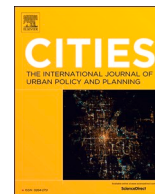




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# Exploring mobility pattern changes between before, during and after COVID-19 lockdown periods for young adults

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## ABSTRACT

The paper aims to investigate changes in travel behavior due to COVID-19 focusing in one of the most active social groups in Greece. A questionnaire survey was conducted and 306 young adults (age 18–34 years) living in various Greek cities responded. The survey collected information about travel-related preferences before, during and after the 1st lockdown and during the 2nd lockdown of the COVID-19 pandemic in Greece. City attributes of the respondent's residency location before and after the 1st lockdown were collected. The data are analyzed descriptively and through statistical modelling techniques. During the 1st lockdown an important increase in physical exercise frequency was observed, but this increase was not permanent. The COVID-19 pandemic resulted in essential reductions in the frequency of public transport use and in an increase of walking frequency. The public transport use reduction was mainly attributed to people that had access to a private car and after the 1st lockdown moved to a smaller city. On the other hand, the changes in walking frequency are closely linked to the city's attributes. Useful policy implications are being derived about how the pandemic can assist in promoting sustainable urban mobility goals.

## 1. Introduction

Almost two years since the appearance of COVID-19, the total number of deaths has soared to 4.05 million and the number of confirmed cases exceeded 188 million (WHO, 2021). At the same time, numerous countries around the world have imposed a form of lockdown using different proactive measures because the virus spreads through human interactions (Nahiduzzaman & Lai, 2020). The measures selected by governments aimed to restrict the mobility of citizens, and they ranged from mandatory measures, such as restricting citizens' mobility and banning gatherings, to suggestions, such as recommending the use of two masks in busy areas. A great percentage of the world population lived under travel restrictions (Shrestha et al., 2020). These measures and restrictions had several effects on the public impacting active and personal transport during the lockdown periods. However, these impacts varied among locations and traveler groups. A review of literature on COVID-19 impacts on mobility aspects highlights recent research attempts to explore changes related to road safety, active mode

utilization, activities, and travel behavior.

Mobility by public transport, railway, airplanes, and ferries has been characterized as high-risk activity that enables COVID-19 transmission, due to the limited space that users must share. Several reports publish daily or periodic traffic data to chronicle statistics throughout the COVID-19 period. These data are used to evaluate traffic behavior changes, which are usually city-based and consider major transport corridors (Apple, 2020; Google LLC, 2020; MOBIS, 2021; Molloy, 2020). Each report uses different indicators and metrics to describe the impact of COVID-19 on mobility. For example, Google LLC (2020) presents how visits to places, such as grocery stores and parks, change in each geographic region, and MOBIS (2021) presents changes in distance travelled by transport mode and sociodemographic characteristics. The general conclusion is that traffic flows were reduced together with trips to transit stations and to recreational activities, whereas the number of bicycle trips and walking distances increased (Google LLC, 2020; MOBIS, 2021).

Road safety studies showed that during the 1st and the 2nd lockdown

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periods the reduction of crashes and fatalities was essential. For instance, in Spain, during the 1st lockdown period (15 March 2020–27 May 2020) road deaths reduced by 62% compared to the same period in 2019 (ETSC, 2020). However, there were also exceptions. For the same period in Netherlands, road deaths increased during COVID-19 lockdown despite a sharp drop in traffic volumes and in Czech Republic vulnerable road user deaths increased–bicyclist deaths increased by 86% and motorcyclist deaths increased by 50% (ETSC, 2020).

COVID-19 also had a significant impact on trip characteristics. In Greece and the Kingdom of Saudi Arabia, trips were found to be shorter, speeds increased, and mobile phone usage during driving increased by 21–42% (Katrakazas et al., 2020). As it was expected, public transportation demand reduced sharply, due to COVID-19 measures in various countries, such as in the United Kingdom, Netherlands and Greece, or because of fear of COVID-19 contagion that urged citizens to avoid public transit (Politis et al., 2021; Tirachini & Cats, 2020). In large metropolitan areas, where public transportation share is higher, the effect was more pronounced. For example, New York City and Wuhan stopped all passenger services or reduced non-essential services during lockdowns (Chang et al., 2021). In New York City, during the 1st lockdown in April 2020 subway trips decreased by 94% on an average weekday compared to April 2019 (Padmanabhan et al., 2021). Chang et al. (2021) explored the causal estimates of COVID-19 on metro use and found that new confirmed cases of COVID-19 reduced metro use by 1.4% in Taipei City and New Taipei City, while the effect was more pronounced for metro stations close to night markets, shopping centers, or colleges.

Sweden opted for a strategy that relied on recommendations rather than mandatory enforcements (Sabat et al., 2020) and experienced a decrease of 40%–60% in public transportation ridership across regions, with travelers shifting from monthly period tickets to single ride tickets, while short period tickets that were used predominantly by tourists, dropped to almost zero (Jenelius & Cebecauer, 2020). Other European Union (EU) regions, with traditionally high public transportation shares, such as Budapest that has a high public transportation share of 45%, experienced a 90% drop in the number of passengers in week 13 of 2020 (i.e., March 23–29) (Bucsky, 2020). In Italy, the shift from public into individual transport (including walking, car travel, and ride sharing) during the pandemic was notable, while a greater tendency for shorter trips to be completed on foot was recorded (Moslem et al., 2020).

Temporal mobility measures to promote active travelling were applied in several cities at European and global level, however, the results may not be as expected in all cases. For example, the Athens' Great Walk in Greece although it improved walking, bicycling and parking conditions (Petraiki et al., 2021), appeared to lack public acceptance (Kathimerini, 2021). Infrastructure changes should consider the travelling characteristics of the users before and after COVID-19 periods (Bucsky, 2020; Jobe & Griffin, 2021; Nikiforiadis et al., 2020a; Nikitas et al., 2021) to design measures that account for local conditions and may be transformed to permanent, if successfully implemented.

Travel distances tended to become shorter during pandemics, trip frequency became lower due to mandatory travel restrictions, and travelers returned to private vehicles and active modes of transport (Abdullah et al., 2020). However, there is not a norm since different travelers and modes were affected differently at various locations. An international survey to study the impacts on mobility behavior during the pandemic focusing on trip characteristics' impacts, showed significant reductions in work and education trips (Brezina et al., 2020), while another international survey concluded that most of the trips were for shopping (Abdullah et al., 2020).

In Trieste, the COVID-19 pandemic significantly altered the transport mode choices, having a large negative impact on public transit shifting its users to private modes, both motorized and non-motorized, where walking is one of the preferred modes to access the city center (Scorrano & Danielis, 2021). Data collected and analyzed for the period between April and August 2020 showed that a potential increase in bicycling did

not translate into an increase in active mobility, since bicycling substituted walking trips (Scorrano & Danielis, 2021). While focusing on active modes, which are popular within city centers, several studies highlighted mobility changes before, during and after lockdown periods (Campisi et al., 2020; Ehsani et al., 2021; Shaer & Haghshenas, 2021; Zhang & Fricker, 2021).

Bicycle trips were negatively impacted in US large cities, such as New York, Chicago, and Boston, by COVID-19 during the 1st lockdown (Padmanabhan et al., 2021). The average bicycle trip duration increased, likely because shorter trips were more affected due to COVID-19 than longer trips (Padmanabhan et al., 2021). Studies on bicycle-sharing systems demonstrated mixed results in US for different social groups. A study in San Antonio, Texas that collected data in June–July 2020 showed that 43% of survey respondents who were unemployed due to the pandemic reported increasing use of the system, whereas 36% of employed respondents decreased ridership; both of these trends demonstrate the sensitivity of bicycle-sharing systems ridership due to the pandemic (Jobe & Griffin, 2021). Another study in Greece investigated people's perceptions towards bicycle-sharing systems and their attractiveness after the appearance of the COVID-19 pandemic (Nikiforiadis et al., 2020a). The study concluded that the pandemic could act as an attraction to increased mode switching from being a passenger in a private car to being a bicycle-sharing user even though COVID-19 would not significantly affect the total number of people using bicycle-sharing for their trips (Nikiforiadis et al., 2020a). Bicycling and bicycle-sharing in Budapest experienced the lowest decrease (23% and 2%, respectively) but at the same time bicycling accounted for the highest growth (4%) in terms of modal share (Bucsky, 2020). In Germany, bicycling in urban public green spaces increased in response to epidemic-control decisions while bicycling in rural areas showed no significant change at the same time (March–June 2020) (Schweizer et al., 2021). Other studies that noted a decrease on active modes include a decrease of 5% in India comparing data before COVID-19 and March 24th–April 12th 2020 (Bhaduri et al., 2020) and a drop of 71% in bicycle-sharing ridership in New York (Teixeira & Lopes, 2020). Furthermore, based on global data, walking was increased by 7% during the COVID-19 (May 09, 2020 and May 31, 2020) compared to pre-COVID period (Abdullah et al., 2020).

The above studies reveal that transport demand during the pandemic was largely affected and the reasons are attributed to travelers' psychological and behavioral aspects (Borkowski et al., 2021). Feelings like anxiety, fear, and stress were correlated to modal choice for the different periods of the COVID-19 pandemic (Campisi et al., 2021). For example, fear was not correlated to bus public transport travel before COVID-19 and during the post-lockdown phase; however, in the September–December 2020 period the frequency of home-based work trips by regional and local buses was negatively associated with levels of fear. In the same study, anxiety did not play an essential role in public transport decisions during the different periods of the COVID-19 pandemic in Sicily. In terms of travel satisfaction, transportation modes like bicycle and walking showed a higher probability to yield satisfaction based on data between March 24th and May 9th 2020 in Kelowna, British Columbia (Khaddar & Fatmi, 2021).

This paper investigates the impact of COVID-19 on trip characteristics (e.g., mode choice, frequency, purpose) and focuses on one of the most active group of people, namely the young adults aged between 18 and 34. The study collects information about the stated preferences of Greek young adults for: a) the period before the 1st lockdown (pre-COVID-19 era), b) the period during the 1st lockdown, c) the period after the 1st lockdown, and d) the period of the 2nd lockdown. The study analyzes how stated preferences changed during the different COVID-19 periods and it examines whether the identified changes are permanent. Moreover, it examines whether the changes in transport mode shares are linked to city attributes, such as population, area, population density, and bicycle lanes density. In this way, policy implications are derived about how the COVID-19 pandemic, despite its effects, may contribute to achieving the aims of sustainable urban mobility.

## 2. The Greek context

The COVID-19 pandemic has affected travel by private car and public transport in Greece and especially in Athens, the capital of Greece. Public transport demand has dropped by 40%–90% since the beginning of the pandemic, and traffic reduced by 80% (compared to the same period of 2019) on the Attica Tollway—the 70 km long ring road of the greater metropolitan area of Athens—during the 1st period of lockdown. Following the 1st lockdown, private car traffic increased, but remained lower by an average of 20% compared to the same period in 2019. Public transport was reduced by 40% for the same period, indicating that cars were the preferred mode of transport during the pandemic (POLIS and Rupperecht Consult, 2021). The time after the commencement of the pandemic in Greece is divided in three periods, based on lockdown periods:

- 1st lockdown (March 23–May 4, 2020):** Although some measures were implemented prior to March 23, the 1st lockdown period is defined on the commencement and termination date for the SMS (short message service) measure. The SMS measure required all citizens to send an SMS to declare the reason for their everyday movements. Only movements for six specific purposes were permitted including medical reasons, shopping to supermarkets, transactions at banks, provision of assistance to elderly people, attending ceremonies such as funeral and marriage, outdoor physical exercise, and movements with a pet. All flights from other countries were banned. During the 1st lockdown period, masks were not mandatory. Students stopped attending in person classes on March 13, and all commercial activities stopped on the same day. Transport between Greek prefectures was banned, schedules for public transport were modified, and metro services after midnight stopped.
- Middle period (May 4–November 6, 2020):** During this period, the use of masks was mandatory. Schedules for public transport maintained the 1st lockdown period changes. The start of work for civil servants was staggered in three time zones, at 7:00, 8:00 and 9:00 a. m. and a corresponding adjustment was also made for the end of the workday. As of May 11, more commercial stores were reopened and after May 18, all transport activities by train and bus between prefectures were permitted. Restaurants and bars resumed operations on May 25, all levels of schools started on June 1, except universities, and on July 1 all touristic activities started following an arrival and departure protocol. Finally, social distancing guidelines were mandatory in all types of activities to prevent spread of COVID-19.

- 2nd lockdown (November 7, 2020–May 14, 2021).** Several smaller communities such as villages, islands and prefectures imposed a 2nd lockdown before the announcement of the national 2nd lockdown on November 7. Schools remained closed until January 11, 2021, when the primary and kindergarten schools reopened, while the elementary schools reopened on February 1. However, schools closed again on February 11 in Athens and in several other areas that were characterized as red zones. Schools closed nationally again on March 15, while universities remained closed, since the beginning of the 1st lockdown. Other measures, such as SMS permissions and mask utilization were mandatory for the whole period. Transport between prefectures was not allowed, with some minor exceptions (i.e., work, health). Sports activities were banned throughout the lockdown and municipal sport facilities remain closed. Sport facilities that do not belong to the municipalities, were excluded and there was no crowd of more than 3 persons.

Fig. 1 presents the evolution of the COVID-19 cases and deaths in Greece. The shaded blue areas indicate the 1st and 2nd lockdown periods. The data shows two peaks in the COVID-19 cases in Greece during the study period. The first is observed in mid-November 2020 and the second, a higher one, is noted in mid-April 2021.

The Greek government established an expedited process for facilitating and speeding up the procedures for the implementation of temporary pedestrian and bicycle infrastructures aiming to decongest public transport and to provide safe mobility alternatives to citizens during the pandemic. Large Greek municipalities, such as Athens and Thessaloniki, took advantage of this expedited process and rapidly established bicycle- and walking-friendly infrastructure. Indicative case is the city of Thessaloniki, which is the second largest city in Greece, where new temporary bicycle lanes were implemented along some of the main roadways.

## 3. Methodology

The methodology followed is shown in Fig. 2 and the specific steps are discussed in Sections 3.1 and 3.2.

### 3.1. Data collection

A web-based survey was conducted between January 15 and February 15, 2021 and used as the tool for collecting data to address the research questions. This period falls within the 2nd lockdown, and well

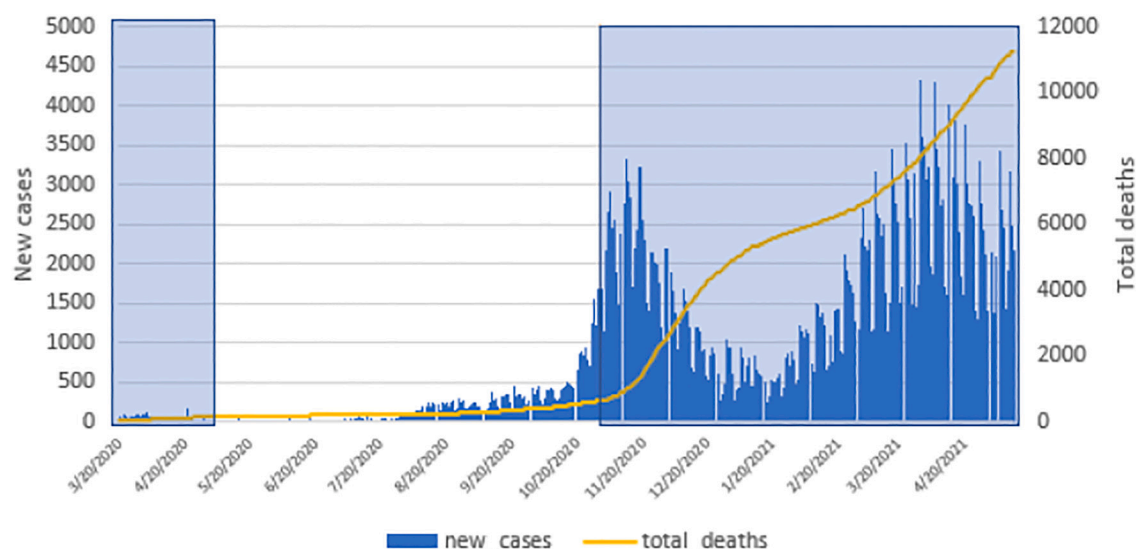


Fig. 1. Evolution of COVID-19 new cases and total deaths in Greece.

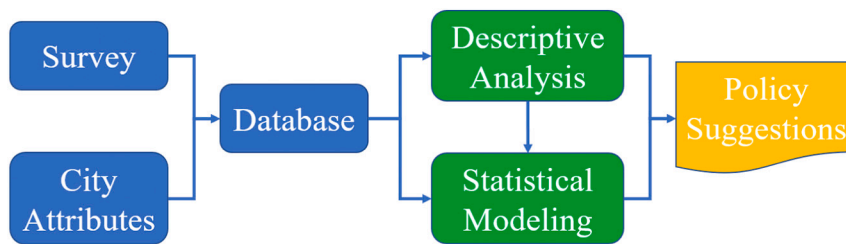


Fig. 2. Description of the main methodological steps.

before any commencement of commercial and market activities as described in Section 2. Also, during this period strict travel restrictions (both within urban areas and between prefectures) were in place. The questionnaire was disseminated through multiple web channels targeting young adults (aged between 18 and 34) in various Greek cities. This manner of survey dissemination was considered appropriate due to the restrictions in place that did not allow for face-to-face interviews and the need to reach respondents in multiple cities. The researchers' social media and e-mail lists were used to solicit potential respondents.

The decision to focus on young adults was based on the reasonable assumption that they constitute the most active and undaunted age group. On the contrary, elderly people have somehow lower levels of social and economic activities. At the same time, the university and college students that constitute a large proportion of the young adults, have been affected by the lockdowns more than other social groups, since universities in Greece have operated with remote lecture delivery from the first day of the 1st lockdown until today (i.e., spring semester 2020 and the whole academic year of 2020–2021). Therefore, investigating the impact of the pandemic on the mobility patterns of this age

group and identifying ways for efficiently serving their special mobility needs in the post-COVID era is of great interest for researchers and policymakers. A total of 306 responses were collected by people living in 28 different Greek cities (Fig. 3). The analysis does not seek to draw conclusions for the different cities and consequently these 306 responses were analyzed together. However, since an aim of the study is to identify how each city's attributes affect transport behavior, it was considered appropriate to collect data from many different cities, which are different from each other in terms of population, area, and density.

As previously noted, this study aims to compare the prevailing mobility patterns in the different lockdown time periods. Thus, a set of questions for each of these periods was included in the questionnaire generating five sections based on the time-period:

- Before the 1st lockdown period: in this section respondents had to state the city that they were living during the last two months before the COVID-19 pandemic, as well as the frequency of using various transport modes. They also had to state the main trip purpose that each transport mode was serving in the specific time-period. Finally,

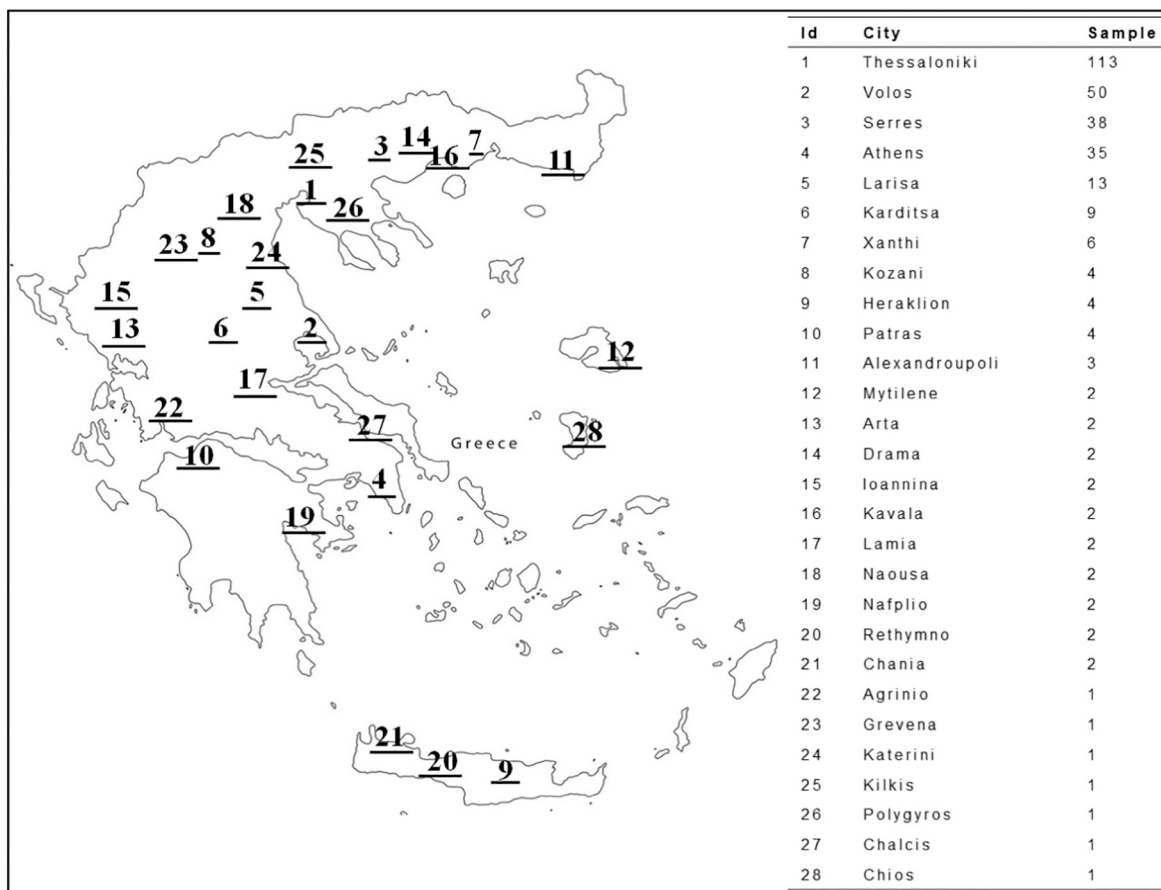


Fig. 3. Distribution of responses per city.

the respondents were asked about how often they performed physical exercise, how much time they spent training and if they bicycled or walked for physical exercise.

- During the 1st lockdown period: in this section respondents had also to state the city that they were living during the 1st lockdown. Moreover, the respondents were asked about the frequency of leaving the home during the lockdown. They were also asked about their main trip purposes during this period (it was possible to state more than one of the pre-selected trip purposes, i.e., work, obligations/essential shopping, visit, exercise). Finally, a set of questions regarding the frequency, the duration and the type of physical exercise was included.
- After the 1st lockdown period: the respondents were asked to state the city that they were living after the 1st lockdown (i.e., summer) in this section. They were also asked if they reduced, increased or kept constant the use of various transport modes comparing its use with the period before the 1st lockdown. The questions about the frequency, duration, and type of physical exercise were also included in this section.
- During the 2nd lockdown period: this section included identical questions as the ones in the section during the 1st lockdown.
- General questions: the final section included demographic questions (i.e., gender, occupation, and education), as well as questions about private car, motorcycle, and bicycle availability. Additionally, the respondents had to evaluate the city's environment in terms of how safe and comfortable it is for walking, bicycling and scooter riding (this set of questions refers to the city that the respondents were living in the period after the 1st lockdown). For this evaluation a 5-point Likert scale was used (Likert, 1932).

As it has been already stated, an additional important aim of the paper is to explore the impact of city's attributes on the identified mobility changes. For this reason, the questionnaire answers obtained from each respondent were augmented with data that are related to the city attributes they reside. More specifically, for each city the following attributes were collected: a) population, according to the latest national census (Hellenic Statistical Authority, 2011), b) area, c) population density, d) bicycle lanes density, using available information about the total length of bicycle lanes networks (Sustainable Mobility Unit, 2021). For the provision of more meaningful and easily interpretable results, the abovementioned attributes were not treated as continuous values, but for each attribute four classes were formed. The formation of the classes was established through a manual process aiming to develop classes where every observation joins the class with the nearest mean. The research team established the classes used and are presented in Table 1.

**Table 1**  
Definition of city attributes' classes.

Attribute	Classes	Values
Population	Low	<50,000 residents
	Medium	50,000–100,000 residents
	High	100,000–500,000 residents
	Very high	≥500,000 residents
Area	Low	<50 km <sup>2</sup>
	Medium	50–100 km <sup>2</sup>
	High	100–200 km <sup>2</sup>
	Very high	≥200 km <sup>2</sup>
Population density	Low	<800 residents/km <sup>2</sup>
	Medium	800–1000 residents/km <sup>2</sup>
	High	1000–1500 residents/km <sup>2</sup>
	Very high	≥1500 residents/km <sup>2</sup>
Bicycle lanes density	Low	<0.02 km of bicycle lanes/city area
	Medium-Low	0.02–0.05 km of bicycle lanes/city area
	Medium	0.05–0.2 km of bicycle lanes/city area
	High	≥0.2 km of bicycle lanes/city area

### 3.2. Data analysis

A database was created that augmented each respondent's record with the city attributes based on their answers. The data were initially analyzed using descriptive statistics, i.e., by computing frequencies and percentages, aiming to provide an overview regarding the sample distribution while considering responses based on demographic and mode availability questions. This also provides a preliminary understanding and comparison of the different time periods examined. The focus of the analysis is on the usage frequency of the different transport modes, while also considering their relationship to city attributes and walking or bicycling frequency. Moreover, using descriptive statistics the frequency and the purposes for leaving their home during the two lockdown periods are explored.

The second step of the analysis deals with the development of a bivariate binary probit regression model. Bivariate models can simultaneously handle two different dependent variables, where each one can be predicted by a different set of independent variables (Chib & Greenberg, 1998). These models are considered appropriate when it is believed that two dependent variables are correlated, since they allow the error terms to be correlated as well (Filippini et al., 2018; Li et al., 2019). The aim of the model used here is to identify and to quantify the impact of certain variables on the usage frequency of specific transport modes before and after the 1st lockdown period. Thus, a bivariate model was used because it is assumed that the changes in the use frequency of one transport mode are linked with the changes in the use frequency of another transport mode.

Bivariate binary probit models have two binary dependent variables— $y_1$  and  $y_2$ —and the outcome is being specified as following (Greene, 2003):

$$y_1 = \begin{cases} 1, y_1^* > 0 \\ 0, y_1^* \leq 0 \end{cases} \tag{1}$$

$$y_2 = \begin{cases} 1, y_2^* > 0 \\ 0, y_2^* \leq 0 \end{cases} \tag{2}$$

where  $y_i^*$  is an unobserved variable and it is equal to:

$$x_i^* \beta_i + \varepsilon_i \tag{3}$$

where  $x_i$  is a vector of observed variables,  $\beta_i$  is a vector of coefficients that need to be estimated and  $\varepsilon_i$  is a vector of error terms. The coefficients are being computed by using maximum likelihood estimation, where the likelihood is the following:

$$L(\beta_1, \beta_2) = \left( \prod P(y_1 = 1, y_2 = 1 | \beta_1, \beta_2)^{y_1 y_2} P(y_1 = 0, y_2 = 1 | \beta_1, \beta_2)^{(1-y_1)y_2} P(y_1 = 1, y_2 = 0 | \beta_1, \beta_2)^{y_1(1-y_2)} P(y_1 = 0, y_2 = 0 | \beta_1, \beta_2)^{(1-y_1)(1-y_2)} \right) \tag{4}$$

## 4. Results

### 4.1. Descriptive analysis

#### 4.1.1. Demographics

The demographic information of the survey respondents is summarized in Table 2. Car and bicycle owners refer to respondents owing at least one such vehicle and only non-missing values are reported. Out of the 306 responses received, most of the respondents were female (60%), university/college students (70%), and undergraduate (64%). Almost half of the sample owns a car and 42% a bicycle.

**Table 2**  
Demographics summary.

Variable	Category	Freq.	%
Gender	Male	122	39.9
	Female	184	60.1
Occupation	Public/private employee	50	16.3
	Freelancer	22	7.2
	Unemployed	16	5.3
	University/college student	214	69.9
	Other	4	1.3
Education	High school	61	19.9
	Undergraduate	195	63.8
	Postgraduate	50	16.3
Car owner <sup>a</sup>	No	128	49.6
	Yes	130	50.4
Bicycle owner <sup>a</sup>	No	112	41.9
	Yes	155	58.1

<sup>a</sup> Only non-missing values.

**4.1.2. Mobility during the period before the 1st lockdown**

The frequency of using the various transport modes before the COVID-19 period is presented in Table 3. The distribution of modes indicates that 68.6% of the respondents never used a bicycle and only 10.1% used a bicycle between 3 and 7 days per week, while 56.2% of them used to walk daily. Out of the 306 respondents, 19.3% used public transport daily and 35.9% never used public transport, while 20.6% used a private car daily and 16.3% never used it. The motorcycle was used the least compared to all other available modes, while 81.7% of them never used it.

Bicycle and walk trips are mainly associated with recreation and sport activities, as Fig. 4 shows. It should be noted that the percentages presented in Fig. 4 have been computed by excluding those who stated that they never bicycled or walked before the COVID-19 period. Respondents use their bicycle 15.1% and 51.6% of the time for education and exercise/recreation purposes respectively, while most of walking trips are also for the same purposes (21.9% and 58.2%, respectively).

**4.1.3. Main travel activities during the lockdowns**

During the 1st lockdown strict restrictions were announced that resulted in reduced daily mobility. During the 2nd lockdown, fewer restrictions were applied, and people travelled more compared to the 1st lockdown. Table 4 summarizes the travel frequency for any purpose as well as the purposes for which respondents were travelling during the 1st and 2nd lockdowns. It should be noted that respondents were able to select more than one trip purpose. During the 1st lockdown, 56.2% of the respondents travelled daily and very often (3–6 times a week) compared to 69.9% of the respondents during the 2nd lockdown. Also, during the 1st lockdown about 15% never or rarely left their homes, while only a small share, about 6%, stayed home during the 2nd lockdown.

The main trip purpose, for both periods, was obligations/necessary shopping (68.0% and 67.3% during the 1st and 2nd, respectively) and exercise (64.4% and 63.7% during the 1st and 2nd, respectively).

One of the allowable travel purposes was outdoor exercise. According to the respondents, the dominant type of exercise in both lockdown periods was walking with 78.4% and 75.2% during the 1st and 2nd

**Table 3**  
Frequency of mode use before the COVID-19 period.

Use frequency	Car		Motorcycle		Public trans.		Bicycle		Walking	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Daily	63	20.6	9	2.9	59	19.3	13	4.2	172	56.2
3–6 times/week	54	17.6	8	2.6	39	12.7	18	5.9	72	23.5
1–2 times/week	64	21.0	11	3.6	45	14.7	24	7.9	40	13.1
Rarely (1–2 times/month)	75	24.5	28	9.2	53	17.4	41	13.4	9	3.0
Never	50	16.3	250	81.7	110	35.9	210	68.6	13	4.2

lockdown, respectively, while bicycling follows with 12.4% and 11.1% respectively (Fig. 5).

Fig. 6 presents the frequency of performing physical exercise during the different time-periods after the appearance of the pandemic. During the 1st lockdown, the percentage of respondents that exercised daily increased twofold (19.3%) compared to the period before (9.5%) probably as a reaction to restrictions that they were experiencing for the first time. However, during the 2nd lockdown, the percentage of respondents that exercised daily decreased slightly (–1.3%) compared to the period before the 2nd lockdown. People still exercised more compared to the period before the 1st lockdown; however, it seems that the shift in exercising that was observed in the 1st lockdown is not so permanent.

Increased physical exercise frequency during the 1st lockdown is also linked to increased duration of physical exercise, as 34.3% of the respondents exercised for over one-hour compared to 29.3% before the 1st lockdown, 27.5% after the 1st lockdown (i.e., summer), and 29.1% during the 2nd lockdown (Table 5).

**4.1.4. Changes in transport mode use “before” and “after” the 1st lockdown period**

A comparison of the transport mode usage between the “before” and “after” periods of the 1st lockdown was conducted to identify potential relative changes. Table 6 shows that the highest reduction was for public transport use of over 62.4%, because of a probable general fear of proximity to other persons. Walking is the mode with the highest increase (53.6%) showing that more than half of the young adults stated an increase of walking trips. Bicycling and motorcycle use remained roughly stable, with 67.3% and 77.4% of respondents stating no changes before and after the COVID-19, respectively.

A more detailed examination of the city attributes where respondents lived after the 1st lockdown (i.e., during the summer of 2020) showed that these attributes may have some impact on bicycling and walking frequency (Table 7). People who reside in cities with a higher bicycle lane density increased their biking by 20% in comparison to 11.2% of those that reside in cities with limited bicycle lane density. Also, walking increased by 60.5% for those who live in low population density cities compared to an increase of 50% for those that live in the very high population density cities and 38% in high population density cities.

**4.2. Modelling changes in public transport and walking frequency**

The aim of the statistical model is to investigate changes in the usage of the transport modes before and after the 1st lockdown and, more specifically, to identify user-related and city-related characteristics that could have an impact on the frequency of specific transport modes. The descriptive statistics identified a significant change in walking and public transport frequency. On the other hand, the frequency of using a private car, a motorcycle and a bicycle was not altered significantly. Therefore, the statistical model focuses only on the changes that are observed in walking and public transport frequency. The descriptive statistics also revealed that the distribution of the responses among the three classes of the two-transport mode (bicycling and walking) frequency was extremely unequal. Therefore, the two examined variables were recoded as shown in Table 8.

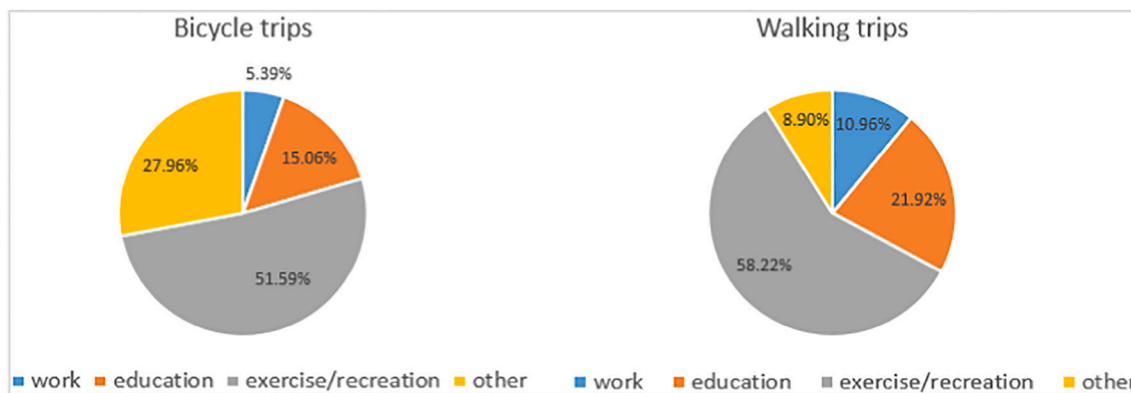


Fig. 4. Bicycle and walking trip purposes before the COVID-19 period.

Table 4  
Travel frequency and trip purposes during the 1st and 2nd lockdown.

		1st lockdown		2nd lockdown	
		Freq.	%	Freq.	%
Travel	Daily	79	25.8	108	35.3
	3–6 times a week	93	30.4	106	34.6
	1–2 times a week	89	29.1	74	24.2
	Rarely (1–2 times a month)	39	12.7	15	4.9
	Never	6	2.0	3	1.0
Purpose <sup>a</sup>	Work	37	12.1	79	25.8
	Obligations/essential shopping	208	68.0	206	67.3
	Visit	56	18.3	83	27.1
	Exercise	197	64.4	195	63.7

<sup>a</sup> More than one answer was allowed for the trip purpose.

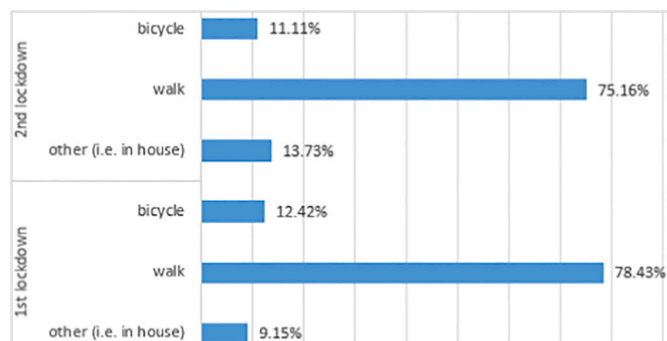


Fig. 5. Preference for exercise during the 1st and 2nd lockdown.

The desired outcome of the recoding was to convert the variables to binary, i.e., 0: no and 1: yes. It became also apparent that the two dependent variables are closely linked, since they both deal with a change in the frequency of using a transport mode before and after the 1st lockdown. To address this linkage, a bivariate binary probit regression mode was developed. Bivariate probit regression models have been used widely in transportation research (Ahmed et al., 2020; Ahmed et al., 2021; Anastasopoulos et al., 2012; Milioti et al., 2015). Their popularity is attributed to the fact that in many cases, transport-related choices are closely related to each other and are influenced by similar variables. For instance, Anastasopoulos et al. (2012) used this type of model to examine the variables affecting automobile and motorcycle ownership, while Ahmed et al. (2021) used it for identifying the factors affecting the willingness of the public to hire and pay for flying taxis.

A list of independent variables were considered including: a) users' demographics (e.g. gender, occupation, education), b) users' mobility habits before and during 1st lockdown (e.g. walking frequency before

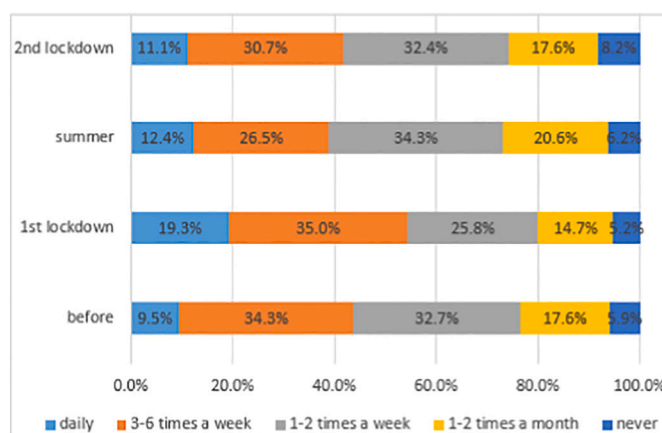


Fig. 6. Frequency of performing physical exercise in the different time-periods.

Table 5  
Physical exercise duration in the different time-periods.

	Before		1st lockdown		Summer		2nd lockdown	
	Freq.	% <sup>a</sup>	Freq.	% <sup>a</sup>	Freq.	% <sup>a</sup>	Freq.	% <sup>a</sup>
>1 h	85	29.3	105	34.3	78	27.5	89	29.1
30–60 min	179	61.7	159	52.0	166	58.7	150	49.0
<30 min	26	9.0	42	13.7	39	13.8	67	21.9

<sup>a</sup> Excluding missing values.

the lockdown, public transport use frequency before the lockdown, walking for exercise before the lockdown, walking for exercise during the lockdown), c) city's environment as perceived by the users (walk, bicycle, e-scooter – friendliness), and d) city's attributes (population, area, population density, bicycle lanes density). It should be noted that the variables regarding the users' perception of the city's environment are related with the cities that they were living after the 1st lockdown, while the variables about city attributes are related with the cities that they were living both before and after the 1st lockdown. There were many respondents who were living in a different city before and after the 1st lockdown. To study the potential effects of this change, a set of new variables was created about comparing the population, area, population density and bicycle lanes density of the city before with the city after the lockdown.

Various models, with different combinations of independent variables were developed and evaluated using the R programming language for statistical computing (R Core Team, 2017) and the GJRM (Generalised Joint Regression Modelling) package (Marra & Radice, 2020). Table 9 presents the results of the selected model. Variable selection was



**Table 6**  
Transport mode changes before and after 1st lockdown.

	Car		Motorcycle		Public trans.		Bicycle		Walking	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Reduced use	78	25.5	55	18.0	191	62.4	53	17.3	36	11.8
Same use	149	48.7	237	77.4	107	35.0	206	67.3	106	34.6
Increased use	79	25.8	14	4.6	8	2.6	47	15.4	164	53.6

**Table 7**  
Changes for biking and walking frequency in terms of city attributes, before and after 1st lockdown.

			Reduced use		Same use		Increased use	
			Freq.	% <sup>a</sup>	Freq.	% <sup>a</sup>	Freq.	% <sup>a</sup>
Biking	Population density	Low	18	20.9	53	61.7	15	17.4
		Medium	14	15.7	64	71.9	11	12.4
		High	14	17.7	52	65.8	13	16.5
		Very high	7	13.5	37	71.2	8	15.3
	Bicycle lanes density	Low	20	16.0	91	72.8	14	11.2
		Medium-low	19	22.9	50	60.2	14	16.9
		Medium	7	16.3	28	65.1	8	18.6
		High	7	12.7	37	67.3	11	20.0
Walking	Population density	Low	9	10.4	25	29.1	52	60.5
		Medium	9	10.1	24	27.0	57	62.9
		High	10	12.7	41	41.3	30	38.0
		Very high	8	15.4	16	34.6	25	50.0
	Bicycle lanes density	Low	18	13.6	32	24.0	78	62.4
		Medium-low	8	10.8	36	43.4	38	45.8
		Medium	5	11.6	16	41.9	20	46.5
		High	5	9.1	22	40.0	28	50.9

<sup>a</sup> Row percentages.

**Table 8**  
Re-coding of the dependent variables.

Initial variable	New variable	Initial classes	New classes
Change in public transport usage frequency	Decrease of public transport frequency	Decrease of public transport frequency	Yes
		The same	No
		Increase of public transport frequency	No
Change in walking frequency	Increase in walking frequency	Decrease in walking frequency	No
		The same	No
		Increase in walking frequency	Yes

based on minimizing the Akaike information criterion (AIC) and the Bayesian information criterion (BIC) while including only statistically significant variables at least within the 90% confidence level.

The interpretation of the parameter estimations for public use pointed to the following conclusions:

- People that moved to a city with a smaller area after the 1st lockdown reduced their use of public transport. This could probably be attributed to the fact that small-size cities provide users with the opportunity to perform many of their trips without using a motorized vehicle.
- The decrease of public transport use was much more likely for people that were frequent public transport users before the 1st lockdown. This result is to a large extent expected, since frequent users could be afraid of getting infected and thus avoided using public transport.
- University students were the group of people that mainly reduced their public transport use. This is attributed to the fact that the remote lecture delivery, which has been in place in Greek Universities from the beginning of the pandemic till now, reduced their obligatory trips typically completed with public transit.

- People that have access to a private car significantly reduced the use of public transport. This result shows that after the 1st lockdown, and after the appearance of the pandemic in general, public transport mainly serves captive users (i.e., users that do not have an alternative).

The following conclusions are drawn based on the interpretation of parameters dealing with walking frequency:

- People who were living in cities with low population density after the 1st lockdown increased walking.
- People that moved to a city with a low bicycle lane density after the 1st lockdown increased walking. This result probably shows that in cases of a more complete bicycle network, bicycle can attract more people also among those who walk.
- People that during the 1st lockdown used to walk for exercise increased the frequency of walking after the 1st lockdown. This is an indication that changes observed during the lockdowns can be preserved, at least in the short-term.
- People that perceive the environment of the cities that were living after the 1st lockdown as walk-friendly increased walking. Therefore, it becomes clear that a walk-friendly environment can significantly motivate citizens to shift to active mobility and especially walking.
- Walking became more frequent for university students and for women. Combining the findings from the two parts of the model, we understand that students were the group of users with the most important changes in the use of the two modes. There seems to be a net change from public transport use to walking. Regarding gender, although the sample consists mainly of women, the z-value and p-value provide a clear difference and it is observed that females increased walking significantly more than males.

Finally, the Rho value, which is positive and statistically significant, indicates that a strong positive correlation between the two dependent variables exists and at the same time justifies the decision for developing

**Table 9**  
Model estimation results.

Variable	Parameter estimation	z-Value	p-Value
Decrease of public transport usage after the 1st lockdown			
Constant	1.257	3.922	0.000
Comparison of the size of the city living before and after 1st lockdown (0 if the city after 1st lockdown is smaller than the one before, 1 if they belong in the same size class, 2 if the city after 1st lockdown is bigger than the one before)	-0.481	-2.943	0.003
Frequency of using public transport before 1st lockdown (scale 0–4, where 0 corresponds to daily and 4 to never)	-0.491	-7.611	0.000
University student (1 if yes, 0 otherwise)	0.501	2.802	0.005
Access to private car (1 if yes, 0 otherwise)	0.553	2.062	0.039
Increase of walking after the 1st lockdown			
Constant	-0.731	-2.362	0.018
Population density in the city living after 1st lockdown (scale 0–3, where 0 corresponds to low density and 3 to high density)	-0.146	-2.077	0.038
Comparison of the bicycle lane density of the city living before and after 1st lockdown (0 if the city after 1st lockdown has lower bicycle lane density than the one before, 1 if they belong in the same bicycle lane density class, 2 if the city after 1st lockdown has higher bicycle lane density than the one before)	-0.277	-2.098	0.036
Frequency of walking for exercise during 1st lockdown (scale 0–4, where 0 corresponds to daily and 4 to never)	0.370	2.052	0.040
Walk-friendliness of the city living after 1st lockdown (scale 0–4, where 0 corresponds to not at all and 4 to very much)	0.192	2.283	0.022
Gender (1 if female, 0 otherwise)	0.340	2.272	0.023
University student (1 if yes, 0 otherwise)	0.445	2.677	0.007
Correlation among dependent variables (Rho)	0.370 (0.189, 0.533)		
Akaike information criterion (AIC)	690.227		
Bayesian information criterion (BIC)	738.505		
Number of observations (N)	306		

a bivariate model, instead of examining each dependent variable separately.

## 5. Discussion

The COVID-19 pandemic has lasted for over 18 months disrupting passenger and freight transport worldwide. Several studies released just after the 1st lockdown in various countries concluded that there was a significant reduction on passenger mobility and changes in travel behavior (Brezina et al., 2020; Jenelius & Cebeceauer, 2020; Padmanabhan et al., 2021; Sabat et al., 2020).

This study explored changes before, during and after lockdown periods in Greece and showed that there were critical mobility changes for young adults that are related to respondents' demographic and city attributes. Governments responded to mobility changes by promoting and supporting sustainable mobility measures, including expansion of pathways, building bicycle lanes, temporary street closures and subsidizing bicycle-sharing systems. For example, Brussels built a 24.9 km network of bicycle lanes on the main corridors of the capital and a 23.4 km traffic calming road resulting to an increase of 44% for bicycling share in 2020 compared to 2019 (Nikitas et al., 2021). Many governments provided financial aid and subsidized bicycle related measures during the pandemic. A recent survey found that 32 of 42 European cities built new bicycle lanes and paths, while 102 of 200 US cities built new bicycle lanes and paths and 96 US cities provided free or cheaper bicycle sharing (Buehler & Pucher, 2021). Active mobility measures

were also used to support urban mobility, revealing the need to support mobility changes that occurred at global level due to COVID-19. A survey of 524 cities in Europe, the US and Asia found that some cities changed their laws to allow the use of public roadway space for pedestrians and bicyclists, expanded or subsidized their bicycle-sharing programs, or subsidized bicycle purchases or/and repairs (Buehler & Pucher, 2021).

Provision of bicycle infrastructure appears to be used as a measure to promote bicycle use. This policy is also supported by the survey results in this study: people who reside in cities with a denser bicycle lane network increased their bicycling compared to those that reside in cities with limited bicycle lane network. In the absence of a bicycle network, young adults after the 1st lockdown inclined to walk more. Implementing mobility plans at the city level that would account for the mobility trend changes noted here may be a valuable input for policy changes aiming to address sustainable mobility. Reforming neighborhoods in metropolitan cities into livable areas by expanding pathways, creating workout areas, using environmentally friendly materials, and increasing accessibility for all citizens, could encourage their residents to be more active, walk more, complete daily errands on foot, and exercise. The Sustainable Urban Mobility Plans (SUMP) implemented in EU and Complete Streets in the US are ideal initiatives for creating such conditions. The SUMP concept has been promoted since 2013 as a strategic planning instrument for local authorities to encourage a shift towards more sustainable modes of transport and improve the overall quality of urban life. However, only a small proportion of European cities have implemented a SUMP. A survey in 2017 among 328 cities showed that only 6% of the participating cities from Greece had completed a SUMP, whereas French cities showed a 78% participation rate (Durlin et al., 2018). Efforts to promote SUMP and implement the actual proposed measures becomes essential to citizens' active mobility. The city of Paris invested more than €20 m since the start of the pandemic in road amendments and bicycle infrastructure (Vandy, 2021). As a result, bicycling share increased by 27% in late 2020 compared with the same time in 2019. Bicycle increase in France, however, is attributed to a broader package of measures, including also a €50 subsidy towards the cost of bicycle repairs and an offer of free bicycling lessons.

Mode shares after the COVID-19 lockdown confirm users' response to mobility measures that promote active mobility (Bucsky, 2020; Nikiforiadis et al., 2020a; Nikitas et al., 2021). This study also explored users' travel behavior in relation to existing infrastructure and specifically addressed young adults' behavior. It proves that walking and public transport mode changes are linked to city attributes. Public transport use was decreased significantly (approximately -62%), which is mainly driven by travelers in large Greek cities, such as in Thessaloniki and Athens, i.e., the two larger Greek cities. Nevertheless, walking was the preferred mode of transport for more than half of the young adults (increased by approximately 54%) whereas bicycle and motorcycle shares were not affected significantly. The city of Athens introduced a temporary pilot project "Great Walk" in June 2020 which included the creation of public spaces, bicycle lanes and pedestrian zones. Four months after that, walking increased roughly by 28%, but bicycle use remained at the same levels (Nikitas et al., 2021). The provision of walking infrastructure appears to contribute significantly towards increased walking rates. The model developed in this study shows that a friendly environment is likely a motivation factor for increased walking in cities, thus enhancing active mobility for citizens. Mobility changes, such as increased walk trips for exercise, that occurred during the 1st lockdown appeared to continue after it, showing that in the short-term travelling habits may be retained; however, in the long term they might have to be supported by appropriate infrastructure facilities.

The survey results showed that walking increased, and public transport use decreased during the COVID-19 pandemic. Young adults, like all other user groups, consider the risk of travelling by public transport and since they are keener on using micromobility modes, such

as bicycles, electric scooters, and kick scooters, than older users, it is expected that they will reduce their public transport trip frequency (Nikiforiadis et al., 2021a). Smaller cities offer shorter travel distances that may be covered easier by walking or micromobility modes compared to large metropolitan cities. The COVID-19 lockdown periods showed that local authorities may create more sustainable transport networks and reduce reliability on private vehicles if transport planning targets travelers' needs.

Jobe and Griffin (2021) suggested the improvement of bicycle-sharing services for unemployed and low-income communities following the pandemic as these two groups are most likely to increase their use of bicycle-sharing systems. The results of this study showed that walking becomes more frequent for university students and women. Smaller cities have the potential to be more sustainable through planning for safe pathways and bicycle routes. Nikiforiadis et al. (2020a) suggested for Thessaloniki that bicycle-sharing is considered safer than travelling in a taxi and much safer than using public transport. Decision makers should explore these opportunities and provide timely solutions to address travelers' needs, whereas pre/post impact assessments are required to monitor their choices.

Transport planners should recommend well-designed measures that are permanent or have a potential to be permanent, since temporary measures may not be accepted by local residents. The Athens' Great Walk although improved walking and bicycling conditions, its pilot character may have caused a public dilemma. A survey of 1108 persons revealed that 87.8% of the respondents were "not at all" or "only slightly" pleased with the interventions. The dilemma is also supported through finding that although 89.3% of the respondents stated that their needs were considered, at the same time 89.4% said that the Athens Great Walk was "badly designed" (Kathimerini, 2021).

The opportunities that are offered to shape urban mobility, as a response to COVID-19 impacts, should be seized. Respondents of the survey noted increased use for bicycling and walking after the 1st lockdown, while bicycling usage increased as the bicycle lanes density increased. Temporary measures, such as pop-up lanes (Nikitas et al., 2021), is a good policy that needs to be sustained and expanded. The maintenance and expansion of active mobility to other traveler groups, depends on the level of service in terms of safety and the friendliness that they offer to the traveler. Assessment of current pedestrian and bicycle conditions in terms of pavement materials, adequate width, route connectivity and separation of other motor modes, becomes essential for bicycle network planning (Nikiforiadis et al., 2020b; Nikiforiadis et al., 2021b).

In the case of larger Greek cities, where public transport use is higher compared to smaller ones, a share of travelers appeared to be captive to public transport due to the absence of travel alternatives. These travelers should be supported by local authorities, and customized policy measures should be formed to sustain their interest in public transport modes or/and provide active modes for the last/first mile of their trip. Furthermore, ride-sharing and carpooling schemes may be appropriate beyond the pandemic for their trip. Collaboration of public transport agencies with carpooling companies and their subsidy by government, would support such an initiative. Provision of dedicated bicycle and walk infrastructure in rural areas to safely direct travelers to public transport stations, in line with measures in other countries that promoted bicycling have the potential to maintain public transport users, attract back travelers that switched to private cars and alleviate traffic congestion in central urban areas (Nikitas et al., 2021).

## 6. Conclusion

This paper examined the changes that the COVID-19 pandemic caused to travelers' behavior by focusing on young Greek adults. Data collected through a questionnaire survey allowed for the analysis of travel-related preferences before, during and after the 1st lockdown and during the 2nd lockdown. The paper also examined whether the

identified changes in young adults' travel behavior are linked to city attributes. In contrast with studies that utilize different sources of data, i. e., other than questionnaires, this study allows the examination of the linkage between socioeconomic characteristics, perceptions, and mobility habits before the pandemic with the travel behavior changes. Moreover, the related studies that have been published and utilized questionnaire data, do not include panel data that cover all the different time-periods, from the period before the appearance of the pandemic until the period of the 2nd lockdown.

The results indicate that young adults mainly reduced their use of public transport and increased walking, without any significant changes in the other transport modes. Bicycling increased in cities with increased bicycle lane density. Walking was especially increased by people that perceive the environment of their city as walk-friendly. These main findings support the policy measures that were implemented in various cities for supporting active mobility during the pandemic. They also underscore that for sustaining the positive trend for active mobility, well-designed measures that are permanent or have a potential to be permanent are needed.

This paper also has some limitations. Firstly, the analysis was conducted for one country, with specific sociodemographic and transportation characteristics. Another limitation is the fact that only specific city attributes are considered, and this was due to the limited availability of quantitative data. Therefore, future research should consider: a) a similar questionnaire survey targeting young adults living in countries with different sociodemographic and transportation characteristics, and b) semi-structured interviews with young adults that changed their travel behavior, in order to examine in a qualitative manner, the factors that motivated the changes.

## CRedit authorship contribution statement

Andreas Nikiforiadis: Methodology, Formal analysis, Writing-Original draft, Writing - Review & Editing

Lambros Mitropoulos: Formal analysis, Writing-Original draft, Writing - Review & Editing

Pantelis Kopelias: Data Collection, Conceptualization, Methodology, Writing-Original draft

Socrates Basbas: Conceptualization, Methodology, Supervision

Nikiforos Stamatiadis: Writing - Review & Editing, Supervision

Sofia Kroustali: Data Collection

## Author statement

All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript. Furthermore, each author certifies that this material or similar material has not been and will not be submitted to or published in any other publication before its appearance in the Cities Journal.

All persons who have made substantial contributions to the work reported in the manuscript (e.g., technical help, writing and editing assistance, general support), but who do not meet the criteria for authorship, are named in the Acknowledgements and have given us their written permission to be named. If we have not included an Acknowledgements, then that indicates that we have not received substantial contributions from non-authors.

## 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.

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