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The role of bike sharing during the coronavirus pandemic: An analysis of the mobility patterns and perceptions of Lisbon’s GIRA users

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ABSTRACT

COVID-19 has dramatically impacted urban mobility, of which public transport (PT) has been particularly affected. With PT ridership plummeting due to infection fears and many people returning to work, there is a danger of a steep rise in car use that would exacerbate environmental and health problems. Therefore, other modes such as bike sharing should be considered as potential alternatives during the coronavirus pandemic.

This study focuses on assessing how coronavirus has impacted bike sharing by implementing a travel behaviour survey to the users of GIRA, the bike sharing system (BSS) of Lisbon. While the coronavirus has led some to decrease the frequency of use or quit the system, other users have increased the usage or joined GIRA during the pandemic. Furthermore, most users who have quit or decreased the usage of GIRA justify their decision not so much on avoiding the risk of infection (although for some it is an important reason) but on having stopped commuting due to COVID-19.

The survey has also revealed substantial changes not only on the usage patterns of GIRA users but also on their relationship with other modes of transport. While before the pandemic, most respondents were shifting from PT to GIRA, that percentage has declined, with an increase on the share of users replacing walking, private car, and personal cycling. Moreover, the motivations for using bike sharing related with avoiding PT and maintaining a social distance during the trip have gained more relevance. Concurrently, the perceived safety of using PT has drastically declined, and while the perceived safety of using GIRA has also decreased it was in a much smaller scale.

Policy insights can be derived from this research on how bike sharing can contribute to a more sustainable and resilient urban transport system. During infectious public health crises such as COVID-19, BSS can be a viable transport alternative, not only providing the population with an affordable mode of transport where social distancing can be maintained in most of the trip but also mitigating a modal shift from PT to the private car.

1. Introduction

The coronavirus pandemic has caused catastrophic impacts on society, provoking one of the worst health and economic crisis in modern history. The large-scale lockdowns implemented all over the world have led to “the Great Pause” (Wolfe, 2020), where entire...
economies simply stopped overnight in order to “flatten the curve”, lowering the rate of infection and providing precious time to the healthcare systems to avoid being overrun by COVID-19.

Perhaps, no better example illustrates such tectonic shocks in our society as the transport sector. With several countries implementing restrictions to the movement of people, limiting mobility to essential trips and strongly promoting or even mandating teleworking whenever deemed feasible, our usually congested transport networks were emptied during lockdown. Lower traffic volumes and a lack of available options for exercising as a result of the closure of most non-essential services (which included exercising facilities such as gyms, swimming pools and even public parks) have led to a new push and acceptability of walking and cycling (Budd and Ison, 2020). Such shift to walking and cycling could not only contribute to a more sustainable mobility but also have positive impacts on the subjective well-being of the population (De Vos, 2020). Furthermore, the lockdown measures had also unexpected positive environmental impacts, including substantial air quality improvements and reductions in noise pollution (Zambrano-Monserrate, Ruano and Sanchez-Alcalde, 2020), as well as leading to the largest recorded decrease in global CO₂ emissions (Liu et al., 2020), offering glimpses of a possible more sustainable world after coronavirus.

However, as countries gradually reopen, traffic levels are slowly returning to pre-pandemic levels (INRIX, 2020) and with COVID-19 still a threat, we are in danger of witnessing a modal shift from public transport (PT) to private car due to infection fears (de Haas, Faber and Hamersma, 2020; Shamshiripour et al., 2020). A surge in car use would undeniably lead to several negative outcomes such as exacerbating climate change (Liu et al., 2020), a likely even bigger threat than the present coronavirus pandemic (Lenton et al., 2019). Thus, and considering that public transport ridership can be expected to continue to be negatively affected by COVID-19 in the foreseeable future (De Vos, 2020), alternative modes of transport such as cycling should be considered.

In the present study we focus on one of the most popular policies promoting cycling – bike sharing. Bike sharing systems (BSS) are characterized by the provision of bicycles typically distributed across a network of stations (docked BSS) or predefined operational areas (dockless BSS) that can be rented for a short-term period (Demaiio, 2009; Fishman, 2016). BSS have seen a remarkable rise in the last decade with more than 2000 systems currently in operation mostly in China, Europe and North America (DeMaio and Meddin, 2020).

The objectives of this research were twofold. Firstly, we aimed at evaluating how COVID-19 has affected the mobility patterns of BSS users (including modal shift dynamics, their frequency and purpose for using BSS). Secondly, we investigated if COVID-19 has changed the perceptions and motivations for using bike sharing, especially those related to safety, health concerns and accessing or avoiding PT. To accomplish this, we implemented a travel behaviour survey to the users of Lisbon’s BSS entitled GIRA. Ultimately, our goal is not only to understand how bike sharing has performed during the coronavirus pandemic, but also what is its potential role within the broad transport system, particularly regarding its ability in avoiding a modal shift from PT to the private car.

The remainder of the paper is structured as follows. Next, we present an overview of the COVID-19 main impacts on urban mobility as well as the potential role of cycling and bike sharing in ameliorating such effects (Section 2). This is followed by a brief presentation of the case-study, the research approach as well as the design and implementation of the survey (Section 3). The results are then presented (Section 4), followed by their discussion (Section 5). Finally, the paper ends with the policy implications of our findings within the perspective of planning for a more sustainable transport system (Section 6).

2. COVID-19 and urban mobility

Virtually in all affected regions a severe decrease in mobility has been observed as a result of the partial or total lockdowns implemented by governments in an effort to slowdown the spread of COVID-19 (Hadjidemetriou et al., 2020; Sharifi and Khavarian-Garmsir, 2020). For instance, in the Netherlands, de Haas, Faber and Hamersma (2020) observed the number of trips and distance travelled to drop, respectively, 55% and 68% comparing with the fall of 2019, while in the UK, Hadjidemetriou et al. (2020) found a 60%, 80% and 60% decline in daily trips from, respectively, car, PT and walking.

PT networks are amongst the most affected modes with ridership levels plummeting to historic lows. For example, the New York City’s subway suffered a 90% ridership drop during the lockdown period (March 20th to June 8th, 2020) comparatively to the same period in 2019, with the ridership levels in September 2020 still just 30% of pre-pandemic levels (MTA, 2020). Likewise, Bucsky (2020) observed a 80% percentual drop in PT trips compared to an overall mobility reduction of 57%. The same trend was also observed in Santander (Spain) with a 93% reduction in PT usage comparatively to an overall mobility decline of 76%, with a less pronounced drop of 68% in car usage (Aloi et al., 2020). The exceptionally severe impact of coronavirus on PT networks can be attributed to infection fears due to the risk of coronavirus transmission in enclosed, and often overcrowded, vehicles. Indeed, several governments have recommended their citizens to avoid using public transport in favour of private modes of transport, including the car (GOV.UK, 2020), although emerging evidence seems to point to a lower transmission risk of PT than previously feared (Hu et al., 2020; The New York Times, 2020). Such public aversion to PT use during the coronavirus pandemic is evident in recently conducted travel behaviour surveys (de Haas, Faber and Hamersma, 2020; Shamshiripour et al., 2020), de Haas, Faber and Hamersma (2020), through a longitudinal survey of a representative sample of 2500 respondents in the Netherlands, assessed daily behaviour and attitudes before and during the coronavirus pandemic. The authors found less than 10% of the respondents to now have a positive attitude towards PT while the attitudes towards the car had improved (de Haas, Faber and Hamersma, 2020). Similarly, a survey of 915 residents from the Chicago metropolitan area found 93% of the respondents to perceive a medium to extreme risk of exposure to the coronavirus associated to PT (Shamshiripour et al., 2020). In contrast, only 14% of the respondents had such a risk perception towards using a private car, while 23% and 29% considered, respectively, walking and using personal bicycles a risk (Shamshiripour et al., 2020).

With public transport ridership expected to remain below pre-pandemic levels as long as COVID-19 remains a threat, there is a risk of a modal shift from PT to private cars which would entail severe repercussions from a sustainability standpoint (Douglas et al., 2011;
Graham-Rowe et al., 2011). Such increase in car use could even worsen the present coronavirus pandemic as evidence has been found on higher levels of air pollution increasing transmission and mortality rates of COVID-19 (Pozzer et al., 2020; Sharifi and Khavarigan-Garmsir, 2020; Wu et al., 2020).

A possible path to ameliorate such undesirable modal shift is to consider alternative modes of transport, especially walking and cycling. Walking and cycling have already been gaining relevance as a sustainable and healthy alternative to public transport and car use during the coronavirus pandemic (De Vos, 2020), with several cities allocating vast swaths of street space to these modes. For instance, according to the European Cyclists Federation more than 2000 km of new dedicated walking and cycling infrastructure has been announced by several European cities, with more than 1000 km already implemented including widening of sidewalks, expansions of cycling networks, implementation of traffic calming measures and car-free zones (ECF, 2020). Such strategies are supported by de Haas, Faber and Hamersma (2020), which observed walking and cycling to be the least affected modes during the pandemic, with the share of walking trips sharply increasing. Furthermore, while the overall average trip distance had decrease in most modes, an increase was observed in the case of cycling and walking trips (de Haas, Faber and Hamersma, 2020).

Cycling can be a particularly viable alternative to car travel in urban areas, being competitive or even faster than driving in distances up to 5 km (J. Dekoster, 1999; Ellison and Greaves, 2011), with e-bikes capable of doubling that range (Annick Roetynck, 2010). Likewise, bike sharing was found to have competitive travel times comparatively to cars in Lyon (Jensen et al., 2010) and to taxis in New York City (Faghii-Imani et al., 2017), with former car users mentioning shorter travel times among the reasons for shifting to BSS (Yang et al., 2016). A recent comprehensive review of the main impacts of bike sharing has reported BSS to be particularly suitable for complementing PT, either by expanding PT catchment areas or by providing an alternative to overcrowded services, and to be able to replace car trips, presenting several potential advantages that could be enhanced to further promote car reductions (Teixeira, Silva and Moura e Sá, 2021). Furthermore, BSS have already been shown to increase the resilience of the transport network to disruptive events prior to the coronavirus pandemic as illustrated by Saberi et al. (2018). Analysing the impact of a subway strike on London’s BSS, Saberi et al. (2018) observed that during the subway strike both the number and duration of BSS trips had increased (85% and 88%, respectively). In fact, Teixeira and Lopes (2020) have already found evidence suggesting BSS to be playing a similar role during the current coronavirus pandemic. Assessing how the BSS and subway of New York City responded during the COVID-19 lockdown in March 2020, the authors noticed that the BSS ridership drop was lower than of the subway (71% versus 90%), with the average

Fig. 1. Location of GIRA stations in Lisbon.
duration of BSS trips increasing from 13 min to 19 min (Teixeira and Lopes, 2020). Moreover, Teixeira and Lopes (2020) uncovered evidence of a possible modal shift from some subway users to the BSS. Such findings are supported by Bucsky (2020), who observed bike sharing to suffer the lowest ridership decrease (2% versus an overall 57% mobility decrease, with personal cycling decreasing 23%) in Budapest. Furthermore, shared bikes had a lower perceived risk comparatively to PT or other shared modes (taxi and ride-hailing) in the Chicago travel survey, albeit the risk perception was significantly higher comparatively to personal modes (Shamshiripour et al., 2020).

3. Data and methods

3.1. Case-Study

3.1.1. Urban mobility in Lisbon before COVID-19

Lisbon is the most populous municipality and the capital of Portugal. According to the Portuguese National Institute of Statistics (INE, 2018), Lisbon has a population of 504,964 inhabitants with a population density of 5047.1 inhabitants/km$^2$. Regarding its modal share, a travel survey conducted in 2017 revealed the municipality to be predominantly car-focused with almost half the trips made by private motor vehicles (46.1%), followed by walking (29.8%), public transport (21.1%) and a residual use of cycling (0.6%) (INE, 2018).

To tackle this overreliance on car use, in the last few years Lisbon has started to implement several measures, including promoting cycling as a mode of transport. Measures such as the construction of dedicated cycling infrastructure (Câmara Municipal de Lisboa, 2019a) and the implementation of 30 km/h zones (Câmara Municipal de Lisboa, 2019b) across the municipality are examples of this policy shift. To further promote cycling, the municipality has decided to implement a public-owned BSS entitled GIRA at the end of 2017. Lisbon’s GIRA is a docked BSS and currently has 700 shared bikes, comprised both by conventional and electric-assisted bikes, distributed across 83 stations located mostly in the city centre (Fig. 1).

Indeed, bike counts conducted before the coronavirus pandemic in the city centre suggest that such measures are being effective. Between 2016 and 2017 bike counts registered a 3.5-fold increase in the number of cyclists and an additional 2.5-fold growth between 2017 and 2018 after the implementation of bike sharing, with 34% of all observed cycling trips in 2018 being conducted by GIRA users (Félix, Cambra and Moura, 2020).

3.1.2. COVID-19 and Lisbon’s policy responses

As in several other European countries, Portugal registered two COVID-19 waves in reported cases throughout 2020 (Fig. 2), with the first wave occurring during the spring and the second one at the beginning of autumn. The first two cases of COVID-19 in Portugal were confirmed on March 2nd, 2020, and by March 18th, the State of Emergency was declared, leading to the full lockdown of the country that lasted until May 3rd. During the summer, the pandemic seemed under control leading to a gradual reopening of the country. However, the number of COVID-19 cases started again to rapidly increase at the beginning of autumn, marking the start of a more devastating second wave which forced the country, on November 9th, to reinstate the State of Emergency and with it new restrictions on mobility (which would culminate in a new full lockdown at the beginning of 2021).

Google’s mobility reports from March to December provide a clear picture of the coronavirus impacts in Lisbon (Fig. 3), revealing a substantial decrease on trips related to commuting, shopping and leisure, as well as a sharp decline in PT ridership.

As a response to the plummeting of PT use and to avoid a surge in car use, Lisbon unveiled in May 2020 a comprehensive package for promoting walking and cycling in the city. Such package included the construction of 76.5 km of pop-up dedicated cycling lanes,
the expansion of safe bicycle parking and the establishment of a 3 million euro fund for subsidizing citizens in buying and repairing bicycles (Câmara Municipal de Lisboa, 2020). Fig. 1 shows in red the already implemented new pop-up cycling lanes.

3.1.3. GIRA usage during COVID-19

Regarding GIRA, in an initial phase the BSS was closed with the announcement of the State of Emergency on March 18th (EMEL, 2020). However, the system was reopened shortly after, first with the aim of supporting food-delivery couriers and later to provide a safe mode of transport for essential workers with healthcare workers, security forces and civil protection agents receiving free trips for two months (Lisbon City Council, 2020). The BSS continued to operate normally throughout 2020 with enhanced cleaning protocols in accordance with the guidelines from the Portuguese Directorate-General of Health.

The COVID-19 impact on GIRA monthly ridership and number of active users is presented, respectively, in Fig. 4 and Fig. 5. Both the number of trips and of active users have drastically decreased during the first lockdown, particularly in April. However, with the end of the lockdown the system starts to rebound, with its summer levels even surpassing those of 2019, particularly regarding ridership. With the beginning of the second COVID-19 wave in the fall, ridership and user levels start again to rapidly decrease but at a lower rate comparatively to the first wave.
4. Research approach and survey design

An online travel behaviour survey was designed aimed at evaluating how COVID-19 has changed the travel behaviour, as well as preferences and motivations related to safety, health and the relationship with PT of BSS users. In this study we will focus on three groups of GIRA users, classified according to the impacts of COVID-19 on their relationship with the system:

- Being a GIRA user before the COVID-19 pandemic and continuing to currently use it
- Have joined GIRA during the COVID-19 pandemic
- Being a GIRA user, but having stopped using the system as a result of the COVID-19 pandemic

To assess the impact of COVID-19 on the users’ behaviour we started the survey with an introductory note explaining that the questionnaire would have an evaluation component of the COVID-19 effects on GIRA usage patterns. Next, respondents were informed that, in certain questions, they would be asked to compare their current daily routines (fully within the COVID-19 pandemic) with those before the pandemic (respondents were asked to refer to the first two months of 2020). We considered the answers of the users who have stopped using GIRA as a result of the COVID-19 pandemic as relevant for analysis of the pre-pandemic period, while the answers of the new users (who have joined the system during the pandemic) as relevant for the pandemic period. Furthermore, for the respondents who were users before the pandemic and continue to currently use GIRA, we have employed additional retrospective questions, asking them to compare their travel behaviour before and during COVID-19. With this categorization we were able to compare the behaviour of GIRA users before and during the pandemic.

Three main groups of questions were considered, all of which with closed-ended responses. The first group aimed at assessing the travel behaviour of respondents, including their main mode of transport, frequency of BSS use, trip purpose, modal shift dynamics (which mode would they use if the BSS was not available) and the multimodal nature of BSS trips (e.g., if BSS is being combined with other modes).

The second group of questions focused on the motivations for using BSS that could have been affected by the coronavirus pandemic, asking respondents to classify the importance of each motivation in their decision to use GIRA through a 5-point Likert scale. Specifically, we hypothesized that the importance of motivations related to accessing or avoiding PT could have changed as people may try to avoid public transport due to infection fears. Likewise, motivations related to health concerns and for maintaining a social distance may have gained relevance. Additionally, as people might now avoid some of their previous options for exercising, particularly indoor facilities, by perceiving a higher risk of infection, we also included the motivation of fitness improvements. Finally, as the pandemic, on the one hand has led to a decrease in traffic volumes and, on the other hand, the municipality of Lisbon has implemented new dedicated cycling lanes, we have also assessed the motivations of low car traffic speeds in the trip’s route and the existence of cycling lanes serving the trip.

Lastly, we requested all respondents to assess, through a 5-point Likert scale, how safe they felt (perceived safety) using several modes of transport (including GIRA) in Lisbon before COVID-19 and in the current situation (the survey question is provided as Appendix). The concept of safety goes beyond the perceived risk of infection due to the coronavirus. For example, regarding using cycling or bike sharing, one of the main barriers is the perceived danger of cycling alongside motor vehicles (Heinen, van Wee and Maat, 2010; Fishman, Washington and Haworth, 2012; Teixeira et al., 2021). As the coronavirus has led to a decline in traffic and the Lisbon municipality has implemented new dedicated cycling infrastructure, the respondents could now perceive a safer environment for cycling (despite the risk of infection).
4.1. Survey implementation and analysis of results

We followed an opportunistic sample approach, disseminating the survey through social media and the local press. The dissemination included publicizing the survey through faculties mailing lists, official pages of parish councils as well as pages and groups containing residents living or working in areas with BSS stations. Furthermore, the survey was widely publicized in cycling and bike sharing associations of Lisbon. The survey was available online for approximately one month between the end of September and throughout October 2020, obtaining a sample of 215 valid answers.

Descriptive statistics as well as the non-parametric Wilcoxon Signed Rank and Mann-Whitney U tests were then applied to the survey’s results to compare and to assess possible significant differences in the behaviour of BSS users before COVID-19 and in the current situation. Wilcoxon Signed Rank and Mann-Whitney U tests are the non-parametric equivalents of the paired and independent t-tests, respectively, and are used when the dependent variable is ordinal (Field, 2013). Wilcoxon Signed Rank test is employed when the same subjects are evaluated under two different scenarios, while Mann-Whitney U test is designed to detect differences between two independent groups. In this study, we have used Wilcoxon Signed Rank tests to compare the answers of the same respondents before the coronavirus pandemic and in the current situation, while employing Mann-Whitney U tests to compare the answers of different groups of respondents.

4.2. Sample

Table 1 summarizes the composition of our sample, presenting standard socioeconomic and demographic characteristics of the respondents. To assess the representativeness of our sample we compared it with a larger survey conducted by GIRA’s operator between January and February 2019 (Moura and Félix, 2019). We also compared the socio-demographic characteristics of GIRA users with the 2017 Household Travel Survey of Lisbon (INE, 2018). As the questions are from different surveys, some matching was necessary to make them comparable.

Most of our respondents live in the city of Lisbon, with a predominance of male users (58%). Furthermore, the majority of respondents have a higher education degree (85%) and are employed (72%). Regarding mobility options, most respondents report to have a driving’s license (87%), as well as access to a car (78%) and a bike (56%), however the majority does not have a public transport monthly subscription (56%).

In general, our sample is similar to the 2019 operator’s survey, although it has a higher percentage of women as well as of users residing in the city of Lisbon. It also presents a lower percentage of respondents working. This can be explained by differences in the questionnaires’ designs (the 2019 survey included working students in the working category, whereas in our survey working students were grouped in the studying category) and by the COVID-19 impact on employment. Comparatively to the general population of Lisbon, GIRA users (in both the 2020 and 2019 surveys) tend to be male, employed, younger and to have a higher education degree, which is in line with previous research characterizing the average BSS user (Ricci, 2015). Additionally, GIRA users also have greater access to personal bicycles.

Table 1

Comparison of the socioeconomic and demographic characteristics of GIRA users, from the 2020 survey (N = 215) and from the 2019 survey (N = 4,970), with the general population of the City of Lisbon (N = 12,890).

|                        | 2020 GIRA Survey | 2019 GIRA Operator’s Survey | 2017 Lisbon Household Travel Survey |
|------------------------|------------------|-------------------------------|-------------------------------------|
| Place of residence     |                  |                               |                                     |
| Lisbon City            | 193              | 90%                           | 71%                                 |
| Lisbon Metropolitan Area | 22              | 10%                           | 29%                                 |
| Gender                 |                  |                               |                                     |
| Female                 | 90               | 42%                           | 33%                                 |
| Male                   | 125              | 58%                           | 67%                                 |
| Age                    |                  |                               |                                     |
| ≤ 24                   | 38               | 18%                           | 15%                                 |
| 25–44                  | 114              | 53%                           | 60%                                 |
| 45–64                  | 62               | 29%                           | 24%                                 |
| ≥ 64                   | 1                | 0%                            | 1%                                  |
| Education              |                  |                               |                                     |
| Basic Education        | 1                | 0%                            | 2%                                  |
| Secondary Education    | 31               | 14%                           | 15%                                 |
| Higher Education       | 183              | 85%                           | 83%                                 |
| Employment status      |                  |                               |                                     |
| Working                | 154              | 72%a                          | 84%b                                |
| Not working            | 10               | 5%                            | 2%                                  |
| Other (of which are students) | 51 (49)        | 23% (96%)                     | 13% (88%)                           |
| Driving’s license      |                  |                               |                                     |
| No                     | 28               | 13%                           | N/A                                 |
| Yes                    | 187              | 87%                           | 67%                                 |
| PT monthly pass        |                  |                               |                                     |
| No                     | 120              | 56%                           | 61%                                 |
| Yes                    | 95               | 44%                           | 39%                                 |
| Car availability       |                  |                               |                                     |
| No                     | 48               | 22%                           | 16%                                 |
| Yes                    | 167              | 78%                           | 84%                                 |
| Bicycle availability   |                  |                               |                                     |
| No                     | 94               | 44%                           | 49%                                 |
| Yes                    | 121              | 56%                           | 51%                                 |

a Does not include working students.
b Includes working students.
Regarding the three groups of GIRA users, the respondents who were already users of GIRA before the pandemic and continue to currently use constitute the largest group (154 valid answers), followed by the new GIRA users who joined during the COVID-19 pandemic (32 valid answers) and the former GIRA users who no longer use the system due to the pandemic (29 valid answers).

5. The effects of COVID-19 on GIRA users

We will focus our analysis in two main themes. First, we will examine the main changes in the usage patterns and travel behaviour of GIRA users (subsection 4.1.). Then, we will look at possible changes in the respondents' motivations and perceptions related to safety, health concerns and with accessing or avoiding PT that could help to explain the observed mobility changes (subsection 4.2.).

5.1. Travel behaviour

5.1.1. GIRA usage

We started by analysing the change in the usage patterns of our subgroups of GIRA users due to the coronavirus pandemic (Fig. 6).

The pandemic has led to very different responses within GIRA users. While 35% of the respondents have decrease or stopped using

![Fig. 6. Classification of GIRA users according to their changes in usage as a consequence of COVID-19.](image_url)

### Table 2

|                         | Decreasing usage (N = 46) | Quitting (N = 29) |
|-------------------------|----------------------------|-------------------|
| The trip purpose no longer exists | 62.0%                     | 53.4%             |
| To avoid the risk of infection | 9.8%                      | 36.2%             |
| Other reasons           | 28.3%                     | 10.3%             |

![Fig. 7. Comparison of GIRA usage frequency before COVID-19 and in the current situation considering all users (N = 215), users before and during COVID-19 (N = 154), respondents who stopped using GIRA due to COVID-19 (N = 29) and new users who joined during the pandemic (N = 32).](image_url)
GIRA as a consequence of the pandemic, 30% have increase their usage or have joined GIRA during COVID-19. The usage patterns of the remaining 35% seem to not be particularly affected by the pandemic.

We asked the respondents to justify their changes in the usage patterns of GIRA during the coronavirus pandemic. For the users who have joined GIRA during the pandemic, 68.8% have indicated that their reason for joining was the consequences of COVID-19. Regarding the users who have stopped or decrease their usage, their reasons for doing so are represented in Table 2.

Most of the users who have decrease or stopped using GIRA during the coronavirus justify such decision on the fact that their main trip purpose for using GIRA no longer exists, with only a small share avoiding using GIRA due to the risk of infection (although infections fears are more substantial among the users who quitted the system).

We also asked respondents to select their typical usage frequency of GIRA. In here, we have compared the frequency of use before COVID-19 and in the current situation (considering all users), as well as the specific frequency of use of our three subgroups (users before and during COVID-19, respondents who stopped using GIRA due to COVID-19 and new users who joined during the pandemic), with the results presented in Fig. 7.

We can assert that most of our respondents are frequent users, meaning users who make 3 or more trips per week, both before the coronavirus pandemic and currently. Remarkably, contrary to what we had expected, which would be a reduction in usage frequency in line with the overall decrease in mobility registered in Lisbon (Fig. 3) and elsewhere, the frequency of use remained stable, with only a slight decline in the overall percentage of frequent users.

5.1.2. Purpose of GIRA trips

The purposes of the trips conducted with GIRA may have also been affected by COVID-19. In Fig. 8 we present the variation on the trip purposes of GIRA before the pandemic and in the current situation.

Comparing both periods, we observe a decline in the share of GIRA trips having as purpose commuting, with such decrease replicated in the subgroups. Furthermore, for most of the respondents who stopped using GIRA due to COVID-19 their main trip purpose was commuting. These results seem to be related to the increase of the share of people no longer commuting as a consequence of the coronavirus pandemic. Interestingly, most of the new users who joined during the COVID-19 pandemic also indicate commuting as their main trip purpose, which may indicate that some people are considering GIRA as an alternative to other modes of transport such as public transport.

5.1.3. Main mode of transport before and during COVID-19

Next, we analysed the main mode of transport used in commuting trips (i.e., trips from home to work or school) of the respondents before the coronavirus pandemic and in the current situation. Respondents could select a single mode or multiple modes, with walking trips being considered only if they were exclusive or represented more than 5 consecutive minutes in a combined trip. In addition, respondents could select the option of no longer commute in the current situation, with 18% (39 respondents) selecting that option.

![Fig. 8. Comparison of GIRA's trip purposes before COVID-19 and in the current situation considering all users (N = 215), users before and during COVID-19 (N = 154), respondents who stopped using GIRA due to COVID-19 (N = 29) and new users who joined during the pandemic (N = 32).]
Fig. 9 presents the modal share of the most frequently chosen modes of transport before the pandemic and in the current situation. The figure reveals a severe decrease in the modal share of public transport, while the share of most the other modes has increased. Indeed, whereas before the pandemic PT was the most chosen mode (36.4%), followed by bike sharing (22.2%) and walking (19.5%), currently PT has been surpassed both by bike sharing and walking with a modal share of 21.9% comparatively to 27.3% and 23.3%, respectively. In fact, GIRA is now the most chosen mode. More worrisome from a sustainability point of view, the modal share of private car has increased from 10.8% before the pandemic to 14.7% nowadays.

We have also explored possible differences regarding the main modes of transport for commuting between the different groups of GIRA users (Table 3). Table 3 reveals that more than half of former GIRA users no longer commute in the current situation (51.7%). In contrast, most of the respondents that use GIRA during COVID-19, either old or new users, continue to commute. Regarding the respondents that continue to commute, we observe considerable differences on the main modes of transport between the different user groups. Former users have massively increased the modal share of private car (increasing from 13.4% to 56.5%) at the expense of GIRA and PT, while also increasing the share of personal bicycle but at a lower scale. In contrast, while the new users have also significantly decreased the modal share of PT (decreasing from 60.8% to 28.3%), they have mostly shifted to GIRA (increasing to 30.2%). Comparatively to the former and new users, the modal share changes of the respondents who were users before and during COVID-19 were much less pronounced, with a decrease in PT and an increase in most of the other modes (particularly GIRA and walking).

5.1.4. BSS multimodality

Another aspect of the travel behaviour potentially affected by the coronavirus is the multimodality of GIRA trips. Fig. 10 presents the share of trips conducted only by GIRA or in combination with other modes before the pandemic and in the current situation.

We can observe that before the pandemic, 66.5% of GIRA trips were conducted in combination with other modes, particularly...
public transport. However, with the pandemic the number of trips conducted in combination with other modes has decreased to 58.9%, while trips conducted using only GIRA has increase from 33.5% to 41.1%. Even though PT continues to be the most common mode combined with GIRA, its share is now much closer to walking trips (longer than 5 min) with a share of 17.2% versus 15.1%, respectively. The share of respondents combining GIRA trips with their private car has also increased from 7% to 9.7%.

5.1.5. Modal shift dynamics

By asking respondents which mode of transport they would use in their most frequent trip with GIRA if the BSS did not exist, we were able to analyse the modal shift dynamics from before the pandemic to the current situation (Fig. 11).

Before the coronavirus pandemic, by far the most replaced mode was public transport with 49.2% of the users reporting shifting from PT to GIRA, followed by walking (22.4%) and private car (12.6%). Interestingly in the current situation, although the most replaced mode continues to be PT, its share has significantly decreased to 35.5%, whereas modal shift has increased in virtually all other modes, particularly walking (increasing to 26.9%) and private car (increasing to 16.7%).

To better understand such modal shift dynamics, we developed a Sankey diagram of the subsample of respondents who were users before COVID-19 and continue to currently use as they allow us to directly compare the modal shift from each particular mode between the two time periods. Fig. 12 presents the Sankey diagram, where on the left we have the percentage of modes replaced before the
coronavirus and on the right we have the percentage of modes replaced in the current situation. The lines represent the total direct shift from a mode before the coronavirus to a mode in the current situation, the thicker the line the bigger the share of the modal shift.

The Sankey diagram reveals that while most users report the same mode being replaced by GIRA before and during the coronavirus, 21.4% of the total amount has switched from replacing PT to replacing other modes, particularly walking (10.4%), private car (5.2%) and personal bicycle (3.2%). There are two possible explanations for such shift from public transport. First, there was a change in the trip purpose of using GIRA, with a small decrease in commuting trips and an increase in trips related to shopping or leisure. However, as we have previously seen in Fig. 8, only a small percentage of users has decreased their share of commuting trips (from 39% to 33% in the case of the respondents who were users before COVID-19 and continue to currently use GIRA). We hypothesize that this considerable shift from public transport may be related to some respondents no longer considering PT a viable transport alternative as they no longer feel safe due to the coronavirus. The next sections, which will focus on the motivations for using GIRA and perceived risks of using different modes will shed some light in this supposition.

5.2. Motivations and safety perceptions

5.2.1. Changes in motivations for using GIRA

By using a 5-point Likert scale, we asked respondents to classify the importance in their decision to use GIRA of accessing or avoiding PT, maintaining a social distance, as well as health concerns and fitness improvements. Moreover, motivations related to low traffic speeds and the provision of cycling lanes along the trip were also evaluated as the pandemic and subsequent policy responses may have led to changes in these motivations. Fig. 13 presents the variation on the level of importance of the motivations to use GIRA that could have been affected by the pandemic.

The figure reveals a considerable change. Firstly, the importance of maintaining a social distance has greatly increased in the current situation with 44% of the respondents now considering it to be very important comparatively to only 11% before the pandemic. Furthermore, the motivations related to public transport have also changed. Firstly, the importance of using GIRA to access PT has decreased with only 17% of the respondents now considering it to be important or very important comparing to 23% before the pandemic. Secondly, the importance of using GIRA to avoid PT has dramatically increase with now 56% of the respondents considering this motivation to be very important, when before the pandemic only 29% had such opinion. The remaining motivations have remained fairly stable with a slight increase in the importance of cycling lanes serving the trip with the percentage of respondents considering it important or very important increasing from 70% to 76%.

To better understand such differences, we have conducted additional analyses focusing on assessing the motivations of the
A subsample of respondents who were users before COVID-19 and continue to currently use GIRA. As we have ordinal and paired data, we have employed Wilcoxon Signed Rank tests to assess if the differences on the motivations’ importance before the coronavirus pandemic and in the current situation were statistically significant. The results of the tests, as well as the variation on the importance of each motivation are presented in Table 4.

5.2.2. Perceived safety of different modes of transport in Lisbon

The coronavirus pandemic, not only due to its infectious characteristics but also to its consequences in the dynamics of the transport system, could have changed the perceived risk of the respondents regarding the different modes of transport that are available to them. To try to capture such impact, we asked the respondents to compare, through a Likert-scale, their perception of safety in using several modes of transport in Lisbon before the pandemic and in the current situation. The results are represented in Fig. 14.

The Wilcoxon Signed Rank tests reveal a statistically significant difference between the period before the coronavirus pandemic and now in the motivations related to accessing and avoiding PT as well as maintaining a social distancing, which are supported by substantial percentual changes. Moreover, for this subgroup of respondents that were users before COVID-19 and continue to currently use the system, the difference on the importance of health concerns between the two periods was also statistically significant, with a 13.9% percentual increase on the number of respondents considering it very important and a 15.8% decrease on the number considering it not important.

### Table 4

| Motivations          | Percentual change (%) | Wilcoxon Signed Rank test Z | Differences significant at p < .05 (test) |
|----------------------|-----------------------|-----------------------------|------------------------------------------|
| **Access PT**        | 23% -33.3% -15.0% -10.0% 14.3% -7.4% | -2.294 | Yes |
| **Avoid PT**         | 124.3% 6.7% -10.7% -10.3% 10.5% -50.0% -43.2% -5.6% | -6.171 | Yes |
| **Fitness**          | 24% 25% 24% 25% 26% 16% 17% 10% | 6.171 | Yes |
| **Health concerns**  | 27% 30% 20% 21% 21% 17% 10% 9% | 2.144 | Yes |
| **Cycling lanes**    | 24% 24% 24% 25% 26% 16% 17% 10% | 6.171 | Yes |
| **Fitness**          | 24% 25% 24% 25% 26% 16% 17% 10% | 6.171 | Yes |
| **Health concerns**  | 30% 30% 21% 21% 21% 17% 10% 9% | 2.144 | Yes |
| **Social distancing**| 4% 5% 6% 1% 1% 1% 1% 1% | 2.144 | Yes |
the coronavirus pandemic, the perceived risk has changed, particularly regarding PT which witnessed a dramatic decrease on the safety perceptions towards it. While before the pandemic 74% the respondents considered using PT to be safe or very safe, in line with the percentage of using a private car (73%) or GIRA (72%), now that percentage is only 16%. Although in a smaller scale, the perceived safety of GIRA and walking has also decreased to, respectively, 62% and 84% of the respondents considering those modes to be safe or very safe. In contrast, the perceived safety has increased both regarding using a private car and a personal bicycle, with now 76% and 64% of respondents considering those modes to be safe or very safe, respectively.

To assess if such differences in the perceived safety were statistically different between before the pandemic and now, we conducted Wilcoxon Signed Rank tests. The results of the tests and the percentual changes in the perceived safety of the different modes between the two periods are presented in Table 5. The tests reveal statistically significant differences in the perceived safety regarding walking, GIRA shared bicycles and public transport.

Lastly, we explored possible statistically significant differences on the safety perceptions of using GIRA between the users who stopped using the system due to COVID-19 and the new users who have joined during the pandemic. To accomplish this, we applied Mann-Whitney U tests (as we now have two independent groups), with its results as well as the percentual differences in perceived perceptions between the two groups represented in Table 6.

The results reveal that before the coronavirus pandemic there was not a statistically significant difference in the perceived safety regarding GIRA between the two groups. But in the current situation we now find a statistically significant difference between the two groups, with the new users having a much more positive perceived safety towards GIRA than the former users (a 450% and 600% percentual change in considering GIRA, respectively, very safe and safe).
6. Discussion of the results

This study has revealed the impacts of coronavirus to differ between BSS users. While some users have decreased or stopped using GIRA because of coronavirus, an almost equal number has actually increased or joined the system during the pandemic. Furthermore, the main reason for respondents decreasing or stopping using GIRA is not so much the fear of infection (although for some it is an important reason) but is more related to their trip purpose no longer existing, mostly due to a decrease in commuting trips.

Significant changes in the travel behaviour of GIRA users have also been found, particularly in their relationship with other modes of transport. First, regarding their main mode of transport in commuting trips, GIRA registered a share increase from 22.2% to 27.3%, now being the most chosen mode of transport at the expense of public transport which suffered a massive decline (with a 39.9% decrease). Furthermore, the share of trips conducted only by GIRA has increased, while the percentage of trips in combination with PT has decreased. Crucially, the modal shift dynamics of bike sharing have also changed. While the most replaced mode continues to be PT, its share decreased from 49.9% to just 35.5%, with users who would previously replace PT with GIRA now replacing other modes such as walking, private car and personal bicycle. Such findings are supported by GIRA actual usage data (ridership and number of active users), which shows a significant recovery during the summer months, even surpassing 2019 usage levels. Likewise, our results are in line with the study from Teixeira and Lopes (2020), which also uncovered evidence of a modal shift from some PT users to the BSS in New York City.

Moreover, the coronavirus pandemic has increased the importance of the motivations related with maintaining a social distance during the trip and avoiding PT. For the respondents that used GIRA before COVID-19 and continue to currently use the system, such changes in motivations were statistically different, with also a statistically significant increase in the importance of health concerns.

Likewise, the safety perceptions of the respondents towards different modes have also changed as a result of coronavirus, with a statistically significant decrease in the safety perception of walking, public transport and GIRA. While before the pandemic, the perceived safety of using PT was similar to the other modes, now it is considered, by far, the most unsafe mode in Lisbon. Furthermore, the perceived safety of GIRA has also decreased, being now the second least safe mode, albeit with a much higher positive score than PT. In contrast, using a personal bicycle, which had the lowest perceived safety pre-pandemic is now the second perceived safest mode, behind private car. The perceived safety before the pandemic of using a personal bicycle and a shared bicycle is particularly curious as one would expect a similar perceived safety as both are ways of cycling, but respondents considered GIRA safer. Previous research has found evidence that bike sharing may be safer than using a personal cycling, having a lower injury risk (Woodcock et al., 2014; Fishman and Schepers, 2016) and higher awareness levels from drivers (Fishman, Washington and Haworth, 2012). However, the coronavirus pandemic seems to have changed that dynamic as now a personal bicycle is considered to be safer than using a shared bicycle. Nevertheless, when comparing the safety perceptions towards GIRA of the respondents who stopped using the system and the users who joined GIRA during the coronavirus, the new users have a much more positive view of GIRA, which was found to be statistically significant. Overall, our findings seem to point to an emerging trend observed in other case-studies, in which bike sharing is perceived as having a lower COVID-19 infection risk than using public transport, but perceived as riskier than using private modes (Nikiforidis, Ayfantopoulou and Stamelou, 2020; Shamshiripour et al., 2020).

As limitations of this study, we relied our analysis on self-reported behaviours, which may in some circumstances not reflect actual behaviour. Another limitation is related to the survey distribution method and the risk of selection bias, which was addressed by using multiple online dissemination channels and by comparing the sample with a representative survey conducted by GIRA’s operator. Furthermore, our comparisons between the pre-pandemic period and nowadays depended on the use of retrospective questions, which are prone to recall biases, although the impact of coronavirus is so severe and disruptive that it is realistic to assume that people still remember their past behaviour prior to the pandemic. Finally, our survey was conducted at the beginning of the second COVID-19 wave and, as such, the behavioural insights of BSS users obtained from it may differ from similar surveys conducted during other phases of the pandemic like, for instance, during periods of low infection rates. The coronavirus pandemic is still an ongoing crisis, with possible new developments having the potential to alter the observed dynamics. Consequently, definitive results on the impacts of coronavirus will only be fully uncovered once this pandemic ends and, as such, our research should be viewed within an exploratory framework.

7. Policy implications and future research

Our findings have several implications for policymakers regarding the role of bike sharing in urban mobility during disruptive public health crises. First and foremost, we have found compelling evidence that bike sharing can act as a substitute to public transport during a pandemic such as coronavirus. Several findings support this hypothesis. We discovered an increase in the modal share of BSS
in contrast to a decrease in PT regarding the main mode of transport in commuting trips as well as an increase in the percentage of single trips conducted by GIRA, while trips in combination with PT have decreased. At the same time, the importance of motivations connected to using BSS to avoid PT and for maintaining a social distance are now much more significant. Likewise, the perceived safety of using PT has dramatically declined, and while the perceived safety of using GIRA has also decrease it was in a much smaller scale (now only 16% of respondents consider PT safe in contrast with 62% still considering GIRA to be safe).

More importantly, our analysis of the modal shift dynamics found evidence that BSS can ameliorate a surge in car use and also prevent users from shifting from PT to the private car. While before the pandemic, 12.6% of GIRA users shifted from private car, now that number has climbed to 16.7%. Moreover, 10.4% of the respondents who before the pandemic would use PT if GIRA was not available, now would use a private car instead. As the respondents no longer feel safe in using PT due to infection fears (as evidenced by the much lower safety perceptions towards PT), they no longer consider public transport as a viable transport alternative and would choose different modes of transport if GIRA did not exist.

Thus, bike sharing can contribute to the resilience of urban transport systems during pandemics and other disruptive events by providing a viable alternative to the most affected modes of transport, such as PT. Indeed, emerging studies exploring BSS ridership during COVID-19 are consistently finding bike sharing to register lower ridership decreases (Bucsky, 2020; Teixeira and Lopes, 2020; Hu et al., 2021a, 2021b) and faster rebounds in comparison with PT and other modes of transport (Hu et al., 2021a, 2021b; Wang and Noland, 2021). This is especially important within the overall push towards a more sustainable future, as bike sharing is an environmentally friendly and healthy mode of transport (Teixeira et al., 2021). Furthermore, it is also very affordable, which can be especially important for people who do not feel safe in using PT but do not have any other alternative modes. For instance, GIRA has an annual subscription cost of 25 € (EMEL, 2019), significantly lower than a PT pass in the city which costs around 30 € a month (VIVA, 2019). Using bike sharing is also much more affordable than buying a personal bicycle, particularly an e-bike, which GIRA provides. Even for those who could afford a new bicycle, it was notorious during this pandemic the difficulty in buying a bicycle due to a surge in demand (BBC News, 2020), including in Portugal (ECO, 2020). Indeed, in this study most of the other reasons for decreasing or stopping using GIRA specified by respondents were actually related to a lack of available shared bicycles, particularly e-bikes.

Still, the perceived safety of using GIRA has decreased, with some users quitting the system due to infection fears. In that sense, special attention should be given for enhancing and publicizing the cleaning of shared bicycles and other surfaces that involve touch, and to try to avoid agglomerations of users near the docked stations, perhaps by deploying smaller BSS stations around the same area instead of a single large station. Even though shared bicycles could be a potential source of infection, the risk should be much lower than enclosed and often overcrowded PT systems, allowing social distancing to be maintained in most of the trip.

As future research, these results need to be compared with other international BSS in operation to assess possible similarities and differences. It would be especially useful to assess the performance of different types of bike sharing, particularly docked versus dockless systems, as well as other types of shared micro-mobility systems such as e-scooter sharing. Likewise, follow-up longitudinal studies could be conducted by employing multiple survey waves throughout the different phases of the pandemic, for instance, comparing the behaviour of BSS users during the peak of a COVID-19 wave versus during a period of low infection rates. Moreover, further research should focus on analysing different subgroups of BSS users regarding behaviour changes as a result of coronavirus. As this research has shown, the responses of BSS users to the coronavirus were very different, with some users decreasing or stopping using GIRA but others actually increasing or joining the system. More in-depth qualitative approaches, such as focus groups or semi-structured interviews, could deliver important insights into the individual behavioural changes provoked by coronavirus on BSS users, particularly regarding their motivations and attitudes.

The coronavirus pandemic presents several challenges for our transport systems but also opportunities such as potentially opening a short window for structural changes towards a more sustainable future. Indeed, several countries have announced that a substantial share of their economic recovery funds will be allocated to sustainable initiatives (European Commission, 2020). Yet, PT ridership levels will continue to be at historical lows as long as coronavirus remains a threat, and perhaps even beyond that timeline. Consequently, bike sharing, and cycling in general, should be seen as an alternative to public transport and car during this pandemic, potentially preventing PT users for shifting to private cars, which would contribute to minimize the detrimental consequences of a surge in car use.

CRediT authorship contribution statement

João Filipe Teixeira: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. Cecília Silva: Supervision, Writing – review & editing. Frederico Moura e Sá: Supervision, 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.

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Appendix A. Survey question regarding safety perceptions

Rate from 1 (not safe at all) to 5 (very safe) how safe you feel in using the following modes of transport in Lisbon. Compare your perception Before the COVID-19 Pandemic and Now.

| Mode of Transport | Before COVID-19 Pandemic | Now |
|-------------------|--------------------------|-----|
| Walking           | 1 | 2 | 3 | 4 | 5 |
| Private car       | 1 | 2 | 3 | 4 | 5 |
| GIRA shared bicycle | 1 | 2 | 3 | 4 | 5 |
| Public transport  | 1 | 2 | 3 | 4 | 5 |

Scale: 1 - not safe at all; 2 - not very safe; 3 - somewhat safe; 4 - safe; 5 - very safe.

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