Physical activity, heart rate and sleep before and during the COVID-19 pandemic in 34 countries

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Abstract

Background: The COVID-19 pandemic disrupted behavior within populations, affecting physical activity (PA), heart rate (HR) and sleep characteristics in particular.

Objective: We analyzed the associations between the features of the COVID pandemic worldwide and PA, HR & sleep parameters, using data collected from wearable sensors over a three-year period.

Methods: We performed a retrospective analysis of data obtained from the Withings Steel HR activity trackers of 208,818 individuals from 34 countries, from 2019 to 2022. Key metrics analyzed included daily step counts, average heart rate and sleep duration. The statistical methods used included descriptive analyses, time-trend analysis and mixed models evaluating the impact of restriction measures, controlling for potential confounders such as sex, age and seasonal variations.

Results: We detected a significant decrease in physical activity, with a 12.3% reduction of daily step count over the three years. A 1.50% decrease in HR occurred during lockdowns, associated with the decrease in activity levels. In 2022, the global population had not returned to pre-pandemic physical activity levels, with a noticeable persistence of inactivity. Particularly, the proportion of sedentary individuals remained elevated compared to 2019, indicating that the impact of the pandemic on reducing physical activity has had lasting effects on populations worldwide. Sleep duration increased during restrictions, particularly in the countries with the most severe lockdowns.

Conclusions: The sustained decrease in physical activity and its physiological consequences highlight the need for public health strategies to mitigate the long-term effects of the measures taken during the pandemic. Despite the gradual lifting of restrictions, physical activity levels have not fully recovered, with lasting implications for global health. If similar circumstances arise in the future, priority should be given to measures for effectively increasing physical activity to counter the increase in sedentary behavior, mitigate health risks and prevent the rise of chronic diseases.

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Abstract

Introduction: The COVID-19 pandemic disrupted behavior within populations, affecting physical activity (PA), heart rate (HR) and sleep characteristics in particular. We analyzed the associations between the features of the COVID pandemic worldwide and PA, HR & sleep parameters, using data collected from wearable sensors over a three-year period.

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Discussion: The sustained decrease in physical activity and its physiological consequences highlight the need for public health strategies to mitigate the long-term effects of the measures taken during the pandemic. Despite the gradual lifting of restrictions, physical activity levels have not fully recovered, with lasting implications for global health. If similar circumstances arise in the future, priority should be given to measures for effectively increasing physical activity to counter the increase in sedentary behavior, mitigate health risks and prevent the rise of chronic diseases.

Keywords: Covid-19, pandemic, physical activity, step, activity tracker, public health, Withings

1 Introduction

On March 11 2020, the Director General of the World Health Organization (WHO) declared a global pandemic of COVID-19. By April 2023, more than 764 million cases had been confirmed and 6.9 million deaths had been reported worldwide (1). Governments implemented various non pharmaceutical interventions, including social distancing, quarantines, lockdowns, closures of offices and schools and various other restrictions that significantly altered everyday behavior. These interventions led to marked decreases in physical activity, by about 28%, and increased sedentary behaviors, posing major challenges to mental health (2–8).

A systematic review highlighted the beneficial effects of physical activity on physical and mental health during the first year of the COVID-19 pandemic (9). It showed that engaging in regular physical activity helped to mitigate the negative impact of pandemic-induced stress (9) and that inactive individuals had lower scores for well-being and higher levels of depression and anxiety than moderately active and active individuals. A large-scale meta-analysis of data for 1,853,610 adults revealed that rates of severe COVID were 34% lower, the risk of hospitalization was 36% lower and COVID-related mortality was 43% lower in subjects regularly engaging in physical activity than in their inactive peers (10).

Even before this pandemic, the WHO and other health bodies had issued warnings about the global decline in physical activity, particularly in high-income countries, and strong gender, territorial and financial inequalities (11,12). Insufficient activity increased by 5% (from 31.6% to 36.8%) in high-income countries between 2001 and 2016, indicating a pre-existing downward trend (13). This decline has been linked to increases in the risks of chronic diseases, such as cancers, cardiovascular diseases and diabetes, by approximately 20 to 30% (14–16). Conversely, one study showed that increasing the amount of moderate-intensity physical activity by 10, 20, or 30 minutes per day is associated with decreases in annual mortality of 6.9%, 13.0%, and 16.9%, respectively (17). The pandemic has drawn further attention to this public health issue, as physical activity levels plummeted (18) and sports participation dropped by 20% in France alone during the first lockdown of 2020 relative to the corresponding period in 2019 (19). In addition to health consequences, a systematic review has shown that physical inactivity is associated with higher healthcare costs, further underscoring the economic burden of insufficient physical activity (20,21). In response, the WHO has established a global action plan aiming to decrease rates of physical inactivity by 15% by 2030 through strategic objectives and specific actions (22).

Advanced digital health technologies, including activity trackers, have emerged as possible tools for monitoring and potentially enhancing physical activity and health metrics, including step counts, heart rate and sleep patterns (23). Such devices provide regular feedback, which may be instrumental for improving physical activity levels and overall health (24–29).

In this study, we investigated the changes in physical activity, sleep duration, and heart rate (HR) among users of wearable Withings Steel HR activity trackers from 34 countries during successive periods of the pandemic in which major public health policies were implemented. By measuring the variations of risk factors and making use of extensive user-generated data, in a real-life context, this study addressed the broader implications of the pandemic for lifestyle changes and health.

2. Methods

2.1 Study design

We performed a retrospective analysis of three datasets (Step, HR & Sleep datasets) collected from Withings Steel HR activity trackers. We included data from individuals with at least 1000 measures of the studied variables over the 3year-period, and compared countries with at least 100 individuals.

2.2 Ethical considerations

During registration for the Withings Health Mate app, all users give consent to the anonymous use of their data for research purposes. They can withdraw this consent at any time and request the deletion of all their data (30).

2.3 Reported outcomes for the study population

All self-reported data were provided at the time of registration to use the application. We collected available data from January 2019 onwards.

2.3.1 Sociodemographic and anthropometric data

The sociodemographic data studied included sex, age, and country of residence. The anthropometric data studied included height (cm), weight (kg) and body mass index (BMI = weight divided by height squared). Participants were classified on the basis of BMI as being underweight (<18.5 $kg.m^{-2}$), normal weight (18.5–24.9), overweight (25–29.9), or obese (≥30), in accordance with WHO guidelines (31).

2.4 Wearable data collection

2.4.1 Number of steps and minutes of activity

The activity tracker collects step data round the clock over 24-hour periods, with a reset occurring at midnight. The number of steps is aggregated for the entire preceding 24-hour period at the daily reset, and the median number of daily steps is then calculated for each individual. Based on a compendium, the tracker's algorithm detects activity throughout the day and provides the durations of low-intensity, moderate-intensity, and high-intensity activities (32). Workouts may be self-reported by users.

2.4.2 Heart rate

HR is measured in beats per minute, with one measurement every 10 minutes. The dataset was composed of aggregated data, with a mean value for each day and night. We considered the HR averaged during sleep to be the resting HR.

2.4.3 Sleep

The sleep data recorded include bedtime and wake-up time, time taken to fall asleep, total sleep duration, duration of deep and light sleep, and the number of sleep interruptions.

2.5 Wearable data processing and missing values

We analyzed data for individuals in five age classes (18-24, 25-39, 40-54, 55-64 and ≥65 years) and four BMI categories: underweight, normal, overweight, obese (31). Outliers were removed on the

basis of Z-score at the intra-individual level. A threshold of 4 was chosen, as values beyond this range are typically considered extreme in statistical analysis, reducing the influence of outliers while retaining most of the data. This choice was particularly appropriate given that step count data often do not follow a normal distribution, necessitating a more flexible approach to outlier detection (33).
The number of steps ranged from 0 to 60,000 steps. A number of steps equal to 0 indicates that the user connected their activity tracker to the application but did not wear the activity tracker. Each line for which 0 steps were recorded were excluded from further analysis. Using the median number of steps in 2019 (reference year), we classified individuals according to the Tudor-Locke categories: Sedentary (<5000 steps), Low Active (5000-7500 steps), Somewhat Active (7500-10,000 steps), Active (>10,000 steps) (29,30).

2.6 Statistical analysis

2.6.1 Physical activity levels (step dataset)

We first calculated the median daily step count for each individual across the entire follow-up period. The median values were chosen to minimize the influence of extreme values. We then computed the mean of these individual median step counts for each country and each year to assess overall trends.
Longitudinal changes in physical activity were analyzed using mixed-effects models, where the median daily step count was the dependent variable. The model included fixed effects (β), which represented factors influencing changes in step count, such as year, season, weekday, and biological gender. Random effects (u) accounted for individual variability and temporal factors, capturing within-subject correlations. The model equation was as follows:

$$Y_i = (\beta + \beta_i) + \alpha X + \epsilon$$

where Y_i represents the median number of steps for individual i, α is the coefficient associated with the X variable, β represents the intercept and β_i represents the random effect of the intercept of individual i, and ϵ is the residual error term. Reference categories were set to *Fall* (season), *Friday* (weekday), and *Man* (gender).

2.6.2 Heart rate

HR data were summarized using means and standard deviations for descriptive purposes, stratified by gender and lockdown status. We applied mixed-effects models to assess differences in HR across time and conditions, with *Man* and *No restrictions* used as reference categories. The models accounted for the hierarchical structure of the data by including individual-level random effects.

2.6.2 Sleep

Total sleep duration was described using means and standard deviations across different conditions. Mixed-effects models evaluated the impact of several variables, including gender (reference: *Man*), physical activity category (reference: *Active*), year (reference: *2019*), lockdown status (reference: *No restrictions*), and cyclical patterns such as season (reference: *Fall*) and weekday (reference: *Friday*).
An alpha risk of 0.05 was used in statistical tests.

3. Results

3.1 Characteristics of the participants

We collected 138,542,717 data for 208,181 activity tracker users from 34 countries around the world

(Figure 1). For the steps dataset, we analyzed 45,556,148 data points for 40,808 users from 34 countries. The study population was composed of 23,989 men (59%) and 16,819 women (41%) with a mean age of 47 years ± 12.6 years.

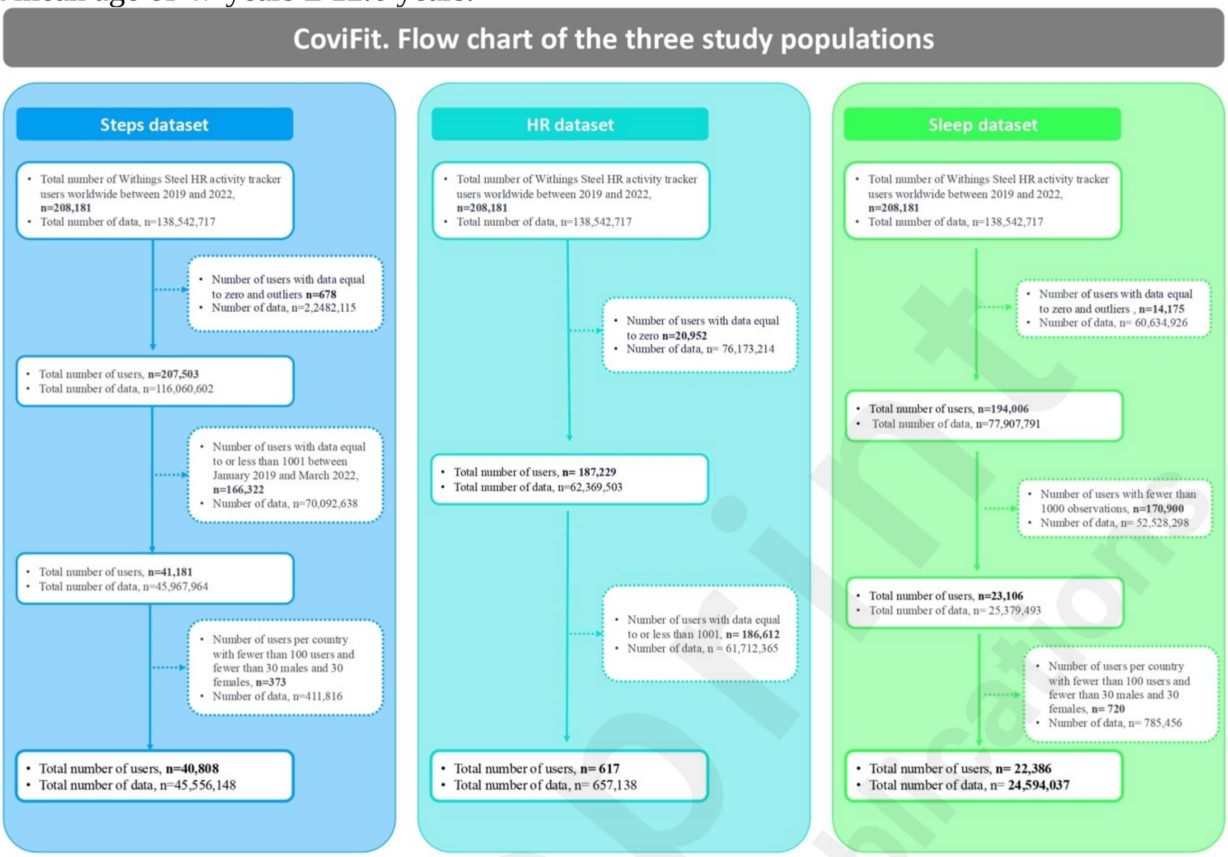


Figure 1: *Flow chart of the three study populations*

Various filters were applied to ensure that sufficient data, monitoring days and individuals were available in the country's database. After filtering, we performed a similar analysis on 22,386 users for the sleep dataset, and 617 users from the HR dataset (Figure 1).

3.2 Changes in the level of physical activity (steps dataset)

The median number of steps per day in 2019, before the pandemic, was 6,004 ± 4,270 steps per day. Changes in the median daily number of steps taken by individuals per country from 2019 to 2022 are shown in figures 2 and 3. Withings Steel HR activity tracker users were mostly located in Europe (primarily in France, Germany, and the United Kingdom), the United States and Japan (supplementary file Table 1).

Between 2019 and 2020, there was a significant decrease of 4 to 23% in the median number of steps taken daily (figure 3, supplementary file Table 2). Between 2019 and 2020, Romania (-23%) and Portugal (-20%) displayed the largest decreases in the median number of steps taken daily (supplementary file, figure 3 and table 2). Finally, a comparison of the first quarter of 2019 with the first quarter of 2022 revealed a significant decrease in the number of steps worldwide (-12.3%) particularly for Japan (-22.9%) and Romania (-19.4%), indicating that two years after the start of the pandemic, activity levels had not returned to their initial levels, particularly in these countries.

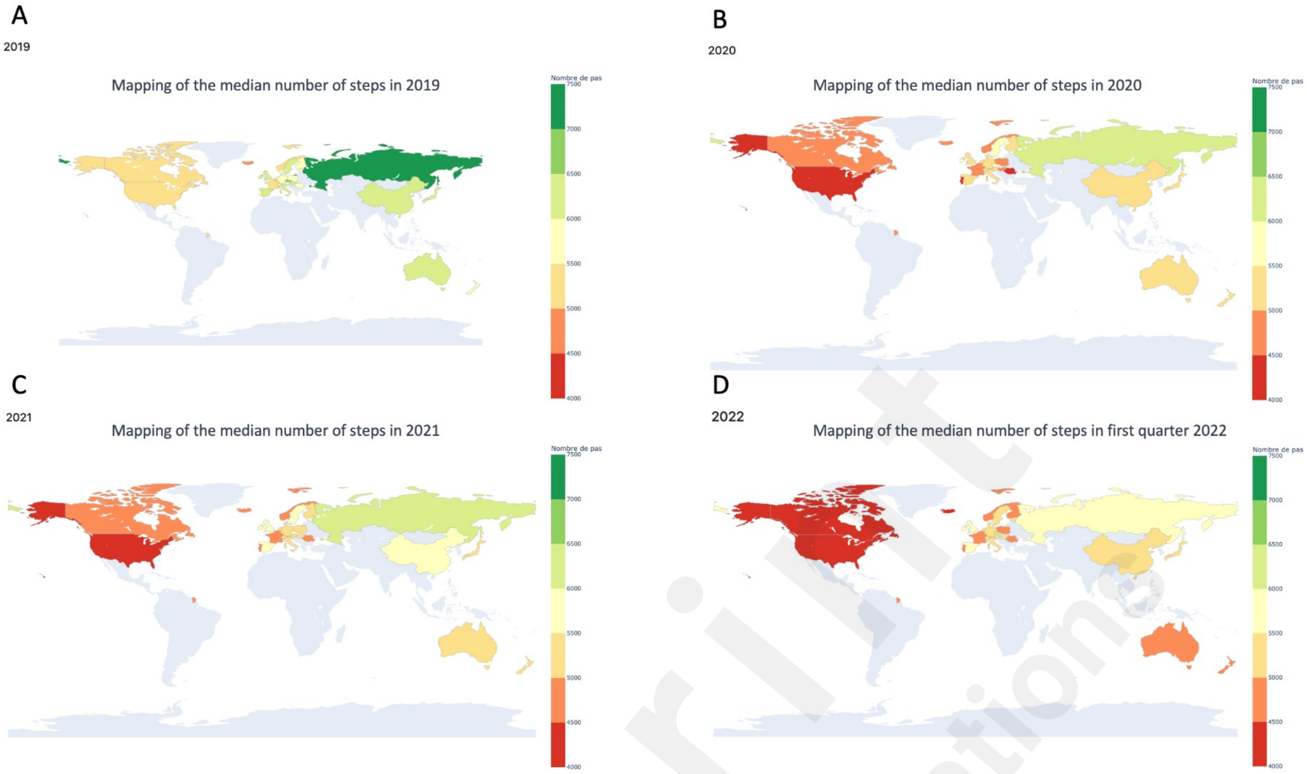


Figure 2: *Changes in the median number of steps taken by individuals, by country, between 2019 and the first quarter of 2022.*

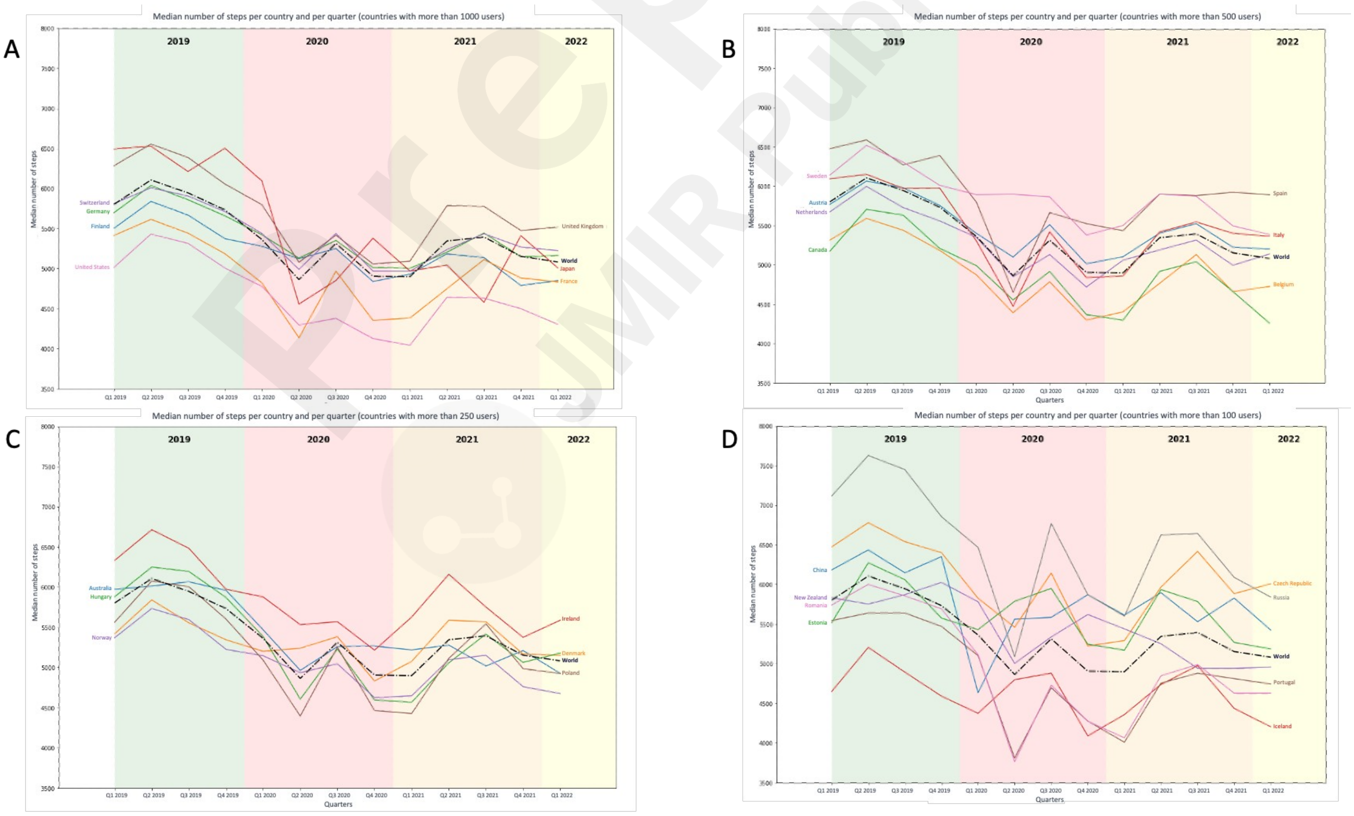


Figure 3: *Changes in the median number of steps taken by individuals, per year and per country, based on the number of users in the country (A) More than 1000 users; (B) From 500 to 999 users; (C) From 250 to 500 users; (D) From 100 to 250 users.*

The decline in the number of steps resulted in an increase in the proportion of sedentary individuals from 38% in 2019 to 52% in 2020; the proportion of sedentary individuals remained at 51% until the first quarter of 2022, with corresponding decreases in the proportions of the “low” and “somewhat” active categories (from 54% to 41%). The proportion of active individuals returned to its 2019 level (8%) at the beginning of 2022 (Figure 4).

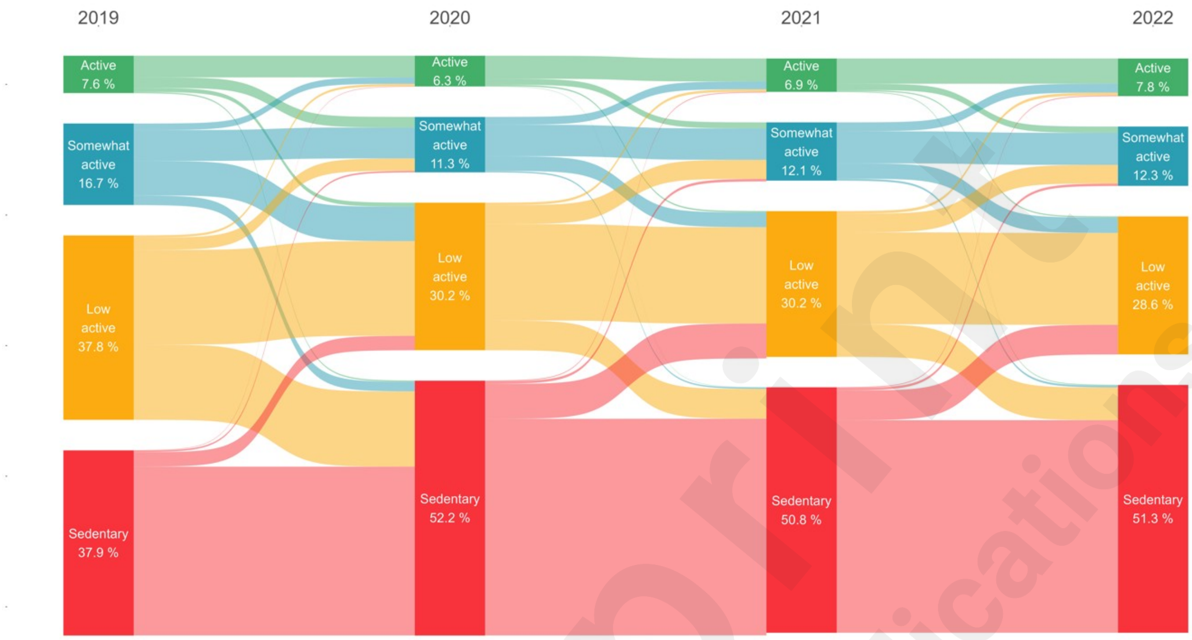
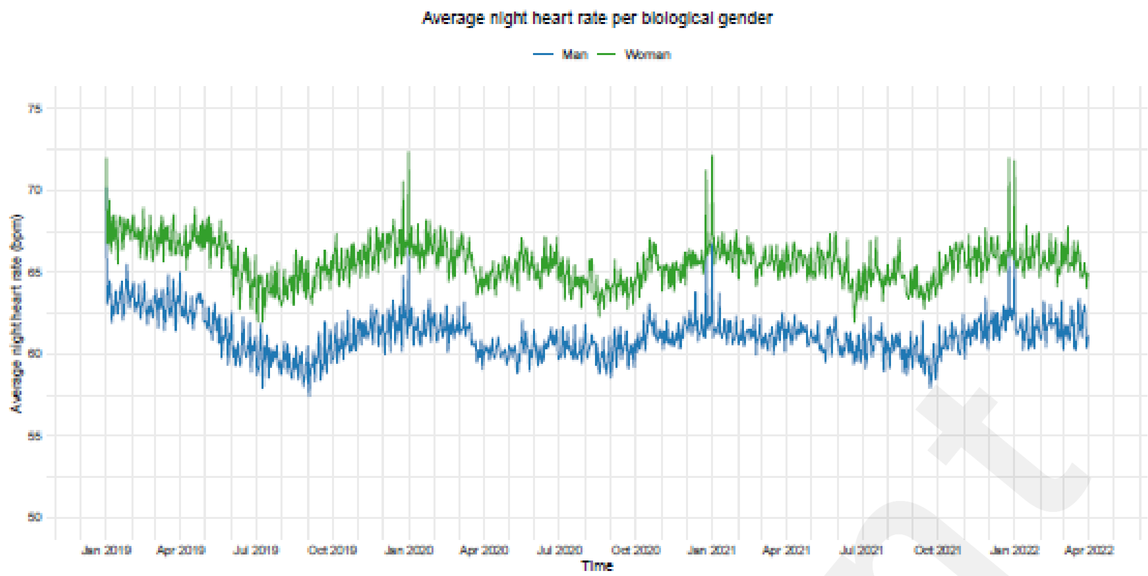


Figure 4: *Distribution of individuals within steps categories during 2019, 2020, 2021 and the first quarter of 2022*

We also observed: i) an expected seasonality, with users walking more during the summer (relative to Fall as the reference category: α_{Winter} = -82.3 ± 1.5, α_{Spring} = 191.1 ± 1.6, α_{Summer} = 264.2 ± 1.6); ii) Sunday was the day on which people around the world walked the least during the week (relative to Friday: $\alpha_{Saturday}$ = 274.8 ± 2.0, α_{Sunday} = -275.4 ± 2.0, α_{Monday} = -211.1 ± 2.0, $\alpha_{Tuesday}$ = -131.7 ± 2.0, $\alpha_{Wednesday}$ = -128.1 ± 2.0, $\alpha_{Thursday}$ = -100.5 ± 2.0); iii) men took more steps daily than women (relative to men, α_{women} = -108.3 ± 25.6).

3.3 Heart rate

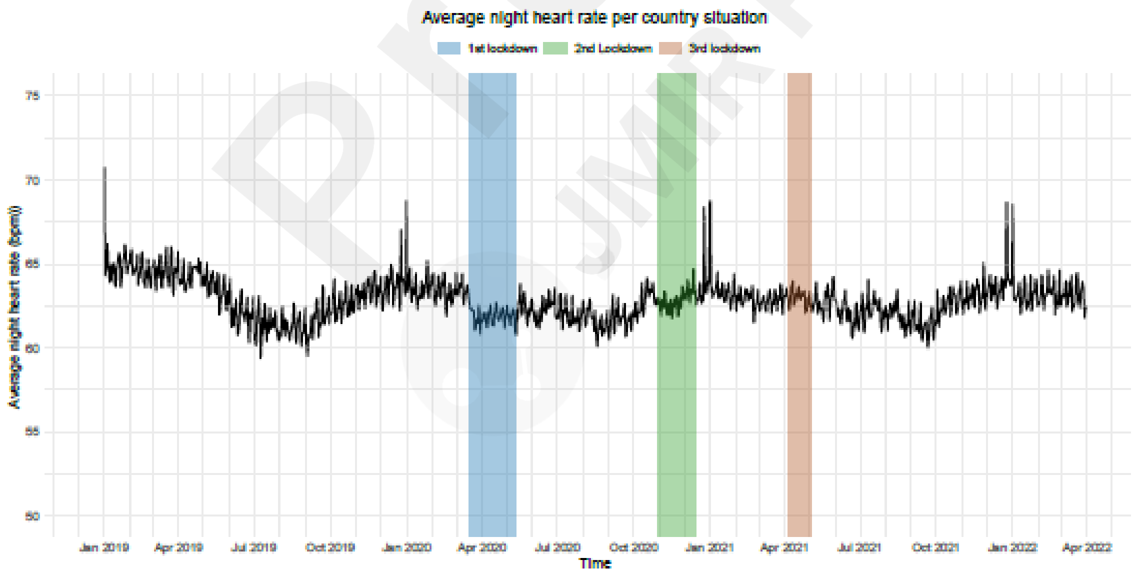
HR results for France (153 users: 95 men and 58 women) are shown in Figure 5. Mean nighttime HR was 62.8 ± 8.2 bpm in France. HR was higher in French women than in French men (65.6 ± 7.8 bpm vs. 61.1 ± 7.9 bpm, respectively) throughout the follow-up period.



gender	coef	sd	pvalue	star
Man	0.000000	NA	NA	REF
Woman	4.422085	1.094524	8.48e-05	***

Figure 5: *Daily mean nighttime heart rate in France, by sex*

Lockdowns were associated with a decrease in HR (Figure 6). Mean nighttime HR was usually 62.8 ± 8.2 bpm in France and 62.5 ± 8.0 throughout lockdown periods. Mixed model analysis showed that lockdown situations had a significant impact on resting HR (relative to No restrictions, $\alpha_{Lockdown} = -0.3 \pm 0.1$). Several cyclic patterns were also observed, with seasonal variations (HR higher in winter than in summer) and peaks related to Christmas or New Year celebrations (Figure 5 and 6).



lockdown_categ	coef	sd	pvalue	star
No restrictions	0.0000000	NA	NA	REF
Lockdown 1	-0.8467441	0.1575745	0.0000001	***
Lockdown 2	0.0953961	0.1714488	0.5780375	
Lockdown 3	0.1900731	0.2108466	0.3675235	

Figure 6: *Changes in mean nighttime heart rate in France over the period studied, with the lockdown periods indicated (blue: March 2020, green: November 2020, orange: April 2021)*

3.4 Sleep

The average total sleep duration for all countries was 7.5 ± 1.4 hours. Men slept 19.5 ± 0.6 minutes shorter than women. Active users also slept less than sedentary users (relative to active users: $\alpha_{somewhat\ active}$ = 4.1 ± 1.2, $\alpha_{low\ active}$ = 9.3 ± 1.1, $\alpha_{sedentary}$ = 13.0 ± 1.1). In 2019, mean sleep duration was 15 minutes shorter than in the other years (relative to 2019: α_{2020} = 15.7 ± 0.0, α_{2021} = 15.1 ± 0.0, α_{2022} = 17.0 ± 0.1). An increase in sleep duration of 4.8 ± 0.1 minutes was observed in countries implementing strict lockdowns (e.g. France, Italy, Spain).

Several cyclic patterns were observed in the variation of sleep duration. At the scale of a week, sleep duration was 30 minutes longer during weekends (relative to Friday: $\alpha_{Saturday}$ = 25.9 ± 0.1, α_{Sunday} = 32.6 ± 0.1, α_{Monday} = 0.8 ± 0.1, $\alpha_{Tuesday}$ = -0.8 ± 0.1, $\alpha_{Wednesday}$ = -0.4 ± 0.1, $\alpha_{Thursday}$ = -0.4 ± 0.1). At the scale of a year, sleep duration was longer in winter than in the fall, and significantly shorter in spring and summer (relative to Fall: α_{Winter} = 3.7 ± 0.0, α_{Spring} = -3.1 ± 0.0, α_{Summer} = -6.5 ± 0.0).

4. Discussion

4.1 Principal findings

Our study highlights a persistent decline in physical activity levels worldwide, with a significant 12.3% decrease in average step count from the first quarter of 2019 to the first quarter of 2022, even among active users. This decline persisted regardless of the stringency of the measures taken by the government or the severity of the pandemic in the country concerned. The pandemic, thus, had an impact on lifestyle behaviors that persisted two years later. In addition, the proportion of individuals with very low levels of physical activity increased considerably, from 38% in 2019 to 51% in 2020.

4.2 Physical activity changes

4.2.1 Physical activity decline

Our results indicate a less significant decrease in physical activity levels than reported in other studies conducted in different countries (3). A British cohort study demonstrated a 30% decrease in physical activity levels, whereas another study comparing Swiss and Brazilian participants found a 23.7% overall decrease in physical activity levels, with 31.6% of Brazilians and 15.8% of Swiss individuals displaying lower levels of physical activity (34). Furthermore, the impact of the pandemic on physical activity depended on pre-pandemic activity levels. In our study, the most affected groups in 2020 were those who were moderately or highly active before the restrictions were imposed. This finding is consistent with the results of a survey conducted across 14 countries that showed a 41% decrease in moderate-intensity activities and a 42% decrease in vigorous activities (5). However, the decline was particularly pronounced among those who were already less active, as they struggled to regain their pre-pandemic activity levels, making this group the most vulnerable and at higher risk of chronic deseases.

4.2.2 Age and sex inequalities

Previous studies have indicated a greater effect on physical activity decline on young adults than on older individuals (35–37), whereas two other studies reported the opposite finding (38,39). However, many studies showed that the individuals most affected by the pandemic were those with pre-existing health conditions, and those from lower socioeconomic groups (5,34). These groups often face greater challenges in maintaining their levels of physical activity due to greater health risks, limited access to exercise facilities, and other social determinants exacerbated during the pandemic. We found that physical activity levels were higher in men, but physical activity declined and sedentary behaviors increased in both sexes, with a stronger impact in women, as previously reported (16).

4.2.3 Seasonality

We found that both day of the week and season influenced physical activity levels: people were least active on Sundays and in winter (40,41). These results are consistent with other studies showing that physical activity levels typically decrease during winter due to colder weather, reduced daylight, and increased indoor activities, while higher levels are seen in summer (42,43). The alignment of our findings with established patterns in physical activity seasonality supports the representativeness and robustness of our data, as similar trends have been observed across various countries and populations. This seasonal variation in physical activity should be considered when interpreting the results and planning public health interventions aimed at increasing activity levels year-round.

4.3 Change in heart rate

Our results are consistent with previous findings showing that women generally have a higher resting HR than men (mean difference of 3 to 5 beats per minute), primarily due to physiological differences in heart size, hormonal influences, and autonomic regulation (44). Regular physical activity tends to lower resting HR by improving parasympathetic tone (45–47). The COVID-19 pandemic led to significant lifestyle changes, including a decrease in physical activity and an increase in stress, which can also affect resting heart rate and its variability. During infections, including COVID-19, HR tends to increase due to the immune and inflammatory responses generated by the body to fight infection, including an increase in metabolic rate and sympathetic nervous system activation (48). HR data from activity trackers are a potentially relevant metric for monitoring, identifying at-risk individuals, and assessing behavioral changes. For example, our data indicate a similar one-night increase in HR across the 34 countries studied on December 31, probably due to late-night partying and the consumption of alcohol (49,50).

4.4 Changes to sleep patterns

Several studies analyzing the impact of sleep on health have shown that too little sleep is associated with various negative health outcomes, including an increase in the risk of chronic diseases, such as obesity, diabetes, cardiovascular disease, and mental health disorders (51–53). Some researchers have further analyzed "sleep health" by quantifying sleep efficiency, sleep disturbances, and the time spent in the various phases of sleep (54,55). We have investigated the impact of the pandemic on sleep patterns (56,57). Some studies have reported no significant change (58), whereas others, including our own, have documented an increase in sleep duration (58–60).

Sleep duration tends to be longer during weekends and varies seasonally, being shorter in the summer and longer in the winter, due to variations in daylight exposure and social activities (61). The pandemic has led to an increase in sleep duration in many populations, probably due to more flexible work schedules resulting in decreases in commuting times, but deteriorations of sleep quality and altered sleep-wake cycles have also been reported. The differences in sleep patterns between the sexes in this study were consistent with published results, with differences in sleep timing preferences between the sexes, highlighting the importance of taking these differences into account in sleep analysis (62). An understanding of these patterns is crucial for the development of interventions to improve sleep health, particularly during disruptive events such as a pandemic.

4.5 Public health implications

One study assessed the impact of pandemic-related measures on the decrease in step count and its correlation with the emergence of chronic diseases and increases in overall mortality (17,63). This study, based on data collected from smart watches in 60 countries between January 2020 and January 2022, showed that a greater severity of restrictions was associated with lower step counts and a nonlinear increase in the modeled risk of all-cause mortality, by up to 40% (63). This finding highlights the significant health risk associated with decreases in physical activity during extended periods of lockdown, such as those experienced in Spain or France (3).
The ongoing global decline in physical activity is a major public health issue, as low levels have been linked to increases in the risk of chronic diseases, such as cancer, heart disease, and diabetes (14,17,64). Not only did the pandemic exacerbate physical inactivity in the population, it also contributed to a 2 kg increase in weight gain (65).
Long-standing habits of physical inactivity are notoriously difficult to change, as they are deeply ingrained in daily routines and influenced by multiple environmental and social factors. Research suggests that it can take years of sustained effort to increase physical activity levels across populations, and setbacks, such as pandemic-related lockdowns, can rapidly reverse these gains (66). These findings suggest that it may be time to develop efficient strategies for enhancing physical activity at multiple levels: individual, community, regional, national and continental. Such strategies are crucial, to mitigate the adverse health impacts of increasing sedentarity.

4.6 Study strengths and limitations

The use of digital health technologies, such as activity trackers, has emerged as a key strategy for monitoring and potentially improving health metrics. These tools provide users with real-time feedback, which can be instrumental in promoting physical activity (23–29). The data collected through such devices in our study provide valuable insight into the impact of the pandemic on physical activity, HR and sleep patterns, providing a model for the use of digital tools in public health surveillance and interventions. The integration of these findings into user-friendly platforms providing users with actionable insight could also increase the efficacy of these tools for promoting health and well-being.
This study highlights trends in physical activity among activity tracker users during the COVID-19 pandemic. One of its strengths is the extensive collection of real-life data from multiple countries worldwide, over a three-year period. The time period analyzed provides a full baseline year (2019) before the start of the pandemic. The detailed data granularity, large sample size, and inclusion of sociodemographic and anthropometric information make it possible to characterize the population accurately.

This study faces several limitations. First, it is important to acknowledge that the population of

Withings Steel HR activity tracker users may not be representative of the general population and its levels of physical activity, particularly in countries with low numbers of users. For example, wearable technology users may be more conscious of health issues, which could potentially bias the results. Second, we did not account for differences in the severity of the pandemic across different regions. Third, the influence of seasonality on the distribution of physical activity over the year makes it difficult to compare different countries. Additionally, the analysis for 2022 only includes data from the first quarter, which may introduce bias due to seasonal variations, as physical activity levels are generally lower in winter compared to other seasons. Fourth, the assessment of physical activity solely on the basis of step counts can introduce biases, especially in cases of a change in mode of transportation, such as an increase in cycling. Finally, this study did not examine specific types of physical activity, which may have a greater impact on health outcomes than step counts alone. We now need to develop user-friendly, broadly applicable algorithms that can capture information about physical activity levels and the duration of sedentary behaviors, making it easier to compare levels across different activities, such as cycling or walking.

4.6 Conclusions

The COVID-19 pandemic has significantly decreased global physical activity levels, especially among people who were inactive or sedentary before the pandemic. Our study of data for more than 200,000 activity tracker users in 34 countries, shows a significant decrease in physical activity, with a 12.3% reduction of daily step count over 2019 up to 2022. A 1.50% decrease in HR occurred during lockdowns, associated with the reduction in activity levels. Sleep duration increased during restrictions, especially in the countries with the most severe lockdowns. These findings highlight the urgent need for public health strategies to promote active lifestyles, to counteract sedentary behaviors and mitigate long-term health risks. Our findings highlight the importance of promoting physical activity as a key component of global health resilience during and after disruptive events, such as pandemics.

6 Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

7 Author Contributions

LD, NF, JFT, FR, VV, PV and AHP conceived and designed the study; LD and NF acquired the data; BW, AD and NB analyzed the data; BW, NF and LD wrote the original draft; all the authors revised the manuscript.

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Table 1. Characteristics of the study population in 2019, by country

Baseline characteristics (in 2019)	Australia (*n*=461)	Austria (*n*=554)	Belgium (*n*=847)	Canada (*n*=947)	China (*n*=167)	Czech Republic (*n*=196)	Denmark (*n*=413)	Estonia (*n*=151)	Finland (*n*=1,196)	France (*n*=9,800)	Germany (*n*=7,565)
Sex (*n*, %)											
Women	221 (47.94)	243 (43.86)	380 (44.86)	371 (39.18)	29 (17.37)	67 (34.18)	178 (43.1)	79 (52.32)	460 (38.46)	4495 (45.87)	3281 (43.37)
Men	240 (52.06)	311 (56.14)	467 (55.14)	576 (60.82)	138 (82.63)	129 (65.82)	235 (56.9)	72 (47.68)	736 (61.54)	5305 (54.13)	4284 (56.63)
Age (years) (mean, sd)	48 (13.36)	50 (13.51)	47 (12.84)	49 (13.96)	39 (10.08)	41 (12.1)	49 (13.6)	42 (9.73)	48 (12.82)	49 (13.53)	51 (12.81)
Age categories (years) (*n*, %)											
18-24	7 (1.52)	10 (1.81)	16 (1.89)	14 (1.48)	10 (5.99)	9 (4.59)	9 (2.18)	4 (2.65)	32 (2.68)	168 (1.71)	124 (1.64)
25-39	141 (30.59)	146 (26.35)	277 (32.70)	296 (31.26)	94 (56.29)	103 (52.55)	115 (27.85)	68 (45.03)	333 (27.84)	2980 (30.41)	1632 (21.57)
40-54	159 (34.49)	197 (35.56)	341 (40.26)	325 (34.32)	52 (31.14)	54 (27.55)	167 (40.44)	63 (41.72)	502 (41.97)	3620 (36.94)	2798 (36.99)
55-64	105 (22.78)	122 (22.02)	144 (17.00)	177 (18.69)	7 (4.19)	21 (10.71)	76 (18.40)	12 (7.95)	196 (16.39)	1795 (18.32)	2046 (27.05)
≥ 65	49 (10.63)	79 (14.26)	68 (8.03)	135 (14.26)	4 (2.40)	4 (2.04)	46 (11.14)	4 (2.65)	133 (11.12)	1234 (12.59)	965 (12.76)
BMI (mean, sd)	27 (5.09)	26 (4.93)	26 (4.33)	27 (4.86)	24 (3.29)	26 (4.73)	26 (4.49)	26 (4.94)	27 (4.67)	26 (4.51)	27 (4.75)

BMI categories (*n*,%)											
Underweight (<18.5 kg/m^2)	4 (0.87)	4 (0.72)	7 (0.83)	6 (0.63)	4 (2.4)	3 (1.53)	2 (0.48)	3 (1.99)	7 (0.59)	143 (1.46)	61 (0.81)
Normal weight (<25 kg/m^2)	226 (49.02)	282 (50.9)	431 (50.89)	430 (45.41)	118 (70.66)	87 (44.39)	195 (47.22)	72 (47.68)	557 (46.57)	5194 (53.0)	3417 (45.17)
Overweight (25-30 kg/m^2)	4 (0.87)	4 (0.72)	7 (0.83)	6 (0.63)	4 (2.4)	3 (1.53)	2 (0.48)	3 (1.99)	7 (0.59)	143 (1.46)	2720 (35.96)
Obese (>30 kg/m$^{2)}$	79 (17.14)	88 (15.88)	115 (13.58)	153 (16.16)	4 (2.4)	30 (15.31)	66 (15.98)	27 (17.88)	235 (19.65)	1314 (13.41)	1367 (18.07)
Number of steps (median)	6 005										
Sedentary	152 (32.97)	193 (34.84)	365 (43.09)	394 (41.61)	42 (25.15)	47 (23.98)	161 (38.98)	55 (36.42)	452 (37.79)	4169 (42.54)	2718 (35.93)
Low active	173 (37.53)	229 (41.34)	331 (39.08)	354 (37.38)	81 (48.5)	83 (42.35)	179 (43.34)	58 (38.41)	521 (43.56)	3611 (36.85)	2958 (39.1)
Somewhat active	96 (20.82)	84 (15.16)	111 (13.11)	137 (14.47)	30 (17.96)	41 (20.92)	49 (11.86)	23 (15.23)	158 (13.21)	1420 (14.49)	1276 (16.87)
Active	40 (8.68)	48 (8.66)	40 (4.72)	62 (6.55)	14 (8.38)	25 (12.76)	24 (5.81)	15 (9.93)	65 (5.43)	600 (6.12)	613 (8.1)

Table 1 Continued. Characteristics of the study population in 2019, country

Baseline characteristics (in 2019)	**Hong Kong (*n*=79)**	**Hungary (*n*=268)**	**Iceland (*n*=109)**	**India (*n*=56)**	**Ireland (*n*=252)**	**Italy (*n*=719)**	**Japan (*n*=1 948)**	**Mexico (*n*=67)**	**Nether lands (*n*=854)**	**New Zealand (*n*=143)**	**Norway (*n*=339)**
Sex (*n*, %)											
Women	17 (21.52)	71 (26.49)	63 (57.8)	9 (16.07)	100 (39.68)	202 (28.09)	402 (20.64)	18 (26.87)	382 (44.73)	76 (53.15)	145 (42.77)
Men	62 (78.48)	197 (73.51)	46 (42.2)	47 (83.93)	152 (60.32)	517 (71.91)	1546 (79.36)	49 (73.13)	472 (55.27)	67 (46.85)	194 (57.23)
Age (years) (mean, sd)	46 (11.05)	43 (10.98)	49 (11.83)	46 (13.35)	47 (12.81)	49 (12.6)	48 (11.13)	49 (14.73)	48 (13.22)	46 (13.32)	47 (13.13)
Age categories (years) (*n*, %)											
18-24	1 (1.27)	12 (4.48)	1 (0.92)	1 (1.79)	3 (1.19)	9 (1.25)	12 (0.61)	2 (2.99)	21 (2.46)	3 (2.10)	5 (1.47)
25-39	28 (35.44)	99 (36.94)	26 (23.85)	22 (39.29)	82 (32.54)	193 (26.84)	517 (26.54)	19 (28.36)	246 (28.81)	55 (38.46)	127 (37.46)
40-54	32 (40.51)	127 (47.39)	46 (42.20)	19 (33.93)	98 (38.89)	311 (43.25)	910 (46.71)	24 (35.82)	310 (36.30)	46 (32.17)	113 (33.33)
55-64	15 (18.99)	18 (6.72)	28 (25.69)	11 (19.64)	47 (18.65)	130 (18.08)	378 (19.40)	13 (19.40)	184 (21.55)	28 (19.58)	65 (19.17)
≥ 65	3 (3.80)	12 (4.48)	8 (7.34)	3 (5.36)	21 (8.33)	76 (10.57)	127 (6.52)	9 (13.43)	89 (10.42)	10 (6.99)	28 (8.26)
BMI (mean, sd)	24 (3.95)	26 (4.02)	28 (5.2)	27 (5.01)	27 (4.61)	25 (4.0)	24 (3.66)	27 (4.56)	26 (4.51)	27 (4.69)	26 (4.49)

BMI categories (*n*,%)											
Underweight (<18.5 kg/m^2)	2 (2.53)	2 (0.75)	0 (0.0)	1 (1.79)	2 (0.79)	10 (1.39)	59 (3.03)	0 (0.0)	13 (1.52)	0 (0.0)	3 (0.88)
Normal weight (<25 kg/m^2)	55 (69.62)	139 (51.87)	34 (31.19)	25 (44.64)	105 (41.67)	404 (56.19)	1325 (68.02)	24 (35.82)	432 (50.59)	60 (41.96)	174 (51.33)
Overweight (25-30 kg/m^2)	15 (18.99)	95 (35.45)	41 (37.61)	22 (39.29)	96 (38.1)	236 (32.82)	454 (23.31)	34 (50.75)	297 (34.78)	52 (36.36)	119 (35.1)
Obese (>30 kg/m$^{2)}$	7 (8.86)	32 (11.94)	34 (31.19)	8 (14.29)	49 (19.44)	69 (9.6)	110 (5.65)	9 (13.43)	112 (13.11)	31 (21.68)	43 (12.68)
Number of steps (median)											
Sedentary	10 (12.66)	81 (30.22)	59 (54.13)	26 (46.43)	71 (28.17)	227 (31.57)	530 (27.21)	28 (41.79)	307 (35.95)	46 (32.17)	132 (38.94)
Low active	31 (39.24)	112 (41.79)	37 (33.94)	20 (35.71)	95 (37.7)	281 (39.08)	716 (36.76)	25 (37.31)	358 (41.92)	58 (40.56)	142 (41.89)
Somewhat active	27 (34.18)	52 (19.4)	9 (8.26)	8 (14.29)	61 (24.21)	155 (21.56)	493 (25.31)	12 (17.91)	137 (16.04)	26 (18.18)	53 (15.63)
Active	11 (13.92)	23 (8.58)	4 (3.67)	2 (3.57)	25 (9.92)	56 (7.79)	209 (10.73)	2 (2.99)	52 (6.09)	13 (9.09)	12 (3.54)

Table 1 Continued. Characteristics of the study population in 2019, by country

Baseline characteristics (in 2019)	**Poland (*n*=331)**	**Portugal (*n*=245)**	**Romania (*n*=205)**	**Russia (*n*=144)**	**Singapore (*n*=73)**	**Spain (*n*=672)**	**Sweden (*n*=653)**	**Switzer land (*n*=1674)**	**Thailand (*n*=77)**	**United Kingdom (*n*=4057)**	**United States (*n*=5898)**	**Vietnam (*n*=21)**
Sex (*n*, %)												
Women	98 (29.61)	85 (34.69)	77 (37.56)	47 (32.64)	26 (35.62)	237 (35.27)	245 (37.52)	818 (48.86)	18 (23.38)	1635 (40.3)	2332 (39.54)	4 (19.05)
Men	233 (70.39)	160 (65.31)	128 (62.44)	97 (67.36)	47 (64.38)	435 (64.73)	408 (62.48)	856 (51.14)	59 (76.62)	2422 (59.7)	3566 (60.46)	17 (80.95)
Age (years) (mean, sd)	43 (10.29)	49 (13.48)	43 (11.38)	47 (12.42)	46 (10.66)	50 (13.19)	49 (12.69)	49 (13.66)	43 (11.37)	50 (13.29)	49 (13.78)	43 (8.58)
Age (years) categories (*n*, %)												
18-24	4	1	3	3	2	11	11	33	2	63	79	0
25-39	143	74	93	45	20	163	176	480	30	1053	1880	7
40-54	143	93	79	63	37	278	262	591	33	1501	1915	12
55-64	31	38	17	21	10	125	131	356	9	891	1190	2

≥ 65	10	39	12	12	4	95	69	213	1	549	834	23 (3.44)
BMI (mean, sd)	26 (4.5)	26 (4.04)	26 (4.35)	26 (4.55)	25 (4.13)	26 (4.15)	26 (4.69)	26 (4.61)	24 (3.91)	27 (4.76)	27 (5.16)	2 (9.52)
BMI categories (*n*,%)												
Underweight (<18.5 kg/m^2)	7 (2.11)	3 (1.22)	1 (0.49)	1 (0.69)	2 (2.74)	8 (1.19)	7 (1.07)	20 (1.19)	3 (3.9)	34 (0.84)	55 (0.93)	14 (66.67)
Normal weight (<25 kg/m^2)	163 (49.24)	133 (54.29)	104 (50.73)	70 (48.61)	45 (61.64)	361 (53.72)	312 (47.78)	902 (53.88)	57 (74.03)	1897 (46.76)	2490 (42.22)	5 (23.81)
Overweight (25-30 kg/m^2)	117 (35.35)	84 (34.29)	75 (36.59)	53 (36.81)	21 (28.77)	231 (34.38)	217 (33.23)	516 (30.82)	10 (12.99)	1431 (35.27)	2103 (35.66)	0 (0.0)
Obese (>30 kg/m$^{2)}$	44 (13.29)	25 (10.2)	25 (12.2)	20 (13.89)	5 (6.85)	72 (10.71)	117 (17.92)	236 (14.1)	7 (9.09)	695 (17.13)	1250 (21.19)	8 (38.1)
Number of steps (median)												
Sedentary	113 (34.14)	90 (36.73)	67 (32.68)	28 (19.44)	19 (26.03)	174 (25.89)	183 (28.02)	581 (34.71)	35 (45.45)	1203 (29.65)	2684 (45.51)	7 (33.33)
Low active	151 (45.62)	108 (44.08)	90 (43.9)	48 (33.33)	37 (50.68)	273 (40.62)	279 (42.73)	687 (41.04)	32 (41.56)	1468 (36.18)	2051 (34.77)	3 (14.29)
Somewhat active	43 (12.99)	32 (13.06)	32 (15.61)	37 (25.69)	14 (19.18)	142 (21.13)	124 (18.99)	273 (16.31)	8 (10.39)	922 (22.73)	799 (13.55)	3 (14.29)
Active	24 (7.25)	15 (6.12)	16 (7.8)	31 (21.53)	3 (4.11)	83 (12.35)	67 (10.26)	133 (7.95)	2 (2.6)	464 (11.44)	364 (6.17)	NaN

Table 2 *Change in the median number of steps relative to the same quarter in 2019*

		1st Quarter			2nd Quarter		3rd Quarter		4th Quarter	
Country	**n=**	Var Q1_20/Q1_19	Var Q1_21/Q1_19	Var Q1_22/Q1_19	Var Q2_20/Q2_19	Var Q2_21/Q2_19	Var Q3_20/Q3_19	Var Q3_21/Q3_19	Var Q4_20/Q3_19	Var Q4_21/Q4_19
Australia	461	-8.4%	-12.6%	-17.5%	-17.5%	-12.2%	-13.3%	-17.3%	-11.6%	-12.6%
Austria	554	-6.4%	-11.5%	-9.8%	-15.9%	-10.9%	-7.8%	-7.6%	-12.9%	-9.2%
Belgium	847	-8.3%	-17.2%	-11.1%	-21.4%	-14.8%	-12.0%	-5.7%	-17.1%	-10.1%
Canada	947	-3.5%	-17.0%	-17.7%	-20.2%	-13.8%	-12.7%	-10.5%	-16.1%	-10.5%
China	167	-25.1%	-9.2%	-12.3%	-13.6%	-8.4%	-9.2%	-10.1%	-7.6%	-8.2%
Czech Republic	196	-10.0%	-18.3%	-7.2%	-19.5%	-12.0%	-6.1%	-1.9%	-18.4%	-8.1%
Denmark	413	-4.0%	-6.3%	-4.9%	-10.3%	-4.3%	-3.1%	0.2%	-9.6%	-3.3%
Estonia	151	-1.6%	-6.3%	-6.0%	-7.7%	-5.4%	-1.8%	-4.6%	-5.9%	-5.5%
Finland	1,196	-4.1%	-10.4%	-11.8%	-12.2%	-11.2%	-7.4%	-9.4%	-10.0%	-10.9%
France	9,800	-10.9%	-19.0%	-10.7%	-26.3%	-15.4%	-8.7%	-6.1%	-16.0%	-5.8%
Germany	7,565	-4.8%	-12.2%	-9.4%	-15.0%	-13.8%	-8.7%	-7.1%	-11.4%	-9.0%
Hungary	268	-8.4%	-22.3%	-11.9%	-26.3%	-19.1%	-15.6%	-12.6%	-21.7%	-13.7%
Iceland	109	-5.9%	-6.3%	-9.6%	-7.8%	-9.0%	-0.3%	1.7%	-10.9%	-3.4%
Ireland	252	-7.2%	-11.1%	-11.7%	-17.6%	-8.3%	-14.1%	-11.3%	-12.7%	-10.0%
Italy	719	-13.0%	-20.2%	-12.0%	-27.2%	-11.9%	-9.2%	-7.1%	-19.0%	-9.6%
Japan	1,948	-6.2%	-23.5%	-22.9%	-30.2%	-22.7%	-21.9%	-26.3%	-17.3%	-16.8%
Netherlands	854	-5.7%	-10.8%	-9.4%	-19.1%	-13.5%	-10.4%	-7.2%	-15.1%	-10.1%
New Zealand	143	-0.9%	-6.7%	-15.0%	-13.0%	-8.7%	-9.1%	-15.8%	-6.7%	-18.0%
Norway	339	-4.2%	-13.4%	-12.9%	-13.9%	-11.1%	-9.8%	-7.9%	-11.5%	-8.9%
Poland	331	-8.5%	-20.4%	-11.5%	-27.6%	-15.8%	-12.5%	-7.7%	-20.3%	-11.0%
Portugal	245	-8.0%	-27.7%	-14.4%	-32.4%	-15.7%	-16.7%	-13.5%	-21.8%	-12.0%
Romania	205	-10.9%	-29.2%	-19.4%	-37.3%	-19.2%	-19.2%	-14.8%	-24.9%	-18.7%
Russia	144	-9.1%	-21.3%	-17.9%	-33.3%	-13.1%	-9.1%	-10.8%	-14.4%	-11.2%
Spain	672	-10.5%	-16.1%	-9.0%	-29.4%	-10.5%	-9.6%	-6.2%	-13.6%	-7.3%
Sweden	653	-4.1%	-10.4%	-12.3%	-9.5%	-9.5%	-7.0%	-6.9%	-10.5%	-8.6%
Switzerland	1,674	-6.4%	-14.5%	-10.1%	-16.9%	-12.8%	-7.9%	-8.0%	-13.0%	-7.7%
United Kingdom	4,057	-7.7%	-19.0%	-12.2%	-22.5%	-11.7%	-15.2%	-9.6%	-16.5%	-9.6%
United States	5,898	-4.7%	-19.4%	-14.2%	-20.9%	-14.5%	-17.6%	-12.9%	-17.6%	-10.1%
All countries	**40,808**	**-7.4%**	**-15.4%**	**-12.3%**	**-20.2%**	**-12.5%**	**-10.6%**	**-9.2%**	**-14.4%**	**-10.0%**

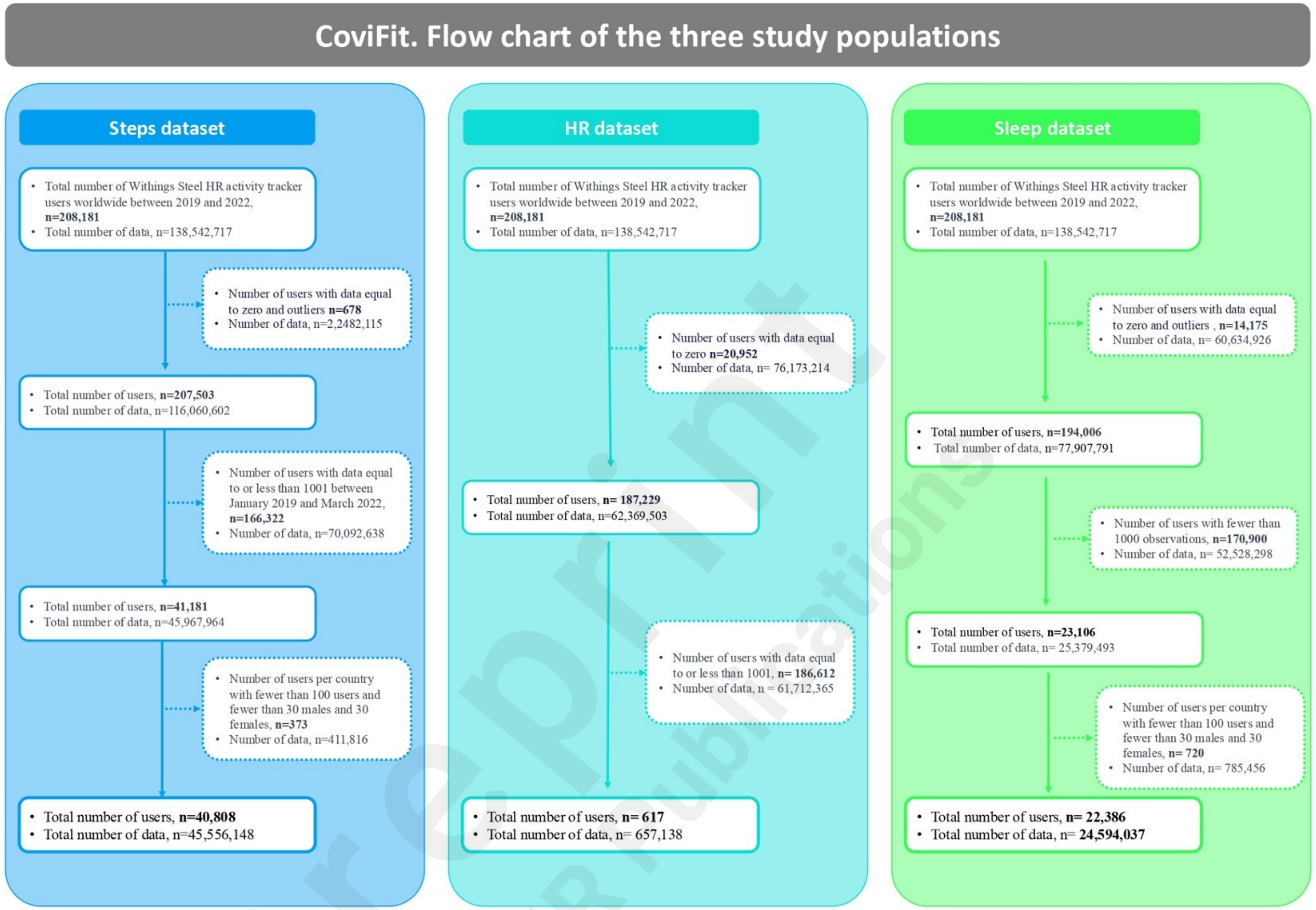


Figure 1: *Flow chart of the three study populations*

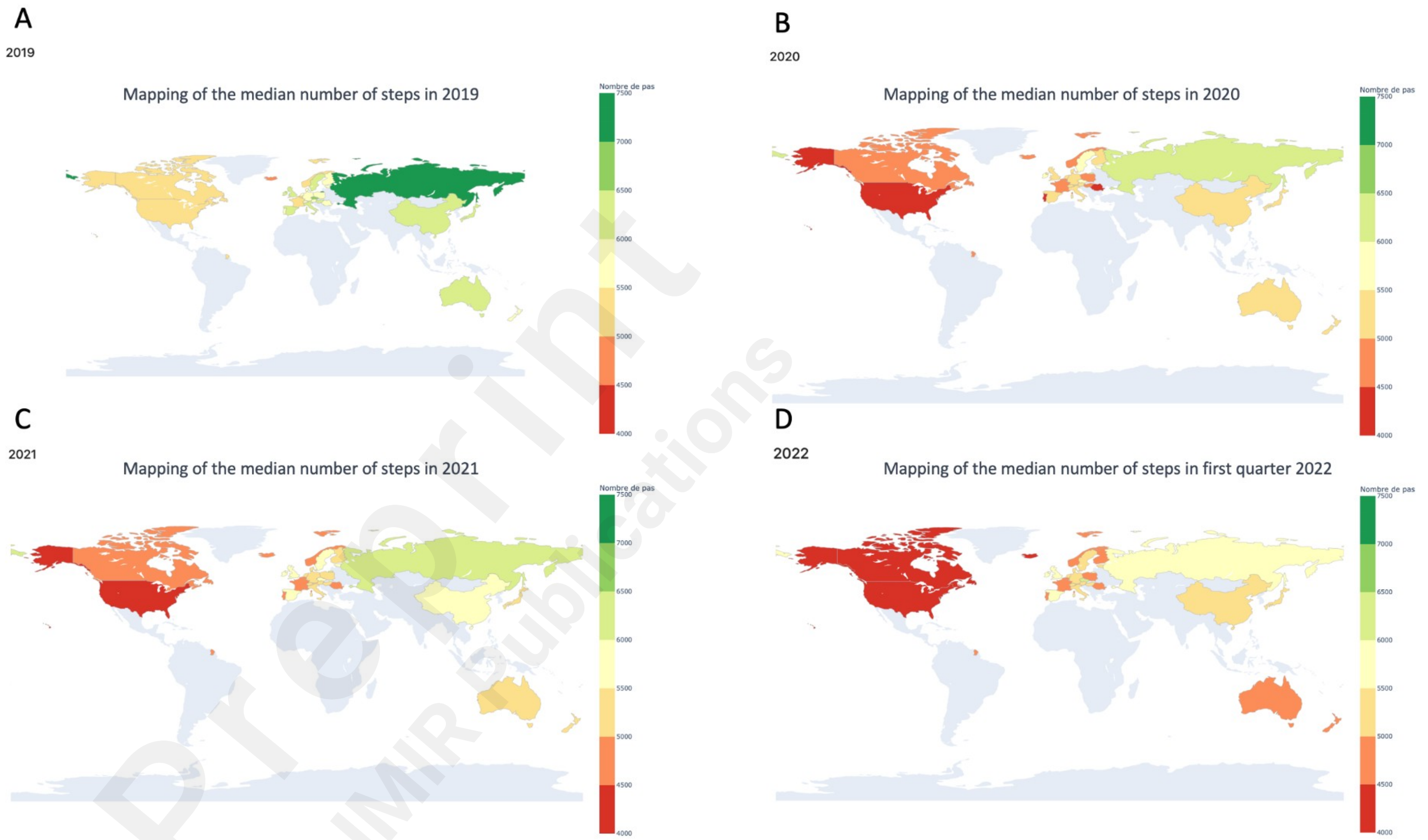


Figure 2: *Evolution of the median number of steps per country between 2019 and 2022*

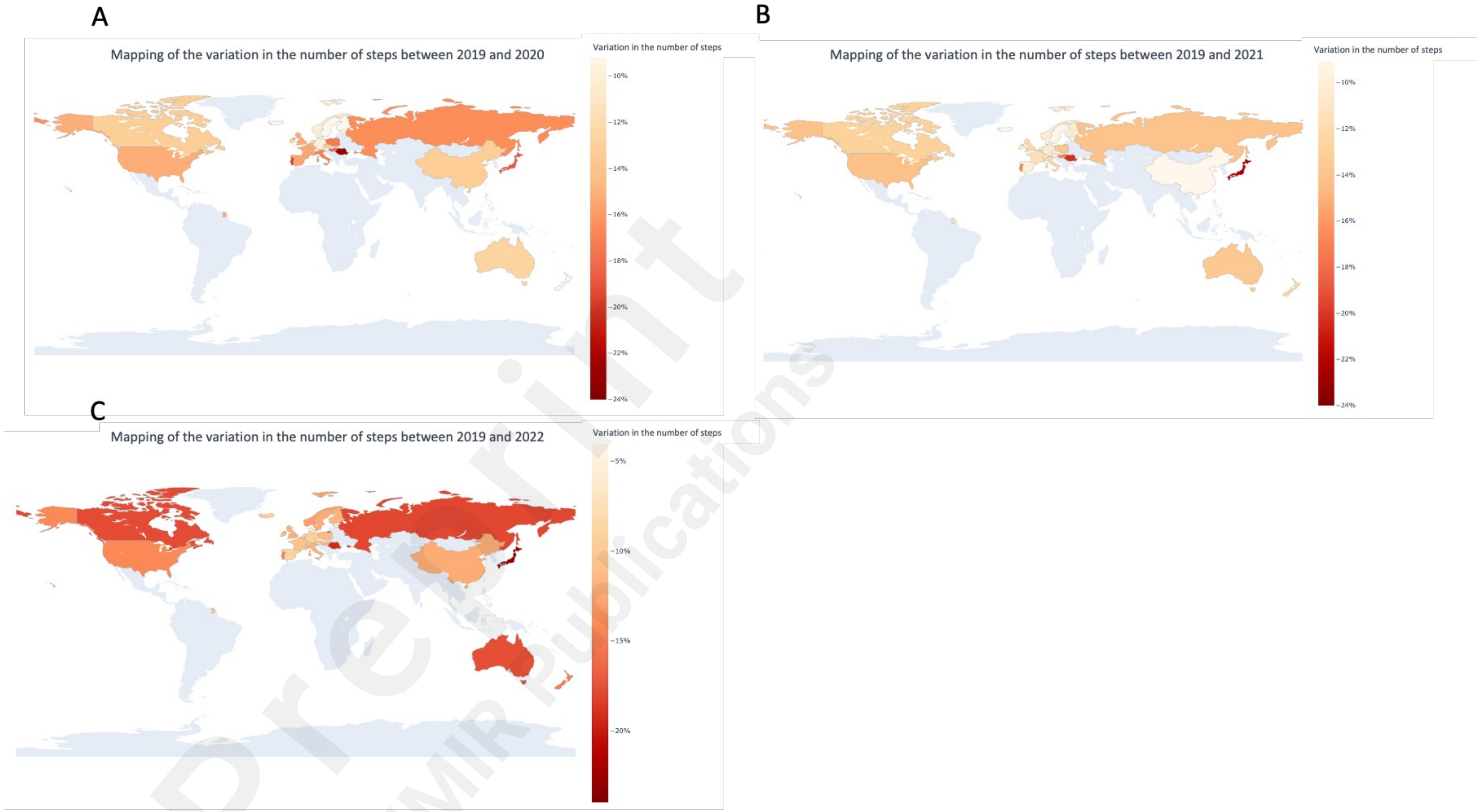


Figure 3: *Variation of the median number of steps per country per year compared to the pre-pandemic reference year (2019)*

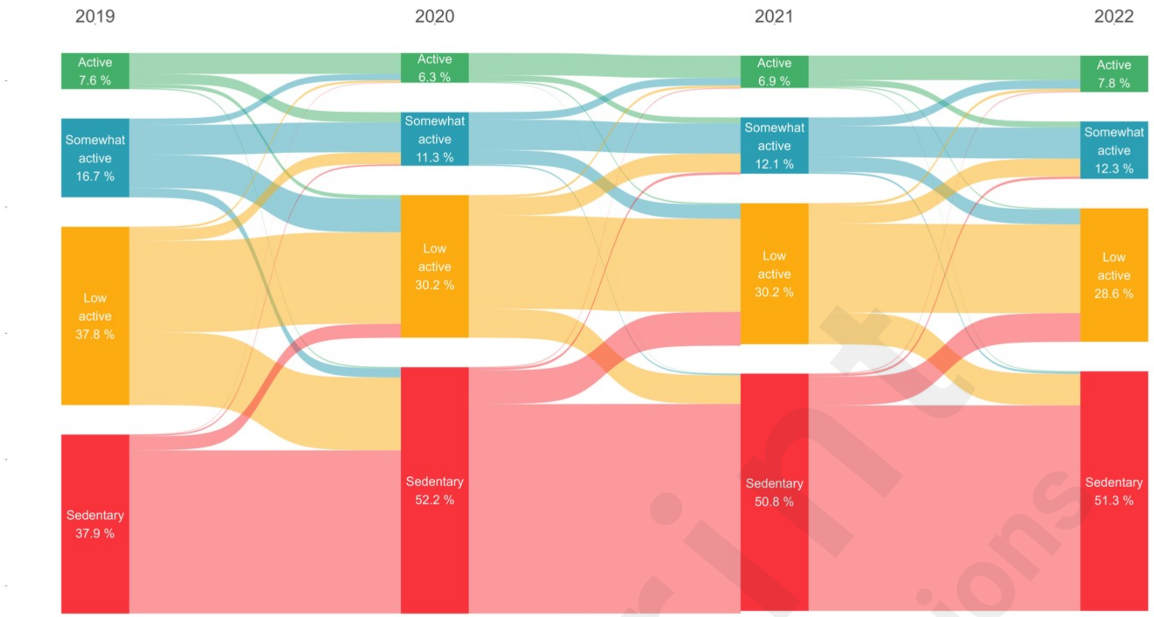


Figure 4: *Distribution of individuals within steps categories during 2019, 2020, 2021 and the first quarter of 2022*

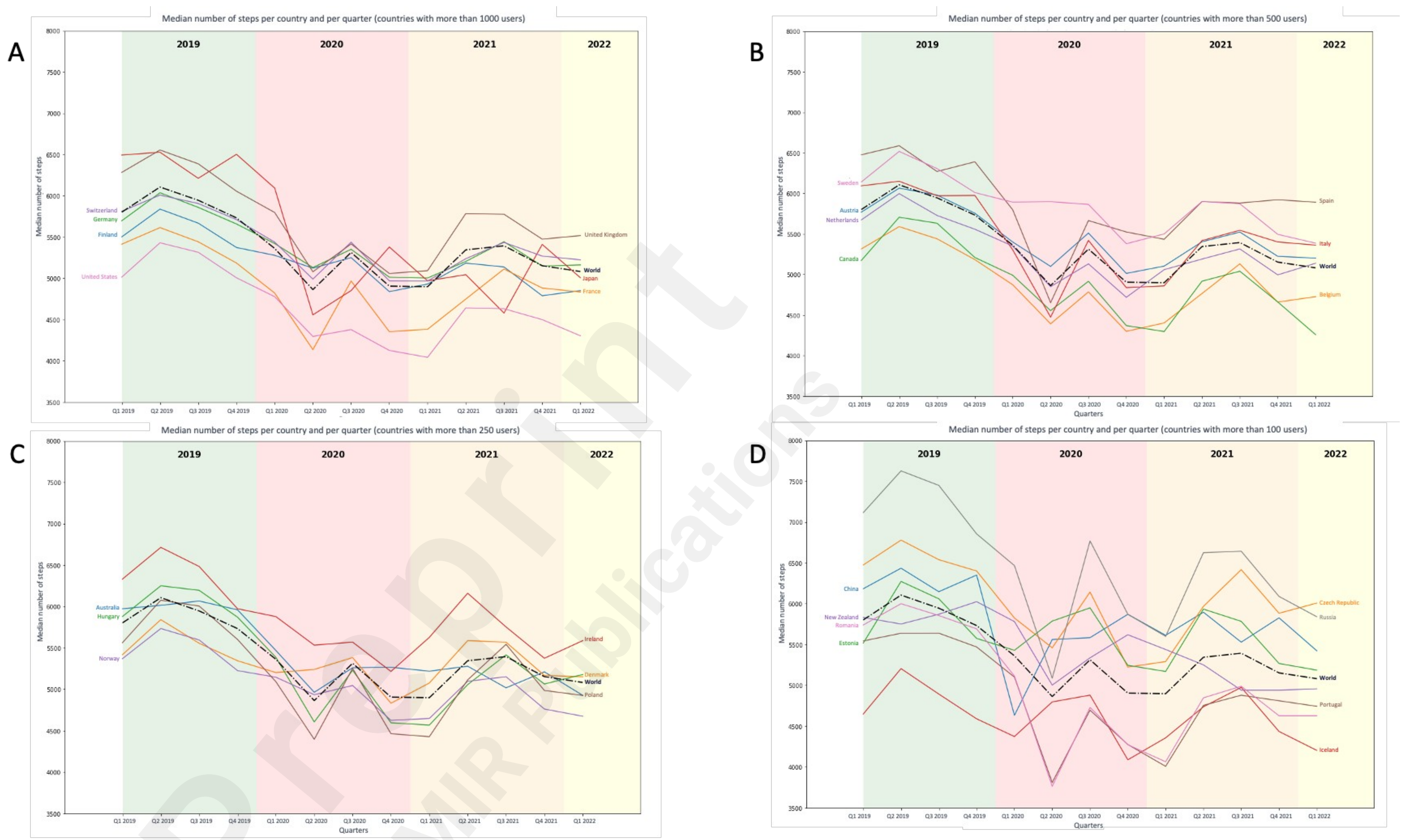
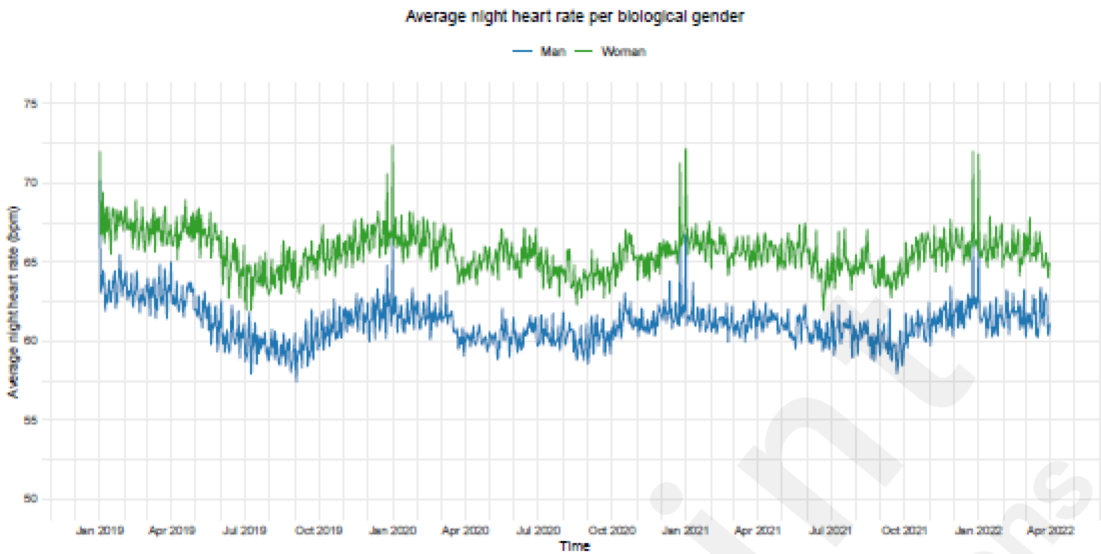


Figure 5: *Evolution of the number of steps per year and per country based on the number of users.*



gender	coef	sd	pvalue	star
Man	0.000000	NA	NA	REF
Woman	4.422085	1.094524	8.48e-05	***

Figure 6: *Daily average of night heart rate in France according to gender*

lockdown_categ	coef	sd	pvalue	star
No restrictions	0.0000000	NA	NA	REF
Lockdown 1	-0.8467441	0.1575745	0.0000001	***
Lockdown 2	0.0953961	0.1714488	0.5780375	
Lockdown 3	0.1900731	0.2108466	0.3675235	

Figure 7: *average of night heart rate in France variation throughout the follow-up with lockdown periods (blue: March 2020, green: November 2020, orange: April 2021)*