:41-16:02	2.4	1665	94	43
Case 3	260828 15:57-16:25	2.1	2192	75	47
Case 4	260906 15:54-16:32	2.0	1744	57	57
Case 5	260914 16:04-16:53	1.6	2180	53	49
Case 5 redounloded	260914 16:04-16:53	Same as above because Health fit data was redounloded using te same WorkOutDoors data.			
Case 6	260921 17:44-18:09	1.2	1398	43	48
Case 7	260928 15:19-16:08	0.9	1357	34	43
Case 8	260930 15:03-15:20	1.9	1141	69	46
Case 9	260930 15:31-15:49	0.9	668	36	44
Cont. Case 1	260922 16:09-16:15	3.7	594	101	61
Cont. Case 2	260930 15:51-15:58	5.2	859	121	72

Table 2: Gait Metrics Across All Cases

Table 3. Signed measurement error rate (MER) by walking-session category. Values are descriptive summaries of distinct walks; positive values indicate RD > MD and negative values RD < MD. The healthy control performed two walks, rather than representing two independent control individuals.

Session group	n	MER mean ± SD	MER range	Positive / negative / zero
PD Tests	13	+38.45 ± 19.92%	+14.29% to +81.08%	13 / 0 / 0
PD Cases	9	+28.28 ± 33.04%	−21.21% to +57.14%	6 / 3 / 0
Healthy control	2	−5.00 ± 7.07%	−10.00% to 0%	0 / 1 / 1

3.2. Under-Recording During Stick-Assisted Walking and Faster Control Walking

In Case 6, RD was 260 m compared with MD 330 m (MER −21.2%), in Case 7, 590 versus 700 m (−15.7%), and in Case 9, 300 versus 330 m (−9.1%). The PD participant used a stick in the right hand in these three walks. Comparable under-recording during stick-assisted walks was also observed subsequently in Fukuoka, although those additional observations are not included in the present Harbin statistics. In the healthy control, RD matched MD (370 m) during the ordinary-pace walk (reported walking speed about 3.7 km/h), while RD was 630 m for a 700-m route during the faster walk (about 5.2–5.3 km/h, MER −10.0%). These

observations establish the occurrence of under-recording in the sampled conditions, without determining its cause.

3.3. Inconsistencies in Total Time, Moving Time, and Re-Imported Outputs

In Cases 1–3, 6, and 8, TT and MT were identical or differed by approximately one second in displayed records, despite the PD participant's experience of intermittent stopping or irregular gait. In Case 4, MT was 31 min 1 s, whereas TT was 29 min 17 s (MT exceeded TT by 1 min 44 s). Following re-import of Case 5, the displayed MT was 41 min 48 s and TT was 39 min 42 s (difference +2 min 6 s). The latter record also displayed changes in other fields. These values are noteworthy because the implied temporal relationships differ from those expected when MT denotes a subset of the recorded TT. Case 1 showed approximately 498 m on one HealthFit display and 910 m on a reloaded display of the same walking session, despite similar mapped tracks and comparable heart-rate trends. In Case 5, the recorded distance changed across saved/reloaded presentations (approximately 1,100 m in the original WorkOutDoors view and about 1,050 m after re-import in HealthFit), together with altered TT and MT. Figures 2–4 document the original displays, no screenshot data were altered.

3.4. Time Display Across Time Zones

For Test 10, a start time of 16:22 in China was displayed as 17:22 after viewing in Japan, consistent with the one-hour time-zone difference. This display conversion is distinct from any disagreement between TT and MT. The correct start time for Case 4 was 15:54.

4. Discussion

4.1. Accessible, Repeatable Real-World Gait Monitoring

The fundamental aim of this research is practical, objective monitoring of walking ability by patients themselves. A smartphone, smartwatch, and publicly available applications can support repeated field tests over routes of different lengths, without requiring patients to visit a specialist laboratory. Rather than replacing all conventional clinical assessments, these measurements can supply longitudinal observations that are otherwise difficult to capture in occasional clinic visits. Our preceding work showed how such measurements can be applied to progression, treatment-related effects, asymmetry patterns, and FOG-related features [4–9]. Repeated observations from the same person are particularly informative for documenting change against that person's own history. Their strength is the reduced influence of between-person clinical heterogeneity when interpreting changes over time. They cannot, by themselves, establish the frequency of technical errors or the accuracy of a method in the wider PD population. The present findings concern important practical features of the recorded data rather than a universal performance rating for the watch or the software.

4.2. Natural Day-to-Day Variation and Device-Related Inconsistency

Walking speed, gait continuity, hesitation, and the proportion of time spent stationary can vary markedly from one day to the next in PD. Such genuine variation is part of the disorder and is among the principal reasons for repeated real-world assessment [4,8]. A slow or unusual walking session should therefore not be labeled technical error merely because it differs from another day. By contrast, contradictory recorded time fields, a difference between two presentations of the same source activity, or a discrepancy between RD and a Google Maps route are features that merit checking as measurements. The observed RD–MD difference is not, on its own, proof of a particular GPS mechanism, it simply describes disagreement between two accessible distance measures.

4.3. Distance Over-Recording, Under-Recording, and Temporal Fields

Distance disagreement was observed in both directions. In particular, under-recording appeared in three stick-assisted PD walks and one faster control walk. We cannot infer from these few observations that stick use or speed causes the discrepancy, but they are practical circumstances to consider when reviewing a test. Differences between TT and MT and changes following re-import are a separate class of problem. The latter may reflect differences in displayed or processed workout records and should not automatically be attributed to satellite positioning alone. Our earlier studies used (TT − MT)/TT as an operational FOG ratio [8,9]. The present cases clarify an important condition for its application: TT and MT must be interpretable and internally coherent. Where the application shows MT > TT or substantially different results from the same imported activity, a computed FOG ratio would not have a meaningful interpretation. This qualification preserves the usefulness of an accessible operational index without presenting every difference between total and moving time as independently verified FOG duration.

4.4. Relevance to Future Walking-Speed Indices

Recorded distance divided by total time (RD/TT) is vulnerable to RD–MD divergence. A route-based alternative, MD/TT, may more directly express the time needed to cover a mapped route when deliberate breaks are paused. MD/MT may complement it by representing progression relative to time classified by the software as moving, provided the MT record is coherent. Their clinical interpretation and comparison are separate from the present investigation and will be addressed in a subsequent study. In this paper, the important point is that a speed index inherits any inconsistency present in its distance or time inputs.

4.5. Practical Implications and Study Boundaries

The observations support a simple workflow: record the walk with the watch, preserve the original activity, note the intended start and end landmarks, compare RD with a Google Maps route when needed, and check whether the time fields are plausible and whether re-importing reproduces the record. These steps use ordinary consumer tools and do not require additional laboratory equipment. The actual route distance was obtained from Google Maps rather than a separately surveyed standard, the results therefore quantify differences relative to this readily accessible map estimate, not absolute positioning accuracy. The underlying raw sensor traces and proprietary processing algorithms were not

examined, so the causal origin of individual discrepancies remains unknown. Our series included only one PD participant and one control participant, and the frequency of flagged sessions must not be generalized to other users or settings. These boundaries do not diminish the practical importance of recognizing obvious inconsistencies in a widely accessible monitoring workflow.

5. Conclusion

Repeated outdoor gait testing with consumer devices can provide accessible quantitative information about PD walking under real-world conditions. In the present series, recorded and map distances sometimes diverged substantially, and certain activity records displayed inconsistent total and moving times or changed following re-import. Genuine day-to-day changes in gait should be considered clinical observations, while inconsistent measurements should be recognized before deriving gait indices. Simple scrutiny of recorded distance and time retains the practical advantages of patient-directed assessment. A separate investigation will examine which walking-speed indices best represent overall and active walking performance.

Declarations

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

Funding: This research received no external funding.

Competing Interests: The authors declare no competing interests.

Ethics and Informed Consent: This report analyzed self-collected walking records from one participant with PD and one healthy adult. Both participants consented to the use and publication of their data. No intervention beyond routine walking tests was performed. [Authors to verify the applicable ethics-review statement before submission.]

Consent for Publication: Both participants consented to use and publication of their anonymized data.

Data Availability: Data supporting the observations are available from the corresponding author on reasonable request.

Use of Generative AI: ChatGPT assisted with manuscript editing, organization, and preparation of document drafts. The authors reviewed the content and remain responsible for the data and conclusions.

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