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Travel Behaviour and Society 31 (2023) 312–322

Contents lists available at ScienceDirect

Travel Behaviour and Society

journal homepage: www.elsevier.com/locate/tbs

Impacts of the COVID-19 pandemic on the profile and preferences of urban mobility in Brazil: Challenges and opportunities

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ARTICLE INFO

Keywords:
Travel behavior
Exploratory factor analysis
Public policies
Sustainable transport
Developing countries
Post-pandemic

ABSTRACT

Daily commuting characteristics were highly affected by the COVID-19 pandemic, since restriction of the movement of people was one of the main preventive measures adopted. Understanding of the effects that the pandemic had on mobility is essential to help in mitigating the problems arising from this crisis, while also providing an opportunity for the implementation of sustainable policies in the post-pandemic period. Therefore, the aim of this study was to identify the impacts of the pandemic on the profile of travel behavior and mobility preferences in Brazil, using a case study of cities located in the state of Rio Grande do Sul. The data obtained from an online survey were modeled using exploratory factor analysis, resulting in the extraction of 15 main factors that explain behavioral changes in mobility due to the effects of the pandemic, as well as future perspectives. In the pandemic period, the use of private vehicles grew as the main mode of transport to the principal activity. Conversely, the use of public transport decreased drastically, due to compulsory measures taken by the health authorities to prevent the spread of the new virus. There was also greater receptivity to the adoption of active mobility, especially the bicycle, although it is necessary to provide better conditions for use of this transport mode. The findings support the development of public policies to reduce urban mobility problems and to provide guidelines for sustainable planning in the post-pandemic period.

1. Introduction

At the end of 2019, the first case of COVID-19, a new disease that spreads rapidly through the airways and initially did not have a vaccine or specific treatment, was recorded in China, and a few months later it became a worldwide pandemic. Due to this, the whole world experienced a drastic change in the way of life, with numerous protocols to be followed in order to slow the spread of infection. The most adopted preventive measures to contain the virus were to restrict social contacts, avoid agglomerations, and reinforce hygiene and the use of masks (Huang et al., 2020). These measures affected the work and study activities in cities, with many being restricted, while others were carried out remotely, and some were intensified during the pandemic. These changes affected mobility preferences and transport demands for commuting to the main activities, as well as for leisure or shopping, as reported in several studies analyzing the impacts of the pandemic in different countries (Aletta et al., 2020; Arellana et al., 2020; Beck and Hensher, 2020; Teixeira and Lopes, 2020; Zheng, 2020; Paul et al., 2021).

Although the entire world has undergone the consequences of the pandemic, the impacts depend on the different COVID-19 preventive measures adopted by responsible authorities, and, in particular, developing countries have experienced an increase in inequalities and fragility of social systems (Balbontin et al., 2021; Vallejo-Borba et al., 2022). Mobility restrictions in the urban environment mainly affected the use of public transport, but many countries also identified a positive opportunity for active mobility (Beck and Hensher, 2020; Teixeira and Lopes, 2020; Chai et al., 2021). In contrast, in the Global South, especially in Latin America, the measures taken and the behavioral changes have increased the preference for private vehicles and made travel and accessibility difficult for low-income and periphery families (Arellana et al., 2020; Guzman et al., 2021; Vallejo-Borba et al., 2022). The literature on the impacts of the pandemic on urban mobility is still small but growing, although it is mainly limited to the effects of the initial stage of the pandemic, and particularly focused on more developed regions (Balbontin et al., 2021; Kim and Kwan, 2020). Therefore, it is necessary to understand how travel patterns during the pandemic will influence long-term urban mobility planning, especially to understand

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https://doi.org/10.1016/j.tbs.2023.01.002
Received 28 January 2022; Received in revised form 21 November 2022; Accepted 6 January 2023
Available online 12 January 2023

the weaknesses in the most vulnerable countries.

In other contexts, a study carried out in China, in January 2020, reported that public transport was closed in 12 cities in Hubei Province, including the capital Wuhan, the largest city in the province. This measure affected the transport of more than 10 million people. In addition to public buses and subways, temporary suspensions also affected airports, railway stations, and all major roads outside cities (Zheng, 2020). Concerns about the safety of public transport arose due to the proximity of people in poorly ventilated vehicles, which could facilitate the spread of the virus (Cui et al., 2020). Another study in China found that 92.4 % of respondents were more concerned about opening windows in public transport vehicles, which was previously considered less important (Huang et al., 2020).

In Australia, the average number of trips made by car decreased from 17 to 8 trips per week, although the proportion of trips for essential purchases remained stable and continued to represent a significant percentage of travel data (Beck and Hensher, 2020). In a study undertaken in the city of New York (USA), it was shown that the bicycle became an alternative transport mode and that use of the free shared bicycle service intensified, especially among health care workers who needed to get to their places of work (Teixeira and Lopes, 2020). This measure contributed to reducing the volume of passengers on the subways. In contrast, in Beijing (China), the pandemic reduced overall bicycle use by 64.8 % (Chai et al., 2021).

Even before the COVID-19 crisis, the greater Boston area (USA) was experiencing an increase in car ownership and a decrease in demand of public transport, while historical socio-spatial inequalities made low-income citizens more dependent on public transport. Reports of overcrowded buses and trains, since early March 2020, increased psychological fear among regular public transport passengers, such that those with economic capacity had already purchased a private vehicle or intended to do so within the next year (Basu and Ferreira, 2021).

In Rome (Italy), the preventive measures adopted during March to April 2020 period to contain the spread of COVID-19 reduced 64.6 % of trips using private vehicles in the city (Aletta et al., 2020). In Colombia, during the pandemic, public transport services were reduced by up to 50 %, the operation of buses was limited to a maximum capacity of 35 %, and taxi services were only authorized to operate by phone or digital platforms. In addition, at some points on Colombian roads, the toll fees for freight vehicles were suspended and the body temperature of drivers was monitored to ensure the continuation of transport services for essential supplies (Arellana et al., 2020).

It is evident that the COVID-19 pandemic brought several changes affecting mobility in cities. Since the start of preventive measures to contain the spread of the virus, there have been alterations of travel patterns, transport demands, and preferences related to mobility (Beck and Hensher, 2020; Paul et al., 2021). Therefore, in order to plan urban mobility in an efficient, sustainable, and safe way in the post-pandemic period, it is essential to obtain a broad and consistent understanding of the changes that have affected mobility preferences and transport mode choice in cities. The analysis of the pandemic impacts in urban mobility and the aspects that have contributed to the changes in the use of different modes of transport in cities is indispensable for planning mobility in the future. This can assist in guiding municipal authorities in the development of new policies appropriate for the changing demands, avoiding the worsening of mobility problems in cities as activities progressively return to pre-pandemic levels (Cui et al., 2020; Beck and Hensher, 2020; Zheng, 2020).

Given this scenario, the aim of the present study is to contribute to the process of mobility planning by providing a diagnosis of the factors that affect the travel patterns and mobility preferences of urban commuting for work or study activities, as well as to identify the impacts of the COVID-19 pandemic on urban mobility and transport choices, in the Latin America context. To this end, a survey instrument based on an online questionnaire was developed to characterize the profiles of the travel behavior of individuals and mobility preferences before and during the pandemic, as well as their intentions for the future. The focus of the study on the cities of the state of Rio Grande do Sul (Brazil) contributes to filling a gap in research that explores the mobility changes due to the pandemic in the Global South, especially in Latin American countries and involving smaller cities.

2. Literature review

The COVID-19 pandemic has affected the travel patterns of people in different ways. In the early stages of the pandemic, due to the need for social distancing and the suspension of certain activities, a reduction in trips was identified (Aletta et al., 2020; Balbontin et al., 2021; Zheng, 2020). However, according to Arellana et al. (2020), with the beginning of the mandatory confinement period in Colombia, trips to supermarkets and pharmacies increased, compared to the situation before the measure, while commuting for retail shopping, recreational activities, and visits to parks decreased by about 80 %. In addition, commuting to work showed a reduction of around 60 %, a value similar to that identified by Beck and Hensher (2020) in Australia, where most people also suspended social activities. The variations in mobility levels were influenced by the different stages of the pandemic, the preventive measures adopted, income levels and other factors (Kim and Kwan, 2020).

Traditionally, literature reports mobility preferences varying according to personal and social characteristics. Gender differences influence travel behavior, as women's mobility is more dependent on public transport while men often use more private vehicles. Moreover, women are worst affected in their level of mobility by family and children routines (Szmelter-Jarosz and Suchanek, 2021). After lockdowns of the first stages of the pandemic, women began to travel by car more than they used to, resembling the male profile, but men were more likely to use active mobility (Facal et al., 2021). During the pandemic, women shifted to studying and working from home, in addition to using more technology services for shopping, which reduced their travel to a greater extent, compared to men. Therefore, women's travel patterns may have been more affected by the pandemic due to suspension of activities, family obligations, measures to reduce working hours, or layoffs (Balbontin et al., 2021; Beck and Hensher, 2020; Paul et al., 2021).

The choice of transport modes differs between young and old people. During the pandemic, young people had a higher average number of trips related to essential purchases, compared to middle-aged and elderly people (Beck and Hensher, 2020). Changes in urban mobility showed an increase in the use of private cars to the detriment of public transport for the age groups corresponding to workers (18–65 years), while for people over 65 years old there were no significant changes in the modal split (Facal et al., 2021). These behavioral changes were due to the different risks presented by COVID-19 for each age group and the restrictive mobility measures adopted. In addition, young people are more likely to switch from private vehicle to sustainable transport modes, such as bicycles or public transport (Kroesen, 2014). Young people are also more likely to use technologies related to transport, such as mobility apps, and are more concerned about the environment, so they are willing to use active mobility and to practice multimodality (Szmelter-Jarosz and Suchanek, 2021).

The preventive measures imposed due to the pandemic restricted the occupation of collective spaces, resulting in the adoption of home office routines and flexible hours for public servants and other workers (Balbontin et al., 2021; Teixeira and Lopes, 2020). Nonetheless, lower-paid work activities remained mostly presential during the quarantine period, so they continued to use public transport, while car users were typically people with higher incomes, whose activities during the pandemic were more amenable to remote working routines (Arellana et al., 2020; Basu and Ferreira, 2021; Guzman et al., 2021; Paul et al., 2021; Kim and Kwan, 2020; Liu et al., 2022). In addition, urban configurations of unequal land use made it difficult for low-income and peripheral families to access essential services (Guzman et al., 2021).

In general, the mobility changes mainly affected the demands for

public transport, with drastic reductions during lockdowns periods that were not recovered after the return of the activities (Basu and Ferreira, 2021; Beck and Hensher, 2020; Cui et al., 2020; Facal et al., 2021; Vallejo-Borba et al., 2022; Zheng, 2020). This was due to increased awareness of the risks of transmission of the virus among passengers sharing spaces in public transport vehicles with little ventilation, despite the existence of centralized air conditioning systems (Butler et al., 2020). The decrease in the supply of transport and service quality and the increase in the cost of tickets were also observed as influential in the fall in preferences for public transport (Thombre and Agarwal, 2021; Facal et al., 2021).

Whereas the users of private vehicles often have biased views regarding public transport, overestimating their travel times and costs, car users who also use public transport tend not to be affected by these biases. Car and motorcycle users cite time as being an important aspect for mode choice, although this group sometimes spends more time commuting between the home and the workplace, compared to users of sustainable transport (Sottile et al., 2021). Relative to single-mode travelers, multimodal travelers generally have perceptions of the available options and their attributes that are more realistic, facilitating adjustment of their behavior patterns. Hence, a person who uses multiple modes of transport can be considered a traveler of deliberate choice, while a person who exclusively uses an individual mode is more likely to be a frequent traveler, and, therefore, a captive user (Kroesen, 2014; Heinen and Ogilvie, 2016).

On the other hand, the pandemic has increased the popularity of private vehicles for all income, age and gender groups, and long-term effects are observed (Basu and Ferreira, 2021; Facal et al., 2021; Thombre and Agarwal, 2021; Vallejo-Borba et al., 2022). The advantages of using a car became more evident during the pandemic. In the study by Beck and Hensher (2020), survey participants in Australia stated that their own car would be the most comfortable form of transport to use in the context of the pandemic, while the use of public transport was perceived more negatively. As well, the respondents considered the use of taxis or ride-sourcing services as being preferable. Similarly, in an Indian study, the risk of contracting the virus and the low supply of transport were the main reasons for the changes in modal choice (Thombre and Agarwal, 2021). According to interviews in Boston (USA), Basu and Ferreira (2021) identified that one out of every-five families that did not have a private vehicle intends to buy a car, in a post-pandemic context.

While studies on commuting during the pandemic suggest that people feel safer traveling by car, active mobility were also a viable alternative to meet the need for short-distance trips in urban areas (Ruiz-Padillo et al., 2022; Thombre and Agarwal, 2021). With mitigation of the pandemic, increases in active mobility were observed in some cities, as in the case of Beijing, where there was an average increase of 15.9 % in the use of shared bicycles, suggesting a recovery trend in sustainable mobility after the resumption of activities (Chai et al., 2021).

Walking and cycling are highlighted for their importance not only in maintaining wellbeing, but also in preserving physical activity levels (especially in the context of the pandemic), reducing the risk of increased obesity and mental health problems (Arellana et al., 2020; Kroesen, 2014; Teixeira and Lopes, 2020). However, perceived behaviors in Latin America suggest that it is difficult to encourage active mobility in response to the changes in mobility caused by the pandemic, because barriers to walking and cycling were already being faced before (Arellana et al., 2020; Ruiz-Padillo et al., 2022; Vallejo-Borba et al., 2022).

Furthermore, it has been predicted that urban mobility is unlikely to return to pre-COVID-19 patterns after the pandemic, due to the expansion of home working (Cui et al, 2020). The pandemic has also favored the development of digitalization of many processes, services, and activities. Most of these are related to e-commerce, whose growth modifies the supply chain activities performed by individuals, accentuating the importance of logistics in urban areas (Carrese et al., 2021). The real and lasting impact of this phenomenon on mobility will also depend on the responsiveness of urban managers in the adoption of new technologies in order to create services and cooperation models that can respond to the emerging reality and needs (Kakderi et al., 2021).

These observations suggest that it is necessary to assess the mobility preferences and travel patterns exhibited by individuals before, during, and after the pandemic. During the pandemic, poorly ventilated and crowded public places, including public transport vehicles, were a focus for disease prevention and control. Consequently, there is a need to eliminate the persistent negative perception of public transport caused by the pandemic, in order to avoid individuals definitively switching to private vehicle in the future. From the perspective of sustainable development principles, urban responses to the pandemic have primarily focused on diversifying transport options, including the promotion of walking and cycling. The changes in lifestyle and behavior of citizens, resulting from lockdowns, were perceived by many urban managers as an opportunity for sustainable development, including promotion of the use of open spaces, parks, and alternative urban transport models. There is a perceived opportunity for transition towards inclusive, green, and smart mobility in cities, although some of the measures that have been adopted were temporary and experimental, and their effects on travel behavior have not yet been fully analyzed (Advani et al., 2021; Basu and Ferreira, 2021; Dong et al., 2021; Kakderi et al., 2021; Paul et al., 2021; Thombre and Agarwal, 2021).

Therefore, it is necessary to plan urban mobility in order to meet the demands of these changes and to facilitate efficient transport management. In cities in developing countries, and in Latin America in particular, which have historically been planned with strong incentives for private vehicle, there is an even greater need for policies to ensure equitable, sustainable, safe, and disaster-resilient mobility for the population (Butler et al., 2020; Dong et al., 2021). Moreover, public transport financial policies may be oriented to reduce overcrowding and strengthen bioprotection measures, reduce gender and social inequalities and improve the quality and integration of service (Basu and Ferreira, 2021; Beck and Hensher, 2020; Kim and Kwan, 2020; Thombre and Agarwal, 2021). Research undertaken to understand the preferences of individuals for different urban transport modes, employing advanced data analysis techniques, can reveal opportunities for the incorporation of active mobility in transport infrastructure investments (Beck and Hensher, 2020; Chen et al., 2020; Ruiz-Padillo et al., 2022).

3. Methodology

3.1. Study scenario

The present study was undertaken in the state of Rio Grande do Sul, southern Brazil, which has an estimated population of 11,466,630 inhabitants, with about 85 % living in cities (IBGE, 2021). The economy of the state is based mainly on light industry, services, and agriculture (Rio Grande do Sul, 2021). The monthly family income of the population shows an uneven distribution of wealth, typical of Latin America countries, with the vast majority of the population being considered low-income: 30.81 % of the population subsist with up to 2 minimum monthly wages (m.w., equivalent to approximately USD$ 200); 39.17 % between 2 and 5; 19.23 % between 5 and 10; 7.44 % between 10 and 20; and 3.35 % more than 20 m.w. (IBGE, 2021).

In relation to transport, the state had 5,527,091 private vehicles (cars and motorcycles) in 2020 (IBGE, 2021; Rio Grande do Sul, 2021), representing an average of 48 vehicles per 100 inhabitants, a very high rate, with a continuous growth trend. Urban transport in Brazil presents a distribution with substantial use of walking, while motorized modes are divided between the car (26 %) and public transport (28 %), with the latter being 24 % buses and 4 % rail (subway or train) (ANTP, 2020). The state of Rio Grande do Sul follows this national trend, with a metropolitan train service only in the capital (Porto Alegre), while the rest of the state is only served by bus routes (where public transport is

available) (Rio Grande do Sul, 2021).

3.2. Survey instrument

The survey instrument applied to the study population comprised a questionnaire structured in tree main blocks that sought to capture information related to:

i. Socioeconomic profile: questions on personal data influencing travel patterns.
ii. Mobility routines for the main activity: questions related to transport modes usually used in commuting (car, public transport, walking, motorcycle, bicycle, ride-sourcing services or others), travel behavior to secondary activities, and pandemic impacts on routine. This block included questions about the scenario before the pandemic, the current scenario (during pandemic), and future intentions of use of transport modes.
iii. Mobility attributes: respondents selected their mobility preferences according to eleven aspects for modal choice, thirteen mobility-related COVID-19 preventive measures, and seven reasons to change mode of transport.

The description of the variables in each block is presented in Table 1.

The questionnaire was made available online in December 2020, in the state of Rio Grande do Sul, at the peak of the pandemic and before the emergence of the vaccine. The online questionnaire was disseminated through social networks and local media channels (radio, newspaper and television). A total of 712 responses were obtained, exceeding the minimum sample calculated with a confidence level of 95 % and a sampling error of 4 %, considering the total urban population of the state, 9.75 million inhabitants (IBGE, 2021). The sample was representative of the population studied, stratified according to age (18 to 29, 30 to 49, and 50 to 65 years) and gender (female and male). The survey obtained respondents from 38 cities in all regions of the state, including cities of various sizes to address the different behaviors and travel patterns (small towns – less than 100,000 inhabitants; medium cities – between 100,000 and 500,000 inhabitants; and large cities – more than 500,000 inhabitants, including the metropolitan area of the capital, Porto Alegre) (IBGE, 2021; Ruiz-Padillo et al., 2022).

The data obtained from the responses collected in the survey instrument were modeled as variables related to the attributes that affect mobility preferences of the population for commuting to the main activities. The set of variables represented the socioeconomic profile of the users, and the travel patterns before and during the pandemic, as well as intentions regarding a future scenario after the current health crisis. The collected variables were firstly analyzed in aggregate form in the three different situations to carry out a diagnosis of the mobility behavior of the population studied and to evaluate the changes in the modal choice due to the impacts of the pandemic. Subsequently, the analyses included the relationships between the variables as well as the comparison of the mobility preferences of the respondents before and during the pandemic. Finally, predictions of future travel behaviors were made with the objective of proposing urban transport planning strategies and public policies to improve the mobility in cities of the Global South.

Table 1
Description of data obtained from the survey instrument.

Socioeconomic profile *"profile_variable"*		- Age; Gender; Family income; Education level; Marital status; Dependent children; Driver license; Vehicle access; Main occupation.
Mobility routines	Travel behavior to the main activity *"travel_variable"*	- Transport mode; Travel times; Days commuting.
	Travel behavior to secondary activities *"activity_variable"*	- Physical activities; Children to school/nursery; Shopping; Lunch (commute to lunch or lunch in the workplace).
	Pandemic impacts on work/study routine *"impact_variable"*	- Main activities remained; Hours reduction; Adoption of home office or total suspension of activities; Usage behavior of ride-sourcing services during the pandemic (began, maintained, did not use).
Mobility attributes	Importance of aspects for mode choice *"choice_variable"*	- Travel time; Cost, Comfort; Public security; Road safety; Health security; Service frequency; Cleaning and disinfection; Vehicle capacity; Access to information; Use of technology.
	COVID-19 preventive measures into mobility *"covid_variable"*	- Mask use; Vehicle cleaning; Bus stop cleaning; Distance between passengers; Temperature measurement; Decrease of maximum bus capacity; Vehicle ventilation; Home office routines; Staggered working hours; Shopping hours restriction; Priority access for high-risk groups; Active mobility incentive; Vehicle access restriction to downtown.
	Reasons to changes in transport mode *"change_variable"*	- To avoid risk of contagion; Due to the decrease in the supply of transport services; Due to the reduction in work trips because of the pandemic; To reduce transport costs; Due to the suspension of main activity; Due to the change of home address (city/neighborhood); Due to benefits in other transport modes.

3.3. Data analysis: Exploratory factor analysis

The questionnaire data were evaluated by application of exploratory factor analysis (EFA), together with descriptive statistics. EFA is a multivariate technique used to elucidate the structure of the relationships among different variables related to the phenomenon analyzed (Hair et al., 2017). In this process, a smaller set of variables, called latent variables (factors), is obtained from the original set. After creating the factor model, adjustments are made by eliminating variables in an iterative process, according to the suitability criteria of the method. The principal components method is then used to extract the factors, which are represented by the set of original variables of the model and describe the behavior of the data evaluated (Hair et al., 2017; Law et al., 2017).

This study aims to make a first exploratory approach to the impacts of the pandemic on urban mobility in the context of cities in the Global South. Therefore, the AFE is suitable for the problem, since it favors the understanding of the complex relationships between the variables, and allows the aggregation of data as a preliminary step in the analysis of the factors involved. Moreover, the EFA has the advantage of providing the structure of the variables influencing the problem and the correlation between them, as well as extracting the factors (latent variables) that

affect the phenomenon. Therefore, the EFA is interesting for the observed context, which seeks to identify the factors that affected the behavior of mobility in the face of the pandemic scenario.

The EFA was applied using IBM SPSS statistical software. The extraction method was principal component analysis (PCA) with Varimax rotation, which is commonly used in factor analysis. The Bartlett sphericity test and the KMO (Kaiser-Meyer-Olkin) test were applied to confirm the suitability of the EFA for the problem. Adjustment of the model was performed by eliminating the variables according to the suitability criteria of the anti-image correlation matrices (diagonals greater than 0.5) and commonalities (extraction value greater than 0.6). The number of factors found by the principal components method was visualized using the matrix of total explained variance, which indicates the total percentage of the variance that is explained by the factors obtained (cumulative variance $\geq$ 60 %). The variables belonging to the factors were extracted from the rotated component matrix. The factor loadings represent the contribution of the variable in the factor, so the identification of the variables belonging to each factor was based on selection of those with the highest absolute values (Hair et al., 2017).

4. Results and discussion

4.1. Characterization of the survey responses

The survey received responses from a balanced proportion sample of population by gender and age, as projected. Fig. 1 compares the travel pattern for the pre-pandemic and pandemic scenarios, together with the intentions of the respondents for travel after the pandemic. Previously, the main modes of transport used were the car (46.2 %) and public transport (28.5 %). However, during the pandemic, 42.8 % of respondents did not travel to the main activity, most likely due to the adoption of COVID-19 preventive measures to avoid the risk of infection, with home office routines or temporary closure of workplaces and educational institutions (Aletta et al., 2020; Zheng, 2020).

Public transport was strongly affected by the pandemic, with a 73 % reduction of trips, while car use was reduced by 22 %, and motorcycle use was only reduced by 9.7 %. Future travel intentions indicated by the respondents suggested that public transport would be able to partially recover its passengers, although there could be a 30 % reduction in demand, compared to the period before the pandemic, while car use would increase by 7.2 %. These results were in line with the findings of other studies concerning the impacts of the pandemic on the use of public transport, with greater preference for private vehicles in different scenarios (Arellana et al., 2020; Cui et al., 2020; Advani et al., 2021). It is important to note that most of the interviewees have a driver license (77.1 %) and access to a car (78.5 %).

Another interesting result concerned the use of bicycles, which, despite being a negligible mode of transport in the overall profile, had the highest increase (87 %) in future projections, reflecting greater receptivity to active mobility in the post-pandemic period. Other research has also reported this possible increase in major cities (Teixeira and Lopes, 2020). Attention should also be paid to the use of ride-sourcing services, which experienced a small reduction of 18.5 % during the pandemic, but future predictions indicate an increase of 66 %, compared to the pre-pandemic period. Therefore, there is the possibility of migration of public transport users to private vehicle, especially the car, while active mobility does not present similar preference levels, but there appears to be an opportunity for the latter to be better explored.

A comparison of the choices of transport mode according to family income is shown in Table 2. The highest rates of use of public transport were among families earning up to 2 m.w. and between 2 and 4 (44.5 % and 39.4 %, respectively). However, during the pandemic, low-income households had the lowest reduction in the use of public transport (57 % and 73 %, respectively), in comparison with other family income rages for this transport mode. Families with incomes above 10 m.w. mostly travelled by car (77.2 % of respondents with between 10 and 20 m.w., and 70 % of population with more than 20), with a reduction of nearly 40 % during the pandemic. More than half of the population (51.5 %) with family income above 20 minimum wages stopped moving during the pandemic, while this rate was 33.6 % for the population receiving up to 2 minimum wages. The transport changes could have been influenced by the adoption of home office practices, which is easier for the office activities typical of workers with higher salaries, as observed in the study by Paul et al. (2021) of middle- and low-income groups in the population of Dhaka (Bangladesh).

4.2. Factors affecting the travel patterns for the main activity

The identification of the main factors affecting the commute between home and the main activity was modeled by the application of EFA. The database initially contained more than 140 variables, extracted from the questionnaire responses. Some of the questions were transformed into dummy variables to enable the application of the method, which explains the substantial number of variables. Adjustments were also made

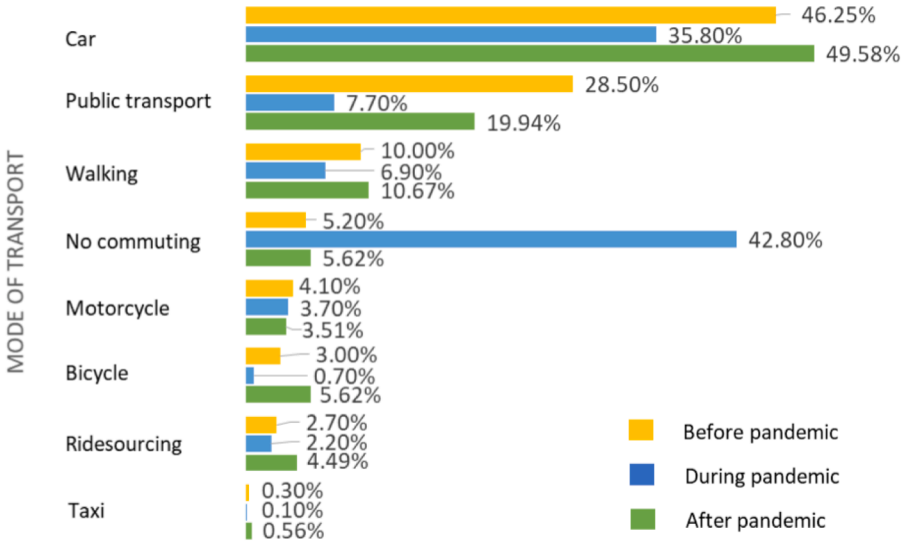

Fig. 1. Distribution of modes of transport used for commuting to main activity before, during and after pandemic (n = 712).

Table 2
Modes of transport used for commuting to main activity before and during the pandemic, according to monthly family income ($n = 712$).

Mode of transport used (%) and relative variation (%)		Family income brackets (and sample size) Up to 2 m.w. (16.6 %)	2 to 4 m.w. (23.7 %)	4 to 10 m.w. (36.7 %)	10 to 20 m.w. (18.1 %)	More than 20 m.w. (4.9 %)
Car	Before	19.1	31.3	51.0	77.2	70.0
	During	22.7	30.4	38.8	47.9	42.4
	Variation	+19	−3	−24	−38	−39
Public transport	Before	44.5	39.4	24.7	8.8	12.0
	During	19.1	10.8	3.7	1.7	0.0
	Variation	−57	−73	−85	−81	−100
Walking	Before	20.9	10.6	8.2	6.1	12.0
	During	14.5	8.2	5.3	4.1	0.0
	Variation	−31	–23	−35	–33	−100
No commuting	Before	2.7	6.9	5.3	0.0	0.0
	During	33.6	42.4	46.1	41.3	51.5
	Variation	+1144	+514	+770	++	++
Motorcycle	Before	4.5	6.9	4.1	1.8	0.0
	During	4.5	6.3	3.3	1.7	0.0
	Variation	±0	−9	−20	−6	–
Bicycle	Before	6.4	1.9	2.9	3.5	0.0
	During	2.7	0.6	0.0	0.8	0.0
	Variation	−58	−68	−100	−77	–
Others	Before	1.8	3.1	3.7	2.6	6.0
	During	2.7	0.0	2.9	2.5	6.1
	Variation	−50	−100	–22	−4	+2

to prevent an excessive influence of multicollinearity in the EFA results (such as a negative correlation matrix). In this process, some variables were modified and other less suitable variables were removed, using a metric known as the variance inflation factor (VIF). This resulted in a final count of 90 variables.

After the iterations required in the fitting process, the EFA resulted in an appropriate model, considering a total of 48 variables, grouped into 15 factors. The results of application of the Bartlett sphericity test (X^2 (1275) = 13150.847; p less than 0.001) and the Kaiser-Meyer-Olkin test (KMO = 0.733 ≥ 0.5) showed that the use of EFA with principal components was suitable for the problem. The total explained variance was 65.52 %. Table 3 presents the factors identified and the results of the contribution of each factor in the model.

The main results of the EFA are presented graphically in Fig. 2, including the factor loadings (Cf) and the correlations between the original variables of the model and the factors. The loading sign indicates the type of correlation (positive or negative), as also for the correlations (Co) between the variables. The 15 factors obtained from the model were used in a process of qualitative interpretation (naming of the quantitative results). At this stage, the group of researchers reached consensus on the description of each factor (such as reasons and causes, among other aspects), as a way of meeting the proposed objectives of the study.

In general, the results can be structured across different types of factors and variables. The factors 1, 2, and 3 included variables related to travel patterns to the main activity (mode of transport, days commuting and travel time), while the factors 7, 13 and 15 are associated with secondary trips (nursey or school, shopping, lunch), also linked to family structure (marital status, children). Other socioeconomic characteristics such as education level, driver license and vehicle availability are also discussed in the factor 10. The mobility preferences influenced by public transport supply (travel time, cost, comfort, information, technology) are grouped in the factor 8, and travel choice variables specifically observed in the pandemic scenario (infection risk, trips reduction, health security, vehicle capacity and others) are included in the factors 9, 12, and 14. The activity routine changes (home office, staggered hours, shopping restrictions, travel reduction) are explicated by the factors 4 and 6. Finally, the bioprotection measures adopted (mask use, temperature measure, priority risk group) and specific preventive measures about transport (vehicles and bus stops cleaning, ventilation, capacity reduction) are discussed in the factors 5 and 11.

Table 3
Results of EFA: factors contribution in explained variance (%).

Factor	Interpretation of the factor	% of variance
1	Predisposition to the car	8.30
2	Commuting profile during pandemic	7.05
3	Motorcycle loyalty	6.14
4	COVID impacts on routine	4.75
5	COVID bioprotection measures	4.48
6	Changes in routine to avoid COVID	4.40
7	Profile of parents	4.23
8	Operational aspects for the choice of transport mode	3.95
9	Reasons to change the mode of transport	3.74
10	Profile of the potential car user	3.56
11	Contradictory preventive measures in public transport	3.44
12	Prerequisites for mode choice in the pandemic	3.19
13	Shopping activities routine	3.04
14	Migration from public transport to ride-sourcing	2.96
15	Lunch travel profile	2.29

Factor 1 referred to the predisposition to use the car, with the composition of the variables in this factor demonstrating that choosing a car both before the pandemic (*travel_car_before*) and currently (*travel_car_now*) implied no use of public transport at any time, because the variables *travel_public_before*, *travel_public_now*, and *travel_public_future* had negative factor loadings (Cf_-). This result was expected even before the pandemic, but when this factor was associated with the decrease in the use of public transport (see Fig. 1), it confirmed that the pandemic strengthened the preference for private vehicles. The change in the mode of transport used is probably related to perceived comfort and hygiene, which made the car more desirable when compared to public transport (Beck and Hensher, 2020).

The operational aspects analyzed for mode choice were indicated in Factor 8, where the positive loadings (Cf_+) of the variables showed the importance attributed to travel time, cost, comfort, information availability, and use of technology. In addition, the prerequisites for mode choice during the pandemic (Factor 12) were health security and vehicle capacity. The results for these factors highlight the importance of the attributes associated to the preference for the private vehicle, especially the car, intensified by the effects of the pandemic on mobility.

The reasons to change the transport mode for commuting during the pandemic were expressed in Factor 9. The positive values of the factor loadings (Cf_+) showed that the main reasons were associated with variables including infection risk, reduction of the number of trips (due

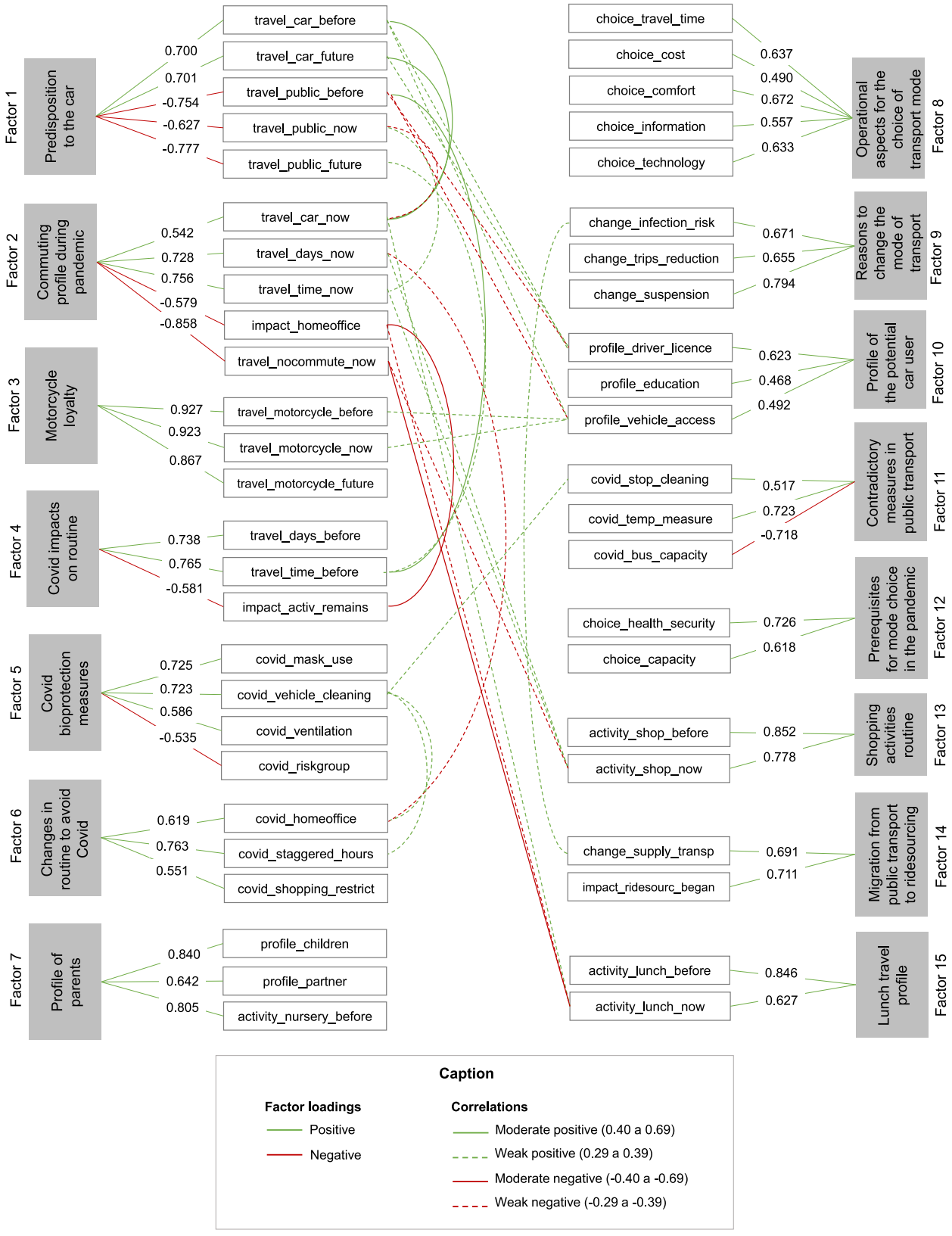

Fig. 2. Results of EFA – Factor Loadings, Factors and Correlations.

to the reduced need to commute), and suspension of activities. In addition, as shown in Factor 14, the reduction in the supply of public transport (*change_supply_transport*, Cf_+) resulted in migration to the use of ride-sourcing during the pandemic (*impact_ridesourc_began*, Cf_+), as also indicated in Fig. 1. On the other hand, those who used the motorcycle seemed to remain loyal to this transport mode. This was shown by the positive loadings (Cf_+) of the variables for Factor 3, related to the use of motorcycles before the pandemic, currently, and in the future,

indicating that the use of this mode of transport was unaffected by the pandemic and was unlikely to change subsequently.

Factor 2 corresponded to the most common profile for trips made during the pandemic. The more people commuted during the week (*travel_days_now*, Cf_+), with longer travel times (*travel_time_now*, Cf_+), the more they would normally use the car (*travel_car_now*, Cf_+). It should be noted that the group engaged in home office working (*impact_homeoffice*, Cf_-) did not need to commute (*impact_nocommute_now*, Cf_-). The profile of the potential car user was described by Factor 10, where variables such as *profile_driver_license*, *profile_vehicle_access*, and *profile_education* were positively correlated with the factor (Cf_+). The education level variable was probably related to the income of individuals, since a higher level of education increases the possibility of a higher income, consequently increasing the likelihood of owning a car. In evaluation of the impacts of the pandemic on the mobility routine, it can be seen from Factor 4 that the individuals who commuted the most before the pandemic (*travel_days_before*, Cf_+), and spent more time in traffic (*travel_time_before*, Cf_+), were those most affected by suspension of their presential activities (*impact_activ_remains*, Cf_-).

Regarding the secondary activities carried out during the commute, Factor 7 described the profile for the routine of families whose commuting involved taking children to schools and nurseries, with positive loadings for the related variables (*profile_children*, *profile_partner*, and *activity_nursery_before*). These results were in line with the study by Szmelter-Jarosz and Suchanek (2021), which indicated a change in the way of commuting after starting a family, especially for women, with less mobility and the usual choice of the car. This demonstrated the influence of gender differences and social characteristics on mobility preferences, conditioned by daily routines and family responsibilities (Paul et al., 2021). Otherwise, in Factor 13, the positive values for the variables *activity_shopping_before* and *activity_shopping_now* showed that shopping activities did not change during the pandemic. This result differed from the travel behavior reported in other studies, such as that of Arellana et al. (2020), which could indicate a greater resistance of the Brazilian population to changing the shopping routine, even in emergencies. It is possible that this result could be explained by aspects such as low income and less implementation of e-commerce, which would require further specific analysis. The variables related to commuting to lunch, with positive loadings in Factor 15, showed that these commutes also had no significant changes.

Bioprotection measures against COVID-19 were grouped in Factor 5, where the positive loadings (Cf_+) for the variables related to mask use, cleaning, and ventilation of vehicles showed that the respondents believed that these measures could be effective against spread of the virus. On the other hand, the special shopping hours reserved for individuals in the risk group showed a negative value (Cf_-), indicating that it was considered to be a less efficient measure. The changes in routine adopted to avoid COVID-19 were grouped in Factor 6, where positive loadings for the variables (Cf_+) showed that measures such as encouraging home office activities, staggering working hours, and restricting shopping were considered to be of interest.

In contrast, a contradictory choice behavior was observed in Factor 11. The variables related to the cleaning of bus stops and the measurement of temperatures (positive factor loadings, Cf_+) were associated negatively with the measure of the reduction of the capacity of the vehicles (negative factor loading, Cf_-). These results showed that hygiene and temperature control practices were not perceived as efficient, when compared to the increase of distance between passengers made possible by the reduction of capacity in public transport. Avoiding agglomeration in buses and subways, through capacity control was a necessary measure during the pandemic (Arellana et al., 2020; Carrese et al., 2021; Vallejo-Borba et al., 2022), but Brazilian authorities failed to follow strict control of the number of passengers, while practices of cleaning stops and temperature control were more easily implemented. However, users observed that the measures of bus stops cleaning and temperature control contradicted their own situation facing overcrowded public transport. The discrepancy found in this factor may be the result of passengers' dissatisfaction with the priority of measures adopted to contain the spread of the COVID-19 in public transport.

Finally, in order to complement the commuting profile results, the correlations among the original variables are shown in Fig. 3. For practical purposes, only the results of the correlations obtained between the variables of different factors are presented, since greater correlation was generally observed among the variables within the factors (this behavior was described in the discussion of the factors). The correlations were differentiated according to the degrees of correlation commonly used, as weak (±0.29–0.39) and moderate (±0.40–0.69), also shown by the solid and dashed lines in Fig. 2, respectively, with positive and negative values indicated by green and red colors, respectively. It should be noted that high correlations (±0.70–0.90) were only found for some variables within the factors. Fig. 3 shows a matrix with the values of correlations between factors plotted for the variables in the analysis.

As main results, the use of public transport was associated with longer travel times, both before the pandemic (*travel_public_before*, *travel_time_before*; *Co* +0.45) and during the pandemic (*travel_public_now*, *travel_time_now*; *Co* +0.35), as well as with the intention to continue using this mode in the future (*travel_public_future*, *travel_time_before*; *Co* +0.36). The profile of public transport users consisted of people who probably did not have a driving license (*travel_public_before*, *profile_driver_license*; *Co* −0.37) or a private vehicle available (*travel_public_before*, *profile_vehicle_access*; *Co* −0.38). Therefore, these attributes characterized the respondents who are captive to public transport, mainly living in the outskirts of the city, far from their main activities, which led to the longer travel times. These characteristics were also related to the population group with lower income, as reported previously (Basu and Ferreira, 2021). Therefore, specific public policies must be designed to meet the needs of most vulnerable population and to improve the attractiveness of public transport systems, so that preference for the service remains, even if the income level increases. Otherwise, this population may also migrate to private vehicles (especially to motorcycles), aggravating congestion and road safety problems in cities in the future.

On the other hand, for motorized trips, there were strong correlations among past, current, and future trips for both car and motorcycle use, as already seen in the factor discussions. The profile of the car users was related to people with driving licenses (*travel_car_before*, *profile_driver_license*; *Co* +0.38), as would be expected. The availability of a vehicle predisposed to car use before the pandemic (*travel_car_before*, *profile_vehicle_access*; *Co* +0.32) and to motorcycle use both before the pandemic (*travel_motorcycle_before*, *profile_vehicle_access*; *Co* +0.37) and for current trips (*travel_motorcycle_now*, *profile_vehicle_access*; *Co* +0.30). In addition, the respondents who subsequently commuted for lunch probably used the car (*travel_car_now*, *activity_lunch_now*; *Co* +0.30), which identified another constraint in the daily routine that did not contribute to more sustainable transport practices. In a way, these individuals could be considered captive users of individual motorized modes of transport, due to their unwillingness to switch to other alternatives.

Regarding trips to secondary activities, those who did not currently commute to work probably ate lunch at home (*travel_nocommute_now*, *activity_lunch_now*; *Co* −0.47) and performed fewer shopping activities (*travel_nocommute_now*, *activity_shop_now*; *Co* −0.34), while those who currently worked at home commuted less (*travel_days_now*, *impact_homeoffice*; *Co* −0.39). On the other hand, current trips for shopping and lunch were related to respondents who traveled on more days of the week (*travel_days_now*, *activity_shop_now*; *Co* +0.30) and had a longer travel time (*travel_time_now*, *activity_shop _now*; *Co* +0.34; *travel_time_now*, *activity_lunch_now*; *Co* +0.38), which also reflected a relationship with presential work activities. These results highlighted that the introduction of home office practices by companies and public entities could be beneficial in terms of reducing mobility problems at peak

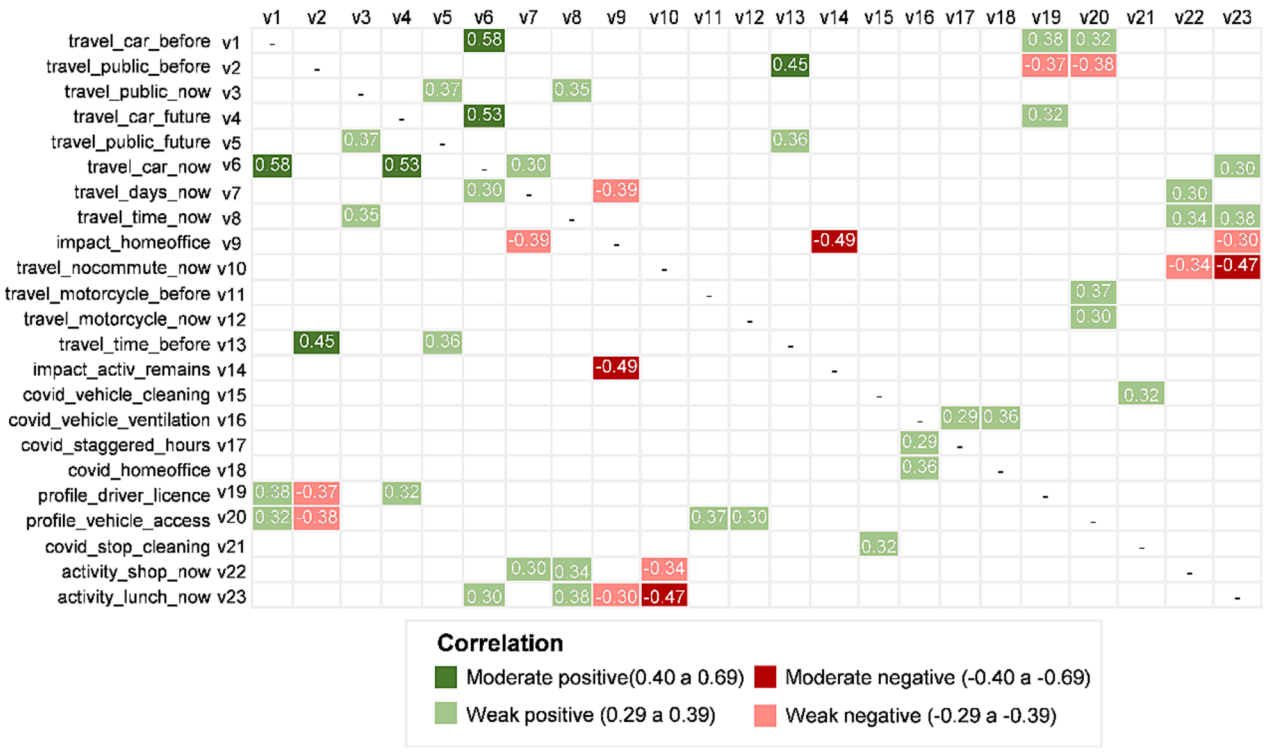

Fig. 3. Results of EFA – Correlations plot of the original variables between factors.

times in large cities. In this way, the pandemic made it possible to identify-one of the real potential advantages that technology could offer in the future.

Therefore, although cities have suffered from the impacts of the pandemic on urban mobility, this is an opportune time to improve transport planning. Understanding of the factors that influence the choice of transport mode, as well as those that are not relevant, make it possible to apply resources more directly and effectively, aiming to encourage the use of public transport and active mobility, reducing the traffic on urban roads. For example, an interest and willingness to use bicycles was observed, but it remains necessary to provide better conditions for this practice to be carried out with comfort and safety (Sottile et al., 2021). In the case of public transport, greater resistance to its use was found, since it competes directly with the car and transport by application, which have advantages in terms of health safety, time, and travel comfort. Therefore, to make public transport attractive for more users, it would be necessary to increase investments related to safety, comfort, availability of schedules, information, and technology, as well as to expand the fleet size, in order to avoid overcrowding. Although this is a very challenging scenario, the pause in mobility caused by the pandemic offers a unique opportunity to rethink the form of commuting, its motivations, and its consequences, reflecting on the current types of mobility found in Latin American cities and the measures for planning the sustainable modes of transport that are so desired and necessary.

5. Conclusions

The COVID-19 pandemic changed the world in terms of many different parameters of society, abruptly forcing people to transform their work, study, and leisure routines, which directly affected the daily commutes made in cities. In many countries, it was possible to monitor the preventive measures implemented to fight the spread of the new virus and to analyze the aspects that have become relevant from the point of view of mobility. However, there is a scarcity of this type of study focusing on cities in developing countries, especially smaller Latin American cities. Therefore, this study contributes to highlight the impacts of COVID-19 on mobility in cities of the Global South, using a case study applied to cities in the state of Rio Grande do Sul, Brazil.

From the methodological perspective, a mobility survey applied virtually to a representative sample of the urban population in the study scenario asked interviewees about choices of mode of transport to main activity (work or study) before and during the pandemic, as well as future intentions (post-pandemic). The exploratory factor analysis (EFA) model identified fifteen factors affecting the travel behavior and mobility preferences considering the impacts of the pandemic. Additionally, the correlations between the variables and the factors were used to complement the analyses. This diagnosis contributes to the planning of urban mobility and the formulation of public policies to be adopted in view of the current scenario of the pandemic, in addition to indicating future perspectives.

During the pandemic, a significant reduction in mobility of the study population was identified, but the shopping trips remained. Changes in mobility behavior in the context of the pandemic are consequences of compulsory measures established by health authorities regarding the restriction or suspension of activities (lockdowns or home office work) and bioprotection procedures (mask use, safety distance, restriction of retail shopping, staggered working hours, priority for risk groups, vehicle cleaning and ventilation, and others), some of which were considered by interviewees to have different degrees of effectiveness.

COVID self-protection behaviors affected mode choices prioritizing health safety, vehicle capacity, ventilation, and cleaning aspects. The changes in mobility preferences further highlighted the advantages of using the private vehicle to the detriment of public transport, which experienced the greatest decrease in use compared to other modes of transport. In addition, the adoption of preventive measures that restricted the supply of public transport acted to increase the preference for ride-sourcing. However, most public transport passengers (from lower income families) were the ones who least experienced the interruption of presential activities.

A positive aspect in the projections of future commuting was that bicycle use presented the greatest growth (despite making a small overall percentage contribution), which showed the interest of the

population in using active mobility alternatives. Other aspects, commonly reported before the pandemic scenario, were related to the profile of motorized trips for those who had a vehicle available and driving license (considered as captive users, especially of motorcycles), longer travel times for public transport, and the influence of dependent children on family mobility. Additional attributes that influenced the mobility preferences were related to operational aspects (time, comfort, information, and technology, among others) and occupancy rates of vehicles, with effects on health safety.

The diagnosis provided a profile of travel behavior and mobility preferences of the population, that deserve to be considered in urban mobility planning for Latin American cities, in the post-pandemic scenario. These findings contribute to the lessons learned as a result of the pandemic, given the economic and social effects experienced worldwide. In this way, new urban mobility strategies may be designed aiming to reduce historical social inequalities, imbalances in the use of urban space, and the impacts associated with unsustainable urban transport practices.

With the perspective of a return to "normality", it is necessary to have a broader knowledge concerning changes in commuting patterns and the factors that influence the preferences for different transport modes, and new challenges will arise. Latin American cities need structural changes mobility to guarantee the commute of the most vulnerable populations, especially changing the financing model of the public transport, improving the quality of service, and investing in infrastructure for active mobility (upgrading sidewalk and cycle path infrastructure, ensuring road safety, and making urban environment more attractive, accessible and inclusive). In addition, it is necessary to consider the new mobility services provided by means of smartphone applications that have intensified since the pandemic. Furthermore, encouraging the permanent adoption of measures to reduce commuting can mitigate congestion and other transport externalities in cities.

The present study had limitations related to future travel choices, since until the moment of the research there was still no consolidated data on the effects that a full return of activities would have, while uncertainties remain concerning many of the temporary measures adopted, and whether they would become permanent. Further studies may focus on potential future changes and their impacts on urban traffic in different scenarios. As other suggestions for future work, it is recommended to apply studies similar to the present one in other cities, as well as to evaluate the influence of different urban area sizes, in order to guide public policies in the planning of more sustainable mobility infrastructures. Moreover, the results of this paper may be used as inputs for the design of experiments for other confirmatory techniques and different approaches on this topic.

CRediT authorship contribution statement

Letícia Oestreich: Investigation, Data curation, Formal analysis, Methodology, Writing – original draft. **Paula Sandri Rhoden:** Investigation, Data curation, Writing – original draft. **Jéssica da Silva Vieira:** Investigation, Methodology, Writing – original draft. **Alejandro Ruiz-Padillo:** Conceptualization, Funding acquisition, Writing – original draft, Writing – review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors thank the CNPq (Processo 310258/2021-9, Processo 422635/2018-9, and Processo 135627/2021-4) and the CAPES (Research grant 88887.522083/2020-00) for the financial support.

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