Transportation Research Interdisciplinary Perspectives 14 (2022) 100609

Contents lists available at ScienceDirect

Transportation Research Interdisciplinary Perspectives

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

Impact of COVID-19 lockdown on the behavior change of cyclists in Lisbon, using multinomial logit regression analysis

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ARTICLE INFO

Keywords:
Cycling
COVID-19
SARS-CoV-2 virus
Lockdown
Behavior change
Lisbon
Portugal

ABSTRACT

The 2019 novel coronavirus outbreak hit most countries and cities globally, dramatically impacting how people live during lockdown periods. Compulsorily, socioeconomic activities and mobility patterns changed while long-lasting structural changes might remain. Focusing on this very particular liminal event, this paper aims to present and analyze the impact of the SARS-CoV-2 virus lockdown on the behavior change of cyclists and previously non-cyclists in Lisbon, Portugal, knowing that no concomitant interventions occurred in the cycling environment during the period analyzed (e.g., pop-up interventions).

From a 1-min questionnaire in 5 locations in Lisbon's existing cycling lanes, we aimed to collect (n = 493) revealed preferences on cycling frequency before and after the lockdown, which we used to calibrate a weighted multinomial logit model to analyze respondents' probability of increasing, maintaining, or decreasing their cycling frequency. Results suggest that people tended to cycle more often after the lockdown than before. For every five cyclists, two cycled more frequently while two others maintained their cycling frequency. Most cycling trips were recreational or to exercise, and these increased after the lockdown, while trips for work and school decreased, as expected. Moreover, the lower the individuals' cycling frequency levels before the lockdown, the more they cycled after it.

Our study diagnoses the impact of the lockdown on cycling habits, indicating an overall propensity to cycling more by the Lisbon citizens. Hence, authorities need to act and make quick infrastructural changes (e.g., pop-up cycling lanes) and encourage the population to use more bikes (e.g., financial incentives for bike purchases).

1. Introduction

The 2019 novel coronavirus pandemic hit most countries and cities globally, massively impacting how people live and work. Many countries have taken extraordinary measures to avoid social contact and prevent the further spread of the virus. Measures such as isolation, quarantine, or community containment (Wilder-Smith and Freedman, 2020) have proven successful in decreasing previous SARS spread and, as such, countries began imposing such measures. Countries like Sweden and The Netherlands have implemented less restrictive measures than other countries like China, Italy, Spain, and Portugal, which have issued mandated lockdowns to impose social distancing.

Due to such measures, socioeconomic activities have changed, and such changes might structurally influence how people behave during and after lockdown periods. As activities change and while many are temporarily unemployed or working from home, corresponding mobility habits and patterns also changed during and after lockdown periods. For example, many may avoid public transportation as this can increase the likelihood of contracting acute respiratory infections (Troko et al., 2011), while people with access to cars may be more inclined to drive more (De Vos, 2020). In New York, both the subway system and the bike-sharing system (BSS) saw a decrease in ridership, with the subway ridership dropping more than that of the BSS (Teixeira and Lopes, 2020). On the other hand, active modes (i.e., walking and cycling) may increase for short trips as social contact can more easily be avoided (Woodcock et al., 2020), for instance, for recreational purposes (De Vos, 2020), with people choosing their mode based on pandemic-related factors (Abdullah et al., 2020).

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https://doi.org/10.1016/j.trip.2022.100609
Received 20 October 2021; Received in revised form 16 April 2022; Accepted 25 April 2022
Available online 11 May 2022

With public transportation being the choice by many citizens for their urban trips worldwide, cities fear people's reaction to transfer back to private vehicles due to the increased exposure to and potential contamination by the SARS-CoV-2. Thus, many cities have begun to implement fast and temporary solutions to avoid such a trend, with cities such as Berlin, Bogotá, and Philadelphia transforming car lanes into sidewalks and cycle lanes temporarily (Laker, 2020; Buehler and Pucher, 2021). Previous work to the current pandemic has shown that interventions and increased walkability were associated with increased pedestrian activity (Cambra and Moura, 2020) and interventions that increased the cycling network infrastructure in Lisbon, Portugal, lead to a 3.5-fold increase of cyclists (Félix et al., 2020). Disruptive events may help reveal the potential changes to individuals' mobility patterns as behavior adaptations are required, and thus the SARS-CoV-2 pandemic might act as a turning point in favor of a more sustainable urban transport system (Nurse and Dunning, 2020; Büchel et al., 2022).

The present paper aims to analyze the impact of the 2019 novel coronavirus lockdown on cyclists' behavior change and previously non-cyclists, in the case of Lisbon, Portugal. We did a 1-minute intercept survey to collect revealed preferences on whether cycling frequency has changed (i.e., increased, continued, or decreased) between the two periods: pre-pandemic (before March 18th 2020) and post-lockdown (after May 2nd 2020), exploring this unique opportunity for research. Following this key data collection and analysis, we successfully calibrated a multinomial logit model to analyze and quantify respondents' probability of changing their cycling patterns, based on the change in cycling frequency, sociodemographic, and mobility characteristics. In all, this article explores how cyclists have changed their cycling frequency during a liminal event, collecting data directly from cyclists while cycling using an intercept survey to better analyze how and why individuals have changed their cycling behavior.

We begin the paper with this introductory section. The explanation of the methodology follows, including the survey description to collect data about the cycling behavior changes and multinomial logit models to estimate and understand such changes. In the following section, we present the survey and modeling results that we discuss in Section 4. Section 5 finalizes the paper with our conclusions.

2. Methods

This section describes the survey design and questionnaire used to collect data and the methods applied to analyze the cycling frequency data before and after the 2019 novel coronavirus lockdown. Next and to better analyze and quantify the impact of each characteristic, we use Multinomial logit models to estimate cycling frequency changes before and after the lockdown in Lisbon, Portugal.

2.1. Survey

Intercept surveys are broadly used to research cycling behavior and bike-sharing demographics, motivations, and preferences (McNeil et al., 2015; Kaviti et al., 2019). These surveys may also be useful in collecting data from bicycle users, even the casual who might be harder to reach through online platforms or newsletters on cycling (Shaheen et al., 2015). These may also serve as a gateway to direct bicycle users to a longer online survey (Buck et al., 2013). In the case of bike-sharing, they are particularly useful as a means of complementing the trip data collected from the bike-sharing systems (NACTO, 2016; Maas et al., 2022).

An intercept survey was designed to take less than one minute long. The main objective was to capture cyclists' behavior changes due to the lockdown and to what extent. The choice was made, of keeping the survey short, so we would have a better acceptance chance when intercepting the cyclists, so as to obtain more responses, acknowledging that cyclists would have to delay their trip. We split the survey into two parts. After intercepting respondents, we stated the questionnaire would only take one minute. If successful, the surveyor would then ask the questions, and proceed to collect the respondents' observable attributes (e.g., type of bike, age group). Those that accept to stop were introduced to the survey and its purposes. Cyclists were informed that all gathered information was anonymous and no identifiable information would be collected. The questionnaire was created with LimeSurvey using tablets with an internet connection to record all answers directly, and answers would be stored in Instituto Superior's servers, fulfilling GDPR requisites and protection of the collected answers. The questions were then posed only to those that accepted to answer the questionnaire.

The survey was deployed next to existing cycle paths and took place throughout a week in May 2020 (after the lockdown period in Portugal) during the afternoon peak hour period (5 pm–8 pm). We selected five locations, including *Campo Grande*, *Saldanha*, *Praça de Londres*, *Parque das Nções* and *Av. Ribeira das Naus*. Fig. 1 depicts all 5 locations alongside the current cycling infrastructure. The first 3 locations correspond to Lisbon's central business district and are often associated with more work and utilitarian trip locations, and the last 2 locations at the riverbank esplanade, are more associated with recreational trips. All locations correspond to places with existing cycle paths (3 segregated bike lanes, and 2 off-road and shared with pedestrians) to facilitate the process of stopping and interviewing cyclists. This convenient option implies a certain bias as it may distort the global trips' purposes, origins and destinations, and the cycling frequency, as it is more probable to find and stop cyclists on cycle paths than in the remaining road network. A random and systematic sampling strategy was used, intersecting all passing cyclists, regardless of their observable characteristics. About 1/3 of the passing cyclists agreed to stop and answer the survey. When a group of cyclists stopped, only one answered the survey (randomly chosen), and the remaining were registered as accompanying cyclists.

As referred above, the two-part survey consisted of (1) questions asked by the interviewer aiming to characterize the cyclist, his/her reasons for cycling, and cycling frequency; and (2) observable characteristics that could be collected directly by the interviewer. In part (1), 6 questions were asked:

- What is the purpose for this trip? From which a category between *Home-Work/School*, *Utilitarian (shopping or doctor appointment)*, *Deliveries or Courier*, *Taking kids to home/school*, *Exercise or Physical activity* or *Leisure* was chosen;
- Where did the trip start (approximately)?
- Where did it end?
- How regularly have you been using a bicycle after the lockdown has ended? An answer from the following set was chosen: *Never*, *Rarely*, *Occasionally (a few times per month)*, *Frequently (a few times per week)* and *Everyday*;
- Before the SARS-CoV-2 pandemic, how often did you cycle? The frequency categories were equal to the previous answer;
- [For *Home-Work/School*, *Utilitarian* trips] What transport mode did you used before the pandemic for this trip?

The starting and destination points allowed to check whether it was a loop trip (equal start and endpoint) and to compute the approximate distance traveled, using OpenRouteService,[1] with "cycling-regular" and "fastest" attributes. The precision used differed between respondents as some were willing to pinpoint the address of their start and endpoint, while others preferred only to mention a certain neighborhood. In this latter case, a central point in the neighborhood was chosen as the start or endpoint, respectively. Part 2 of the questionnaire aimed to capture additional data about the respondents that the interviewer could deduce without increasing the survey's answering time. Those additional characteristics included:

[1] https://openrouteservice.org/services/.

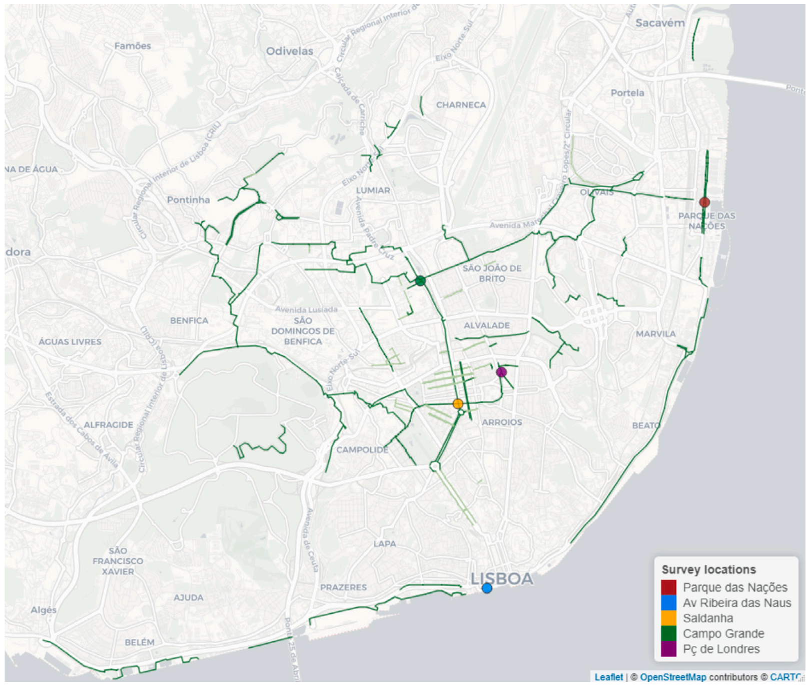

Fig. 1. Lisbon's cycling network (May 2020) and survey locations.

- Gender;
- Age group, between *Kid*, *Teenager*, *Adult* or *Senior* (the interviewer made a subjective evaluation and assigned an age group);
- Did the cyclist wear a helmet (which is not mandatory in Portugal)?
- Type of bicycle among the options of *city*, *mountain*, *electric*, *road*, *BMX*, *cargo*, *kids*, *foldable* or *rented* bike;
- Did the cyclist travel alone? And if not, what were the age groups and genders of the accompanying cyclists.

2.2. Lisbon case study

Lisbon hosts about 0.7 million inhabitants over 100 km^2, while 2.8 million people live in the Lisbon Metropolitan Region, i.e., 27% of the Portuguese population. Lisbon has an irregular orography, being perceived as a hilly city, although 54% of the streets are considered flat (<3% inclination) (Félix, 2012). The city is described by having a plateau area in the Centre-North of the city, the Monsanto forest on the Westside, and 18 km-long riverbanks along the Tagus River. Lisbon used to offer a highly fragmented bicycle network and lacked places to store or lock bikes safely (Moura et al., 2017).

Major urban and mobility transformation happened in 2016 in Lisbon's Central Business District (CBD), with road dieting measures to reduce main avenues' car capacity and driving speeds. Since 2016, the municipality has committed to expanding the cycling infrastructure with a more comprehensive, connected, and commuting-oriented bicycle network, and to a public bicycle-sharing system, covering mainly the central business areas and the waterfront. These investments have contributed to increased levels of cycling in Lisbon: from 0.2% in 2011, to 0.6% in 2017 and currently being 1.0% (Félix et al., 2020). However, no changes occurred in the cycling system of Lisbon after the lockdown and before the survey. Pop-up cycling lanes have been introduced since then, with the cycling network extension reaching 150 km by 2021 (Câmara Municipal de Lisboa, 2021).

As for the time which encompasses the mandated lockdown period in Lisbon, Google's COVID-19 Community Mobility Reports (Google, 2020) show a clear decrease in mobility patterns. Fig. 2 show a decrease for mobility trends for different places. A decrease in mobility patterns started to occur about one week before the lockdown and reached their maximum values during the lockdown, with trends ranging from −60% for groceries and pharmacies to −86% for retail and recreation. In turn, residential movements increased to about 35%. In the particular case of cycling, data from the automatic cyclists' counter (Eco-Counter, 2020) revealed that cycling levels drastically decreased after March 18th 2020, and recovered up to normal levels in May 2020, despite observing different patterns: with increased activity during the weekdays, in contrast with lower activity on weekends (before March 2020, the pattern was the inverse). In October 2020, cycling levels increased, after the liminal period of observation for this research, as shown in Fig. 3.

2.3. Multinomial logit models

Unordered multinomial discrete outcome models were employed. By choosing unordered models, we prefer not to consider the ordered nature of the data in favor of unrestricted how explanatory variables affect the outcome probabilities. The freeware software PandasBIOGEME (Bierlaire, 2020) was used for model estimation thanks to its simplicity and versatility in specifying the models formulated for this analysis.

Multinomial Logit (MNL) models are traditional discrete outcome models that consider, in this case, three outcomes (increase, maintain or decrease the cycling frequency) and do not explicitly consider the ordering that may be present. Let us consider the probability of a cycling frequency change i for an observation n. The alternative specific latent variables for MNL take the form of (Washington et al., 2020):

$$U_{in} = \beta_i X_{in} + \epsilon_{in}, \tag{1}$$

where β_i is a vector of coefficients to be estimated for outcome i and cyclist n, X_{in} is a vector of exogenous variables, U_{in} is a function of covariates determining the utility, ϵ_{in} is the random component assumed to follow a Gumbel type 1 distribution. Thus, the probability expression is as follows (Washington et al., 2020):

$$P_n(i) = \frac{exp(\beta_i X_{in})}{\sum_{\forall I} exp(\beta_i X_{in})} \tag{2}$$

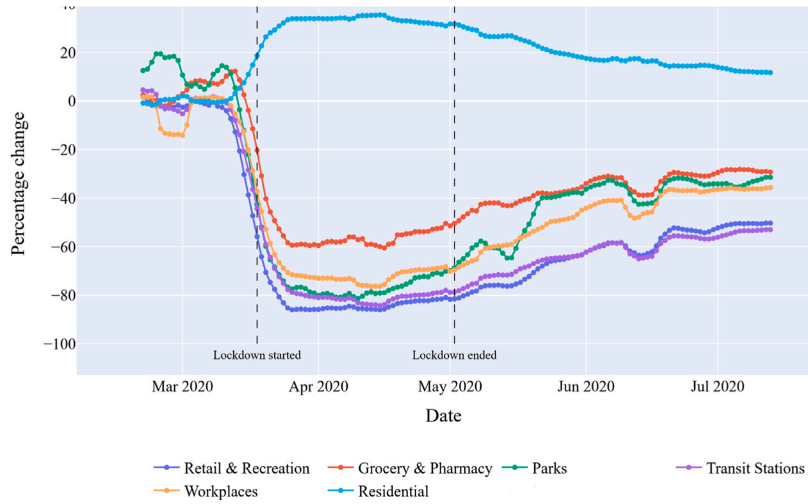

Fig. 2. Google's COVID-19 community mobility report for Lisbon.

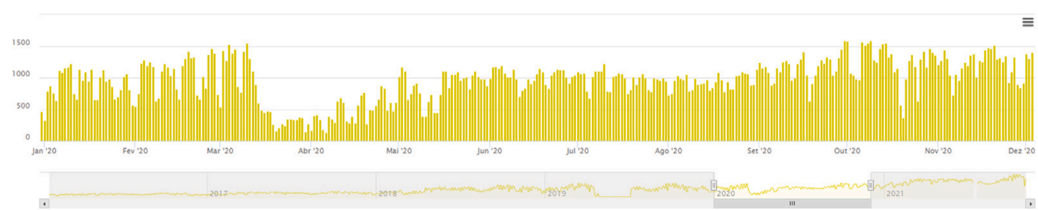

Fig. 3. Automatic counting data for cycling between Jan and Dec 2020 in Av. Duque de Ávila situated in the central business district close to the Saldanha intercept location.

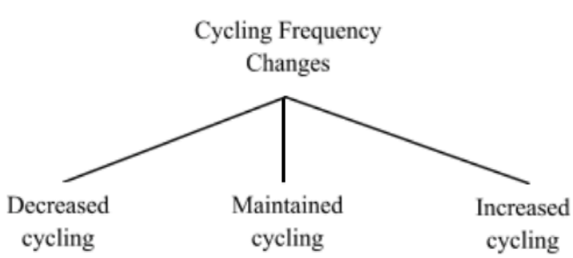

Fig. 4. The MNL structure of the models of cycling frequency changes.

The MNL model presented in (2) can lead to serious specification problems because this particular form requires us to assume that the unobserved terms (ϵ_{ij}'s) are independent of one frequency change category to another. This restriction is the Independence of Irrelevant Alternatives (IIA) (Washington et al., 2020). The violation of IIA property is very much data-dependent, with sometimes the property holding and other times not. If some of the frequency categories levels share unobserved terms and thus be correlated, the logit formulation will erroneously estimate the coefficient vector and outcome probabilities (Shankar et al., 1996). A formal test ensures whether the MNL specification is appropriate. The Hausman and McFadden IIA specification test (Hausman and McFadden, 1984) holds with the final MNL specifications, which are shown in Fig. 4 and expressed as (2). This structure is used in our model, and, such that there are no identification issues, we use the "maintain frequency" as the reference alternative for the *a priori* tastes (fixing the Alternative Specific Constant).

Since data was collected using an intercept survey there is a fear of the representativeness of the collected data. Thus, to ensure consistency in estimating the model based on an intercept sampling strategy, we weight each observation using exogenous sampling maximum likelihood estimator (Manski and Lerman, 1977). This weighting procedure is usually done by comparing previous large collected samples of data with our own intercept sample. Consequently, we use previously manual municipality collected data about Lisbon's cycling population (see Table 2) to better approximate our sample. In other words, each observed cyclist's characteristic (gender, age, helmet use, and bike-sharing use) is compared to the overall cycling population and a weight is assigned to each observation, such that, in the end, our intercept sample is proportional to Lisbon's cycling population. Henceforth, during the estimation of the multinomial logit model, each log-likelihood function term is weighted (Manski and Lerman, 1977) with the inverse frequency of its observable characteristics in comparison to Lisbon's population.

A Likelihood ratio (LR) test was used to compare the χ^2 value (with the corresponding degrees of freedom) and test whether the estimated model (restricted) is significantly different from the a priori model (unrestricted). The LR test statistic is computed as:

$$LR = -2[LL_U - LL_R] \tag{3}$$

where LL_U and LL_R are the log-likelihood of the unrestricted and the restricted models, respectively.

2.3.1. Elasticities

Adding to the assessment of individual variable coefficients, we can use elasticities to measure the magnitude of the impact of specific variables on the cycling frequency changes (outcomes) probabilities (Washington et al., 2020). Analyzing individual coefficients is not sufficient to explore how changes in the explanatory variables affect outcome probabilities. Since the marginal effect of a variable depends on all coefficients in the model, the actual net effect cannot readily be determined from just any isolated coefficient. In other words, this means that elasticities measure the percent-change effect of one explanatory variable k has on the percent-change of the outcome variable i. In the case of dummy or indicator variables, elasticities are not applicable and so pseudo-elasticities are employed. These can be computed by (Kim et al., 2007):

$$E_{x_{ink}}^{P_n(i)} = \frac{P_n(i|x_{ink} = 1) - P_n(i|x_{ink} = 0)}{P_n(i|x_{ink} = 0)} \tag{4}$$

where $P_n(i|x_{ink} = 1)$ is the probability of outcome i given the value x_{ink} of variable k being equal to 1 and $P_n(i|x_{ink} = 0)$ is the probability of outcome i given the variable x_{ink} being equal to 0. We can estimate the elasticities either at the average value of the regressors or average the elasticities over the sample. Average elasticities were used since it is not reasonable to use the average value of dummy variables.

Elasticity values can be interpreted as the effect that a 1% change in x_{ij} has on the probability $P(i)$ of the cycling-frequency-change outcome. The pseudo-elasticity of a variable concerning a cycling-frequency-change category represents the percent change in that frequency-change category's probability when the variable varies from zero to one. Thus, a pseudo-elasticity of 95% for a variable in the "decrease frequency" category means that when the values of the variable in the subset of observations where $x_i = 0$ are changed from 0 to 1, the probabilities of the "decrease frequency" outcome for these observations increased, on average, by 95%, when all other characteristics remain equal.

3. Results

3.1. Data description

A total of 493 valid answers were collected at the 5 locations in Lisbon, having stopped 635 cyclists when counting for the escorting cyclists. The survey responses are summarized in Table 1. *Saldanha* and *Campo Grande* were the locations where more answers were collected (32.3% and 21.9% respectively) with a survey answered every 2 min approximately, while *Praça de Londres* only accounted for 11.3% of the number of collected answers. Table 2 compares the frequency of cyclists, helmet use, women, and people using the municipal bike-sharing system (GIRA) between May 2019 and May 2020, when the city performs its annual bicycle counting surveys (Moura et al., 2020), using the methods from Félix et al. (2020). This data will later be used to weigh our sample of interviewed cyclists in the MNL model using the *sample ratio* such that our sample of intercepted cyclists better approximates the cycling population of Lisbon. Next, we highlight the main findings from the collected data.

3.1.1. Trip purpose

The most frequent revealed trip purposes for cycling were Recreation (42%), followed by Commuting (22%), Sports (16%), Utilitarian—such as shopping, errands, visiting friends or family (16%), and Deliveries as a courier (4.5%). There is a difference between the survey locations combined with trip purposes: commuting and utilitarian trips are more frequent (about 50%) in the central business district. The recreational and sports trips are more frequent (>60%) near the riverbank. Deliveries trips were more frequent in *Saldanha* and *Praça de Londres*, being almost non-existent on the riverbank.

3.1.2. Loop trip

Almost half of the respondents (48%) revealed that their trip's destination would be the same as the origin (e.g., they left home and return home). There was a clear difference between the proportion of trips made in a loop: about 75% of the recreational and sports trips were loops, while about 85% of the remaining purposes had origins different from destinations.

Loop trips had a special relevance during the pandemic period, as the bicycle was used for exercise and for recreation, when other activities were not allowed (van Leeuwen et al., 2020; Büchel et al., 2022; Buehler and Pucher, 2021; Nguyen and Pojani, 2022). Recreational trips are also an important step in the transition to becoming a commuting cyclist, as they allow for cycling experimentation, and positively influence bicycle commuting over time (Muñoz et al., 2016; Kroesen and Handy, 2014).

3.1.3. Previous transport mode

Among 177 respondents, whose trip purpose was commuting or utilitarian, the majority of cyclists (54%) responded that they already used to travel by bicycle, although 35% of respondents stated that they had used public transport previously for that same trip, and 7% stated that they had replaced the car by a bicycle. 4% of the participants said they had replaced walking with cycling. The pandemic period brought changes in the transportation mode choice of about 46% of respondents, with a striking 42% coming from motorized modes.

3.1.4. Gender and age

About a quarter of cyclists (26%) surveyed were female. Regarding the age group, 83% were adults, 12% were teenagers (under 18 years old), and 4.5% were seniors (over 65 years old), while the remaining 0,5% were kids.

3.1.5. Helmet

30% of cyclists used a helmet. The use of helmets varies by survey location, with more cyclists wearing helmets in Campo Grande, Parque das Nações and Ribeira das Naus than in Saldanha and Praça de Londres. Helmet usage might be related to the trip's purpose as more cyclists are wearing a helmet for leisure or sports trips (34%) and less for commuting, utility, or delivery trips (25%). As referred before, trip purpose frequency seems to be correlated with survey sites' location.

3.1.6. Bicycle type

Above a third of cyclists (37%) rode a shared bike from the municipal bike-sharing system, GIRA. More cyclists used GIRA bicycles in the city center (46%) than owned bicycles, and less on the riverfront (19%). On the other hand, 53% of cyclists with a GIRA bicycle used it for commuting, utility, or delivery trips. From another angle, from all cyclists with commuting, utility, or delivery trip purposes, 47% used a GIRA, and of the couriers, 91% also used a GIRA. Lisbon's bike-sharing program offers a 25€ annual pass, which is more affordable for a courier to invest than purchasing a private bicycle. Only 14% used a GIRA for sports. Most private bicycles (61%) were mountain bikes, which is quite common in Portugal. 23% rode an urban/utilitarian bicycle, 12% of the bicycles were folding bikes, and 4% were electric-assisted bikes.

3.1.7. Accompanying cyclists

We collected the observable attributes of the 142 accompanying cyclists (i.e., number, gender, and age group). There were a higher proportion of accompanied (vs. single) cyclists in Parque das Nações, Campo Grande, and Av. Ribeira das Naus. On average, 1.4 cyclists would follow respondents cycling in a group. As expected, a higher proportion of the cyclists' group cycled for recreational and sports purposes rather than for commuting, utility, or deliveries. Many families were observed (i.e., 34% children and some adults). The majority of the companions were male, both adults (69%) or children (65%). No senior cyclists were observed accompanying other cyclists. Table 1 summarizes the descriptive statistics of the survey variables related to changes in cycling frequency.

3.2. Cycling frequency changes

This study's main objective was to understand how the change of habits resulting from the pandemic situation (COVID-19 virus) also influenced the change of mobility habits, particularly cycling. In the survey, we asked cyclists how regularly they used to cycle and their cycling frequency before the pandemic situation.

From Table 1, 32% of the intercepted cyclists revealed that they cycled daily, 57% at least several times a week, and 76% at least a few times a month. Several cyclists changed their cycling habits after the confinement, including 42% riding every day, 77% bicycling several times a week, and 90% a few times a month. Overall, there has been

Table 1
Descriptive statistics related to changes in cycling frequency.

Cycling frequency conditioning variable	n	%	Cycling frequency conditioning variable	n	%
Purpose	493		Pre-pandemic cycling frequency	493	
Home-work/School	107	21.7	Never	75	15.3
Utilitarian	79	16.0	Rarely	43	8.8
Leisure/Recreation	205	41.6	Occasionally (a few times per month)	93	18.9
Physical activity	80	16.2	Frequently (a few times per week)	124	25.2
Deliveries or Courier	22	4.5	Everyday	156	31.8
Loop trip (same destination as starting point)	493		Post-lockdown cycling frequency	493	
Yes	285	57.8	Never	22	4.5
No	208	42.2	Rarely	28	5.7
Previous transport mode (for work/Utilitarian trips)	177		Occasionally (a few times per month)	64	13.1
Bicycle	81	45.8	Frequently (a few times per week)	171	35.0
Car	12	6.8	Everyday	204	41.7
Public transportation	62	35.0	Bicycle type (if not shared bicycle)	311	
Walking	7	4.0	Urban	72	23.2
Shared bicycle	15	8.5	Mountain	189	60.8
Gender	493		Road	23	7.4
Female	124	25.2	BMX	1	0.3
Male	369	74.8	E-bike	13	4.2
Age	484		Folding	36	11.6
Teenager	60	12.4	Cargo	2	0.6
Adult	402	83.1	Kids	2	0.6
Senior	22	4.5	Accompanying cyclists	493	
Helmet	493		0	390	79.1
Yes	146	30.5	1	76	15.4
No	332	69.5	2	18	3.6
Shared bicycle (Gira)	493		≥3	9	1.8
Yes	182	36.9			
No	311	63.1			

Table 2
Comparison of manual counts of cyclists in May 2019, May 2020 and number of intercepted cyclists which were interviewed post-lockdown.

Location			Campo Grande	Parque das Nações	Saldanha	Praça de Londres	Av. Ribeira das Naus
# Cyclists	Manual counts (per hour)	2019	178	77	287	42	99
		2020	151	111	173	50	85
	Intercepted (per 3 h)		108	83	159	56	87
		Sample ratio	24%	25%	31%	37%	34%
Females (%)	Manual counts (per hour)	2019	25	17	23	21	21
		2020	25	21	26	18	18
	Intercepted (per 3 h)		36	19	35	13	21
Age: Under 15 (%)	Manual counts (per hour)	2019	4	10	2	7	1
		2020	10	6	7	11	1
	Intercepted (per 3 h)		2	2	4	1	2
Age: Senior (%)	Manual counts (per hour)	2019	2	2	2	1	3
		2020	0	8	0	2	2
	Intercepted (per 3 h)		1	1	1	1	1
Helmet use (%)	Manual counts (per hour)	2019	39	24	26	27	40
		2020	35	43	28	26	44
	Intercepted (per 3 h)		34	38	25	11	41
Bike sharing use (%)	Manual counts (per hour)	2019	30	42	50	43	30
		2020	30	14	43	40	15
	Intercepted (per 3 h)		39	16	50	50	22

an increase in the frequency of cycling. In total, 41% of the surveyed cyclists increased their cycling frequency, with 39% maintaining the frequency before and after the confinement period, and 19% reducing their bike usage.

Table 3 shows the matrix of changes in the cycling frequency between the "Pre-Pandemic" and the "Post-confinement" scenarios. The matrix diagonal corresponds to the cyclist who maintained their trip frequency. 68.6% of the daily cyclists maintained their trip frequency, while 20% reduced to "several times a week". 44% of those who bicycled several times a week also maintained the frequency, while 28.5% began to cycle daily, which is remarkable. There are large transfers of cycling frequency from those who bicycled less to those who started using bikes more regularly. For instance, 40.5% of those who "never" bicycled changed to daily trips or to "several times a week" (32.4%). Another particular fact is that some interviewees answered with "never" while being intercepted riding a bicycle. When asked why they responded by saying that it was a one-time off event and they would not be riding more. Also, of those who rarely cycled, they changed to "several times a week" (42%) or every day (28%). We can also observe that almost half of those who bicycled "a few times a

Table 3
Matrix of cycling frequency transfers before pandemic and after confinement.

		After lockdown				
		Never	Rarely	Occasionally	Frequently	Everyday
Before lockdown	Never	9.5%	5.4%	12.2%	32.4%	40.5%
	Rarely	4.7%	7.0%	18.6%	41.9%	27.9%
	Occasionally	3.3%	6.5%	21.7%	47.8%	20.7%
	Frequently	6.5%	8.1%	13.0%	43.9%	28.5%
	Everyday	1.3%	3.2%	7.1%	19.9%	68.6%

Percentages relative to rows.

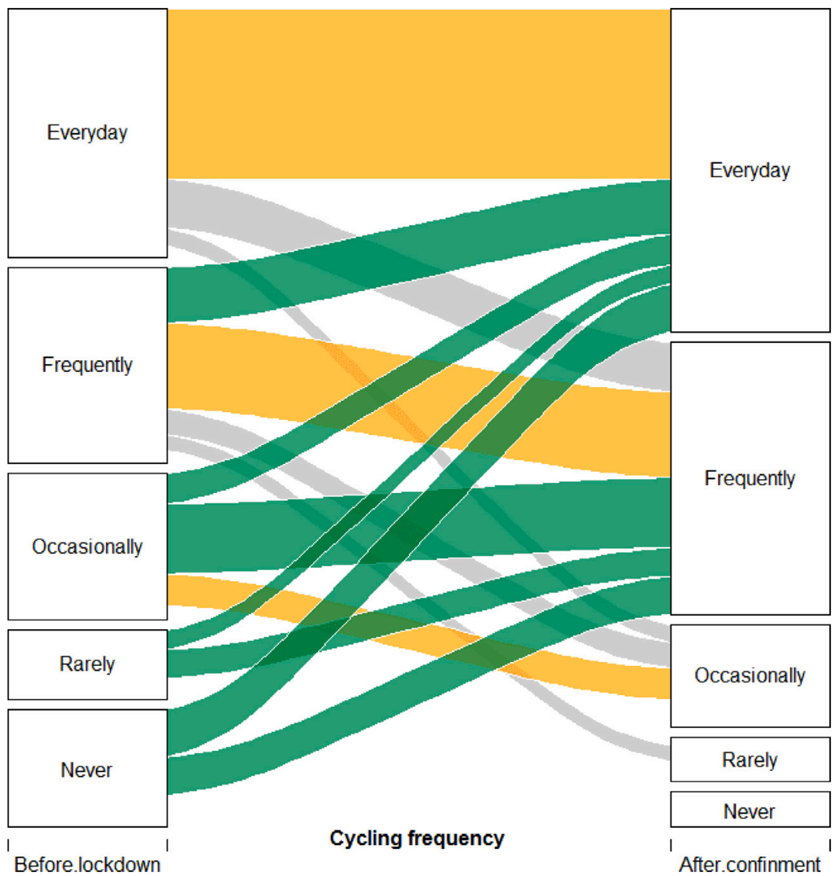

Fig. 5. Cycling frequency change, before pandemic and after confinement.

month" (47.8%) increased the frequency to "several times a week", and 20.7% to daily. Among those who decreased the frequency, highlighted in gray, the percentages are much lower, below 10%. However, 20% of cyclists who bicycle "every day" reduced the frequency to "several times a week". In this regard, several cyclists claimed that they used their bicycles every day to go to work, but they ended up cycling less as they have been working at home.

Fig. 5 shows how the "pre-pandemic" and "post-confinement" bicycle frequency transfers occurred between trip frequency categories. The yellow bars represent those that "Maintained" the frequency, and the green bars declared to "Increase" their cycling frequency. Several cyclists did not ride a bicycle "ever" and changed to cycling "every day" (40%) or "several times a week" (32%). The proportion of those who bicycled less regularly also decreased considerably, increasing the proportion of those who bicycle more frequently: the proportion of those who cycle every day or several times a week rose from 57% to 77%.

3.3. Modeling results

We modeled the change in cycling frequency between the period before and after the mandated COVID-19 virus confinement in Lisbon, Portugal, with a multinomial logit. The changes (mutually exclusive alternatives) for each individual are *Increase*, *Maintain* and *Decrease*, corresponding to individuals' changes in their cycling frequency between the two periods. We weighted each observation based on its representativeness in the overall population by classifying the population according to gender, age group (youth, teen, adult, or senior), using bike-sharing, and helmet usage. Previous data about Lisbon's cycling population regarding this fraction was then used and compared to this survey to compute the weights. This procedure better approximates our intercepted sample to the overall cycling population in Lisbon, Portugal. Modeling each alternative was a lengthy process of careful and thoughtful evaluation of the available data and model results, trying different utility specifications and variable interactions. Changes in urban cycling frequency may result from different factors as each type of change most certainly result from different individual characteristics. The enumerated variables in Table 4 for each alternative show the model with the best results, harvesting the best relation between model results and interpretability as to why individuals have changed or kept their cycling frequency. Also, Table 4 shows the model's goodness of fit indicators. Particularly, all coefficients are arranged to be positive to make analysis and interpretation easier. Furthermore, as the model's

Table 4
MNL model variable results.

Variable	Decrease		Maintain		Increase	
	Value	T-test (p-value)	Value	T-test (p-value)	Value	T-test (p-value)
ASC *Decrease*	−1.852	−4.273 (0.000)				
ASC *Maintain*			0			
ASC *Increase*					−4.042	−4.394 (0.000)
Female	0.411	1.256 (0.209)				
Shared bike for work/Util.	2.027	4.167 (0.000)				
Shared bike for leisure	0.498	1.325 (0.185)				
City bike (Type of bicycle)	1.150	3.076 (0.002)				
Leisure	1.340	2.995 (0.003)				
Prev. mode: Walking	1.571	1.389 (0.165)				
Teenager for Util.	1.543	0.877 (0.381)	1.543	0.877 (0.381)		
Adult for exercise			0.632	1.911 (0.056)		
Prev. mode: Bicycle			0.929	2.276 (0.023)		
Prev. mode: Shared bike			1.083	1.551 (0.121)		
Helmet use for leisure			0.975	2.465 (0.014)	0.975	2.465 (0.014)
Accompanied for work/Util.					0.761	0.840 (0.401)
Loop type of trip					1.658	1.466 (0.143)
In city center for work					1.496	2.320 (0.020)
Prev. mode: PT (trips > 5 km)					3.012	3.994 (0.000)
Work/Util.					1.233	1.449 (0.147)
Prev. freq. for leisure: Never					6.714	6.763 (0.000)
Prev. freq. for leisure: Rare.					6.447	6.215 (0.000)
Prev. freq. for leisure: Occ.					5.097	5.390 (0.000)
Prev. freq. for leisure: Freq.					3.440	3.745 (0.000)
Prev. freq. work/Util.: Rare.					5.314	2.825 (0.005)
Prev. freq. work/Util.: Occ.					2.836	3.995 (0.000)
Prev. freq. work/Util.: Freq.					1.373	2.482 (0.013)
Goodness of fit						
LL_U		−532.039				
LL_R		−334.803				
LL Ratio Test		394.472				
ρ^2		0.371				

Note: LL Ratio Test proved model to be significantly different from the null model ($\chi^2 = 15.379$ at 5% significant level for 26 degrees of freedom).

goodness-of-fit indicators did not change significantly, we decide to leave some less significant variables at the 5% *p*-value in the model to still indicate their relation to the alternatives.

Our results exhibit a valid model, significantly different from the unrestricted model, meaning that the estimated multinomial logit model can significantly represent the changes in cycling frequency before and after the confinement period in Lisbon. An analysis of the IAA assumption using the Hausman and McFadden IIA specification test (Hausman and McFadden, 1984) proves that the MNL IAA assumption holds.

Analyzing the estimated parameters (Table 4) provides a plausible explanation of why individuals have shown such cycling frequency behavior changes. Here, we highlight the following results:

- Despite 40% of interviewees maintaining their frequency and another 40% increasing their frequency, the inherent choice of cyclists was to maintain their cycling frequency, as corroborated by the Alternative Specific Constant of the alternatives.
- Female bikers correlate more with a slight decrease in cycling frequency after the pandemic confinement;
- While using GIRA both for leisure, work, or utilitarian trip correlates more with the alternative "Decrease" (although less significant at 5%-level) work or utilitarian trips alone correlate even more with decreasing cycling frequency. The fear of contamination by sharing vehicles with other individuals influences the decision to use the bike-sharing system GIRA;
- The model results show that the individuals that were cycling for leisure decreased their frequency. This makes sense compared to the commuting trips, which before the pandemic were more frequent, and after the confinement, those trips were replaced by less often leisure trips. Nevertheless, the individuals that used to cycle for recreation cycled much more often after the lockdown for the same purpose (see *Previous Frequency for Leisure trips* values in Table 4).
- Adults who cycle for sports tend to maintain their cycling frequency levels. Cycling provides none to shallow contact with others, and as such, adults who already cycled for sports continue to view cycling as a safe option for exercising;
- Making a commute or utilitarian trip that would previously have been made by either bike or bike-sharing increases the "Maintain" alternative utility, which means that people that already tended to use a bike (or shared bike) tend to maintain their cycling frequency levels before and after the confinement;
- Wearing a helmet for recreational cycling increases the odds of individuals maintaining or increasing their cycling frequency;
- Prior work or utilitarian trips by public transit for distances greater than 5 km greatly increase the odds of higher cycling frequency, which is perhaps due to the fear of SARS-CoV-2 virus contamination when commuting with transit. As such, cycling appears to be a valuable alternative for such individuals, who, for that reason, increase their cycling frequency;
- Individuals who cycle for work or utilitarian trips near the city center tend to increase their cycling frequency. This location has more cycling infrastructures and better connectivity, and hence, cycling frequency is expected to increase;
- The cycling frequency before the pandemic proved very significant, with lower levels of cycling frequency increasing the utility of the "Increase" alternative, meaning that the fewer individuals cycled, for both work, utilitarian, or leisure trips, the more they would cycle after the lockdown period.

Table 5 shows all direct pseudo-elasticities computed for the estimated MNL model variables. As all variables are dummy, the pseudo-elasticities can be interpreted as the percentage of probability variation if the variable changes its value from 0 to 1. The pseudo-elasticities for previous cycling frequencies are also interesting. The lower the basis of cycling prior to the confinement period, the higher the impact

Table 5
Average direct pseudo-elasticities of MNL coefficients.

Variable	Decrease	Maintain	Increase
Female	39%		
Shared bike for work/Utilitarian trips	166%		
Shared bike for leisure trips	30%		
City bike (Type of bicycle)	102%		
Leisure	203%		
Previous mode: Walking	95%		
Teenager for utilitarian trips	11%	11%	
Adult for exercise trips		37%	
Previous mode: Bicycle		28%	
Previous mode: Shared bike		31%	
Helmet use for leisure trips		12%	11%
Accompanied for work/Utilitarian trips			12%
Loop type of trip			43%
In city center for work trips			85%
Prev. mode: PT (trips > 5 km)			115%
Work/Utilitarian trips			122%
Previous frequency for leisure trips: Occasionally			1691%
Previous frequency for leisure trips: Never			2467%
Previous frequency for leisure trips: Rarely			1788%
Previous frequency for leisure trips: Frequently			687%
Previous frequency for work/Utilitarian trips: Occasionally			187%
Previous frequency for work/Utilitarian trips: Rarely			397%
Previous frequency for work/Utilitarian trips: Frequently			62%

is expected to be, in percent-relative terms. For leisure trips, low (*never*, *rarely* or *a few times a month*) cycling frequencies previous to the pandemic, greatly increases the odds of increasing the cycling frequency, ranging from 1691% to 2467%. Riding a bicycle with others also increases the likelihood of cycling more often by 12%. Using a shared bike increases the probability of decreasing cycling frequency. However, if the trip is for work or utilitarian trips, that increase is much more prominent (166%) than when for leisure trips (30%), which again reflects the fear that some might have of sharing a mode in these uncertain times. Similarly, such fears are also reflected when the previous trip was made using public transport for distances above 5 km, which increases the probability of cycling more often by 115%.

4. Discussion

The survey highlights significant cycling behavior changes between before and after the COVID-19 related lockdown. From the collected data, we remark that 41% of the interviewees cycled more often (2 out of 5 cyclists), and another 2 out of 5 cyclists maintained their cycling frequency. The amount of daily or frequent riders increased from 57% to 77% and, notably, among those that never cycled (15%), about 72% began using a bicycle daily or frequently. The lockdown has potentially made individuals think about the bicycle as a viable transportation mode, regardless of the reason for traveling, which is in line with de Haas et al. (2020) where 20% of people expect to cycle and walk more in the future. Lisbon's increase in cycling follows a similar trend abroad (Fuller et al., 2021; Lock, 2020), with the number of cyclists and their frequency also increasing. This underlines the pandemic as potentially changing the behavior of individuals when it comes to cycling.

Home to work or school (and vice-versa), utilitarian, and delivery trips accounted for 42% of the trips. 35% of those commuting by bicycle or making utilitarian trips shifted from public transportation, while 7% have replaced their private car. Such results are in line with other recent works that also mentioned decreasing transit ridership levels and car modal shares (Bucsky, 2020; Abdullah et al., 2020). These results also highlight that public transit operators might have to think about ways to engage and better address their users' needs as fear of contamination might have long-lasting effects. Re-gaining trust is vital as lower ridership and more significant financial burdens might lead to service quality drops and create a vicious circle of declining ridership. 42% of interviewees shifted from motorized modes, making the bicycle a valid alternative.

Expectably, more teenagers have decreased their cycling frequency than the proportion of those that increased or kept their cycling levels, as most schools were closed (except for high schools). However, despite the higher levels of teleworking, a more significant proportion of adults either increased or kept their cycling levels. Leisure or sports trips accounted for 65% of those that increased their cycling frequency. The pandemic has possibly propelled the bicycle as a valid option for exercising or unwinding from the stress of working from home. Other studies support this conclusion as active modes correlate more with satisfaction than motorized modes (De Vos, 2019; Lades et al., 2020).

As referred to previously, replies varied among survey sites. *Saldanha* and *Praça de Londres* showed similar results, as well as *Av. Ribeira das Naus* and *Parque das Nações*. While the first pair corresponds to Lisbon's central business district and is associated with more work and utilitarian trip locations, the latter pair was more associated with recreational trips along the riverbank esplanade. 26% of the interviewees were females, slightly higher than the percentage registered during the same week of 2018 with the municipality's counts at 45 locations in the city, 22% (Félix et al., 2020). This slight bias could be justified as females may show a greater willingness to stop to answer a survey, or the lockdown has created a distinct opportunity with reduced traffic for women to ride bicycles (Fuller et al., 2021). Also, helmet usage (30%) is similar to 2018's Lisbon numbers (30%) before the pandemic (Félix et al., 2020), i.e., showing that the SARS-CoV-2 virus did not impact helmet usage in Lisbon. Cyclists wear helmets more for sports and leisure trips (34%) than for work or utilitarian trips (25%).

Following the survey and its results, we estimated a multinomial logit model to better quantify and interpret how each characteristic may potentially impact the behavior change. For example, from the survey results about 2 in 5 maintained their cycling levels, and another 2 cycled more often. Yet, analyzing the model's outputs, we see that there is a greater willingness for people to maintain their cycling levels (evident by the lower ASC from the increase alternative vs. the maintain alternative) than to increase their cycling frequencies. As such, municipalities and authorities should provide adequate cycling conditions such that these individuals interested in cycling do not return to their previous mode.

Fear of the SARS-CoV-2 virus contamination in transit or shared vehicles is visible in the modal shifts as those who used public transportation for work, or utilitarian trips over 5 km, raised by 115% the probability of increasing their cycle frequency, which is in line with similar studies in Budapest, New York, and Australia (Bucsky, 2020; Teixeira and Lopes, 2020; Beck and Hensher, 2020). These studies also found that, albeit low in absolute numbers, active modes, and cycling, in particular, have increased their modal share. The same fear of sharing vehicles also was apparent in the shared bike's system of GIRA, with individuals who used a shared bike being associated with a decrease in cycling frequency, similar to what happened in other cities such as Chicago or Beijing (Hu et al., 2021; Shang et al., 2021).

Thirdly, it seems that those that do not cycle or rarely cycle were more enthusiastic about cycling after the lockdown period. From the model's estimated elasticities, we note a corresponding higher percent variation for increasing cycling frequency. This means that the fewer people cycled, the more they were willing to increase their cycling frequency, something that was unapparent from the survey results alone. Again, although some might be eager to cycle, good cycling infrastructure and conditions must be provided. Fear of cycling and unpleasant past experiences are often cited as significant cycling barriers (Félix et al., 2019; Muñoz et al., 2013). Other research (Hong et al., 2020; Kraus and Koch, 2021; Lin et al., 2021) has studied the impacts of infrastructure during the pandemic and, again, accentuated the need for increased safety, connectivity, and accessibility, which can rapidly and more significantly increase cycling numbers.

Fourthly, our study is based on data from a 1-minute intercept survey of passing cyclists. Such a choice of keeping the survey short increased the number of respondents given the liminality of the pre/post-confinement period. However, it also meant that a more detailed and conclusive study on the reasons behind the behavior changes of cyclists was not conducted, including understanding whether more socio-demographic characteristics (e.g. income, level of schooling, employment, or household status) had any impact on such cycling frequency changes. More, intercept surveys may introduce a certain bias towards those that were not cycling after the lockdown, as these individuals are not captured in our sample. This means that those that cycled before the pandemic and no longer do so, were not captured and thus their cycling behavior change was not noticed.

Data from the automatic counter and from systematic observations made in May and October 2020 in Lisbon (Eco-Counter, 2020; Moura et al., 2020) showed that there was not a general increase in cycling levels in May 2020, compared to the period pre-covid, although data from the intercept survey revealed a change in cycling behavior, sustained by the automatic counter data that shows a cycling behavior change in week-weekend patterns, and the results of the systematic observations that revealed a change in hour-of-day patterns. Interestingly, since the survey took place, Lisbon's municipality has followed other European municipalities and has introduced some cycle lanes during the lockdown periods. This evidences that although cyclists showed a greater willingness to increase their cycling levels just after the lockdown, the pandemic (and resulting lockdowns) acted as a liminal event and has not translated into an overall noticeable increase in the number of cyclists for the entire city of Lisbon in May 2020. In fact, cycling levels increased a few months later, in October 2020, for which the behavior change from the lockdown experience and the introduction of cycling infrastructure may have influenced this increase, as people were willing to change their behavior. This phenomenon was also reported in other cities (Buehler and Pucher, 2021, for instance) Such results underscore the need for cities and authorities to increase the number and quality of cycling infrastructures as a means to increase the number of cyclists in cities.

5. Conclusions

This paper presents some findings on the impact of the SARS-CoV-2 virus lockdown on cycling frequency in Lisbon, Portugal, knowing that no concomitant interventions occurred in the cycling environment during the period analyzed (e.g., pop-up interventions or pro-cycling campaigns). It draws its results from an intercept survey of about 500 participants, in May 2020, just after the lockdown in Portugal. It, therefore, aims to characterize cycling behavior between the periods before and after the imposed confinement. We use the survey data to estimate a multinomial logit model that can interpret cycling frequency changes and quantify how individuals have decreased, maintained, or increased their cycling frequency.

The survey covered both behavior and mode choice characteristics and observable characteristics, such as age group, bicycle type, or helmet usage. The cycling trip purposes and corresponding pre-lockdown modal choice are aimed at capturing an individual's travel context. Differently, the information about pre-pandemic cycling frequency and post-lockdown frequency captured whether people were cycling more, the same, or less. The survey and model suggest an uptake in cycling frequency, with individuals who never or rarely cycled beginning to cycle daily or several times a week. A shift from public transportation to cycling also seemed prominent, explained by fears of contamination. Indeed, concerns about hygiene in buses and shared vehicles must be thought of by public transport operators.

Finally, despite all harm done by the SARS-CoV-2 virus pandemic, it has created an opportunity for authorities to potentially increase active and sustainable modes of transportation associated with less pollution and better well-being. This increase in cycling frequency must then pair with adequate cycling infrastructure and connectivity to better address cyclists' needs and prevent them from reverting to motorized modes.

CRediT authorship contribution statement

Miguel Costa: Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Rosa Félix:** Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Manuel Marques:** Formal analysis, Supervision, Writing – original draft, Writing – review & editing. **Filipe Moura:** Conceptualization, Formal analysis, Methodology, Supervision, Writing – original draft, Writing – review & editing.

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

This work was partially funded by Fundação para a Ciência e Tecnologia via grant [PD/BD/142948/2018], by the Lisbon Municipality via Project "CML-ATIVOS Monitorização e Avaliação do Impacte Socioeconómico de Modos Alternativos de Mobilidade" [1018P.05721], and the authors are also grateful for the Fundação para a Ciência e Tecnologia's support through funding [UIDB/04625/2020] from the research unit CERIS and [UIDB/50009/2020] from the research unit LARSyS.

All authors approved the version of the manuscript to be published.

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