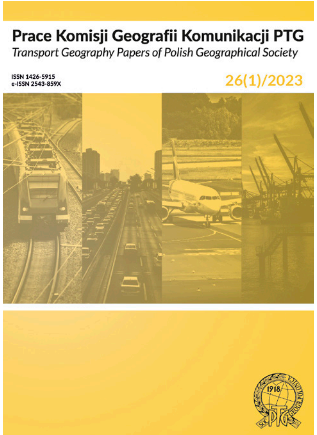

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EFFECTS OF THE COVID-19 TRAVEL RESTRICTIONS ON METROPOLISES MOBILITY: EMPIRICAL EVIDENCE FROM THE TRICITY METROPOLIS (POLAND)

Wpływ ograniczeń podróży związanych z COVID-19 na mobilność metropolitalną: dowody empiryczne z metropolii trójmiejskiej (Polska)

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Abstract: This paper aims to assess changes in mobility and modal shift caused by COVID-19 travel restrictions among the residents of Gdańsk Bay Metropolis (Poland). Measurement's moments were assumed in periods differing in the level of restrictions. The computer-assisted telephone interview (CATI) was carried out in November and December 2020. The results did not confirm the expected modal shift. However, significant changes in the number of trips between periods were observed. Restrictions in the first period of the pandemic resulted in a greater decrease in mobility than the restrictions at the end of the year. Moreover, significant associations were found between transport behaviour and place of residence. Nevertheless, possible negative changes in the modal split after the pandemic ends should be counteracted by improving the quality of public transport services. As the most important attributes of public transport attracting passengers after the pandemic respondents recognized: high frequency of vehicles, low cost of travel, not overcrowded vehicles. However, some residents declared they will not use public transport regardless of service improvements. Consequently, to meet the objectives of sustainable mobility policy, it can be necessary to increase the share in the modal split of other sustainable modes of travel.

Keywords: COVID-10, lockdown, travel restrictions, mobility, transport, modal shift

1. Introduction

Two main approaches can be distinguished in research on transport and pandemic relations. The first concerns the impact of transport on the spread of the virus, the second concerns the impact of the pandemic on mobility and transport. The movement of individuals across territories has been shown to be a primary vector of COVID-19 transmission (SAGE – Environmental and Modelling Group, 2020). As a result, lockdown policies have been decreed in many countries to stop the spread of the disease. Travel restrictions imposed on national level varied within the countries and periods. Apart from the common obligation such as covering mouth and nose and keeping social distance to meet WHO recommendation (WHO, 2020) the limitation introduced in public transport mostly referred to travel distance or purpose and reduced capacity limits (Gkiotsalitis, Cats, 2020). In Poland, due to the number of COVID-19 cases and the scope of the restrictions, three periods could be distinguished in 2020: from March to June, from July to August, from September to December.

As in other countries, the first restrictions in Poland were introduced in March 2020. They were aimed at limiting the spread of the virus by:

– remote learning and, if possible, remote work,
– obligation to maintain a distance of 2 m (from May – 1.5 m) between people,
– obligation to cover nose and mouth, wear gloves and disinfect hands,
– isolation of people suffering from COVID-19 and quarantine of people who had contact with them,
– ban on organizing cultural and sports events,
– closing of restaurants and cafes and other eateries, hotels, sanatoriums, cinemas, theaters and sports facilities,
– closing large-area stores and shopping malls,
– introducing limits on the number of people served simultaneously in grocery stores and pharmacies. At that time, restrictions influencing the functioning of public transport were also introduced. The number of people allowed to travel by public transport at the same time is limited to:
– 50% of the number of seats, either
– 30% of the total number of seats and standing positions, while at least 50% of the seats are vacant in the vehicle.

In the Tri-City metropolis, the organizers and carriers additionally took steps to protect passengers and their employees from falling ill with COVID-19. To this end, in-vehicle ticket sales were suspended, standard-capacity vehicles were replaced with articulated vehicles, and the number of vehicles on the most filled journeys was doubled. The general drop in mobility resulted in a visible change in traffic in Tri-City Metropolis. In the case of commuting to the business and science centre in Gdańsk Oliwa from Gdynia, Sopot and Gdańsk, the average travel time was shorter by 18%; by 15% during the morning peak and by 21% in the evening (Tarkowski et al., 2020).

During the summer holidays, i.e. in July and August, certain restrictions were eased and removed by the government authorities. Previously closed shops, restaurants, cafes and other facilities were opened. However, the limits of people using different facilities at the same time were kept. Enterprises and institutions limited the scope of remote work. As a result, the demand for transport services increased. The number of passenger seats in public transport vehicles was increased to 50% of all available seats. Ticket sales in vehicles were restored.

Schools started in September. Soon, however, as a result of the increase in the number of COVID-19 cases, a return to remote learning was made.

In the Tri-City metropolis, already in mid-October 2020, the number of COVID-19 cases increased so much that the restrictions from the March-June period returned.

Again, the state authorities reduced the number of seats in public transport vehicles, allowing 30% of all seats and standing places, taking into account the principle that half of the seats must remain vacant. By the decision of local authorities in the Tri-City metropolis, the sale of vehicle tickets was suspended. Despite remote learning, timetables were kept as in school days, standard buses were replaced with articulated buses wherever it was possible and encore vehicles were launched on an ongoing basis.

2. Aims, methods and data

The aim of the article is to present the impact of restrictions related to the SARS-COV-2 pandemic on mobility and modal split. The authors conducted research and analysis of changes in the mobility of Tri-City metropolis residents.

The Gdańsk Bay Metropolitan Area is located in the Pomeranian region in northern Poland. The Public Transport Metropolitan Association in this area is formed by 8 towns and 6 rural communes inhabited by over 1.07 million inhabitants (Fig. 1). Three cities: Gdańsk, Gdynia and Sopot form the core of the agglomeration inhabited by 70.7% of its population. The metropolis is characterized by specific limitations in spatial and urban development. From the east, the border of the metropolis is marked by the coastline of Gdańsk Bay. From the west, the development of the metropolis is limited by moraine hills covered with forest, which has the status of a landscape park. The presented conditions determined the development of the public transport network. The basic mean of metropolitan public transport is urban rail. In Gdańsk buses and trams are operated, in Gdynia and Sopot – buses and trolleybuses. The rest of the metropolis is served by buses only. The public transport network in the metropolis consists of four subsystems that are not fully integrated and have different fares. Residents who travel over one subsystem can use metropolitan tickets. The lack of full integration of public transport in the metropolis is the most important barrier to achieving sustainable mobility goals.

Fig. 1. Tri-City Metropolis.

Source: Own source.

Public transport in individual cities and communes of the metropolis is mainly financed from budgetary subsidies. Ticket revenues in 2019, i.e. before the COVID-19 pandemic, covered about 40% of the costs. In 2020, this level dropped to an average of 25%.

Based on the literature review and the results of the research on transport behaviour, the authors formulated the following research questions: (1) Has the pandemic caused significant changes in transport behaviour? (2) Were changes in transport behaviour correlated with the intensity of the restrictions? (3) Has the number of trips changed significantly during the pandemic? (4) Has there been a shift in modal split during the pandemic? (5) Have changes in transport behaviour occurred with varying intensity depending on the persons residence? (6) Did certain transport behaviour prior to the pandemic have an impact on the travel behaviour during the pandemic? (7) What can be done to counter the negative effects of a pandemic on public transport and more broadly on sustainable mobility after the pandemic is over? (8) Should the significance of individual public transport attributes for passengers be expected to change once the pandemic is over?

Questions 1-4 relate to the research already carried out presented in the literature review. Their purpose is to confirm the conclusions of research carried out in other cities. Answers to questions 5-8 complete the existing knowledge on transport behaviour during the pandemic and the transport preferences of residents after its end.

The choice of the research method was determined by the conditions and limitations related to the COVID-19 pandemic. Social isolation made it impossible to conduct home interview research. The use of the telephone interview method set the procedure for selecting the research sample and reduced the number of units participating in the research. The study was conducted by a research company that has a database of telephone numbers of metropolitan residents. The company collected a sample of residents for research in accordance with the authors' guidelines and was responsible for carrying out the interviews. As part of the research control, telephone numbers were selected to check whether the interview was conducted in accordance with the accepted standards. The questionnaire, selection method and sample size were designed by the authors in accordance with the research objective and the adopted hypotheses. The study was conducted between November 17 and December 14, 2020. The timing of the study allowed for varying periods of restriction caused by the pandemic to be taken into account in order to identify changes in transport behavior. Random stratified selection allowed to examine the specificity of behavior and transport preferences depending on the respondents' place of residence – the distance from the metropolis core.

The main subject of the research was the transport behavior of residents before the pandemic, during the pandemic and expected after the end of the restrictions. Analyzing the collected data, a cross-examination of the relation between the use of a specific means of transport before, during and after the pandemic was conducted. The sample included 3,000 respondents selected proportionally to the number of inhabitants in individual administrative units of the Gdańsk Bay Metropolitan Area – cities and municipalities. The share of women and men was 45% and 55%, respectively. The average interview time was 20 minutes.

The main part of the study dealt with the number of journeys and the modal split. Due to the specifics of the study, the so-called photography of the respondent's transport behavior on the day preceding the survey, using the two-dimensional Likert scale to measure attitudes. Three periods, different in terms of the applicable restrictions, were taken into account: March-June, July-August and September-December. Respondents were also asked about the attributes that should be met by public transport in order to encourage residents to use its services after the pandemic. The results were compared in the following sections: transport behavior, place of residence, gender, age. Selected statistically significant differences are presented in the article.

In order to determine the differences in transport behavior in separate periods of the pandemic, an analysis was performed using the χ^2 compliance test. Based on the value of standardized residuals, the differences between the frequency of individual responses within each group were estimated.

In order to determine the differences in transport behavior in particular periods of the pandemic by place of residence (the core of the metropolis and the surroundings of the metropolis), analyzes were carried out using the Pearson χ^2 test. In order to establish the nature of the differences between the responses, the post hoc analysis with the Z test with the Bonferroni significance level correction was used.

The frequency of using particular means of transport during a pandemic was analyzed depending on the way of travel before the pandemic. Statistical analysis was performed using the χ^2 concordance test. The tables also summarize the p values – test probability for the χ^2 test, which indicates whether there is a statistically significant difference between the observed and expected values in individual groups. If the difference between these values is statistically significant, it can be concluded that there is a relation between those two variables.

3. Scientific framework

Sustainable mobility is an alternative paradigm that can explore the complexity of cities and strengthen the link between land use and transport (Banister, 2005). It provides easy, comfortable, economically and spatially accessible travel to a destination, with minimal impact on the environment and other people (Lam, Head, 2012).

Sustainable urban mobility requires actions that should lead to: reducing the need to travel, reducing the travel distance, changing the means of transport to more ecological ones, ensuring higher transport efficiency, improving the accessibility of infrastructure, in particular for pedestrians and cyclists (Karoń et al., 2017).

Western European cities undertook radical actions aimed at reducing the number of car journeys already in the mid-1980s. It is indicated that cities with a low level of motorized transport development still have a chance for better functional integration than cities with a large number of cars (Buehler, Pucher, 2011).

The large transport capacity of public transport predestines it to fulfill the main part of transport needs in cities. The increase in the number of car trips in cities leads to the emergence of the so-called vicious circle of public transport.

The habitual character of daily mobility is seen to be a major barrier for changes towards a more sustainable behaviour. A variety of socio-psychology variables are the main determinants for decisions pro and contra sustainable behaviour. However, the perception and behaviour can be nurtured and changed to be more environmentally responsible. If the lack of facilities is used as an excuse to behave unsustainable, then the deficiency should be improved to promote changes in the residents' behaviour (Nasrudin et al., 2014).

A. M. May et al. (2006) have identified four categories of barriers of sustainable mobility, i.e. legal and institutional, financial, political and cultural, practical and technological. D. Banister (2005) has identified six categories, i.e., resource-related, institutional and political, social and cultural, legal, side effects, and other physical barriers. Seven categories of barriers are identified by J. Åkerman et al. (2011): cultural, political, legal, organizational, knowledge-related, technological, and financial.

The SARS-COV 2 pandemic turned out to be unidentified barrier to sustainable mobility until 2020. The lockdown and related mobility restrictions have affected transport behaviour and dramatically reduced public transport fare revenue.

The suppression of travel related to the pandemic demonstrated how dramatically people can change mobility patterns. Many journeys were avoided due to technological efficiencies (remote work or education), some due to anxiety, health concerns, job losses, and other effects of the pandemic and associated economic slowdown. Numerous worldwide, cross-sectional studies of transport demand confirm this trend in numbers in general (Barbieri et al., 2020) and in relations to particular modes of.

A smaller number of trips was also recorded in public transport. The decline of journeys in public transport varied depending on the country and city about 30-80% (Bernhardt, 2020; (Gkiotsalitis, Cats, 2020). As a result of the COVID-19 pandemic, the passenger turnover at the world's largest airports in 2020 compared to 2019 decreased by an average of 1.5-4 times (Tarkhov, 2021).

During the lockdowns, the use of nearly every mode of transportation fell precipitously. Due to the decrease in the number of trips, especially those made by motorized means of transport, for the most part, people across the world are experiencing an air quality improvements (Watts, 2020). The results of cross-sectional studies within of major cities in Europe confirm that dwellers do not want to go back to pre-pandemic air pollution levels (Posaner et al., 2020). B. Ricco (2020) suggests that pandemic may be a fly-wheel for sustainable mobility in many polluted urban areas like an economic and social crisis in the seventies decade of 20th Century was for the 'bike revolution' in the Netherlands. It is mainly an opportunity for an increase in the role of active mobility, but also of public transport. However, accommodating the changing demand and supply conditions is an challenge for public transport. Moreover, these changes are subject to great uncertainty and the dynamics of the pandemic often do not follow a consistent recovery path (Gkiotsalitis, Cats, 2020).

The pandemic has changed the importance of individual public transport attributes. Crowded vehicles and crowded stops/stations have been identified as the most damaging factor affecting the sense of safety while driving during the COVID-19 epidemic (Lucchesi et al., 2022).

In Greece research results suggest that walking and cycling were only marginally improved. Traffic delays for car users were considerable. Car usage declined somewhat, with the exception of ride-sharing. Public transport ridership numbers suffered a lot because of concerns about sharing closed space with many others during the pandemic (Kyriakidis et al., 2023). In Scotland over a third of residents declare to use buses (36%) and trains (34%) less, whilst a quarter expect to drive their cars more (Downey et al., 2022).

Tracking changes in travel demand is possible thanks to the use of Big Data, which removes the limitations of the sample and allows for cross-sectional research in many cities or countries in parallel (Barbieri et al., 2020; Pullano et al., 2020). However, finding out about travelers' preferences or future behaviour requires the use of questionnaires. These researches need more money and time-consuming and have sample limitations (Helbin, Wyszomirski, 2019).

In Spain more than 75% of respondents would accept restrictions on car use after the return to normal life, and more than 90% agree on increasing the space for pedestrians and cyclists on streets. Furthermore, 75% of respondents would change the primary transport mode towards a more sustainable one if it would decrease the incidence or severity of the COVID-19 (Awad-Núñez et al., 2021). The same authors convine that the respondents expect a new urban transport policy that gives more importance to the most sustainable modes, reducing the public space devoted to cars, which means the possibility of turning the COVID-19 crisis into an opportunity to make Spanish cities more sustainable.

Similar conclusion present N. Valenzuela-Levi et al., (2021): "a more sustainable post COVID-19 world requires urban transport policies aiming for resilience, social equity and decarbonisation. Instead of just focusing on the transport sector, the authors propose an integrated approach to housing and mobility". Analysis of sustainable mobility policy and policy instruments relative to three narratives (electro-mobility, low-carbon societies and collective transport 2.0) suggests that a move towards car-free transportation via regulations and pricing, complimented by information campaigns could be an effective strategy (Griffiths et al., 2021).

A review of the literature (Olayode et al., 2022) on the impact of the pandemic shows that:
- COVID-19 has significantly and negatively affected the public's perception of public transport, especially if it is about maintaining the physical distance imposed by different countries to stop the spread of the virus in public transport systems,
- the importance of using face masks is confirmed by research on the spread of COVID-19, however,

NGOs and individuals oppose its use in public spaces (shopping malls, supermarkets and schools),
- governments should provide special funding to public transport operators to deal with the aftermath of the pandemic and maintain public transport systems,
- reaction of developing countries (mainly countries with African population) to the COVID-19 pandemic was weak,
- there seems to be a significant paradigm shift in the use of public road transport facilities. This has changed the way commuters view public transport due to the fear of contracting the COVID-19 pandemic.

Another literature review (Paul et al., 2022) present that restriction on public transit usage is viewed as an emergency, the response to which, at least in the short term, is an increased reliance on private modes. Non-motorized vehicle usage and walking prevalence increased mostly in European countries.

The results of studies on mobility from the country and regional (voivodeships) perspective in Poland in the time of the COVID-19 Pandemic indicate the decrease in mobility too. Moreover, there have been significant differences observed regarding the changes in mobility in public transport depending on the level of stringency of anti-COVID-19 regulation policy (Wielechowski et al., 2020). In the study of transport behaviour of employees of the Wrocław University of Sciences and Technology, no significant effect of travel distance on modal split in different periods of the pandemic was found. Regardless of the period of the pandemic, the relationship between public transport standards and its participation in modal split was evident (Szczepanek, Kruszyna, 2022).

The demand studies in Poland are also based on Big Data (Wielechowski et al., 2020; Tarkowski et al., 2020). The survey researches for Poland known to the authors are limited to research on the impact of COVID-19 on public transport users willingness to travel and their safety criteria perceptions (Przybylowski et al., 2021) and on factors influencing change in travel times and in modal split under epidemic (Pullano et al., 2020). The factors influencing the shortening of the trip were the destination, means of transport, the size of the traveller's household, fear of the coronavirus, the main occupation and the change in it caused by the epidemic.

To the best of the authors' knowledge, there is no more in-depth research on the impact of COVID-19 on transport patterns and influence of covariables such the pandemic period, scale of restrictions, place of residence or transport patterns before COVID-19. This article aims to fill this gap.

The results of this study complement international data sets on transport demand in pandemic and position Poland on global map of COVID-19 related modal shift. Similarly to (Shakibaei et al., 2021), changes in public transport were analyzed in three periods distinguished depending on the specificity of the restriction. The transport behaviour before, during and after the pandemic and their mutual relations were analyzed. This can support the transition from the initial ad-hoc planning practices to a more evidence-based decision making (Gkiotsalitis, Cats, 2020). It would like to stress that, at the moment, there is only a limited number of papers on changes in expectations for public transport in the context of COVID. Using the advantages of the surveys, changes in the expectations regarding the standards that public transport should meet to encourage residents to use it were analyzed. This knowledge can be crucial in post-pandemic transport planning.

4. Results

4.1. Change in transport behaviour in particular periods of the pandemic

The analysis of responses to transport behaviour in particular periods of the pandemic did not show significant differences in the frequency of travel mainly by passenger car (private or company car), mainly by public transport, mainly by car, mainly on foot, equally by car and public transport, and in other way in separate periods of a pandemic. On the other hand, there were significant differences with regard to trips mainly by bicycle – in the period from July to August, the percentage of people who traveled this way was significantly higher than in the period from March to June by 1.2 per cent and than in the period from September to December by 1.6 percentage points. These differences can be explained by the specificity of the transport behaviour of cyclists in Poland, whose travel intensity increases in the warm months of the year (Okraszewska et al., 2016). This explanation is confirmed in comprehensive studies of transport behaviour carried out in one of the metropolitan cities in 2018 on a representative random sample (Public Transport Board, 2019).

There were also significant differences in the absence of travel. The percentage of people who did not travel in the period from March to June was significantly higher than in the period from July to August by 1.7 pp. and than in the period from September to December by 1.5 pp. The presented differences result from the intensity of the restrictions.

The results of the research indicate that the change in the intensity of the restrictions did not significantly affect the modal split. The results of the analyzes are presented in Tab. 1. These differences can be explained by the specificity of the transport behaviour of cyclists in Poland, whose travel intensity increases in the warm months of the year, i.e. from March to October (Okraszewska et al., 2016).

The analysis of the number of trips in particular periods of the pandemic showed significant differences in the frequency of responses among people traveling mainly by public transport and private or company passenger car.

For the period from March to June, the analysis showed that 32.8% of the respondents who traveled mainly by private or company car before the pandemic did not change their transport behaviour and continued to travel that way. 23.6% of car travelers before the pandemic slightly reduced the number of trips. 16.3% of these inhabitants significantly decreased or ceased their travels. Among people traveling mainly by public transport, a significant reduction or discontinuation of travel occurred in 49.7% of the respondents, and in 27.0% this change did not occur or was insignificant. In the case of respondents who travel by bicycle, no change or a slight change in the number of trips was recorded in 51.1%, and a significant decrease or discontinuation of travel – in 29.6%. In the group of people traveling with a passenger car as part of carsharing, no change or a slight reduction in the number of trips was recorded in 37.6% of the respondents, and a significant change or discontinuation of travel – also in 37.6%. As many as 69.4% of the respondents who traveled on foot stopped or significantly reduced the number of trips. 34% of those traveling by car and public transport to an equal extent reduced or stopped traveling significantly between March and June. 60.9% of residents who traveled otherwise have stopped all travel altogether. The results of the analysis are presented in Tab. 2.

Tab. 1. Frequency analysis with a χ^2 concordance test for transport behaviour in different periods of the pandemic.

Method of travel used mainly	time range in months							
	III-VI		VII-VIII		IX-XII			
	n	%	*n*	%	*n*	%	χ^2	*p*
Car*	1593	53.1	1527	50.9	1567	52.2	1.41	0.494
PT**	898	29.9	959	32.0	990	33.0	4.62	0.099
Bike	141	4.7	177	5.9	129	4.3	8.38	0,015
Carsharing	15	0.5	18	0.6	17	0.6	028	0.869
Walk	150	5.0	136	4.5	127	4.2	1.95	0.377
Car/PT	105	3.5	132	4.4	118	3.9	3.08	0.214
Other	5	0.2	9	0.3	5	0.2	1.68	0.432
no travels	93	3.1	42	1.4	47	1.6	26.05	<0.001

**(including railways); * private or company; PT – Public transport

Tab. 2. Analysis of the frequency of changes in the number of trips from March to June depending on the type of travel before the pandemic (N = 3000).

Number of trips from March to June	Method of travel used mainly before pandemic						
	Car*	PT**	Bike	Carsharing	Walk	Car/PT	Other
	n (%)	*n* (%)	*n* (%)	*n* (%)	*n* (%)	*n* (%)	*n* (%)
no change	492 (32.8)	110 (10.9)	44 (32.6)	3 (18.8)	15 (12.1)	9 (4.8)	1 (4.3)
slight decrease	354 (23.6)	163 (16.1)	25 (18.5)	3 (18.8)	5 (4.0)	38 (20.2)	2 (8.7)
decrease +/- 50%	341 (22.7)	237 (23.4)	26 (19.3)	4 (25.0)	18 (14.5)	77 (41.0)	3 (13.0)
significant decrease	244 (16.3)	349 (34.5)	18 (13.3)	1 (6.3)	43 (34.7)	42 (22.3)	3 (13.0)
no trips	70 (4.7)	154 (15.2)	22 (16.3)	5 (31.3)	43 (34.7)	22 (11.7)	14 (60.9)
Results	χ^2 (4) = 324.77; p < 0.001	χ^2 (4) = 173.35; p < 0.001	χ^2 (4) = 14.81; p = 0.005	χ^2 (4) = 2.75; p = 0.601	χ^2 (4) = 48.26; p < 0.001	χ^2 (4) = 70.03; p < 0.001	χ^2 (4) = 24.61; p = 0.006

**(including railways); * private or company; PT – Public transport

In the summer months (July-August), when the restrictions were reduced, the decrease in the number of trips was smaller. For example, in the pre-pandemic segment, mainly by passenger car, the share of people who did not travel at all decreased to 1.5%, and the share of people whose number of trips did not change increased to 45.1%. In the segment of traveling by public transport, the share of people who did not travel decreased to 3.5%, while the share of people whose number did not change increased to 25.6%. From September, authorities gradually reintroduced pandemic restrictions. However, the number of trips that significantly reduced the number of journeys were those who used mainly public transport before the pandemic. In the initial period of the pandemic, 49.7% of these inhabitants either stopped traveling or significantly limited them. This percentage decreased to 23.9 and 25.4% in two consecutive periods.

The share of people who stopped their travel or significantly reduced it in terms of travel arrangements before the pandemic is presented in Fig. 2.

Detailed results of the analyzes for the periods July – August and September – December are presented in Appendix A.

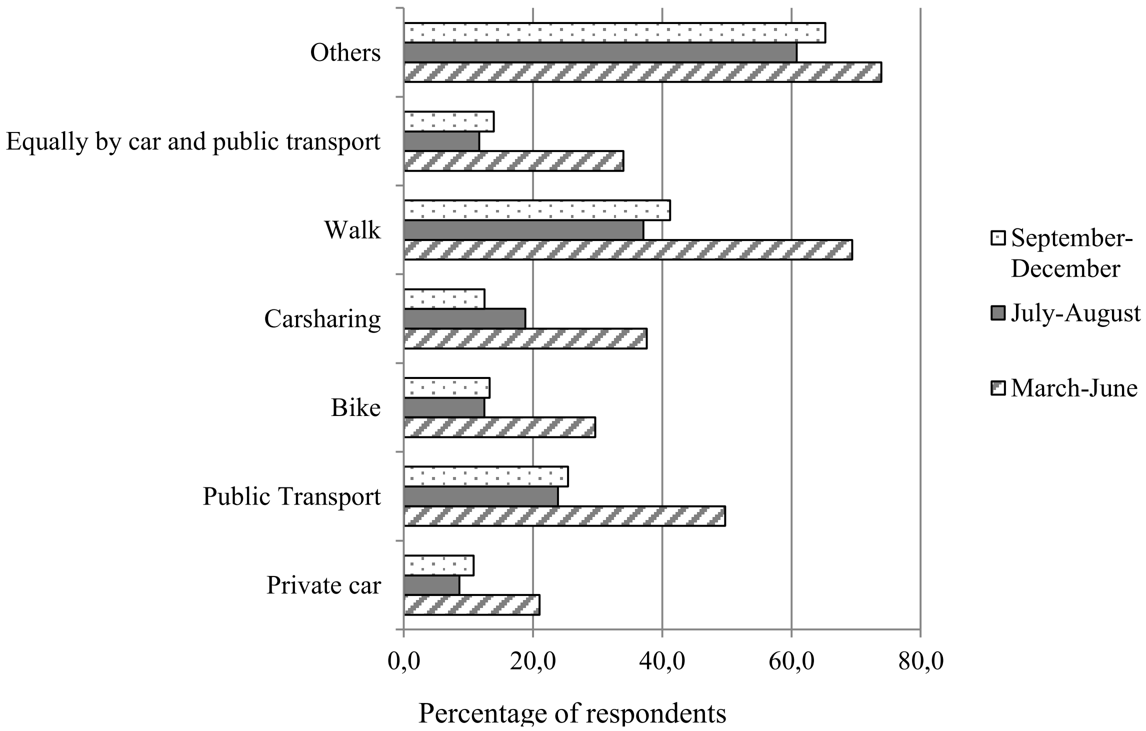

Fig. 2. Share of people who discontinued or significantly reduced the number of trips during the pandemic period, depending on how they traveled before the pandemic.

in this period remained at a level similar to the holiday period (July-August). For example, in the segment of traveling mainly by car, the share of people whose number of trips did not change amounted to 43.6%, and in the segment of traveling mainly by public transport –20.0%. Disregarding people traveling in a different way due to their number on the verge of statistical error, the analyzes show that during the pandemic the number of travels was the greatest reduction in the number of travels by residents traveling before the pandemic, 69.4% of whom stopped traveling in the initial period of the pandemic or significantly limited their number. In the following months, the percentage of people who radically limit their pedestrian travel decreased to 37.1% (July-August) and 41.2% (September-December). The second segment

4.2. Influence of the place of residence on transport behaviour during the pandemic

A detailed analysis of the results of the influence of the place of residence (the core of the metropolis and the surroundings of the metropolis) on transport behaviour showed significant differences in behavior in all analyzed periods.

The sample for the research was quota sample – proportional to the number of inhabitants of cities and communes making up the metropolitan area. Quota selection made it possible to compare changes in behaviour in individual metropolitan areas. People living in the core of the metropolis (Gdańsk, Sopot and Gdynia) significantly less often than people living in the vicinity of the metropolis (other cities and rural communes making up the metropolis) traveled by private or company car in all analyzed periods. However, they used public transport significantly more often. Inhabitants of the metropolitan core significantly less frequently gave up all travels altogether. Moreover, in the period from September to December, the inhabitants of the core significantly more often traveled by bicycle than the inhabitants of other cities and communes of the metropolis. There were no significant intergroup differences in car travel as part of carsharing, car and public transport to the same extent, and traveling in other ways. The results of the analyzes are presented in Tab. 3 for the period March-June and for the remaining months in Appendix A.

from July to August and the same (94.4%) in the period from September to December. 85.3% of pre-pandemic users mostly using public transport in the period from March to June were using this mode of transport. In the period from July to August, the share of these people increased by 3.9 points. percentage point, and in the period from September to December by another 1.2 percentage points. percentage. Among pre-pandemic travelers alike by car and public transport, only 21.3% between March and June, 37.8% between July and August and 36.2% between September and December continued to travel in this method. Most of the respondents in this group changed to a private or company car (48-68% depending on the analyzed

Tab. 3. Frequency analysis with Pearson's χ^2 test for differences in transport behaviour in the period from March to June according to the place of residence.

Method of travel used mainly	The core of the metropolis		The surroundings of the metropolis	
	n	%	*n*	%
Car*	1036_a	49.3	557_b	61.9
Public transport**	719_a	34.2	179_b	19.9
Bike	107_a	5.1	34_a	3.8
Carsharing	7_a	0.3	8_a	0.9
Walk	108_a	5.1	42_a	4.7
Car/PT	73_a	3.5	32_a	3.6
Other	3_a	0.1	2_a	0.2
no travels	47_a	2.2	46_b	5.1
Results	χ^2 (7) = 85.56; $p < 0.001$; V = 0.17			

Columns not dividing the letter index differ at the level of p <0.05 (Bonferroni correction)

**(including railways); * private or company; PT – Public transport

4.3. The impact of pre-pandemic travel patterns on transport behaviour during a pandemic

The frequency of using particular means of transport during the pandemic was analyzed depending on the way of travel before the pandemic. The results showed significant differences in the frequency of transport behaviours for all analyzed relations.

In the period from March to June, 94.4% of respondents traveling by private or company car before the pandemic still used this mode of transport. A similar percentage of the respondents – 92.9%, used the car

period). Before the pandemic, the vast majority of people who traveled by bicycle remained with this mode of transport (approx. 93% of respondents), and in the period from September to December there was a decrease in the frequency of using this mode of transport to 85.2%. In the group of respondents using cars as part of carshing, 75-81% of the respondents remained with this type of travel. Over 90% of the respondents continued to travel on foot in each of the analyzed periods. Detailed results of the analyzes for the period March-June are presented in Tab. 4 and for the remaining periods in Appendix A.

Tab. 4. Analysis of the frequency of use of a given transport mode in the period from March to June, depending on the method of travel used before the pandemic (N = 3000)

Method of travel used mainly from March to June	Method of travel used mainly before pandemic (N = 3000)						
	Car*	PT**	Bike	Carsharing	Walk	Car/PT	Other
	n (%)	*n (%)*	*n (%)*	*n (%)*	*n (%)*	*n (%)*	*n (%)*
Car*	**1417 (94.4)**	39 (3.8)	3 (2.2)	1 (6.3)	1 (0.8)	128 (68.1)	4 (17.4)
PT**	25 (1.7)	**864 (85.3)**	4 (3.0)	0 (0)	0 (0)	3 (1.6)	2 (8.7)
Bike	5 (0.3)	6 (0.6)	**125 (92.6)**	0 (0)	2 (1.6)	3 (1.6)	0 (0)
Carsharing	1 (0.1)	1 (0.1)	0 (0)	**12 (75.0)**	0 (0)	1 (0.5)	0 (0)
Walk	6 (0.4)	24 (2.4)	3 (2.2)	0 (0)	**115 (92.7)**	2 (1.1)	0 (0)
Car/PT	31 (2.1)	33 (3.3)	0 (0)	1 (6.3)	0 (0)	**40 (21.3)**	0 (0)
Other	1 (0.1)	0 (0)	0 (0)	0 (0)	1 (0.8)	0 (0)	**3 (13.0)**
no travels	15 (1.0)	46 (4.5)	0 (0)	2 (12.5)	5 (4.0)	11 (5.9)	14 (60.9)
Results	χ^2 (7) = 9210.59; $p < 0.001$	χ^2 (7) = 4924.49; $p < 0.001$	χ^2 (7) = 792.94; $p < 0.001$	χ^2 (7) = 59.00; $p < 0.001$	χ^2 (7) = 731.23; $p < 0.001$	χ^2 (7) = 583.40; $p < 0.001$	χ^2 (7) = 55.26; $p < 0.001$

**(including railways); * private or company; PT – Public transport

4.4. Expected public transport service standards after the pandemic ends

The standards that public transport should meet in order to encourage residents to use its services after the end of the pandemic were also analyzed. 23.2% of the surveyed respondents indicated a high frequency of operating. The second highest standard indicated was the low cost of travel (18.2%). The third place was taken by the lack of congestion in the vehicle (17.6%). 39.8% of residents do not want to use public transport services regardless of the standards met. A detailed distribution of the results is presented in Tab. 5.

Tab. 5. Analysis of the frequency of responses regarding public transport standards encouraging to use this mode of travel after the pandemic is over.

Standard	*N*	% of answers	% of observations
No crowds in the vehicle	342	10.7	17.6
High frequency of operating	450	14.0	23.2
Short distance to stops	266	8.3	13.7
Low travel cost	352	11.0	18.2
Convenient travel time	249	7.8	12.8
Dirctness	321	10.0	16.6
Modern vehicles	175	5.5	9.0
Punctuality	235	7.3	12.1
I will not decide regardless of the standards met	772	24.1	39.8
Other	43	1.3	2.2
	3205	100.0	165.4

5. Conclusions and discussion

The results of the study did not confirm the first hypothesis. In particular periods of the pandemic, apart from cycling, the transport behaviour did not change significantly with regard to the way of travel. The share of individual travel methods remained at a similar level throughout the pandemic, regardless of changes in the intensity of the restrictions. On the other hand, the number of trips changed significantly, which partially confirmed the second of the hypotheses. These changes occurred with varying intensity depending on the analyzed period. The results of the questionnaire surveys are consistent with the results of research using Big Data (Wielechowski et al., 2020) and publications on the subject (Gkiotsalitis, Cats, 2020; Bernhardt, 2020). The greatest travel restrictions were recorded in the initial period of the pandemic from March to June. In these months, almost 70% of the population traveling before the pandemic mainly on foot, and 49.6% of those traveling before the pandemic mainly by public transport, abandoned or significantly reduced their number. In the first period of the pandemic, the number of trips was the least limited by the inhabitants who used a private or company car before the pandemic. Restrictions in the first period of the pandemic (March-June) resulted in greater limitations in mobility than the corresponding re-restrictions at the end of the year (October-December).

The analyzes of the relation between the way of travel before and during the pandemic showed that the most stable transport behaviour in terms of the way of travel was characterized by people traveling mainly by private or company cars: 92.9-94.4% of these people did not change their behaviour during the pandemic period. Residents traveling before the pandemic mainly by public transport were more likely to change the way of travel: 85.3-90.4%, however, did not change their behaviour in this respect. 62.2-78.8% of residents who used public transport and a passenger car to an equal extent before the pandemic decided to change the way of traveling. This proves that the possibility of using a car contributed to the abandonment of public transport services during the pandemic. Hiking was limited to the greatest extent in the first period of restrictions (March-June). However, they were still implemented by 92.7% of the residents who had walked before the pandemic.

The hypothesis about the influence of the place of residence on transport behavior was confirmed. The residents of the cities forming the core of the metropolis more often chose public transport than the residents of the metropolitan area. This is understandable in the light of the restrictions on the number of passengers in public transport vehicles and the more modest off-core offer of public transport services, primarily in terms of vehicle frequency. In the core of the metropolis, there is a possibility of substituting travel by various means of transport that operate at high frequency. In the surroundings, the average travel distance is also greater, determining its time and thus the time spent with other people in the vehicle. The adopted hypothesis was based on the modal split in the analyzed areas in the pre-pandemic period. Core residents also reduced the number of travels during the pandemic to a lesser extent than those in the surrounding area. Again, the hypothesis was based on pre-pandemic mobility rates.

The lower decrease in the use of public transport in the metropolis we analyzed compared to the cities of the Netherlands (Badr et al., 2020) can be explained by the use of bicycles to a greater extent as an alternative means of transport in the Netherlands compared to the analyzed metropolis in Poland (Okraszewska et al., 2016). The role of bicycles in achieving the goals of sustainable mobility in post-COVID conditions will depend on infrastructure development and climatic conditions (Shakibaei et al., 2021).

The results of the study confirmed the hypothesis that possible unfavourable, from the point of view of sustainable mobility goals, changes in the modal split after the end of the pandemic should be counteracted by improving the quality of public transport services. The most important attributes were: high frequency of vehicle journeys, low travel cost, no vehicle congestion. Taking the first place by frequency can be considered as an evident impact of the pandemic on the significance of this attribute. In studies conducted before the pandemic, frequency was considered the most important attribute only in some municipalities located in the vicinity of the metropolis, far away from its core. In the two cities of the metropolitan core (Gdańsk and Gdynia) with the highest population (67% of the metropolitan population) and a relatively high share of public transport in the modal split (32.1% and 37.1%, respectively), the results of comprehensive traffic studies and transport behavior studies residents from before the pandemic showed that the most important attribute is directness. The frequency was classified in third place (ZKM Gdynia, 2019; VIA VISTULA, 2016). Under the influence of the pandemic, frequency became the most important postulate of both the residents of the core and the surroundings of the metropolis. Therefore, ensuring high frequency of journeys becomes not only a manifestation of the appropriate quality of services, but also a condition for considering the services as reliable and safe from the health point of view. The possibility of substituting car journeys with high-frequency public transport journeys becomes the most important factor determining the use of public transport services.

Our study has limitations. The use of the telephone interview method set the procedure for selecting the research sample and reduced the number of units participating in the research. Consequently, it limited the possibility of generalizing the results to the entire population.

6. Recomendations

The implementation of the high-frequency demand will be difficult for financial reasons. Other results of the authors' own research showed a significant 30% decrease in demand and revenues from public transport tickets in the metropolis during the pandemic, compared to the year preceding the pandemic. The decrease in ticket revenues resulted in the need to increase public transport subsidies from local government budgets. The duplication of some routes increased the costs and deepened the deficit of this transport in the metropolis. This resulted in a situation in which some cities and municipalities faced a lack of funds for further increasing subsidies to public transport. In the light of the analyzed research results, the right solution is not to increase prices for public transport services, as the residents expect the cost of travel to be low. It is possible that they are even lower than today. As a result, it is necessary to postulate the involvement of national authorities in financing public transport activities, especially in those cities and metropolises where this task rests almost exclusively with local authorities.

The high third place in the ranking of the lack of congestion in a vehicle should also be considered as a manifestation of the impact of the pandemic on the importance of public transport attributes. Before the pandemic, the comfort of travel was only ranked 7-10 in the ranking, and the majority of passengers accepted a seat in easy conditions. This reflects the concerns of the residents of the metropolitan center, where the greater use of the transport capacity of public transport vehicles is noted. This postulate is related to the sense of security resulting from maintaining a safe distance (Bert et al., 2020). The level of congestion may mean the risk of infection, which according to aggregated results from China, U.S and European Cities is the top criterion when choosing transport mode, overtaking even destination time in importance (Hattrup-Silberberg et al., 2020). Regardless of the subjective understanding of the concept of non-congestion and travel convenience, it can be concluded that public transport faces new challenges in terms of ensuring the expected differentiation conditions.

The stages of people's behavior in a pandemic, distinguished by (Yuen et al., 2020): panic, adaptation and new normality, do not answer the question of what this new normality will be: cyclically repeated cases of restrictions or awareness of epidemic threats influencing changes in transport behavior of residents in long period of time.

During the transitional period of returning „to normality", increased car traffic will be possible, which will lead to more onerous congestion (Beck et al., 2020). It is therefore necessary to take measures to ensure that the role of public transport is maintained, due to its high transport capacity, as the foundation of sustainable mobility. The research of S. Shakibaei et al. (2021) showed that residents perceive public transport as one of the main sources of the spread of the virus, which may have an impact on the transport behavior of residents. At the stage of return to normalcy, it is advisable to demonstrate disinfection of vehicles and to ensure universal access to disinfectants (Shakibaei et al., 2021).

In the presented conditions, it is necessary to postulate the implementation of the organizational solution Mobility as a Service (MaaS) in public transport. This solution uses an information platform in order to be able to offer substitutive and complementary means of public transport during travel and to easily pay for all services that make up the trip (Smith et al., 2018). In the analyzed conditions, MaaS should offer one more important functionality – information about the use of available seats in the vehicle, along with an indication of alternative options for travel by public transport in the absence of a convenient place in the vehicle selected by the passenger. This solution may become necessary in view of social pressure to maintain the level of air pollution at the beginning of the pandemic period (Posaner et al., 2020).

Organizers of public transport must be prepared for quick, comprehensive changes to timetables in such a way that the change itself and the pace of its introduction do not cause additional difficulties for passengers resulting, for example, from the lack of coordination of vehicle journeys when the restrictions reappear.

Failure to take appropriate measures to shape the offer of public transport services may result in the increase of 24% of people who according to the research do not intend to use public transport after the end of the pandemic, regardless of taken actions, will increase by those who will assess public transport as a travel method without the required attributes. Consequently, meeting the goals of sustainable mobility will require shifting the demand to other sustainable ways of travel (bicycle and walking). As examples of cities such as Turin (Buzatu, Pianta, 2020) or Freiburg (ZKM Gdynia, 2019) show this is possible, but in large metropolitan areas it may not be realistic.

Acknowledgment

The research was prepared based on data from Public Transport Metropolitan Association of Gdańsk Bay.

Appendix A

Tab. A-1. Analysis of the frequency of changes in the number of trips from July to August depending on the type of travel before the pandemic (N = 3000).

Number of trips from July to August	Method of travel used mainly before pandemic						
	Private car	Public transport (PT)	Bike	Carsharing	Walk	PT+private car	Other
	n (%)	*n* (%)	*n* (%)	*n* (%)	*n* (%)	*n* (%)	*n* (%)
No change	677 (45,1)	259 (25,6)	64 (47,4)	4 (25,0)	24 (19,4)	41 (21,8)	3 (13,0)
Slight deacrease	485 (32,3)	293 (28,9)	28 (20,7)	5 (31,3)	15 (12,1)	86 (45,7)	2 (8,7)
50% decrease	211 (14,1)	219 (21,6)	26 (19,3)	4 (25,0)	39 (31,5)	39 (20,7)	4 (17,4)
Significant decreasse	106 (7,1)	207 (20,4)	11 (8,1)	3 (18,8)	37 (29,8)	20 (10,6)	3 (13,0)
No trips	22 (1,5)	35 (3,5)	6 (4,4)	0 (0)	9 (7,3)	2 (1,1)	11 (47,8)
Result	$\chi^2(4) = 996{,}65$; $p < 0{,}001$	$\chi^2(4) = 196{,}11$; $p < 0{,}001$	$\chi^2(4) = 76{,}59$; $p < 0{,}001$	$\chi^2(4) = 4{,}63$; $p = 0{,}327$	$\chi^2(4) = 28{,}10$; $p < 0{,}001$	$\chi^2(4) = 104{,}61$; $p < 0{,}001$	$\chi^2(4) = 11{,}57$; $p = 0{,}021$

Tab. A-2. Analysis of the frequency of changes in the number of trips from September to December depending on the way of travel before the pandemic (N = 3000).

Number of trips from September to December	Method of travel used mainly before pandemic						
	Private car	Public transport (PT)	Bike	Carsharing	Walk	PT+ private car	Other
	n (%)	*n* (%)	*n* (%)	*n* (%)	*n* (%)	*n* (%)	*n* (%)
No change	654 (43,6)	203 (20,0)	53 (39,3)	4 (25,0)	28 (22,6)	40 (21,3)	1 (4,3)
Slight deacrease	469 (31,2)	277 (27,3)	38 (28,1)	6 (37,5)	14 (11,3)	80 (42,6)	3 (13,0)
50% decrease	216 (14,4)	276 (27,2)	26 (19,3)	4 (25,0)	31 (25,0)	42 (22,3)	4 (17,4)
Significant decreasse	135 (9,0)	222 (21,9)	15 (11,1)	2 (12,5)	41 (33,1)	21 (11,2)	3 (13,0)
No trips	27 (1,8)	35 (3,5)	3 (2,2)	0 (0)	10 (8,1)	5 (2,7)	12 (52,2)
Result	$\chi^2(4) = 875{,}04$; $p < 0{,}001$	$\chi^2(4) = 194{,}42$; $p < 0{,}001$	$\chi^2(4) = 56{,}22$; $p < 0{,}001$	$\chi^2(4) = 6{,}50$; $p = 0{,}165$	$\chi^2(4) = 26{,}08$; $p < 0{,}001$	$\chi^2(4) = 84{,}07$; $p < 0{,}001$	$\chi^2(4) = 15{,}91$; $p = 0{,}003$

Tab. A-3. Frequency analysis with Pearson's χ2 test for differences in transport behavior in the period from July to August depending on the place of residence.

Method of travel used mailny	**The core of metropolis**		**The sourroundings of the metropolis**	
	n	**%**	***n***	**%**
Private car	986_a	47,0	541_b	60,1
Public transport	757_a	36,0	202_b	22,4
Bike	134_a	6,4	43_a	4,8
Carshing	11_a	0,5	7_a	0,8
Walk	94_a	4,5	42_a	4,7
Private car+public transport	94_a	4,5	38_a	4,2
Other	4_a	0,2	5_a	0,6
No travel	20_a	1,0	22_b	2,4
Results	χ^2 (7) = 74,28; p < 0,001; V = 0,16			

Columns not dividing the letter index differ at the level of p <0.05 (Bonferroni correction)

Tab. A-4. Frequency analysis with Pearson's χ2 test for differences in transport behavior in the period from September to December depending on the place of residence.

Method of travel used mailny	**The core of metropolis**		**The sourroundings of the metropolis**	
	n	**%**	***n***	**%**
Private car	1016_a	48,4	551_b	61,2
Public transport	7751_a	36,9	215_b	23,9
Bike	102_a	4,9	27_b	3,0
Carshing	10_a	0,5	7_a	0,8
Walk	89_a	4,2	38_a	4,2
Private car+public transport	82_a	3,9	36_a	4,0
Other	3_a	0,1	2_a	0,2
No travel	23_a	1,1	24_b	2,7
Results	χ^2 (7) = 68,48; p < 0,001; V = 0,15			

Columns not dividing the letter index differ at the level of p <0.05 (Bonferroni correction)

Tab. A-5. Analysis of the frequency of use of a given transport mode in the period from July to August, depending on the method of travel used before the pandemic (N = 3000).

Method of travel used mainly from July to August	Method of travel used mainly before pandemic						
	Private car	Public transport (PT)	Bike	Carsharing	Walk	PT+private car	Other
	n (%)	*n (%)*	*n (%)*	*n (%)*	*n (%)*	*n (%)*	*n (%)*
Private car	**1395 (92,9)**	35 (3,5)	2 (1,5)	0 (0)	1 (0,8)	91 (48,4)	3 (13,0)
Public transport	36 (2,4)	**904 (89,2)**	1 (0,7)	0 (0)	0 (0)	17 (9,0)	1 (4,3)
Bike	15 (1,0)	22 (2,2)	**124 (91,9)**	2 (12,5)	5 (4,0)	7 (3,7)	2 (8,7)
Carshing	3 (0,2)	1 (0,1)	0 (0)	**13 (81,3)**	0 (0)	1 (0,5)	0 (0)
Walk	1 (0,1)	17 (1,7)	4 (3,0)	0 (0)	**114 (91,9)**	0 (0)	0 (0)
Private car+public transport	37 (2,5)	21 (2,1)	2 (1,5)	1 (6,3)	0 (0)	**71 (37,8)**	0 (0)
Other	2 (0,1)	0 (0)	1 (0,7)	0 (0)	1 (0,8)	0 (0)	**5 (21,7)**
No travel	12 (0,8)	13 (1,3)	1 (0,7)	0 (0)	3 (2,4)	1 (0,5)	12 (52,2)
Results	χ^2 (7) = 8887,13; *p* < 0,001	χ^2 (7) = 5461,43; *p* < 0,001	χ^2 (7) = 777,77; *p* < 0,001	χ^2 (7) = 71,00; *p* < 0,001	χ^2 (7) = 716,77; *p* < 0,001	χ^2 (7) = 393,36; *p* < 0,001	χ^2 (7) = 40,65; *p* < 0,001

Tab. A-6. Analysis of the frequency of use of a given transport mode in the period from September to December, depending on the method of travel used before the pandemic (N = 3000).

Method of travel used mainly from September to December	Method of travel used mainly before pandemic						
	Private car	Public transport (PT)	Bike	Carsharing	Walk	PT+ private car	Other
	n (%)	*n (%)*	*n (%)*	*n (%)*	*n (%)*	*n (%)*	*n (%)*
Private car	**1417 (94,4)**	44 (4,3)	5 (3,7)	0 (0)	1 (0,8)	96 (51,1)	4 (17,4)
Public transport	35 (2,3)	**916 (90,4)**	10 (7,4)	1 (6,3)	5 (4,0)	19 (10,1)	4 (17,4)
Bike	5 (0,3)	6 (0,6)	**115 (85,2)**	0 (0)	1 (0,8)	2 (1,1)	0 (0)
Carshing	1 (0,1)	1 (0,1)	1 (0,7)	**13 (81,3)**	0 (0)	1 (0,5)	0 (0)
Walk	0 (0)	9 (0,9)	4 (3,0)	0 (0)	**113 (91,1)**	1 (0,5)	0 (0)
Private car+public transport	28 (1,9)	20 (2,0)	0 (0)	2 (12,5)	0 (0)	**68 (36,2)**	0 (0)
Other	0 (0)	1 (0,1)	0 (0)	0 (0)	1 (0,8)	0 (0)	**3 (13,0)**
No travel	15 (1,0)	16 (1,6)	0 (0)	0 (0)	3 (2,4)	1 (0,5)	12 (52,2)
Results	χ^2 (7) = 7147,02; *p* < 0,001	χ^2 (7) = 5634,72; *p* < 0,001	χ^2 (7) = 657,12; *p* < 0,001	χ^2 (7) = 71,00 *p* < 0,001	χ^2 (7) = 702,19; *p* < 0,001	χ^2 (7) = 416,60; *p* < 0,001	χ^2 (7) = 41,35; *p* < 0,001

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