Gendered Mobility Patterns in Île-de-France: Insights from High-Resolution GNSS Traces

Daniela Perrotta[1,*], Egor Kotov[1], Tom Theile[1], and Emilio Zagheni[1]

[1] Max Planck Institute for Demographic Research, Rostock, Germany
[*] corresponding author: perrotta@demogr.mpg.de

ABSTRACT

Mobility patterns reflect deep social inequalities, with gender shaping how people move through cities. Leveraging high-resolution GPS data from over 3,000 participants in the Île-de-France region, we analyze gendered differences in daily mobility at fine spatial and temporal scales. The dataset provides seven consecutive days of GNSS traces recorded every 2–3 seconds, linked to demographic and socioeconomic attributes and calibrated with population weights to ensure representativeness. We compute five mobility indicators—unique and core locations, radius of gyration, Shannon entropy, and immobility rate—disaggregated by gender and age group. Results show consistent gender gaps: women visit fewer unique (20%) and core (25%) locations, travel over smaller areas (668 m radius), display lower mobility diversity (0.22 entropy), and exhibit higher immobility rates (+0.25) compared to men. Differences peak among adults aged 25–44, corresponding to caregiving and work–life balance constraints. Income-stratified analyses reveal that gender disparities are largest in low-income communes, where men travel 1.4 km farther on average, while gaps narrow in higher-income areas. These findings demonstrate that socioeconomic context both structures overall mobility and amplifies gender inequality. By leveraging high-resolution, representative GNSS data, this study provides one of the most detailed assessments of gendered mobility in Europe, showing how structural and contextual factors jointly shape everyday movement patterns.

1. INTRODUCTION

Mobility is not gender-neutral. Across cities worldwide, patterns of movement—how far, when, and where people travel— are deeply shaped by social roles, access to resources, and safety concerns that vary systematically between men and women. Women's mobility often reflects caregiving responsibilities, constrained time use, and concerns over personal security, which translate into distinct spatial and temporal travel behaviors, often leading to shorter, more complex, and less flexible trips [1, 2]. These inequalities are especially pronounced for women in lower-income or informal employment, who face further barriers to affordable and accessible transportation [3].

Despite the importance of understanding mobility as a lens on gender inequality, studies on gendered mobility patterns have often been marginal or limited in scale. Traditional travel surveys are often limited by small samples, recall bias, and low temporal and spatial resolution [4]. Digital traces such as call detail records, transaction data, and social media have increasingly been used to reveal mobility disparities [5–8]. However, many existing analyses are constrained by coarse spatial resolution or unrepresentative samples, limiting their ability to fully capture how gender intersects with age, social roles and other demographic characteristics in shaping mobility.

To address this gap, we leverage high-resolution GPS traces to examine gendered mobility patterns in Île-de-France. We compute and analyze several individual-level mobility indicators—including the number of unique and core locations, radius of gyration, Shannon entropy, and immobile day rates—disaggregated by gender and adjusted using calibrated population weights. The granularity of GPS data enables a more precise characterization of spatial mobility patterns than mobile phone data, while population weights ensure representativeness. This approach enables a fine-grained and representative characterization of spatial mobility inequalities.

2. DATA

Mobility data We leverage a high-resolution dataset comprising individual-level mobility data collected in the Île-de-France (Greater Paris) region between October 2022 and May 2023. It covers 3,337 volunteer participants aged 16 to 80, who each carried a dedicated GPS tracker recording locations every 2-3 seconds over a continuous 7-day period and kept a trip log. The released data is organized in three linked parts: (i) an Individuals database with demographic, socioeconomic and household attributes; (ii) a Trips database with over 80,000 annotated displacements (with timestamps, transport modes, trip purposes); and (iii) a Raw GPS Traces database with about 500 million high-frequency points. A statistical weighting mechanism is provided for population-level inference, and thorough anonymisation ensures compliance with GDPR while preserving analytical value. The data were released as part of the NetMob 2025 Data Challenge (https://netmob.org/www25/datachallenge); further details are available in Ref. [9].

Income data Commune-level income data was derived from the INSEE Filosofi 2019 dataset [10], which provides income statistics on a variable-resolution "natural grid" with a maximum spatial precision of 200m in densely populated areas. To aggregate this data to the administrative commune level, each grid cell was first assigned to a commune based on the location of its representative point (point-in-polygon). Subsequently, the mean income from all grid cells assigned to a commune was calculated to produce a single, representative income value for that administrative unit.

3. METHODS

We analyzed high-resolution GPS trace to study gendered mobility patterns in Île-de-France at high spatial and temporal resolution. The dataset includes individual- and trip-level weights calibrated to regional sociodemographic profiles, ensuring representativeness. We computed five user-level mobility indicators:

- **Unique locations visited**: Number of distinct communes visited over the observation period.
- **Core locations visited**: Number of communes accounting for 80% of an individual's recorded activity, capturing routine spatial anchors.
- **Radius of gyration**: A measure of spatial dispersion, calculated as the root mean square distance from the user's center of mass. This is interpreted as a proxy for out-of-home

movement, given limited nighttime data. For an individual i with N GPS points $\vec{r}_j$, the radius of gyration is:

$$r_g = \frac{1}{N}\sqrt{\sum_{j=1}^{N} \| \vec{r}_j - \vec{r}_{cm} \|^2},$$

where $\vec{r_{cm}}$ is the center of mass (i.e., the average location) defined as $\vec{r}_{cm} = \frac{1}{N}\sum_{j=1}^{N} \vec{r}_j$.

- **Shannon entropy**: A normalized metric quantifying the unpredictability or diversity of visited locations. It is defined as: $S = -\sum_{l \in L} p_l ln_{p_l}$, where L is the set of locations visited by a user and p_l is the probability of the user being at location l, calculated as the fraction of visits to l. A higher S indicates that a user distributes visits more evenly across multiple locations, whereas a lower S reflects greater regularity with a smaller set of frequently visited locations [11].
- **Immobility rate**: The proportion of immobile days over the total number of valid GPS-recorded days. Immobile days are defined as days with no recorded trips in the trip diary or a daily radius of gyration below 200 meters.

Metrics were computed per user, disaggregated by sex and age group, and weighted to ensure representativeness. We excluded out-of-region traces and duplicates, retaining 308 communes. To control for local composition and context, gender comparisons were made at the commune level. Distributions were summarized with weighted statistics and visualized with bar and box plots. Paired t-tests compared men's and women's mobility within the same commune, accounting for local variation.

4. RESULTS

Our findings reveal consistent and systematic gender differences in individual mobility behaviors across communes in the Île-de-France region.

Unique and Core Locations We first examined gender differences in the total number of unique locations visited. Women tended to visit fewer distinct locations than men (see Fig. 1A). On average, women visited 23.64 communes (95% CI [22.29, 25.00]) compared to 28.30 communes for men (95% CI [26.32, 30.28]), a difference of 4.66 locations (95% CI [2.41, 6.91]; $p < 0.001$), corresponding to approximately 20% fewer visited locations. This gap was particularly pronounced among individuals aged 25–44, where men visited 7.87 more communes on average than women in the same age group (95% CI [4.25, 11.48]).

A similar pattern emerged for core locations, defined as those accounting for 80% of daily activity. Men visited on average 8.46 core locations, compared to 6.77 for women—a difference of 1.69 locations (95% CI [0.95, 2.44]; $p < 0.001$), representing a 25% increase. The largest differences were observed among individuals aged 25–44, where men averaged 2.60 more core locations than women (95% CI [1.40, 3.79]; Fig. 1B).

Spatial Extent and Diversity of Mobility Gender disparities were also evident in the spatial extent and diversity of mobility. Women exhibited more localized travel, with a radius of gyration on average 668.46 meters shorter than men (95% CI [99.56, 1237.36]; $p < 0.05$). This difference was particularly marked among individuals aged 25–44, where men's radius of gyration exceeded that of women by 1,258 meters (95% CI [361, 2,154]; Fig. 2A).

Moreover, women's trips were more concentrated among a smaller set of locations, as reflected in lower Shannon entropy scores: women averaged 0.22 points lower than men (95% CI [0.10, 0.34]; $p < 0.001$), indicating less spatial and probabilistic diversity in their routines (see Fig. 2B). Consistent with this finding, women spent more time at their most frequented locations. A frequency rank plot (Fig. 3) shows that women had higher visit probabilities for their first and second ranked locations, while probabilities were comparable between men and women from the third ranked location onward.

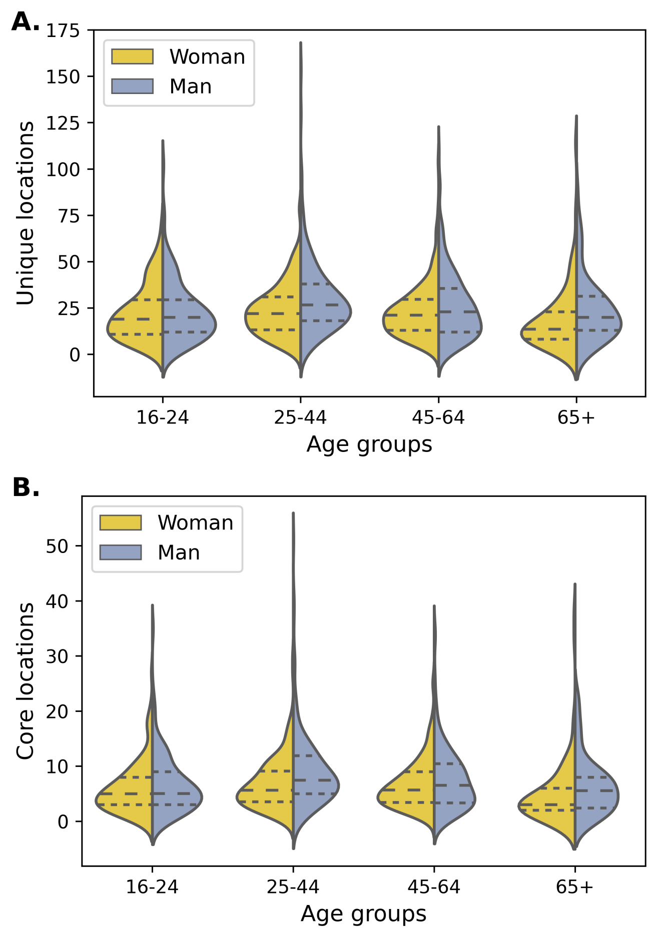

Fig. 1. Distributions of the number of unique locations (A) and core locations accounting for 80% of a user's activity (B), by gender and age.

Immobility Rates Women also experienced higher rates of immobility. Across the study period, the average immobility rate was 1.11 for women (95% CI [1.01, 1.20]) versus 0.86 for men (95% CI [0.76, 0.96]), with a difference of -0.25 (95% CI [-0.38, -0.11]; $p < 0.001$). Notably, the youngest participants (aged 16–24) exhibited the highest immobility rate overall (1.26, 95% CI [1.09, 1.42]), even compared to older adults aged 65 and above (1.09, 95% CI [0.89, 1.29]).

Income and Gender Disparities in Mobility To explore socioeconomic influences, communes were stratified into tertiles of median monthly disposable income, ranging from the lowest (Q1) to the highest (Q3). Fig. 4 shows the distributions of the radius of gyration by income tertile and gender. We found that the average radius of gyration decreased with income: individuals in the lowest-income areas (Q1) exhibited the widest spatial reach, while those in the wealthiest group (Q3) showed the shortest. Importantly, the gender gap was also largest in Q1, with men traveling on average more than 1,410 meters (95% CI [86.93, 2732.46]) further than women. This gap diminished for higher-

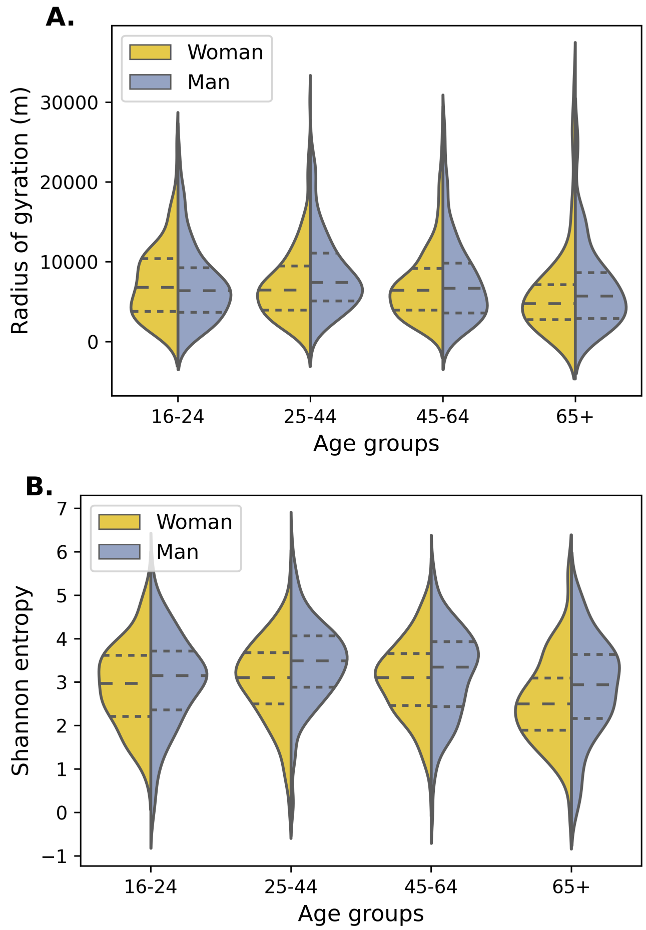

Fig. 2. Distributions of the radius of gyration (A) and Shannon entropy (B), by gender and age.

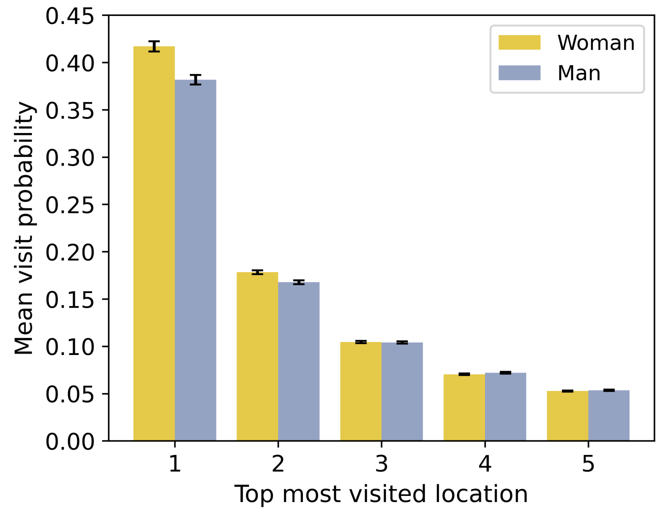

Fig. 3. Distributions of the mean probability of visiting the 5 most frequented locations of each user, by gender. Error bars correspond to the standard deviation of the mean.

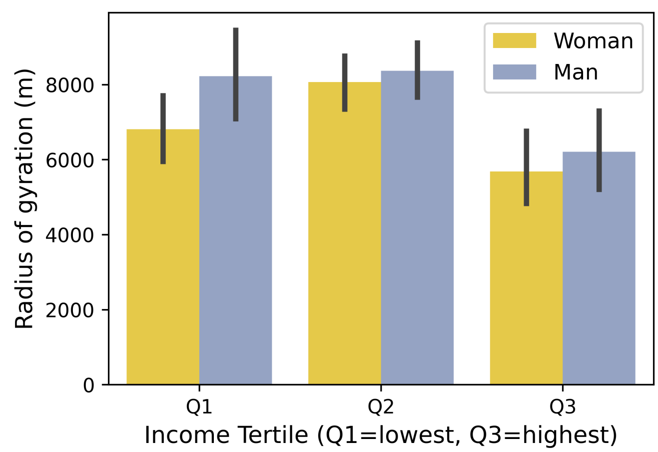

Fig. 4. Distributions of the radius of gyration, by income tertiles (Q1=lowest, Q3=highest) and gender. Error bars correspond to the standard deviation of the mean.

income tertiles. These results suggest that socioeconomic context not only shapes the overall extent of mobility but also amplifies gender inequalities in spatial behavior.

5. DISCUSSION

Our findings highlight systematic gendered patterns of spatial behavior that cut across life stages, with women consistently exhibiting more constrained and localized mobility. Across multiple metrics, women visited fewer unique and core locations, displayed shorter radii of gyration, and exhibited lower entropy in their mobility patterns compared to men. Women also showed higher rates of immobility, and these differences were particularly pronounced in early adulthood (ages 25–44), a period often associated with intensified household and caregiving responsibilities. Together, these results point to persistent structural inequalities related to access, autonomy, and daily responsibilities.

The income-stratified analysis further revealed how socioeconomic context interacts with gender disparities. While individuals in lower-income communes exhibited the widest spatial reach overall, the gender gap in mobility was also largest in these areas, with men traveling substantially further than women. By contrast, mobility extents were shortest among the wealthiest groups, and gender differences diminished substantially in high-income communes. These findings suggest that socioeconomic disadvantage not only shapes the scale of mobility but also exacerbates gender inequalities in spatial behavior.

Our results echo prior work by Gauvin et al. [5], which used mobile phone data to uncover gender differences in travel patterns in Santiago, Chile. We find similarly lower spatial mobility and more constrained activity spaces among women, reinforcing broader evidence of structural constraints on women's movement. Importantly, the GPS data enables us to capture these disparities with much higher resolution and local contextual detail, allowing for a finer-grained understanding of how gender and socioeconomic factors jointly shape mobility.

Building on these insights, next steps will extend this analysis in multiple directions. First, we will incorporate additional individual-level variables—such as education, household size and composition, and car ownership—to better capture how intersecting social and economic factors shape mobility. Second, we will analyze trip-level metrics including distance, duration, mode, and revisit frequency, alongside environmental factors like POI density and income gradients. We also plan to explore differences in travel mode and timing, including nighttime mobility, solo versus accompanied trips, and the use of public versus private transport—all of which are critical to understanding the gendered experience of urban space.

This dataset offers a rare combination of high spatial resolution and demographic representativity, enabling fine-grained analysis of gender disparities in mobility. We see this work as a step forward in an interdisciplinary research agenda to better understand—and ultimately address—the structural inequalities embedded in everyday mobility.

REFERENCES

1. A. Loukaitou-Sideris, Secur. journal **27**, 242 (2014).
2. D. Brown, G. McGranahan, and D. Dodman, *Urban informality and building a more inclusive, resilient and green economy* (JSTOR, 2014).
3. C. Tacoli, *Urbanization, gender and urban poverty: paid work and unpaid carework in the city* (Human Settlements Group, International Institute for Environment and . . . , 2012).
4. R. M. Groves, Int. J. Public Opin. Q. **70**, 646 (2006).
5. L. Gauvin, M. Tizzoni, S. Piaggesi, *et al.*, Humanit. Soc. Sci. Commun. **7**, 1 (2020).
6. D. Garcia, Y. Mitike Kassa, A. Cuevas, *et al.*, Proc. National Acad. Sci. **115**, 6958 (2018).
7. M. Lenormand, T. Louail, O. G. Cantú-Ros, *et al.*, Sci. reports **5**, 10075 (2015).
8. E. Jacobs, T. Theile, D. Perrotta, *et al.*, Popul. Dev. Rev. (2024).
9. A. Chasse, A. J. Kouam, A. C. Viana, *et al.*, "The netmob25 dataset: A high-resolution multi-layered view of individual mobility in greater paris region," (2025).
10. INSEE, "Revenus, pauvreté et niveau de vie en 2019 – données carroyées (au carreau niveau naturel) – dispositif fichier localisé social et fiscal (filosofi)," (2023). Institut National de la Statistique et des Études Économiques (INSEE), Ministère de l'Économie et des Finances, France.
11. C. Song, Z. Qu, N. Blumm, and A.-L. Barabási, Science **327**, 1018 (2010).