Determining the Minimum Number of Monitoring Days for Accurate Weekly Step and Activity Count Estimation Across Four Different Sensor Locations in Chronic Low Back Pain Population

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INTODUCTION: Wearable sensors are increasingly used to monitor physical activity, such as step and activity counts, in both clinical and research settings. Continuous monitoring for seven days, to account for differences in activities during week days and weekend days, may not always be feasible due to participant burden, adherence issues, and resource constraints. Prior studies suggest that fewer monitoring days may be sufficient[1], but the minimum number of days needed remains unclear and may differ by sensor location. The aim of this study is to determine the minimum number of monitoring days required to accurately estimate weekly averages of step and activity counts across four placements (L1 spinal section, L5 spinal section, wrist, and waist) in individuals with chronic low back pain (cLBP). The findings will inform best practices for activity monitoring protocols in both clinical and research contexts, especially in cLBP population.

METHODS: This study analyzed data from the University of Pittsburgh's Low Back Pain: Biological, Biomechanical, Behavioral Phenotypes (LB3P) Mechanistic Research Center, part of the NIH Back Pain Consortium (BACPAC) within the HEAL Initiative. A total of 1,007 adults with chronic low back pain were enrolled. Participants wore four accelerometer-based sensors for seven days: two custom inertial measurement unit sensors placed at the L1 and L5 levels of the lumbar spine, one ActiGraph GT9X device on the non-dominant wrist, and one ActiGraph GT9X device at the waist (Figure 1). Accelerometer data from the L1 and L5 sensors were collected at 20 Hz, preprocessed in Python, and aggregated into 60-second epochs. Activity counts and step counts were calculated using validated ActiGraph algorithms[2,3]. Data from the waist and wrist ActiGraph sensors were processed in ActiLife to calculate activity counts and step counts. Only participants with at least seven valid days (≥10 hours/day) were included. To determine the minimum number of monitoring days needed to estimate weekly averages, two analyses were conducted: (1) multiple linear regression models to evaluate all possible combinations of consecutive one to six days against the seven-day criterion, using adjusted R^2 as the performance metric, and (2) intraclass correlation coefficients (ICCs) calculated with a one-way ANOVA model. Adjusted R^2 and ICC values ≥ .80 were considered acceptable indicators of reliability.

RESULTS: Valid seven-day data were available from 293 participants at L1, 268 at L5, 288 at the waist, and 642 at the wrist. Regression analyses showed that three monitoring days were sufficient to achieve adjusted R^2 values above .80 for L5 and waist sensors for both step counts and activity counts, as well as for L1 step counts. Four monitoring days were required for L1 activity counts and for both step and activity counts at the wrist. At three days, adjusted R^2 values ranged from .83–.85 for L1 steps, .85–.87 for L5 steps, .83–.87 for L5 activity, .86–.90 for waist steps, and .87–.91 for waist activity across all day-of-week combinations (Table 1). At four days, adjusted R^2 values ranged from .86–.90 for L1 activity, .85–.89 for wrist steps, and .86–.90 for wrist activity (Table 1). ICCs supported these findings, with values ≥ .90 for the corresponding day groups across sensor placements (Table 2).

DISCUSSION: This study provides evidence-based guidance on the minimum number of monitoring days required to reliably estimate weekly step and activity counts in individuals with cLBP. Three days of monitoring were sufficient for waist and L5 placements and for step counts at L1, while four days were required for L1 activity counts and for both step and activity counts at the wrist. These findings indicate that reliable estimates can be obtained with fewer than the commonly used seven monitoring days, reducing participant burden and improving feasibility in both clinical and research settings. The results also highlight the importance of sensor placement, as wrist-worn devices required more days to achieve reliable estimates compared to waist and lumbar sensors. A limitation of this study is the substantial reduction in usable data compared to the 1,007 participants initially enrolled, underscoring the need to determine whether fewer days of monitoring can still yield reliable results. Despite this reduction, the study still retained a large sample size across all placements.

SIGNIFICANCE/CLINICAL RELEVANCE: Reliable estimates of weekly physical activity in individuals with chronic low back pain can be obtained with only three to four days of monitoring, depending on sensor placement. These findings support more efficient, lower-burden monitoring protocols and can inform standardized guidelines for wearable sensor use in both clinical and research settings.

REFERENCES: 1) Almeida, et al., *Physical Therapy*, 2011. 2) Neishabouri, et al., *Scientific Reports*, 2022. 3) Hoydick, et al., *Sensors*, 2024.

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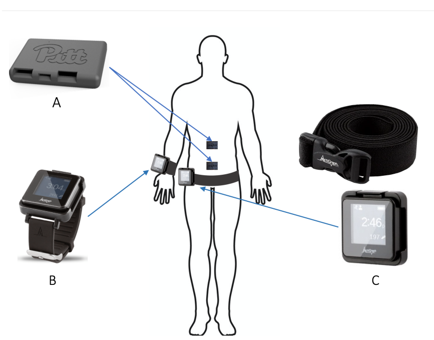

Figure 1. Sensor placement (posterior view): A. Two custom back sensor placed at the L1 and L5 lumbar segment; B. ActiGraph GT9X with a watch band worn on wrist; and C. ActiGraph GT9X with a belt worn on waist.

Number of days	Mon	Tue	Wed	Thu	Fri	Sat	Sun	L1 Step Counts	L1 Activity Counts	L5 Step Counts	L5 Activity Counts	Waist Step Counts	Waist Activity Counts	Wrist Step Counts	Wrist Activity Counts
1	Mon							.31	.14	.40	.37	.44	.55	.10	.12
1		Tue						.44	.22	.37	.22	.46	.51	-.23	-.10
1			Wed					.29	.12	.37	.34	.53	.61	.00	.07
1				Thu				.36	.11	.42	.38	.51	.53	-.04	.01
1					Fri			.40	.17	.51	.44	.50	.57	.02	.06
1						Sat		.43	.39	.46	.42	.32	.54	.26	.37
1							Sun	.54	.43	.59	.54	.59	.68	.41	.44
2	Mon	Tue						.74	.60	.75	.69	.76	.79	.55	.57
2		Tue	Wed					.73	.66	.72	.69	.80	.83	.55	.60
2			Wed	Thu				.69	.58	.73	.69	.76	.77	.54	.56
2				Thu	Fri			.70	.55	.76	.74	.79	.80	.53	.55
2					Fri	Sat		.72	.64	.79	.80	.78	.82	.63	.67
2						Sat	Sun	.75	.72	.74	.74	.75	.82	.64	.68
2	Mon						Sun	.69	.63	.74	.74	.76	.82	.65	.66
3	Mon	Tue	Wed					.85	.78	.85	.84	.90	.91	.77	.79
3		Tue	Wed	Thu				.85	.82	.86	.83	.87	.89	.77	.78
3			Wed	Thu	Fri			.84	.78	.86	.84	.87	.87	.74	.74
3				Thu	Fri	Sat		.83	.76	.86	.87	.89	.90	.77	.79
3					Fri	Sat	Sun	.85	.82	.87	.87	.89	.91	.80	.82
3	Mon					Sat	Sun	.85	.82	.85	.84	.86	.89	.78	.79
3	Mon	Tue					Sun	.84	.77	.86	.85	.87	.89	.76	.77
4	Mon	Tue	Wed	Thu				.92	.90	.93	.92	.94	.95	.89	.90
4		Tue	Wed	Thu	Fri			.92	.90	.92	.91	.92	.94	.88	.88
4			Wed	Thu	Fri	Sat		.91	.87	.92	.92	.93	.94	.87	.87
4				Thu	Fri	Sat	Sun	.91	.87	.92	.91	.94	.95	.87	.88
4	Mon				Fri	Sat	Sun	.92	.90	.92	.91	.93	.94	.87	.88
4	Mon	Tue				Sat	Sun	.91	.87	.92	.91	.93	.93	.85	.86
4	Mon	Tue	Wed				Sun	.90	.86	.92	.93	.94	.95	.87	.88
5	Mon	Tue	Wed	Thu	Fri			.96	.96	.96	.96	.96	.97	.94	.95
5		Tue	Wed	Thu	Fri	Sat		.95	.94	.96	.96	.96	.97	.94	.95
5			Wed	Thu	Fri	Sat	Sun	.96	.94	.96	.95	.96	.97	.93	.93
5	Mon			Thu	Fri	Sat	Sun	.96	.94	.95	.95	.97	.97	.93	.94
5	Mon	Tue			Fri	Sat	Sun	.95	.93	.96	.95	.96	.96	.93	.93
5	Mon	Tue	Wed			Sat	Sun	.95	.93	.96	.96	.97	.97	.93	.93
5	Mon	Tue	Wed	Thu			Sun	.95	.94	.97	.97	.96	.97	.94	.95
6	Mon	Tue	Wed	Thu	Fri	Sat		.99	.98	.99	.99	.99	.99	.98	.98
6		Tue	Wed	Thu	Fri	Sat	Sun	.98	.98	.98	.98	.98	.99	.98	.98
6	Mon		Wed	Thu	Fri	Sat	Sun	.98	.98	.98	.98	.99	.99	.97	.97
6	Mon	Tue		Thu	Fri	Sat	Sun	.98	.98	.98	.98	.99	.99	.97	.97
6	Mon	Tue	Wed		Fri	Sat	Sun	.98	.98	.98	.98	.99	.99	.97	.97
6	Mon	Tue	Wed	Thu		Sat	Sun	.98	.98	.99	.98	.99	.99	.97	.97
6	Mon	Tue	Wed	Thu	Fri		Sun	.98	.98	.99	.98	.98	.99	.98	.98

Table 1. Adjusted R² for each day group combination. Green numbers indicate values ≥ .80, and yellow blocks indicate the minimum days needed to estimate the weekly average.

Number of days	L1		L5	
	Step Counts	Activity Counts	Step Counts	Activity Counts
1	.900	.872	.908	.899
2	.953	.938	.958	.955
3	.974	.966	.977	.975
4	.985	.981	.987	.986
5	.992	.990	.993	.993
6	.997	.996	.997	.997

Number of days	Waist		Wrist	
	Step Counts	Activity Counts	Step Counts	Activity Counts
1	.914	.929	.846	.857
2	.962	.968	.931	.935
3	.980	.983	.962	.964
4	.989	.990	.979	.980
5	.994	.995	.989	.990
6	.998	.998	.996	.996

Table 2. Intraclass correlation coefficients by number of monitoring days.