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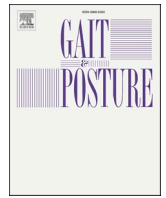
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Short Communication

How our homes shape the way we move

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ABSTRACT

Background: Human movement within the home remains poorly understood despite growing interest in smart environments and aging-in-place technologies. Investigating walking behavior within domestic spaces, which are subject to specific constraints and obstacles, may reveal significant differences from outdoor walking and provide a deeper understanding of human-environment interactions in indoor settings.

Methods: We present a four-year longitudinal study of natural indoor walking behavior, conducted using proximity-sensitive flooring in a smart apartment located in Montpellier, in southern France. Eight participants, organized into pairs, were monitored to observe their natural indoor walking behavior.

Results: The data, processed through algorithmic analysis, enabled the characterization of walking behavior indoors. By analyzing 2.5 million steps and over 346,000 individual walking trajectories, we show that indoor locomotion is fragmented, variable, and strongly constrained by the environment.

Conclusion: Though step counts were lower than in public spaces, home-based walking comprised a meaningful share of daily activity. Changes in walking patterns may serve as early indicators of functional decline, offering new avenues for health monitoring and smart home design.

1. Introduction

Walking has been widely studied in outdoor and lab settings [1], where it tends to be linear and optimized for efficiency. In contrast, indoor walking — especially at home — is spatially constrained and embedded in daily routines. It not only reflects mobility but also reveals how individuals interact with their surroundings [2], organize activities [3], and sustain independence [4]. Yet, no longitudinal data exist on real-world indoor walking patterns. However, studies converge to show that the reduction and complexity of walking space — whether it be a narrow corridor, a short route, or a furnished environment — lead to a decrease in fundamental locomotor parameters, particularly stride length, speed, and dynamic regularity [5–7].

To address this, we conducted a four-year study in a 72 m² smart apartment in Montpellier, France (Fig. 2A). Using a proximity-sensitive floor, we unobtrusively tracked walking behavior of eight adults living in pairs, across nine months per pair (Fig. 2B), generating over 346,000 walking trajectories and 2.5 million steps. We present a detailed quantification of indoor walking in real-life conditions, including step count, walking time and distance, speed, and temporal patterns. Findings show

walking indoors is fragmented, variable, and closely shaped by environmental and temporal constraints — offering insights for smart home design and understanding movement in context.

2. Materials and methods

2.1. Study design and participants

This four-year study (2018–2022) was conducted as part of the *HUMAN at home project* (HUT). Each academic year (September–June), a pair of participants lived for nine months in a fully equipped smart apartment in Montpellier, France. Eight adults ($Mean_{age} = 23.3$ years, $SD = 2.7$) participated in total. All dyads were female except one mixed-gender pair in the third year. Participants were selected through a competitive application process led by the HUT committee. They were informed about the sensing systems and gave written consent. No behavioral instructions were given; participants were simply asked to live their daily lives as usual. Monthly individual and pair interviews provided qualitative insights. To ensure anonymity, data were pseudonymized and participants referred to alphabetically (e.g., Ana & Bea,

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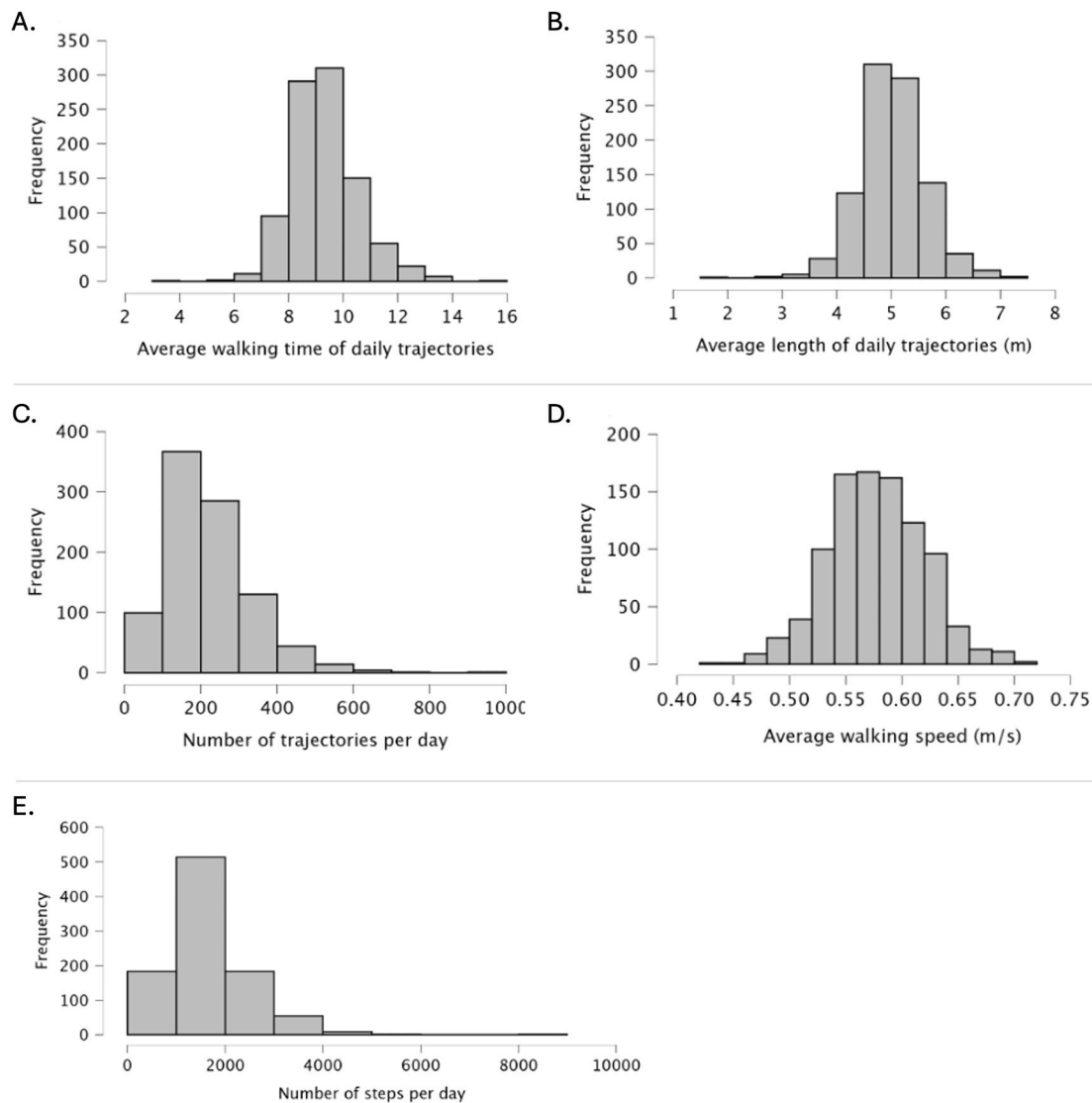


Fig. 1. Histograms of walking data distribution. (A) Average walking time – duration – for daily trajectories. (B) Average length of daily trajectories. (C) Number of trajectories per day in the apartment. (D) Average walking speed in the apartment. (E) Number of steps per day.

Cathy & Dany).

2.2. The smart home environment

The apartment includes an entrance hall, corridor, living room-kitchen area, bathroom, separate restroom, two private bedrooms, and one shared office. The home was outfitted with various connected technologies, and most importantly for this study, an intelligent flooring system called SensFloor [8], embedded beneath the flooring (see [Supplementary material](#) for details).

2.3. Calibration and validation of measurements

SensFloor uses capacitive proximity sensors that work in binary mode. A specific calibration phase was conducted, comprising (i) *ex-situ* pre-tests performed on a prototype of the sensor system, testing scenarios of presence, absence, and movement and establishing the expected response—capacitance loss, conductive presence—of the signal around the capacitive threshold; (ii) *in situ* accuracy tests, where signals were synchronized with video recordings and time measurements to verify their correspondence with real events. The data was then cleaned—by removing overactivations, correcting zero values, and filtering

artifacts—to ensure the accuracy and internal consistency of the measurements before processing [9].

2.4. Data processing and locomotor metrics

We developed a custom pipeline, the Walk@Home algorithm, to reconstruct walking trajectories and extract key behavioral metrics (See Ref. [9] for more details). These included: (1) walking speed (mean, variability); (2) daily distance walked; (3) trajectory length and duration (mean, variability); (4) number of trajectories and steps per day; and (5) total walking time. To estimate individual-level data, daily values from double occupancy were halved (except for speed and trajectory-level averages). All data were time-stamped, enabling temporal analyses by weekday and month. Daily metrics were aggregated into monthly or annual means or totals, depending on the variable.

2.5. Statistical analysis

Initial Shapiro-Wilk tests revealed that all variables, except mean speed ($P = 0.47$), were not normally distributed. A general statistical analysis (ANOVA for speed and Kruskal-Wallis for other metrics) across the four years showed significant year-based variation in all metrics

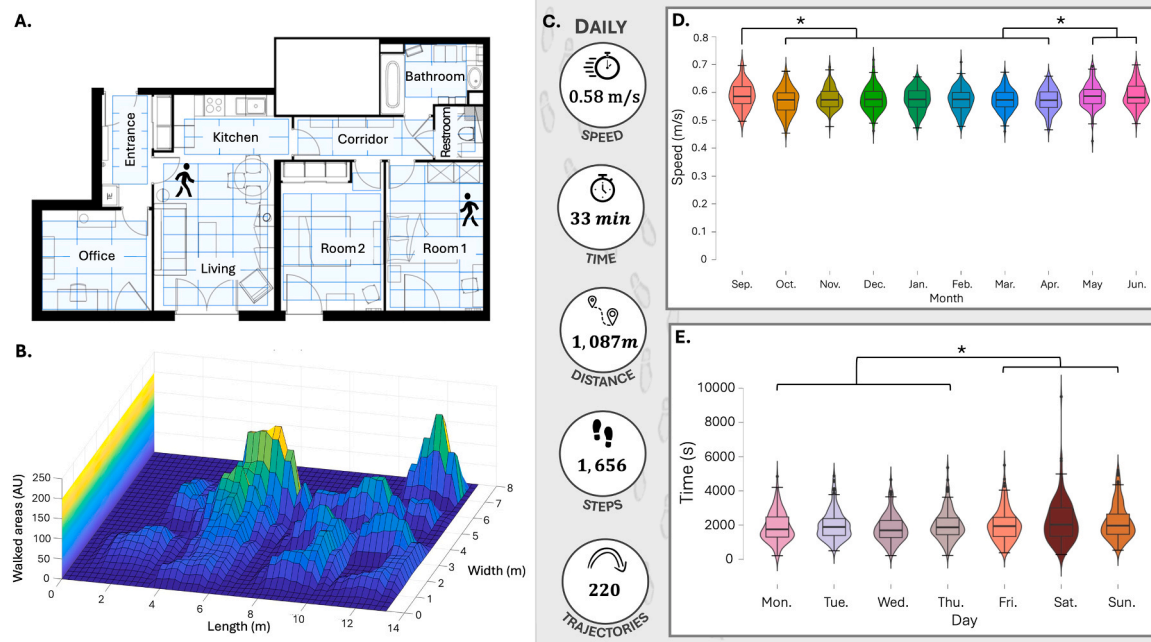


Fig. 2. View of the apartment and summary of main results. (A) Map of the apartment. (B) Walked areas in arbitrary units, computed from the number of foot contacts on the floor, over nine months of occupancy for one dyad (Year 1). (C) Daily walking parameters averaged across the four years of occupancy. Violin plots with box plot overlay of (D) daily walking speed over the nine months, and (E) daily walking time across the seven days of the week—both averaged across the four years. For (D) and (E), $N = 946$ independent data points, $** P < .01$.

($P < 0.05$), consistent with dyad-specific behavioral differences. Consequently, analyses were performed separately for each year. Temporal effects were tested across two factors: day of the week and month. Parametric ANOVA (with planned post-hoc comparisons) was applied to normally distributed metrics (e.g., speed), while non-parametric Kruskal-Wallis tests were used for other measures (with Mann-Whitney U tests for post-hocs).

2.6. Ethical compliance and privacy protocols

The study was conducted in accordance with the Declaration of Helsinki (1964) and approved by the Montpellier University ethics committee (CER-UM 2022-019). All participants signed detailed consent forms and data sharing agreements. The research team operated under strict non-disclosure protocols, ensuring anonymity about participants' identities, physical characteristics, and apartment address.

3. Results

3.1. Indoor locomotion is fragmented and spatially constrained

Over the four academic years, we recorded 346,447 walking trajectories, corresponding to an average of 220 trajectories per individual per day. These trajectories, though short — averaging 5.02 m in length and 9.34 s in duration — accumulated into substantial daily movement. On average, participants covered 1087 m and walked for 33 min per day, amounting to 391,718 steps per person per year. The observed walking patterns are highly fragmented, characterized by frequent, short transitions between functional areas (e.g. Fig. 1). Unlike outdoor walking, indoor walking is tightly linked to micro-tasks and spatial navigation around obstacles. Despite the average length of each trajectory being just five meters, the high frequency of movements resulted in a total average of 1656 steps per day (Fig. 2C).

3.2. Walking indoors is slower and context-dependent

The average walking speed was 0.58 m/s (SD = 0.22 m/s), significantly lower than typical walking speeds observed in outdoor settings (1.2–1.5 m/s) [10]. Monthly analysis showed a modest but significant variation in walking speed ($F(9,935) = 2.83$, $P < 0.05$), with faster speeds observed in temperate months (May, June, September) and slower speeds in colder months (October to April, Fig. 2D), post-hoc $P < .001$. This seasonal modulation of walking speed suggests that even within a controlled indoor environment, ambient temperature and seasonal context may influence motor behavior—mirroring findings from outdoor settings [11].

3.3. Seasonal and weekly modulation of activity

Locomotor activity varied significantly across months (Kruskal-Wallis, $H > 57$, $P < 0.01$ for all metrics), with September, November, December, and June showing the highest levels of activity in terms of distance walked, walking time, and number of trajectories (all Mann-Whitney $U > 85,462$, all $P_s < .01$). These peaks likely correspond to key transition periods: September and June involve move-in/move-out activities, while November and December include school breaks and holidays, with more time spent at home. On weekends (particularly Fridays through Sundays), participants tended to spend more time in the apartment, resulting in longer walking durations ($H = 13.55$, $df = 9$, $P < 0.05$, Mann-Whitney $U = 98,305$, $P < .01$, Fig. 2E), but also distance walked ($U = 99,187$, $P < .01$), and number of steps ($U = 99,124$, $P < 0.01$).

3.4. Our home as a high-frequency movement space

Despite spatial constraints and obstacles, the apartment supported over 2.5 million steps in four years. Although participants walked fewer steps at home (1656 daily) than in workplaces or malls (3742–5055) [12], indoor walking still comprised a significant share of daily activity. However, its health benefits may be limited due to low speed and high

fragmentation, which reduce cardiovascular intensity. Since only brisk steps count toward the recommended 10,000 daily steps [13], we estimate indoor walking contributes just 10–20 % toward this goal in terms of effective physical activity.

4. Conclusion

These findings highlight a distinct category of locomotion — neither exercise nor transport but ecologically situated navigation within lived space. Indoor walking is not a scaled-down version of outdoor gait, but a unique behavioral mode shaped by tasks, spatial layout, and routines. This study also demonstrates the value of passive, longitudinal monitoring for capturing not only movement quantity but its temporal structure, spatial logic, and variability. Understanding how people move at home opens new interdisciplinary avenues in human locomotion, architecture, health technology, and behavioral analytics. As homes evolve into smart environments, these insights can inform the design of spaces and technologies that promote safer, healthier, and more autonomous living.

CRedit authorship contribution statement

Benoît G. Bardy: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Mérodie Sannier:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Gérard Dray:** Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Stefan Janaqi:** Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

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Declaration of Competing Interest

The authors report no conflicts of interest in this work.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.gaitpost.2025.110089](https://doi.org/10.1016/j.gaitpost.2025.110089).

Data availability

Anonymized data of this 4-year longitudinal study can be accessed here: https://osf.io/sdneq/?view_only=0b94e28bb29349a49d39febaf4d59fc

References

- [1] M.C. Gonzalez, C.A. Hidalgo, A.L. Barabasi, Understanding individual human mobility patterns, *Nature* 453 (2008) 779–782, <https://doi.org/10.1038/nature06958>.
- [2] M. Sannier, S. Janaqi, G. Dray, P. Slangen, B.G. Bardy, Obstacles shape the way we walk at home, *Front. Comput. Sci.* 5 (2023) 1270520, <https://doi.org/10.3389/fcomp.2023.1270520>.
- [3] J.E. Arnold, E. Ragazzini, E. Ochs, A.P. Graesch, *Life at Home in the Twenty-first Century: 32 Families Open Their Doors*, ISD, 2012.
- [4] V. Rialle, F. Duchene, N. Noury, L. Bajolle, J. Demongeot, Health "smart" home: information technology for patients at home, *Telemed. J. E-Health* 8 (2002) 395–409, <https://doi.org/10.1089/15305620260353188>.
- [5] N.D. Gilson, G. Faulkner, M.H. Murphy, M.R.U. Meyer, T. Washington, G.C. Ryde, K.A. Dillon, Walk@ Work: an automated intervention to increase walking in university employees not achieving 10,000 daily steps, *Prev. Med.* 56 (5) (2013) 283–287.
- [6] C. Lo Zoppo, V. Belluscio, G. Vannozzi, Impact of walking path length on gait parameters during the 2-minute walk test in healthy young adults, *Biomechanics* 5 (4) (2025) 82.
- [7] A.H. Mason, A.S. Padilla, A. Peer, M. Toepfer, K. Ponto, K.A. Pickett, The role of the virtual environment on characteristics of over-ground locomotion in natural and virtual environments, *Int. J. Hum. Comput. Stud.* 169 (2023) 102929.
- [8] A. Steinhage, C. Lauterbach, SensFloor® and NaviFloor®: large-area sensor systems beneath your feet, in: N.-Y. Chong, F. Mastrogiovanni (Eds.), *Handbook of Research on Ambient Intelligence and Smart Environments: Trends and Perspectives*, IGI Global, 2011, pp. 41–55, <https://doi.org/10.4018/978-1-61692-857-5.ch003>.
- [9] M. Sannier, S. Janaqi, V. Raducanu, V. Barysheva, H.A. Haddou, S. Pla, G. Dray, B. G. Bardy, Extracting walking trajectories at home from a capacitive proximity sensing floor, *IEEE Sens. J.* 22 (2021) 3695–3703, <https://doi.org/10.1109/JSEN.2021.3051049>.
- [10] R.W. Bohannon, A.W. Andrews, Normal walking speed: a descriptive meta-analysis, *Physiotherapy* 97 (2011) 182–189, <https://doi.org/10.1016/j.physio.2010.12.004>.
- [11] S.P. Obuchi, H. Kawai, J.C. Garbalosa, K. Nishida, K. Murakawa, Walking is regulated by environmental temperature, *Sci. Rep.* 11 (2021) 12136, <https://doi.org/10.1038/s41598-021-91213-6>.
- [12] S.A. Clemes, S.E. O'Connell, C.L. Edwardson, Office workers' objectively measured sedentary behavior and physical activity during and outside working hours, *J. Occup. Environ. Med.* 56 (2014) 298–303, <https://doi.org/10.1097/JOM.000000000000101>.
- [13] C. Tudor-Locke, Y. Hatano, R.P. Pangrazi, M. Kang, Revisiting "how many steps are enough?", *Med. Sci. Sports Exerc.* 40 (2008) S537–S543, <https://doi.org/10.1249/MSS.0b013e31817c7133>.