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Immobility and COVID-19: comparing mobility reduction among socio-demographic groups in a large German city during the pandemic

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Abstract

The COVID-19 pandemic and the public health measures imposed to tackle the spread of the virus have changed the everyday life and severely reduced the mobility of many. In this paper, we investigate the relationship between changed transport behavior and complex socio-demographic groups. Drawing on a survey on mobility and transport use during the pandemic for the Hanover region (Germany), we find three distinct clusters in our data related to changed mobility behavior: (1) people with no change in transport behavior, (2) people heavily reducing public transport use in the inner city, and (3) people reducing public transport use for their commute. In a second step, we use logistic regression models to understand the socio demographic factors determining each of these change patterns. The results show that women and younger participants were more likely to experience an impact on their travel behavior as well as reducing the use of inner-city public transport, while the reduction of commuter transport seems to be mostly homogeneous once controlled for teleworking. We also find a complex interplay between gender and other socio-demographic factors, especially caring responsibilities for children and student status, to have shaped the reported extent of mobility reduction. We show that we need to think about socio-demographic variables in a more complex way instead of perceiving of them as stand-alone variables. Our analysis hence helps to uncover the complex reality of mobility reduction during the pandemic, providing deeper insights into the (im)mobile reality of people's lives in times of COVID-19.

Keywords COVID-19 · Socio-demographic groups · (im)mobility · Transport behavior · Cluster analysis · Hanover region (Germany)

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Introduction

On 12th August 2022, the World Health Organization (WHO) reported 6,425,422 confirmed deaths worldwide from the novel coronavirus (SARS-CoV-2) (WHO Coronavirus Disease Dashboard [2022](#)), first discovered in China in late 2019. Especially during the first months of the pandemic (spring and summer 2020), public health measures such as social distancing and shutdowns altered daily routines in important domains, including childcare, work, and education, and disrupted mobility and transport at various scales (e.g., public transport limitations, suspended air travel) (Askitas et al. [2020](#); Hale et al. [2020](#)). Mobility reduction was a declared goal and direct outcome of the combined policies taken by multiple national governments to combat the spread of the virus.

Research shows that the pandemic has not been a level playing field, as not only has the virus affected different socio-demographic groups unequally (e.g., differentiated by age, ethnicity, income, gender) (Quan et al. [2021](#); Islam et al. [2021](#)), but it has also affected the related public health systems in distinct ways (Brenner and Bhugra [2020](#); Lehberger et al. [2021](#)). Importantly, studies suggest that socio-demographics such as age, gender, and income work in *combination* in further differentiating the risks and vulnerabilities among groups during the crisis (Dragano et al. [2021](#)). From the perspective of gender studies, this complex combination of a person's socio-demographic features can be understood as "intersectionality" (Butler [1990](#)), in which different socio-demographic categories meet and enhance or decrease particular vulnerabilities and risks, or privileges and protection.

In our paper, we investigate transport-behavior change during the pandemic, over a range of transport modes. We contribute novel insights to the field by not only gauging individual socio-demographic features in isolation, but also by determining 10 complex socio-demographic groups based on intersecting socio-demographic categories (gender, education, childcare responsibilities, etc.). The premise here is that membership of a certain group increases or decreases social experiences of risk and vulnerability, or of privilege and protection. In this way, our paper accounts for mobility reduction among complex social groups. The research question guiding our paper is thus: Did the public health measures designed to stop COVID-19 transmission (e.g., social distancing; telework; closure of schools, kindergartens, and universities) affect mobility reduction of certain transport types equally across different urban socio-demographic groups?

To answer this question, we draw on survey data for the Hanover region in Germany to demonstrate how car, public transport, or bike use changed during the height of public health measures, between March and June 2020. Our paper follows a two-step approach: first, we distinguish between 10 socio-demographic groups and establish three distinct clusters of transport-behavior change in our data. We then analyze the associated socio-demographic characteristics and groups to demonstrate how they reduced their mobility to markedly different extents. In other words, through this detailed analysis, we can show that the extent of mobility reduction is shaped by the interplay and *combination* of socio-demographic aspects, especially gender, education, childcare, and student status.

Looking at the precise nature of the groups most affected is politically important, as it has been widely acknowledged within transport and mobility studies that personal (im)mobility is shaped by socio-demographics and related to wider questions of social equality and justice (Karner et al. [2020](#); Verlinghieri and Schwanen [2020](#); Sheller [2018](#); Martens [2017](#); Pereira et al. [2017](#)). Furthermore, immobility has been associated with various negative attributes (e.g., loneliness, social exclusion, reduced well-being, and satisfaction with life) within the literature (Delbosc et al. [2020](#)). Establishing which

groups have become more immobile than others during the pandemic could hence help to locate the suffering involved in (unintended) negative consequences from the health measures implemented.

(Un)equal (im)mobility of socio-demographic groups during COVID-19

Changing transport behavior during the pandemic

Transport-behavior and mobility preferences and practices are not uniform across populations, as they are influenced by complex socio-demographic factors, lifestyles, and available infrastructures (Wittwer and Hubrich 2016; Cass and Faulconbridge 2016). Mobility and transport studies have contributed valuable insights into the disruption of both transportation systems and individual mobility practices during times of crisis, finding that disruptive events tend to lead to behavioral change and alter people's transportation use (Marsden et al. 2020; Cook and Butz 2013; Sheller 2013). This has also been the case amid the ongoing pandemic, as public health measures have had the declared goal to reduce and alter mobility patterns and transport behavior (Hale et al. 2020).

Public transport (from bus services to inner-city light rail use to train rides) declined most of all, while car and (to some extent) bike use increased in many cities (Schaefer et al. 2021; Currie et al. 2021; Das et al. 2021; Dingil and Esztergar-Kiss 2021; De Vos 2020). Hence, both mobility reductions and behavioral changes have been observed during the pandemic, although not equitably: Studies from the United States, Australia, and India point to a strong link between levels of transport disruption and socio-demographics such as income, education, and gender, as well as fear of the virus (Brough et al. 2021; Currie et al. 2021; Das et al. 2021), where especially lower-income groups have continued to rely on public transport, as specifically described below.

Research from King County, Washington (USA) suggests that factors such as education and income have influenced the extent of public transport use during the pandemic (Brough et al. 2021). People with lower income and education have been found to reduce their public transport use to a lesser extent than more affluent and better-educated groups. For Melbourne, Australia, a team of researchers reports that apart from socio-demographics, fear of infection is a top driver behind public transport decline during the pandemic (Currie et al. 2021). Previous research from the United Kingdom and Taiwan for the 2009 "swine flu" and 2003 SARS outbreaks confirms that fear of infection can lead to a decline in public transport use (Rubin 2009; Wang 2014). Thus, in investigating transport-behavior change, we expected to find varying responses on mobility reduction and transport-behavior change in the survey sample taken as a first step, to then examine the impact of socioeconomic factors.

Variegated responses to public health measures

For this study, we seek to combine various socio-demographic features to paint a more nuanced picture of such transport-behavior changes and mobility reductions. Below, we discuss in more detail the expected effects of three key public health measures on behavioral change among different socio-demographic groups across transport modes.

Telework versus essential jobs

Survey findings from recent years have pointed to a constant rise in job-related mobility among Germans, who have been making longer trips to work, while their mobility for leisure-related activities has declined (INFAS 2017). Commuting relies on various factors and is seen as a social practice, since it combines both individual preferences and capacities with available infrastructures (Wittwer and Hubrich 2016; Cass and Faulconbridge 2016). In Germany, the mobility culture of getting to work in urban settings often entails multi-modal trips and offers a range of options, while in more rural or suburban areas, people tend to be more dependent on the automobile (Buehler et al. 2017; Klinger et al. 2013). Furthermore, commuting practices are influenced by gender roles and household income (García-Jiménez et al. 2020).

Earlier in the pandemic, people were asked to do telework whenever possible. At the same time, the Lower Saxony state government ordered essential businesses (e.g., supermarkets, bakeries, pharmacies, doctors) to remain open, while forcing most retailers (e.g., clothing stores, florists) to suspend operations for several weeks. We assume that people with lower income and skill sets (education), in particular, remained more mobile than people with higher income and education levels who could more easily switch to telework.

While telework was a viable solution for some, the situation was more complex for families with young children who had lost their institutional childcare support due to the temporary closure of schools and kindergartens. Here, work and childcare had to be juggled simultaneously, showing telework to be a challenging multi-tasking endeavor (Ellér 2020; Verhoef et al. 2016; Hilbrecht et al. 2008; Hartig et al. 2007).

Closure of childcare facilities, schools, and universities

Transport studies have established that having children in the home significantly shapes the travel behavior among the household (McCarthy et al. 2021; Craig and van Tienoven 2019; Fan 2017; Scheiner and Holz-Rau 2017; Scheiner 2014; Schwanen 2007). In Germany, research has found women's routine trips to be considerably more complex than their male counterparts', due to the disproportional amount of child-serving trips they take on (Scheiner and Holz-Rau 2017). We therefore assume that, due to the suspension of their duties to drop off and pick up children from activities and institutions during the COVID-19 shutdowns, people living with children under 18 years of age in the household experienced mobility reductions, and that these affected women possibly more so than men.

University closures might have had less of a gendered effect: Younger people tend to make more trips per day than older citizens (INFAS 2017), and students of all genders are among this highly mobile group. Research on student mobility has found that students tend to lack access to cars (Mohammadzadeh 2020) and prefer active modes of travel such as biking (Cadima et al. 2020; Mohammadzadeh 2020; Nash and Mitra 2019). Moreover, students rely disproportionately on public transport and cycling for financial reasons, besides lifestyle choices (Mohammadzadeh 2020). In the Hanover region, students have access to free public transport with their university cards. We assume that the imposed university closures, with courses offered online instead, had a severe effect on the mobility of students.

Social distancing and the closure of public/leisure spaces

Another measure taken early on by the government to slow the spread of the virus entailed the closure of most recreational spaces (e.g., gyms, clubs, bars, cinemas, museums), thus reducing trips to leisure activities (De Vos 2020). As younger people tend to take more leisure trips (Graham et al. 2020; INFAS 2017), the measure has potentially affected them more than, for instance, pensioners, who tend to spend more time at home (Motte-Baumvol and Bonin 2018). The closure of leisure and sports facilities and retail shops may also have affected the (im)mobility of younger people as they are the ones most often working in these places.

The existing literature demonstrates that it is paramount to investigate the combination of socio-demographic factors (e.g., gender and education, as well as aspects such as carework) to understand how the public health measures to stem the pandemic have affected people unequally. We assume that it is precisely the combination of such factors that is causing distinct and variegated extents of mobility reduction and changes in transport behavior.

Methodology

To address our research question on whether mobility reduction occurred equally among socio-demographic groups and transport options during the first wave of the pandemic, we look at the impact of socio-demographics on transport-behavior changes during the pandemic.

Seeking to analyze the behavior of more complex socio-demographic groups, we first determine groups based on binary socio-demographic indicators of interest, such as gender, education, occupation, and childcare responsibilities. This allows us to better understand the interplay among socio-demographic indicators when viewing shifts in use for each mode of transportation. We then assess differences in travel behavior shifts among the groups via analysis of variance (ANOVA) and Tukey HSD, as a post-hoc test to gauge which groups' mobility was affected most. For the dependent variable, we employ cluster analysis to build groups based on changes in the use of bicycles, private cars, *Stadtbahn* (light rail), buses, and regional trains, toward insights into how the study participants' transport use shifted during the pandemic. In other words, the cluster analysis reveals common patterns of change in transport use across means of transportation, sorting the participants into the corresponding clusters. Subsequently, we apply logistic regression to estimate the impact of stand-alone socio-demographic indicators such as gender, age, income, education, occupation, and childcare responsibilities as well as the most distinct complex social groups we analyzed before, on the transport change type. This is intended to show how each indicator affects the broader shifts in transportation use observed during the pandemic.

For data analysis, we employ the “cluster,” “NbClust,” and “factoextra” packages in R, as well as the “tidyverse,” “data.table,” “stargazer,” “pastecs,” “wesanderson,” and “ggpubr” packages for data cleaning and visualization.

Case study region

For the analyses, we draw data from an online survey about mobility conducted in June 2020 with participants living or working in the Hanover region. Hanover, the capital of the northwestern federal state of Lower Saxony, had a population of 543,319 in late 2019. Another 635,646 people lived within the city region at that time, bringing the population of the metropolitan area to 1,178,965 (Region Hannover 2020). The city is a commercial, educational (e.g., Leibniz University Hanover, University of Applied Sciences and Arts), and administrative (e.g., regional parliament, federal ministries) hub within its federal state. Hanover's excellent transport infrastructure comprises buses, well-developed bike lanes, and the *Stadtbahn*, a light rail system that goes below and above ground within the metropolitan area.

On Friday, 13th March 2020, the regional government announced a long list of public health measures meant to “flatten the curve” of infections. The most important of such measures to stop community transmissions which reduced mobility within the city region (and beyond) were social distancing, telework whenever possible, and the temporary closure of schools, universities, and childcare facilities (Niedersächsisches Kultusministerium 2020). In the second half of June, when the survey was conducted, many of these measures remained in place: for instance, childcare facilities were only partially re-opened for parents working in essential jobs, social distancing was still recommended, meetings in larger groups were still forbidden, and clubs and bars were still closed (Landesregierung Niedersachsen 2020). People had already begun to arrange their new daily routines around them.

Data collection

We conducted the online survey over two weeks in mid-June 2020, in cooperation with the regional administration, *Region Hannover*, and distributed it via the website of the local public transport agency *Großraum-Verkehr Hannover* (GVH), social media, and e-mails to public stakeholders and the regional university. The survey supplies our analysis with information about socio-demographic indicators, participants' transport use before and during the pandemic, as well as the pandemic's effects on them. The aim of the questionnaire was to gauge the travel behavior and attitudes of the population regularly using transport in the Hanover region and living or working there. A total of 6153 people were reached, and 4359 of them, or over 70%, completed the survey. It had a maximum of 201 questions if no filters were applied, and took 22 min on average to complete. The survey was conducted in German.

Official statistics do not account for the demographics of people working in the Hanover region, but only for those living there. Therefore, we cannot compare our sample demographics in detail with the main overall population from which we are sampling.

Looking at the sample's demographic statistics in Table 1, we can say that students are generally overrepresented, while people with lower income who are not students are underrepresented. Students' overrepresentation also leads to a skewedness of the age distribution toward younger people. We account for this overrepresentation by including “student status” in our analysis as a separate group and controlling for it in our multivariate analysis. Hence, older generations are underrepresented, which is a common issue for online surveys; our sample is not fully representative of the main population, in particular retired, unemployed, and low-income individuals, which needs to be considered when interpreting

Table 1 Sample demographics

Variable	Value	Percentage of participants
Age	< 30	52.21
	30–44	20.53
	45–65	24.75
	> 65	2.51
Gender	Female	49.14
	Male	50.31
	Diverse	0.54
Income	< = 1.000 €	38.30
	> 1.000–1.500 €	11.43
	> 1.500–2000 €	10.68
	> 2.000–2.500 €	14.36
	> 2.500–3.000 €	10.83
	> 3.000 €	14.39
Education	University degree	54.24
Job status	School student	1.68
	University student	46.20
	Employed	49.14
	Unemployed	0.36
	Retired	2.61
Place of residence	Hanover city	74.00
	Hanover region (except Hanover city)	25.97
	Outside Hanover region	0.03
Mobility needs	People with reduced mobility	7.43

the findings. However, due to the large overall size of the sample, we find that most socio-demographic groups have sufficient representation in it, which makes it a valid source of information for the questions under analysis.

Analysis of socio-demographic groups

Understanding how distinct socio-economic factors influence the changes in transport behavior is an important first step. However, this approach neglects the complex interactions of socio-economic factors such as being a woman with higher-education status as well as childcare obligations in comparison to all other groups, as it only shows the effect of an independent variable (or at most interaction with one more variable) *ceteris paribus*. To gain insights into more complex and fine-grained socio-economic groups and how the pandemic affected their travel behavior, we build groups based on gender, student status, childcare, and education to compare shifts in transportation use. In building the groups, we use a dichotomous variable for gender, as less than 1% of participants classified their gender outside this dichotomy. Since, for the group of students, it is not possible to distinguish between siblings, roommates, or children under 18 who live in the same household, and there are very few observations among students that do live with minors, we do not

interpret this variable for the groups of students. Moreover, we do not distinguish between students with and without a degree, as we do not expect a systematic variation in transport change between bachelor and master students.

Figure 1 displays the size and composition for each group. For instance, Group 1 represents female students and Group 10 men with neither a university degree nor childcare obligations. Groups 1 and 2 are the largest, also because they are the least disaggregated groups.

Clustering approach

Cluster analysis is employed in discovering homogeneous groups of observations based on selected variables. We apply this approach to understand more complex underlying patterns of transportation behavior shifts during the pandemic by building clusters based on changes in the number of days (in an average month with 30 days) in which cars, bicycles, *Stadtbahn*, buses, and regional train were used. For instance, if a participant used the bus usually 20 days per month before the pandemic but reduced this to only eight days during the pandemic, the change in bus use would be -12 days. Thus, theoretically, the minimum is -30 days for cases where the transport option was used every day in a month before and then reduced to zero during the pandemic, while the maximum, for the opposite, is $+30$ days. Table 2 shows the distribution of the five variables.

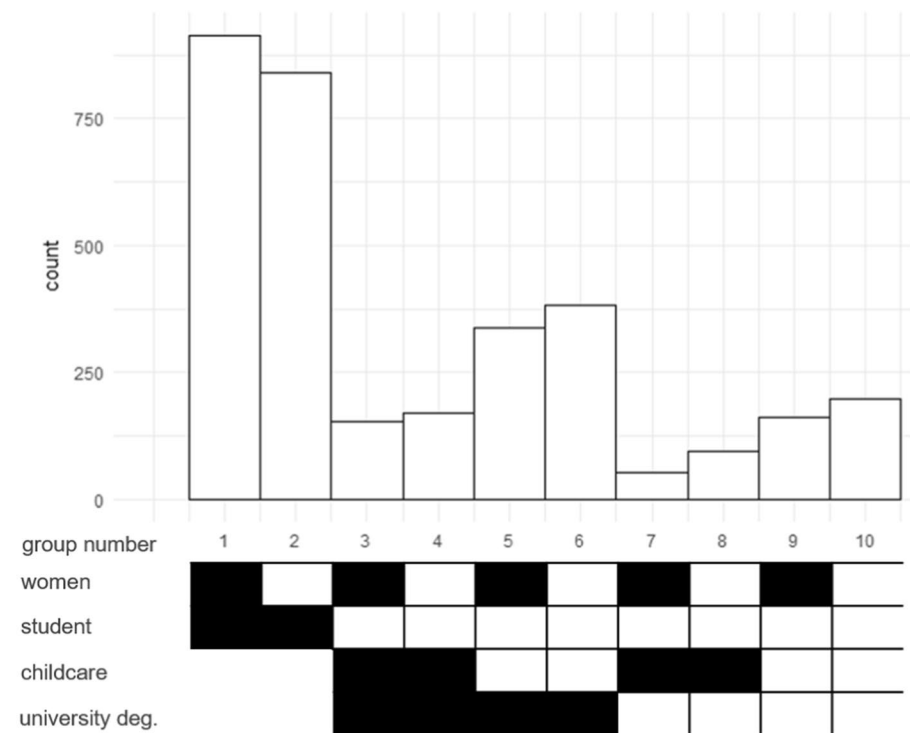


Fig. 1 Group characteristics and size

Table 2 Distribution of input variables for cluster analysis

Variable: Change in...	Scale	Min	Max	Median	Mean	SD
Car use	Discrete	−29	30	0	0.26	5.92
Bike use	Discrete	−30	30	0	0.3	8.19
<i>Stadtbahn</i> use	Discrete	−30	25	−3	−6.99	8.68
Bus use	Discrete	−30	20	0	−2.22	5.22
Train use	Discrete	−30	20	0	−3.14	6.41

As all variables are measured on the same scale, the values do not need to be normalized before dissimilarities are calculated. To calculate the distance matrix for our sample of 3708 observations with complete information on transportation mode use, we employ the Manhattan distance, which is more robust toward outliers than the commonly used Euclidean distance, as the former takes the sum of absolute differences instead of root sum-of-square differences. The Manhattan distance between two observations x and y is calculated as follows:

$$distance_{manhattan}(x, y) = \sum_{i=1}^n |x_i - y_i|$$

For the partitioning, we adopt the CLARA (Clustering Large Applications) algorithm based on the PAM (Partitioning Around Medoids) algorithm, which works better for larger data sets such as ours. Compared to the commonly employed k-means algorithm, medoids are usefully more robust to noise and outliers, as they employ real observations as cluster centers instead of centroids.

In conducting cluster analysis, it is important to find a good balance between aggregating the data to make it easier to handle and interpreting it while keeping the groups homogenous. To determine the appropriate number of clusters, we follow the gap statistic plot for cluster solutions between one and ten, which recommends the extraction of three clusters from our data, as shown in Fig. 2. The gap statistic compares the intra-cluster variation for multiple cluster solutions, with the optimal number of clusters being determined by the first local peak in the gap statistic. Moreover, as a robustness check, we compare the optimal number retrieved from the gap statistic with results from the Elbow and Silhouette methods. The Elbow plot is found to confirm three as the optimal number of clusters, while the Silhouette plot recommends extracting two clusters. We therefore opt for a three-cluster approach, as the gap statistic is the most elaborate approach for determining the number of clusters, and two out of three tests recommend extracting three clusters.

Modeling

Toward better understanding the impact of socio-economic backgrounds on transportation pattern shifts, we use logistic regression to model participants' sorting into clusters. We create dummy variables for cluster membership as dependent variables and include socio-economic independent variables for the first step. In a second step, we include the socio-economic groups that showed a significant difference in transport behavior change from the other groups in the descriptive analysis. As controls we add (1) the distance between a participant's residence and Hanover city center in kilometers; (2) how much the participant worked from home during the pandemic; (3) unemployment due to the

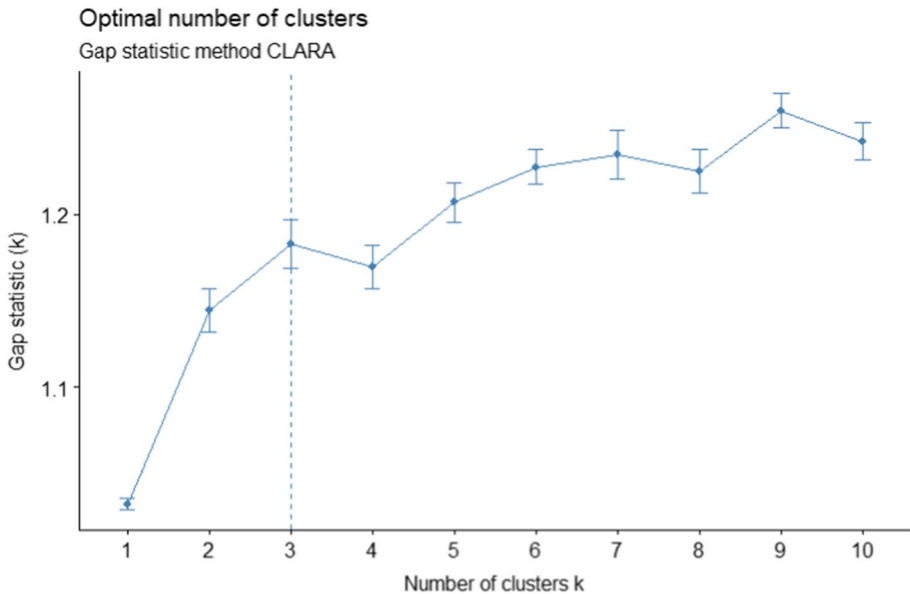


Fig. 2 Gap statistic plot for cluster solution of 1–10 clusters

pandemic; (4) additional childcare due to closures of kindergartens/schools; and (5) fear of infection while using public transport, on the same scale. These questions are rated on a scale of one (“fully disagree”) to six (“fully agree”). The descriptive statistics for these variables are displayed in Table 3. Finally, having employed the Spearman correlation coefficient to ensure the absence of excessive correlation between control variables, we find that the variables are not correlated.

Table 3 Variable descriptions

Variable	Scale	Min	Max	Median	Mean	SD
Woman	Dummy	0	1	0	0.49	0.5
Age	Discrete	15	88	27	33.39	13.88
Income	Ordinal	1	6	2	2.79	1.86
Student	Dummy	0	1	1	0.51	0.5
Childcare	Dummy	0	1	0	0.2	0.4
University degree	Dummy	0	1	1	0.53	0.5
Distance residence to city center in km	Continuous	1.45	177.9	27	28.93	10.75
Telework due to pandemic	Ordinal	1	6	5	4.18	1.87
Unemployed due to pandemic	Ordinal	1	6	1	1.54	1.29
More childcare due to pandemic	Ordinal	1	6	1	1.47	1.15
Fear of infection due to pandemic	Ordinal	1	6	4	3.45	1.67

Results

Complex socio-economic groups

Starting with the analysis of complex socio-economic groups, Fig. 3 displays the group means for days of transport use before and during the pandemic, as well as the 95% confidence interval of each mean. These plots facilitate group comparisons and gauging of the initial level of transport mode use and whether it increased or decreased during the pandemic. Where the whiskers of the confidence interval do not overlap, the change in transport mode use is significant for this group, while where they do overlap, we cannot be certain that the mean difference will hold outside this specific sample. We can see that the changes in car and bike use are not as clear for all groups, while a decrease in use is very apparent across all public transport modes for almost all groups.

Specifically, we find that female students increased their car use during the pandemic slightly but significantly. None of the other groups exhibited significant shifts in car use. For bike use, groups 9 and 10, respectively women and men with neither a degree nor children, were the only groups to significantly increase their bike use during the pandemic, with women displaying a higher increase than men. For Group 2, the male students, we find a small but significant decrease in bike use.

As for public transport, we observe a much higher and significant decrease in use for all groups during the pandemic. Group 7, which comprises women with childcare obligations and without a higher-education degree, is the only group that did not significantly decrease train or bus use. However, this might also be due to the lower number of observations in this group, at 51. We can also see that the pre-pandemic level is significantly higher for the two student groups for all means of public transport, while it falls to a level similar to other groups' during the pandemic.

Finally, *Stadtbahn* use before the pandemic is found to have fluctuated the most strongly between groups. Students display the highest number of days of use per month, followed by people with neither a university degree nor childcare obligations. While students clearly

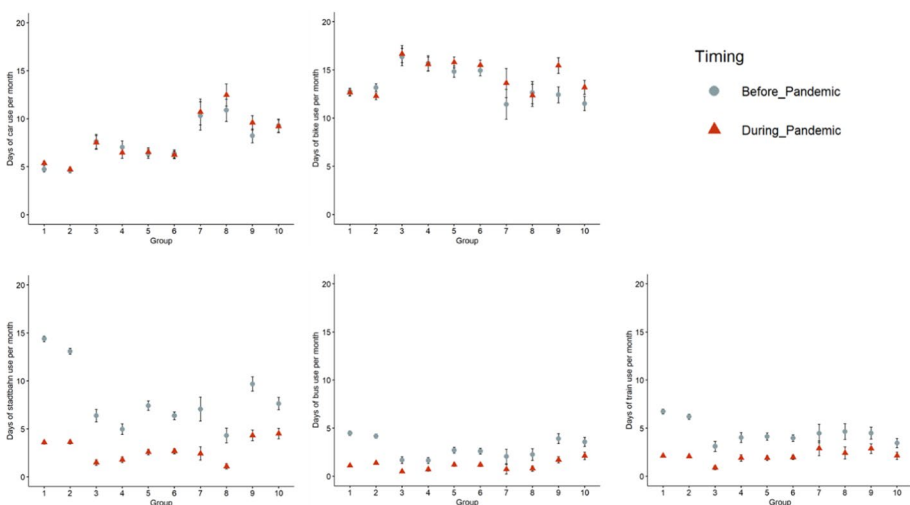


Fig. 3 Change in transportation mode use per group

show the highest reduction here, the latter group maintains the highest level of use among all groups during the pandemic.

For the next step, we use an ANOVA test to investigate whether the change in days of transport use before and during the pandemic differed significantly between groups. We observe a less significant difference between groups when looking at car use, which is significant at the 0.01 level; for all other modes of transport, we can see a strong significant difference when comparing groups. We then employ Tukey HSD (honestly significant difference) as a post-hoc test to compare all groups to each other and identify which have a significantly different mean. Table 4 shows the results of the between-group comparison of change in transport use, in days per transport mode. We find no groups differing significantly for transportation by car, below the 0.1-significance level. For biking, we find a significant difference, at the 5% significance level, between Group 9 (women with neither a university degree nor childcare obligations) and groups 1, 2, 3, 6, and 8; as well as Group 10 (men with neither a university degree nor childcare obligations) and the two student groups.

In public transport, we find most groups to significantly differ from the two student groups. For bus and train use, we find that groups 7, 8 (and 9 for bus use) are the exception, as they do not differ significantly from the group of male students who had a slightly smaller reduction in public transport use. However, this difference is only significant for *Stadtbahn* use, where female students exhibit a significantly higher reduction than their male counterparts do.

Overall, the analysis of the groups reveals that students experienced the highest reduction in transport use, particularly in public transport, while study participants with no children, in combination with no higher-education degree, maintained the highest levels of transport use. The significant difference between some socio-demographic groups also shows that we need to include groups 1, 2, 4 and 9 when analyzing the transport behavior change in the following step.

Cluster analysis

Moving to the cluster analysis of transport behavior change, Table 5 illustrates the medoids for shifts in transportation use during the pandemic. We can see that for the observation that best represents Cluster 1, no change in transportation use was experienced during the pandemic. This does not mean that no observations in this cluster were subject to a shift in transportation use, but that they are most similar to the case representing the overall cluster. This effect is driven by the difference in the magnitude of transport-use change between bicycles and automobiles on the one hand and public transport on the other, as shown in Table 2 by the means for the variables. Overall, Cluster 1 is the largest and yet most homogeneous cluster, with the smallest average dissimilarity among all clusters.

The observation that best represents Cluster 2 shows a high reduction in *Stadtbahn* use and a small reduction in that of other means of public transport, such as bus and train. This cluster seems to represent a pattern of transport-use change among city-dwellers frequently riding public transport before the pandemic.

The medoid for Cluster 3 points to a strong reduction in *Stadtbahn* and train use, most likely representing commuters who rode the train and *Stadtbahn* in combination before the pandemic to get to work from outside the city. This is the smallest cluster with the highest average dissimilarity.

Table 4 Significance levels of Tukey HSD test results per transportation mode only modes with significance level < 0.1 are displayed

	2	3	4	5	6	7	8	9	10
1	Stbahn**	Stbahn*** Bus*** Train***	Stbahn*** Bus*** Train***	Stbahn*** Bus*** Train***	Stbahn*** Bus*** Train***	Stbahn*** Bus*** Train***	Stbahn*** Bus*** Train***	Bike*** Stbahn*** Bus*** Train***	Bike*** Stbahn*** Bus*** Train***
2	-	Stbahn*** Bus*** Train***	Stbahn*** Bus*** Train***	Bike** Stbahn*** Bus*** Train***	Stbahn*** Bus*** Train***	Stbahn*** Train*	Stbahn***	Bike*** Stbahn*** Train***	Bike*** Stbahn*** Bus*** Train***
3		-						Bike**	
4			-				Car*	Bike***	
5				-				Bike*	
6					-			Bike**	
7						-			
8							-	Bike**	
9								-	Stbahn**

Table 5 Medoids for days of transport mode change during the pandemic

Number	Cluster label	Size	Average dissimilarity	Max dissimilarity	Car use	Bike use	<i>Stadtbahn</i> use	Bus use	Train use
Cluster 1	No change	2306	9.63	60	0	0	0	0	0
Cluster 2	City public transport	1039	21.06	75	0	0	−14	−0.5	−0.5
Cluster 3	Commuters	363	24.89	86	0	0	−20	0	−20

Modeling the effects of socio-economic indicators

Table 6 lists the results from the first part of the logistic regression analysis. As a dependent variable, we created three new dummy variables, one for each of the three clusters, coded “1” if the observations belonged to the respective cluster, and “0” if not. In this way, we compared each of the clusters to all observations outside the cluster. From the results, we can see that being a woman reduced the chance of membership in cluster one, which includes the participants with no change in public transport use. We therefore find women to have had a lower chance of experiencing no impact on their travel behavior. We also find that being a woman did significantly increases the chance of having a high reduction in public transport use. These findings are stable also after the inclusion of further control variables.

When it comes to participants’ age, we find that older people tended to experience less disruption in their travel patterns, with a younger age decreasing the chance of having experienced a large reduction in high inner-city public transport use. The effect of age on membership in clusters 1 and 2 is stable after the control variables are included, while the effect for membership in Cluster 3, in which people reduced train and *Stadtbahn* use considerably, vanishes. Income does not seem to have an impact on membership in any of the three clusters; while one’s presently being a student had the largest effect on cluster membership among all independent variables. It considerably decreased the chance of no impact on travel behavior and increases the chance one has experienced a reduction in inner-city public transport use as well as commuting specifically by train. However, the effect on commuting patterns is voided in the model that includes distance to city as a control variable.

Childcare seems to only have an effect on reduced public-transport commuting, and only in the model without further pandemic-related impact variables. Possession of a higher-education degree does not play a role for the models without control variables but is significant on the 0.05-level for membership in clusters 1 and 3 once controls are introduced. Higher education therefore increases the chance one has experienced no impact on travel behavior and decreases the chance one has experienced reduced commuting activity.

When turning to the pandemic-related items we introduced into the model, we find that telework due to the pandemic decreases the chance of being in Cluster one, which shows no mobility reduction. Similarly, the fear of catching the virus negatively correlates with this cluster. Members of Cluster 2, who significantly reduced their public transport use, however, show a positive correlation with the survey item “fear of catching the virus,” indicating that higher levels of fear lead to higher reduction in inner-city public transport use. Furthermore, childcare-related work due to the pandemic does not significantly affect membership in any of the clusters. Finally, there is a positive relation between

Table 6 Logistic regression models for cluster membership

Dependent variable: Dummy variable for membership in...	Cluster 1 Model 1	Cluster 1 Model 2	Cluster 2 Model 3	Cluster 2 Model 4	Cluster 3 Model 5	Cluster 3 Model 6
Woman	−0.380*** (0.086)	−0.341*** (0.113)	0.363*** (0.089)	0.413*** (0.117)	0.095 (0.139)	−0.147 (0.191)
Age	0.031*** (0.006)	0.030*** (0.007)	−0.025*** (0.006)	−0.030*** (0.008)	−0.039*** (0.013)	−0.017 (0.016)
Income	0.019 (0.047)	−0.018 (0.058)	−0.021 (0.050)	0.027 (0.062)	−0.020 (0.088)	−0.035 (0.117)
Student	−0.960*** (0.157)	−0.611*** (0.210)	0.684*** (0.166)	0.476** (0.222)	0.961*** (0.295)	0.509 (0.421)
Childcare	−0.011 (0.120)	0.103 (0.174)	−0.209 (0.130)	−0.203 (0.186)	0.586*** (0.195)	0.242 (0.303)
University degree	0.142 (0.090)	0.289** (0.118)	−0.045 (0.094)	−0.135 (0.122)	−0.180 (0.150)	−0.408** (0.202)
Distance residence to city center		−0.012** (0.005)		−0.014** (0.006)		0.038*** (0.006)
Telework due to pandemic		−0.173*** (0.036)		0.087** (0.038)		0.330*** (0.075)
Unemployed due to pandemic		0.149*** (0.054)		−0.123** (0.057)		−0.099 (0.093)
More childcare due to pandemic		0.059 (0.065)		−0.041 (0.071)		−0.050 (0.112)
Fear of infection due to pandemic		−0.123*** (0.034)		0.148*** (0.035)		−0.046 (0.057)
Constant	0.149 (0.252)	1.148*** (0.383)	−0.591** (0.267)	−0.676* (0.410)	−1.877*** (0.500)	−4.233*** (0.759)
Observations	2,774	1,752	2,774	1,752	2,774	1,752
Log Likelihood	−1,613.452	−989.372	−1,532.320	−936.762	−754.736	−425.492
Akaike Inf. Crit	3,240.903	2,002.744	3,078.641	1,897.523	1,523.471	874.983
Note:	* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$					

unemployment due to the pandemic and membership in Cluster 1, as well as a negative relation significant at the 0.05-level with membership in Cluster 2.

From the analysis of socio-economic groups in chapter 4.1 we learned that some groups changed their transport behavior significantly and that there is great variance within the changes between the different groups. In order to reflect these complex socio-demographics we included these groups in models 7, 8 and 9 displayed in Table 7 replacing the underlying grouping variables, namely gender, education, childcare

Table 7 Logistic regression models for cluster membership

Membership in...	Dependent variable		
	Cluster 1	Cluster 2	Cluster 3
	Model 7	Model 8	Model 9
Group 1	−0.827*** (0.225)	0.758*** (0.237)	0.386 (0.433)
Group 2	−0.528** (0.222)	0.336 (0.236)	0.636 (0.422)
Group 4	0.593** (0.283)	−0.455 (0.298)	−1.098 (0.759)
Group 9	−0.571** (0.285)	0.625** (0.294)	−0.010 (0.771)
Age	0.031*** (0.007)	−0.031*** (0.008)	−0.019 (0.016)
Income	−0.012 (0.058)	0.025 (0.062)	−0.013 (0.116)
Distance residency to city center	−0.012** (0.005)	−0.015*** (0.006)	0.039*** (0.006)
Telework due to pandemic	−0.177*** (0.036)	0.097** (0.038)	0.324*** (0.076)
Unemployed due to pandemic	0.153*** (0.053)	−0.124** (0.056)	−0.115 (0.093)
More childcare due to pandemic	0.043 (0.055)	−0.048 (0.060)	0.018 (0.097)
Fear of infection due to pandemic	−0.128*** (0.033)	0.155*** (0.035)	−0.052 (0.056)
Constant	1.179*** (0.382)	−0.602 (0.408)	−4.461*** (0.761)
Observations	1782	1782	1782
Log Likelihood	−1009.061	−957.353	−433.573
Akaike Inf. Crit	2042.123	1938.706	891.145

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

responsibilities and being a student. Group 1 and 2 represent women and men students, group 4 are men with children and a university education and group 9 are women without childcare responsibilities in their own household and no higher education degree.

The results show that the student groups as well as group 9 have a significantly negative relation with the cluster that did not change its transport behavior, while group 4 has a strong positive relation here, showing that men with children and higher education tended not to change their transport behavior as much as other social groups. Looking at the relations with Cluster 2, that is characterized by a reduction of *Stadtbahn* usage, in particular female students and respondents in group 9 are more likely to belong to this cluster while there is no effect for male students (group 2) and participants in group 8. None of the groups have a significant relation to Cluster 3, which confirms what we

found earlier in Model 6, that the reduction for commuters did not depend on socio-demographic variables but on telework and commuting distance.

In summary, the analysis demonstrates that the socio-economic dimensions of gender and age determined if and how travel behavior changed during the pandemic. Being a woman reduced the chance that one did not experience any change and increased public transport reduction, while the same is true for younger respondents. Moreover, the results show that one's presently being a student had a particularly strong effect on mobility reduction during the pandemic. In our sample, students had the highest chance of having changed their mobility behavior and reduced public transport use. Moreover, telework and fear of catching the virus interact with the clusters. People unable to switch to telework are less likely to be part of the cluster with people that did not change their travel behavior and people scared of virus transmission are more likely to be part of Cluster 2, in which public transport use was reduced. Overall, the change in transport behavior for commuters was not determined by socio-demographic features while inner city transport use, namely the Stadtbahn, as well as having no changes in transport behavior depended clearly on these features. We find that combining socio-demographic features to more complex groups uncovers robust difference between these groups. For instance, women without children or a higher education diploma reduced inner-city public transport use and increased bike use significantly more than other respondents. However, men with children and a higher education diploma were more likely to not experience any change in transport use. This shows that we need to think about socio-demographic variables in a more complex way instead of as stand-alone variables.

Discussion

Our findings demonstrate that changes in mobility patterns were not equal across socio-economic factors. A closer look into how such factors played out in combination with each other provides nuanced insights into the differentiated effects public health measures had on socio-demographic groups.

Changing transport behavior: cluster analysis

We identify three distinct clusters of transport behavior during the pandemic. The medoids in Cluster 1 show no change in transport use for the cluster overall. This lack of change is driven by the low increase in bike and car use compared to public transport, whose effects dominate the cluster results. Two effects partially cancel each other out and cause a very low increase in car and bicycle use when looked at in the overall population. First, since people in general decreased their transport use, there was less activity for each mode of transport. Second, and conversely, they replaced their decreased public transport use with that of bicycles and cars, which in turn increased use for these modes of transport. Therefore, a small overall increase in bike and car use and a strong decrease in that of public transport is observed. This causes clusters 2 and 3 to differ markedly within public transport reductions. The decline in inner-city transportation use was a common feature for many study participants forming Cluster 2, while the reduction in public transport use for commuting into the city was a common feature for those in Cluster 3.

Interestingly, we find an interaction with gender here, as well, as women were less likely to be part of Cluster 1 that did not change mobility. This finding attests to the importance

of considering a greater variety of attributes in explaining mobility reduction during the pandemic. Although we find that income does not have an effect on membership in any of the three clusters identified, we know from other studies on the subject that it does play a role in determining the ones able to replace public transport with automobile use during the pandemic (Schaefer et al. 2021). We should also keep in mind that this online survey did not reach very low-income households; we infer that the absence of a statistically significant effect here points toward a non-linearity of the income effect, meaning that there might be no effect when going from medium to high-income households, but rather between very low to low-income households. Thus, we assume that people who neither reduced their mobility nor changed their mode of travel might still have faced economic constraints to their choices.

The control variables we include in the models provide additional insights. They reveal that, while on the one hand, people who did not (could not) opt for telework during the pandemic were the ones who did not reduce their mobility, on the other, people who reported more telework reduced their commutes and inner-city travel significantly. This matches previous findings that so-called “essential workers” remained more mobile during the pandemic (Shibayama et al. 2021), especially those with less education and lower income (Brough et al. 2021).

Cluster 2 is particularly dominated by women and younger participants. It seems interesting that the fear of catching the virus interacts positively with this cluster, which relates to established evidence from risk psychology on higher risk sensibility among women (Finucane et al. 2000). Our findings sharply contrast with those by Rubin (2009) in the context of the “swine flu” pandemic, in which only 2% of survey respondents reported high fear of using public transport; while aligning with findings from Melbourne pointing to fear of infection with COVID-19 having significantly motivated people to reduce public transport use (Currie et al. 2021). It remains to be seen whether the higher reported fear of COVID-19 and the associated immobility will have negative long-term psychological effects, and whether these will disproportionality affect women, as scholars have warned (Elcheroth and Drury 2020; Delbosc et al. 2020). The jury is also still out on whether the reduced public transport during the pandemic is only a short-lived phenomenon or signals a more fundamental shift in transport behavior, which could have negative ecological consequences if people were to opt for more automobile than bicycle use (see Currie et al. 2021).

Variegated responses: Complex socio-demographic groups

Looking more closely at how different complex socio-demographic groups changed their travel behavior and limited their mobility, we find the combination of gender, childcare, and education to have significantly shaped mobility reduction during the pandemic, confirming previous research (Brough et al. 2021; Shibayama et al. 2021; Balbontin et al. 2021; Dingil and Esztergar-Kiss 2021). In contrast to other research, however, our sample does not indicate a dramatic increase in car use (Das et al. 2021); in fact, only the group of women without a university degree and with children, and that of men with neither a university degree nor children, tended to increase their car travel. Our data also suggests that both men and women without higher education degrees or childcare obligations picked up biking as a mode of transport during the pandemic to remain mobile, expanding the range of people who commonly use this mode (e.g., for students, see Cadima et al. 2020; Mohammadzadeh 2020; Nash and Mitra 2019). It remains unclear whether this uptake was

for leisure and recreation, as De Vos (2020) would suggest, or could signal a broader transport-behavioral shift. Moreover, while men and women without higher education or children both increased their bike use, a more direct comparison shows that women increased biking more than men did. This is a noteworthy finding, and can be perceived cautiously as a positive step toward gender equality in transport, considering that studies over the past several years suggested that women in Europe still cycled less frequently than men (Goel et al. 2022; Pucher and Buehler 2012), often citing fear of accidents and missing infrastructure as reasons (Prati et al. 2019).

Furthermore, looking at women and men with childcare duties and higher education more closely, we observe that they form the only groups reducing their mobility across all transport modes. This suggests that childcare duties had a limiting effect on mobility during the survey period for those with higher education and therefore likely to have jobs allowing for telework.

Our data also points to severe mobility reductions across (almost) all transport types, and an especially severe reduction in public transport use, among both male and female university students. Hence, we can conclude that these were the groups most affected by the public health measures the state imposed. These findings contrast with German news reports accusing younger people of flouting social distancing measures and resuming or returning to highly active lifestyles at that time (Musall 1.8.2020; Bayrischer Rundfunk 9.8.2020). Meanwhile, according to previous research from Poland, students perceived the decline in commutes to campus as a disadvantage; this perception was particularly pronounced among students who utilized active modes of travel, such as biking or walking, before the pandemic (Paradowska 2021).

Conclusion

Before drawing a conclusion from our insights, we need to acknowledge a few limitations in our study. First, we did not collect information on participants' ethnicity or cultural background, which could have provided a better understanding of how (im)mobility affected people amid the pandemic. Second, it is apparent that the survey underrepresents elderly and lower-income people; this is probably due, in part, to a higher reluctance to share income information in a survey and less online access than other groups. Instead, we find an overrepresentation of students within our sample. Lastly, we did not obtain information on people who went into quarantine during the pandemic. This must be viewed as an omission, as this public health measure enforced extreme immobility, and is known to have taken a heavy psychological toll on people, ranging from post-traumatic stress symptoms to generalized fear and anger (Brooks et al. 2020).

These shortcomings can be attributed to the use of an online questionnaire for the survey method, known to produce blind spots when it comes to capturing the responses of hard-to-reach populations. A follow-up study could use more varied ways of reaching out to these populations, e.g., by sending out questionnaires via post, conducting telephone surveys, or diversifying advertisements of online surveys and directly targeting underrepresented groups. Such a study could also usefully include scales of satisfaction with life, and questions on (dis)satisfaction with mobility reduction due to public health measures, to better understand experiences with social distancing, telework, and closures of educational institutions.

As new pandemics can strike anytime, it is politically important to know more about the reality of (im)mobility within the population and think of policies to counterbalance the potential negative consequences of unequally (im)mobile lives. Our study results show that public health measures to stop community transmission—namely social distancing, telework whenever possible, and the temporary closure of kindergartens, schools, and universities—did not affect people’s travel behavior and (im)mobility equally. Mobility reductions are found to have been most severe for women and student respondents during the first wave of the pandemic in the Hanover region. However, immobility during the pandemic ought to be carefully contextualized, as it can be experienced either as a burden or privilege. While we uncovered a complex picture of mobility reductions during the pandemic, it is less straightforward to evaluate such immobility from the data we have obtained. We agree with scholars that warn that (im) mobility can be a political concern, as it entails questions of equity and justice (Karner et al. 2020; Verlingheri and Schwanen 2020; Sheller 2018; Martens 2017; Pereira et al. 2017). Access to transportation, the right to move (e.g., across borders), and the subjective feeling of safety when commuting or traveling, are all important elements in pondering the relationship between equality and transport (Verlingheri and Schwanen 2020). At the same time, during a pandemic, the ability to reduce one’s transportation needs through telework or online education can be a privilege, and seemingly more common among people with a university degree, for example. Within mobility studies, such a perspective—that “staying put” is a privilege, rather than a sign of exclusion or injustice—is not often voiced. To our knowledge, scholarship on asylum-seekers and refugees who long to stay within the confines of a safe home or protective institution to avoid the dangers that (forced) mobility might mean for them (Tuitjer and Batréau 2019; Gill 2009) are among the exceptions. Within the context of the COVID-19 pandemic, we thus ought to be careful in equating immobility with injustice per se, when exposure to the virus tends to be more prevalent for people spending more time being mobile outside. Further research (e.g., through in-depth interviews or focus groups) seems necessary to shed light on the lived experiences of immobility during the pandemic.

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Declarations

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