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COVID-19, internet, and mobility: The rise of telework, telehealth, e-learning, and e-shopping

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ABSTRACT

This study provides new evidence on changes in a range of online activities due to the Coronavirus disease (COVID-19) pandemic. Online activities replaced physical participation in activities and contributed to changes in urban mobility during the pandemic. Using data from a nationwide survey in Greece, the paper examines changes in the importance and the frequency of engaging in online activities before and during COVID-19. Findings show that both the importance and the frequency of engaging in telework, teleconferencing, online learning (e-learning), telehealth, and online shopping (e-shopping) significantly increased during COVID-19 compared to pre-COVID-19. Substantial increases in importance were reported for telework (31% increase), teleconferencing (34% increase), online learning (34% increase), and telehealth (21% increase). Those who, on a daily basis, teleworked, teleconferenced, and made video calls with family or friends quadrupled during COVID-19, while daily online learners increased seven-fold. Telehealth and online shopping also increased but more modestly. Urban mobility in the post-COVID-19 era is likely to depend on the degree of prevalence and acceptance of these remote online activities, together with a set of complex and interconnected factors related to urban form, the spatial planning and decision-making system, and social awareness about the future of cities.

1. Introduction

The Coronavirus disease (COVID-19) pandemic has triggered a strong, global increase in the adoption of online activities substituting in-person activities (Eurofound, 2020; Nguyen, Gruber, Fuchs, Marler, Hunsaker & Hargittai, 2020; Pierce, Perrin, Tyler, McKee, & Watson, 2021; Wijesooriya, Mishra, Brand, & Rubin, 2020). To reduce the spread of the infection during COVID-19, governments applied lockdown and social distancing measures that disrupted ordinary daily life and in-person participation in activities. The development in information and communications technology (ICT) allowed citizens in many parts of the world to continue performing at least some of the activities of their daily lives virtually instead of physically. Telework, telehealth, online learning (e-learning), online shopping (e-shopping), and video calls were some of the remote online activities (also called "teleactivities") that were employed to replace, when possible, in-person work, healthcare, education, shopping, and meetings.

The ongoing changes in ICT, the fast digitalization, and the expansion of opportunities offered by the internet and online activities altogether form a "virtual mobility". People can now perform numerous activities online without the need to travel in the physical sense, and this leads to changes in traditional urban mobility and other types of travel (Gössling, 2018; Levinson & Krizek, 2017; Mouratidis, Peters, & van Wee, 2021). This phenomenon has been boosted by COVID-19 and its impacts on society and mobility are ongoing. Post-COVID-19 impacts are still unknown. The investigation of changes in online activities due to COVID-19 offers essential input for shedding light on ongoing and future changes in mobility (Conway, Salon, da Silva, & Mirtich, 2020). Overviews of changes in different types of online activities due to COVID-19 are needed to comparatively understand the degree of change in each online activity. A variety of contexts need to be examined as online activities are adopted in varying degrees in different settings. Comparing data on online activities before and during COVID-19 is particularly useful for providing estimates on the degree of possible changes. Empirical studies compiling such evidence on a wide range of COVID-19-related changes in different types of online activities are scarce since most studies have examined changes in a specific online activity rather than a range of online activities.

In this paper, we aim to address this need and provide new empirical evidence on whether and how a wide range of online activities changed

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due to COVID-19. Two research questions are addressed. (1) How has the importance of different online activities changed before and during COVID-19? (2) How has the frequency of engaging in different online activities changed before and during COVID-19? We then discuss urban mobility implications of COVID-19 and related changes in online activities. The study is based on data from a nationwide questionnaire survey carried out in Greece during the country's first COVID-19 lockdown in 2020. The paper is structured as follows. Section 2 presents the data collection and data analysis methods used. Section 3 presents the results of the statistical analysis. Section 4 discusses findings and implications for urban mobility. Section 5 presents concluding remarks.

2. Literature review

Urban mobility was largely affected by COVID-19. Due to lockdowns, restrictions, and the risk of infection, people in several parts of the world had to dramatically reduce their daily trips (Abu-Rayash & Dincer, 2020; Beria & Lunkar, 2021; Bucsky, 2020; De Vos, 2020; Shakibaei, de Jong, Alpkökin, & Rashidi, 2021). Public transport had the steepest decrease in use as it was associated with a higher risk of infection especially when vehicles were crowded and/or trips were long (Hu, Roberts, Azevedo, & Milner, 2020; Politis et al., 2021; Sun & Zhai, 2020; Zheng, Xu, Wang, Ning, & Bi, 2020). Walking, particularly utilitarian walking, also decreased during lockdowns (Hunter et al., 2021) but less sharply than public transport (Shakibaei et al., 2021; Teixeira & Lopes, 2020). One travel mode with increased use during COVID-19 was the bicycle. Cycling increased substantially in 2020 in several geographical contexts (Europe, North America, and Australia), especially after lockdown periods, and cycling modal share rose in several cities as total travel decreased dramatically during the pandemic (Buehler & Pucher, 2021). The reduction of total travel (sum of all modes) and activity in the streets contributed to significant reductions in noise and air pollution in cities (Basu et al., 2021; Rumpler, Venkataraman, & Göransson, 2020; Sharifi & Khavarian-Garmsir, 2020).

The adoption of online activities replacing in-person activities during COVID-19 provided opportunities to continue some parts of daily life without the need to physically travel. When possible, travel to participate in activities was replaced with online activities that were performed mainly from home (Beck, Hensher, & Wei, 2020; de Haas, Faber, & Hamersma, 2020; Shamshiripour, Rahimi, Shabanpour, & Mohammadian, 2020). This replacement and reduction in travel would not have been possible if ICT did not allow people to remotely perform several types of activities. Replacing travel with online activities, however, was not possible for all types of activities or all groups of people. It was observed that trips, and especially those with public transport, were more significantly reduced in areas of higher socioeconomic status (Hu & Chen, 2021). In areas of lower socioeconomic status, more people are occupied in jobs requiring physical presence, and therefore continued to travel to work when COVID-19 restrictions allowed.

COVID-19 triggered a strong boost in online activities in several parts of the world. Telework (or telecommuting) substantially increased during COVID-19 compared to the pre-COVID-19 period in several contexts including Asia, Europe, and the United States (de Haas et al., 2020; Eurofound, 2020; Okubo, 2020; Shamshiripour et al., 2020). Telehealth services (or telemedicine) offering remote health consultation experienced considerable growth during COVID-19 (North, 2020; Perrin, Pierce, & Elliott, 2020; Pierce, Perrin, Tyler, McKee, & Watson, 2021; Wijesooriya et al., 2020). Online learning (or e-learning or online education) was under significant growth during COVID-19 in several countries (Favale, Soro, Trevisan, Drago, & Mellia, 2020; Hilburg, Patel, Ambruso, Biewald, & Farouk, 2020). Online shopping (e-shopping) of food became more popular during COVID-19 (Alaimo, Fiore, & Galati, 2020). Some forms of online shopping such as online shopping of airplane tickets naturally declined during COVID-19. Overall digital communication and social media use also increased during COVID-19 (de Haas et al., 2020; Nguyen et al., 2020). Despite the growth in the use of the internet to perform online activities, numerous people worldwide did not have the opportunity to substitute in-person activities with online activities because of the nature of their profession (professions that require physical presence) or the lack of equipment, resources, and infrastructure (e.g. lack of or poor internet connection, lack of personal computer or smartphone, living in a small dwelling).

Online activities are shaping what could be called "virtual mobility". This phenomenon affected traditional urban mobility before COVID-19 as well as during COVID-19. Post-COVID-19 impacts are also expected. Online activities and virtual mobility may reshape urban mobility as they are linked to changes in travel behavior, transport systems, and land uses (Andreev, Salomon, & Pliskin, 2010; Battarra, Gargiulo, Tremiterra, & Zucaro, 2018; Ettema, 2018; Gössling, 2018; Kwan, Dijst, & Schwanen, 2007; Levinson & Krizek, 2017; Line, Jain, & Lyons, 2011; Mokhtarian, Salomon, & Handy, 2006; Mouratidis et al., 2021; Ozbilen, Wang, & Akar, 2021; van Wee, 2015; van Wee, Geurs, & Chorus, 2013). Online activities substitute some trips by allowing people to participate in activities remotely but may generate other types of trips via the time and money saved from this substitution. Performing activities remotely via ICT may also have long-term implications for land use. Residential and workplace locations may adjust to remote online activities such as telework and online shopping. People or workplaces may, for example, relocate to more remote locations. Physical workplaces may disappear. These changes, in turn, may also lead to changes in travel behavior. The wider adoption of online activities that occurred during COVID-19 is likely to play an important role in mobility in the long run (Conway et al., 2020). The increased engagement in online activities and the technological and institutional development of online activities during COVID-19 are expected to contribute to increased online activities post-COVID-19 compared to pre-COVID-19, with subsequent impacts on mobility. Changes in urban mobility will not only depend on the degree of adoption of online activities but also on other factors such as transport systems, adoption of shared mobility, advances in transport technologies, urban form, urban policies and regulations, and societal factors (Lyons, Mokhtarian, Dijst, & Böcker, 2018; Mouratidis et al., 2021; Shokouhyar, Shokoohyar, Sobhani, & Gorizi, 2021). Understanding the degree of change in different online activities due to COVID-19 is a necessary step for obtaining insights into the present and future of virtual mobility and its related implications for transportation in cities.

3. Data and methods

3.1. Data sources

The study is based on data from a population-based questionnaire survey carried out in Greece from the end of April until the end of May 2020. This was during the first lockdown in the country due to COVID-19 pandemic. Fig. 1 shows the approximate residential locations of the survey participants. The final sample was $N = 1201$ individuals aged 18–79 years, inhabitants of Greece. The sample consists of 523 inhabitants of Thessaloniki urban region, 489 inhabitants of Athens urban region, 185 inhabitants of other areas of Greece, and 4 inhabitants of Greece who did not fill in their place of residence. The sample from Thessaloniki is slightly larger than the sample from Athens. Thessaloniki urban region has approximately 1 million inhabitants, and Athens urban region has approximately 4 million inhabitants so the difference in sample size from each urban region is even larger relative to their population.

The research design of the study is shown in Fig. 2. The survey was distributed through a social media campaign combined with snowball sampling. The distribution was based on four channels: campaign in Facebook groups, research project webpage, an article in an online magazine on city issues, and snowball sampling using social networks. These four channels distributed an invitation to participate in the research and a link to an online survey. The survey was posted in 216 Facebook groups in Greece. These included citizens groups of each

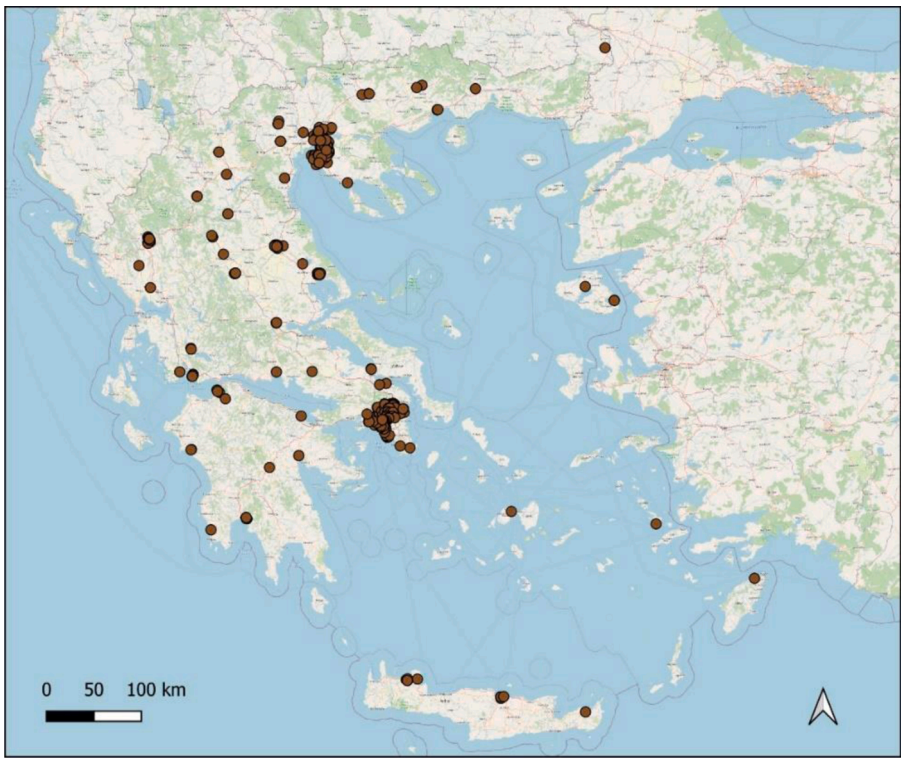

Fig. 1. Map of Greece showing approximations of the residential locations of survey participants ($N = 1201$).

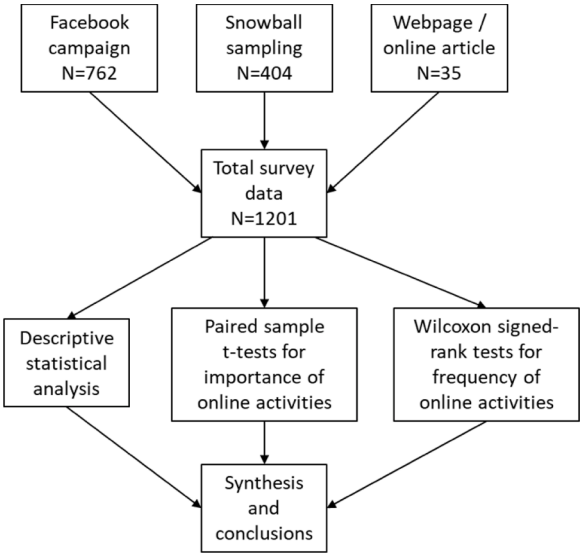

Fig. 2. Research design of the study.

neighborhood or district of Athens and Thessaloniki (the country's two major cities), as well as groups about a broad range of topics such as culture, travel, history, local news, politics, sports, urban issues, parenthood, disabilities, and childcare. Snowball sampling was conducted by distributing the survey to social networks in Greece through email or Facebook. These contacts were asked to subsequently distribute the invitation to the survey to their own networks. The survey was not distributed to colleagues to increase the representativeness of the sample. Overall, the Facebook group campaign recruited 762 participants, snowball sampling recruited 404 participants, while 35 participants were recruited through the research project webpage and the online article. The survey distribution resulted in a sample that covers residential locations all over Greece, but mainly the urban regions of Athens and Thessaloniki. A high diversity of locations (urban, suburban, peripheral, rural) and socioeconomic profiles (richer versus poorer areas) was achieved. The survey was pilot-tested and revised before its final distribution. No monetary or other incentives were offered to study participants. The invitation letter and survey questions were only in the Greek language, so this might have hindered the participation of residents who did not speak Greek.

3.2. Variable descriptions

Data on online activities before and during COVID-19 were obtained via the survey. The survey was conducted during the first lockdown due to COVID-19. Therefore, the evaluations for the COVID-19 period were real-time measurements, while evaluations for before COVID-19 were measured retrospectively. The following guidelines were given to survey participants: "Consider your life during the coronavirus pandemic (COVID-19) (During COVID-19). Also consider your life right before the COVID-19 pandemic (Before COVID-19)."

To evaluate the importance of online activities, participants were asked: "How important is it for you to do (or use) the following…?" The question was asked for both "before COVID-19" and "during COVID-19", on a scale from "not at all" (1) to "a great deal" (5). Online activities were described in the survey as follows. *Telework* was described as "work remotely using laptop/internet". *Teleconferencing* was described as "online meetings for work (e.g. with Skype)". *Online learning* was described as "online learning (e.g. online courses)". *Telehealth* was described as "online consultation (e.g. with doctor, therapist, coach)". *Online shopping* was described as "online shopping/booking/tickets". *Online dating* was described as "online dating (e.g. Tinder)". *Internet use* was described as the use of "the internet in general". *Social media use* was described as the use of "social media". *Smartphone use* was described as the use of "smartphones".

To measure the frequency of engaging in online activities, the same guidelines were used as those for evaluations of the importance of online activities. Participants were asked: "How often do you do (or use) the

following…?". The scale used for this question consisted of five options: "never" (1), "sporadically (less than once a month)" (2), "occasionally (sometimes a month)" (3), "often (sometimes a week)" (4), and "every day" (5). The question was asked for both "before COVID-19" and "during COVID-19". The following activities were assessed: telework, teleconferencing, online learning, telehealth, online shopping, online dating, internet use, social media use, and smartphone use. With the same guidelines and for both before and during COVID-19, the frequency of engaging in *video calls with family or friends* was also measured. The question was phrased as: "How often do you meet friends and relatives virtually with video calls? (Do not consider friends/relatives who live within your household.)". The scale used for this question was: "never" (1), "less than once a month" (2), "once a month" (3), "2–3 times a month" (4), "once a week" (5), "2–3 times a week" (6), "4–6 times a week" (7), and "every day" (8). This question was adapted according to an item from the European Social Survey (2012), and therefore was measured on a different scale than the other questions assessing frequencies.

Table 1 shows sociodemographic characteristics of the sample. Individual sociodemographic variables were measured via the survey. Sociodemographic variables included: age, gender, cohabitation status (living with partner or spouse), citizenship, personal net monthly income, presence of children in the household, employment status, religiosity, and level of education. Comparing these characteristics to population data by the Hellenic Statistical Authority (EL.STAT) and Eurostat, it is observed that the sample has some similarities but also deviations from the population. There is a good representation of both genders in the sample. The representation of unemployed citizens is good. Mean unemployment in the sample is 19%, while it was approximately 18% in the population of the country in June 2020. The sample is younger than that of the population. Individuals older than 79 years are missing from the sample. The low representation of older adults is typical for online surveys and especially for surveys with themes related to technology (see e.g. Nikitas, Vitel, & Cotet, 2021). The median age of the sample is 41 years, while the median age in Greece in 2020 was 45 years. The percentage of immigrants in the sample is very low compared to the population. The level of education is higher in the sample compared to the population: 71% have higher education in the sample compared to around 42% in the population. Mean net monthly income is higher in the sample than in the population: 1166 Euros versus 780 Euros. Income is higher for participants among the sample who live in Athens than those who live in other regions of Greece. This is also the case for the population.

3.3. Analytical method

To compare the importance and the frequency of online activities before and during COVID-19, we used paired sample t-tests of difference in mean and Wilcoxon signed-rank tests. Paired t-tests and Wilcoxon signed-rank tests are suitable for analyzing pre- and post-test results for one group. In other words, they are suitable for analyzing outcomes for the same subjects at two time points with an intervention between the two, in this case: the COVID-19 pandemic. The tests were used to identify significant differences in the values of each online activity before and during COVID-19. Since this is a comparative study between pre-COVID-19 and COVID-19 periods, this analytical technique is appropriate and there is no need for regression analysis or similar. If the aim of the study was to understand the factors behind behavior related to online activities, then a different survey questionnaire would be needed, and a regression model or structural equation model would have to be applied.

The importance of online activities was measured with ordinal variables on a 1–5 scale of importance. This ordinal scale can be treated as continuous, and parametric tests such as t-tests are considered to be robust (Norman, 2010). For the frequency of online activities, we used Wilcoxon signed-rank test, which is a non-parametric test suitable for ordinal variables. We chose this test since differences between each point in the frequency scales used in the study are not necessarily equal. However, analyses were also performed with paired *t*-tests (not reported here) and the produced significance levels were substantially the same, thus providing additional robustness to the results. The analyses on teleworking and teleconferencing were performed only for workforce participants and students ($N = 836$) since these groups are more likely to engage in teleworking and teleconferencing for work purposes. The whole sample was analyzed for all other online activities ($N = 1201$). The results of these analyses are as follows.

4. Results

4.1. Importance of online activities before and during COVID-19

Results on the importance of online activities before and during COVID-19 are presented in Figs. 3 and 4. Fig. 3 displays remote online activities that substitute activities requiring physical presence (also called "teleactivities"). Fig. 4 displays general online activities.

Fig. 3 shows that the importance of most online activities increased during COVID-19, compared to the pre-COVID-19 period. The importance of telework, online shopping, teleconferencing, online learning, and telehealth all significantly increased on average during COVID-19. Substantial increases in importance were reported for telework (31% increase), teleconferencing (34% increase), online learning (34% increase), and telehealth (21% increase). The increase in the importance of online shopping (3% increase) was considerably smaller. The importance of online dating was not found to have changed significantly during COVID-19. On average, the most important online activities both before and during COVID-19 were found to be telework and online shopping, followed by teleconferencing and online learning, while telehealth and online dating were considerably less important.

Fig. 4 shows that the importance of general online activities increased during COVID-19 in comparison with before COVID-19 times. The importance of internet use, social media use, and smartphone use significantly increased during COVID-19. The increases in the importance of general online activities are considerably smaller in size than the substantial increases observed for online teleactivities. As seen in

Table 1
Sociodemographic characteristics of the sample.

Variables	N	Min/Max	Athens ($N = 489$)		Thessaloniki ($N = 523$)		Other parts of Greece ($N = 185$)	
			Mean	s.d.	Mean	s.d.	Mean	s.d.
Age (years)	1200	18/79	43.81	(12.81)	41.74	(13.85)	39.21	(14.04)
Female	1201	0/1	0.52	(0.50)	0.56	(0.50)	0.65	(0.48)
Unemployed	1201	0/1	0.19	(0.40)	0.21	(0.41)	0.11	(0.32)
Living with partner/spouse	1201	0/1	0.63	(0.48)	0.62	(0.49)	0.54	(0.50)
Immigrant	1201	0/1	0.01	(0.08)	0.02	(0.12)	0.01	(0.07)
Income (personal net monthly income in Euros)	1201	0/4250	1336.20	(987.31)	1062.14	(855.11)	1014.86	(910.15)
College degree or higher	1201	0/1	0.73	(0.45)	0.70	(0.46)	0.68	(0.47)
Household with children	1201	0/1	0.44	(0.50)	0.41	(0.49)	0.39	(0.49)
Religious	1196	0/1	0.52	(0.50)	0.47	(0.50)	0.58	(0.49)

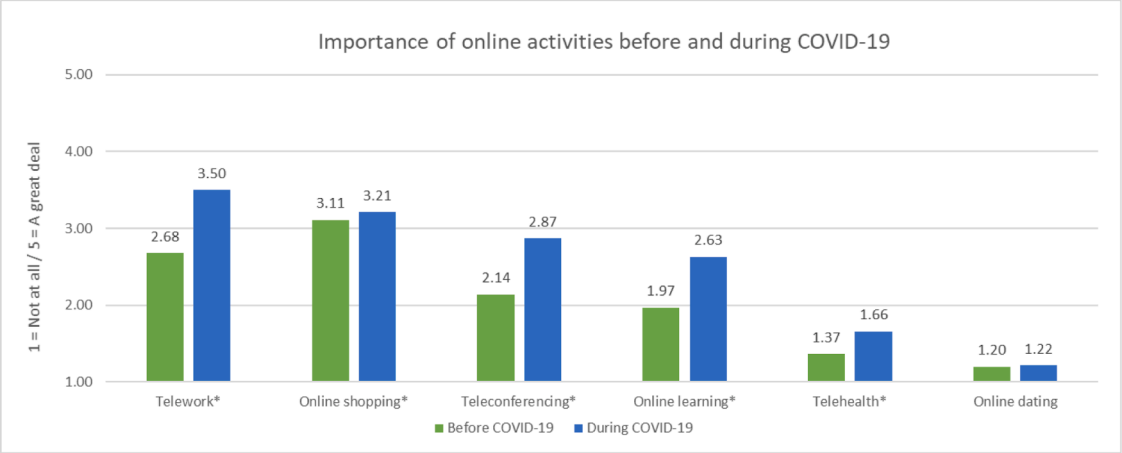

Fig. 3. Mean values of importance of online activities before and during COVID-19. *Notes*: Paired t-tests of difference in mean show significant differences at: * $p < 0.001$. Telework and teleconferencing were analyzed only for workforce participants and students among the sample ($N = 836$). For the other activities, the whole sample was analyzed ($N = 1201$).

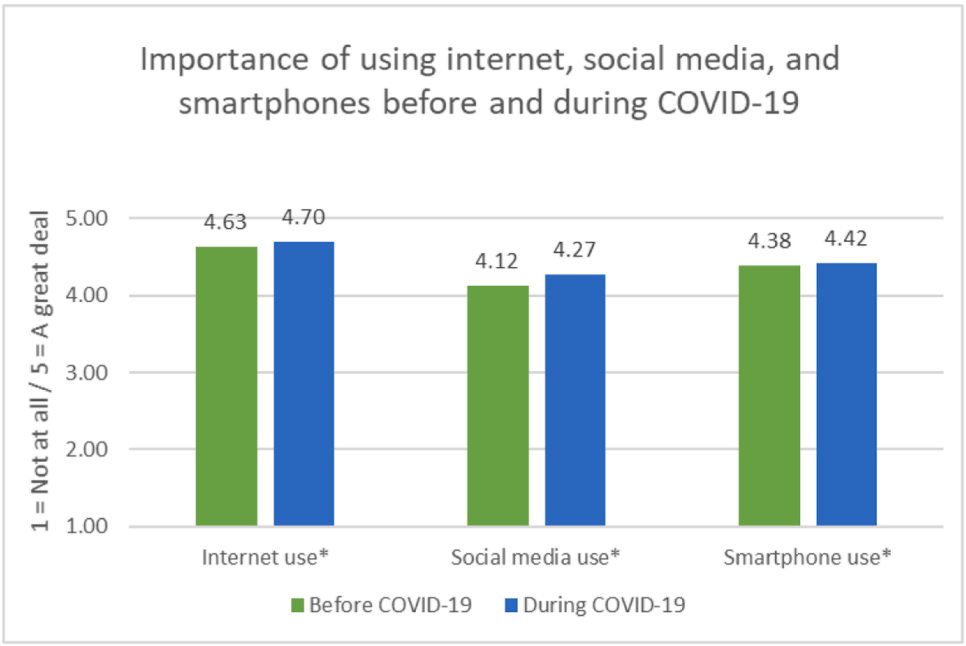

Fig. 4. Mean values of importance of general online activities before and during COVID-19. *Notes*: Paired t-tests of difference in mean show significant differences at: * $p < 0.001$. Sample size: $N = 1201$.

Fig. 4, internet use, social media use, and smartphone use were considered very important both before and during COVID-19.

4.2. Frequency of online activities before and during COVID-19

Comparisons of the mean frequencies of online activities before and during COVID-19 are presented in Figs. 5, 6, and 7. Detailed comparisons of frequencies of online teleactivities are presented in Figs. 8 and 9. Overall, the results suggest that the frequency of online activities increased during COVID-19 compared to before COVID-19. Fig. 5 shows that telework, online shopping, teleconferencing, online learning, and telehealth all significantly increased during COVID-19. Substantial increases were observed for telework (49%), teleconferencing (57%), and online learning (53%). The increases in online shopping (5%) and telehealth (11%) were smaller in size. Online dating did not increase significantly during COVID-19. Fig. 6 shows that video calls with family or friends increased during COVID-19. The increase was statistically significant and substantial in size (55%). Fig. 7 indicates that the use of the internet, social media, and smartphones increased during COVID-19. The increase is statistically significant but very small in size. This is reasonable since, as seen in Fig. 7, the internet, social media, and smartphones were used almost every day both before and during COVID-19. Figs. 8 and 9 illustrate the rise in remote online activities, and particularly the rise in telework, teleconferencing, online learning, and video calls with family and friends. Those who teleworked, teleconferenced, and made video calls on a daily basis quadrupled during COVID-19 compared to the pre-COVID-19 period, while daily online learners increased seven-fold. Fig. 8 shows that online shopping and telehealth also increased but more modestly, and online dating remained stable.

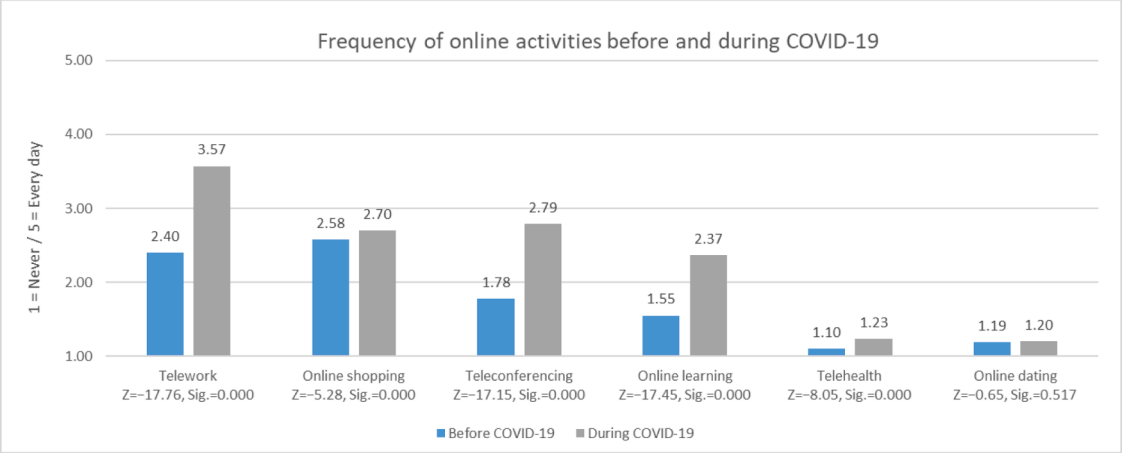

Fig. 5. Mean frequency of online activities before and during COVID-19 and Wilcoxon signed-rank tests comparing frequencies before and during COVID-19. *Notes*: Telework and teleconferencing were analyzed only for workforce participants and students among the sample ($N = 836$). For the other activities, the whole sample was analyzed ($N = 1201$).

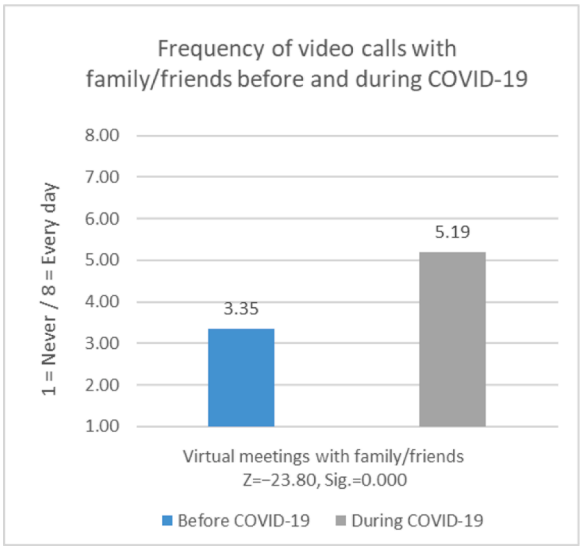

Fig. 6. Mean frequency of video calls with family or friends before and during COVID-19 and Wilcoxon signed-rank tests comparing frequencies before and during COVID-19 (sample size: $N = 1201$).

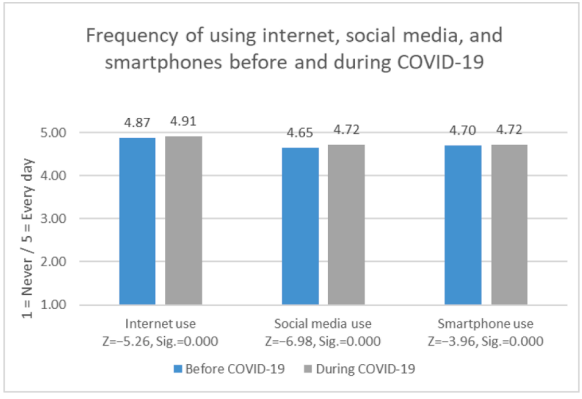

Fig. 7. Mean frequency of general online activities before and during COVID-19 and Wilcoxon signed-rank tests comparing frequencies before and during COVID-19 (sample size: $N = 1201$).

5. Discussion

5.1. Discussion of findings

Findings from this paper suggest that the importance and the frequency of engaging in online activities significantly increased due to COVID-19. The importance of telework, teleconferencing, online learning, and telehealth substantially grew during COVID-19 compared to the pre-COVID-19 period. The importance of online shopping also increased but more modestly, while the importance of online dating remained the substantially same. Internet use, social media use, and smartphone use were considered very important both before and during COVID-19. The frequency of engaging in telework, teleconferencing, online learning, and video calls with family or friends substantially increased during COVID-19. Telehealth and online shopping also increased, but more modestly, during COVID-19. Online dating remained stable during COVID-19. The internet, social media, and smartphones were used almost every day both before and during COVID-19.

As the measurement of online activities was conducted for the same individuals at two time points, pre-COVID-19 and during COVID-19, the increase in the importance and frequency of online activities observed for the COVID-19 measurement can be mostly attributed to the pandemic. The time period between the two measurements is short and no major changes have occurred in-between, other than the global COVID-19 pandemic. Naturally, some personal changes might have occurred for certain individuals among the sample, but these are not expected to materially affect the general trends observed in the results. The magnitude of the increases in importance and frequency of online activities during COVID-19 found in the present study is probably somewhat inflated compared to possible increases among the general population of Greece. This is due to differences between the sample composition and the general population. The results better reflect the tendencies in the population younger than 80 years. The higher average socioeconomic status that characterizes the sample may have also contributed to inflated results. However, all these differences are likely to influence only the magnitude of changes, and not the general trends observed in the study.

The increased engagement in online activities found in the overview of trends in the study is in accordance with recent studies focusing on specific online activities in various contexts: telework (Conway et al., 2020; de Haas et al., 2020; Eurofound, 2020; Okubo, 2020; Shamshiripour et al., 2020), telehealth (Koonin et al., 2020; North, 2020; Perrin, Pierce, & Elliott, 2020; Pierce, Perrin, Tyler, McKee, & Watson, 2021;

Fig. 8. Frequency of online activities before and during COVID-19. Telework and teleconferencing were analyzed only for workforce participants and students among the sample ($N = 836$). For the other activities, the whole sample was analyzed ($N = 1201$).

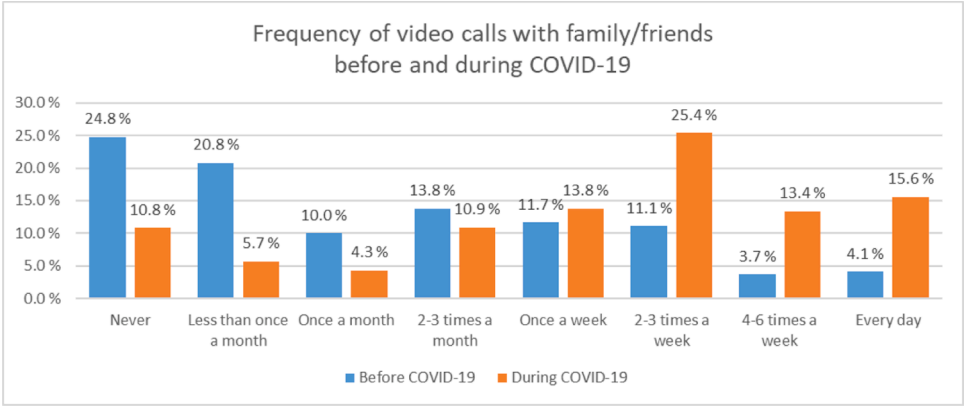

Fig. 9. Frequency of video calls with family or friends before and during COVID-19 ($N = 1201$).

Wijesooriya et al., 2020; Wosik et al., 2020), online learning (Favale et al., 2020; Hilburg et al., 2020; Soni, 2020), certain types of online shopping such as online food-shopping (Alaimo et al., 2020; Chang & Meyerhoefer, 2021), and overall digital communication (de Haas et al., 2020; Nguyen et al., 2020).

Compiling these changes in remote online activities has been missing from literature on human mobility behavior under COVID-19 (Benita, 2021; Kutela, Novat, & Langa, 2021). These changes suggest that

COVID-19 forced a sharp rise in "virtual mobility" that replaces the need to travel in the physical sense. Virtual mobility, which can be considered as part of smart or emerging mobility, leads to changes in traditional human mobility and other types of travel and can have important implications for sustainable mobility by affecting both travel behavior and the built environment (Mouratidis et al., 2021; Ozbilen et al., 2021). Although the levels of virtual mobility in the post-COVID-19 era are yet unknown, it can be expected that they will be higher than the pre-COVID-19 era, as already suggested by preliminary studies (Baert, Lippens, Moens, Weytjens, & Sterkens, 2020; Conway et al., 2020).

5.2. Implications for urban mobility

Urban mobility as well as any other type of travel in all spatial scales are significantly reduced during periods of spreading of infectious diseases like COVID-19 (Abu-Rayash & Dincer, 2020; Beria & Lunkar, 2021; Bucsky, 2020; Shakibaei et al., 2021). The insecurity of people facing the danger of infection combined with travel restrictions imposed on them by the governments shape novel mobility behaviors on a global scale (Beck & Hensher, 2020; Hu, 2020; Pawar, Yadav, Akolekar, & Velaga, 2020). During the pandemic, there has been a turn to private modes (cars, bikes, and motorbikes) and a decrease in the demand for public transport (Hasselwander et al., 2021; Meena, 2020; Przybylowski, Stelmak, & Suchanek, 2021; Rajput, Li, Gao, & Mostafavi, 2021; Wilbur et al., 2020). The reduced urban mobility and travel in general seem to have a direct positive environmental impact on urban space since they lead to a reduction of emissions and transport-driven atmospheric pollution (Tardivo, Carrillo Zanuy, & Sánchez Martín, 2021; Wang & Li, 2021). In urban areas, there has been observed an increase in the modal share of walking and bicycling, which ensure better conditions of social distancing (Bucsky, 2020; Teixeira & Lopes, 2020).

A nationwide online survey in Greece (sample size $N = 1259$) noted an increase in car use for trips to and from the workplace, and an increase in trips by foot for work and grocery shopping purposes, while, at the same time, public transport use decreased significantly (Politis et al., 2021). In another survey on the quality of service and user satisfaction (sample size N=426) in three representative bus routes in Thessaloniki (second largest city in Greece), 50% of passengers stated that they use buses (the only mass transit system in the city) during the pandemic much less than they used to Chatzistogiannis (2021). In addition, the majority of bus users felt insecure regarding the possible non-compliance of their co-passengers with the COVID-19 protection measures and the high occupancy of buses during rush hour. The pandemic also seems to reinforce pre-existing deficiencies in the operation of the transit bus route network and to have a negative effect on the perceived quality of services, as passengers report low satisfaction with the quality level. Finally, in an online survey (sample size $N = 396$) conducted in the city of Trikala (mid-size Greek city with 81,355 inhabitants), a statistically significant reduction in trip frequencies is detected for all purposes except for commuting, as well as in trip frequencies by car as a passenger, by bus, by motorbike, and by taxi (Olympisiou, 2021). On the antipode, statistically significant increases are observed in the frequency of bicycle use and walking. Worth mentioning is the fact that older people have the tendency to alter their routes when travelling by foot, possibly due to their increased vulnerability to contamination.

It is unclear how the above short-term changes in the mobility characteristics that appeared during the implementation of social distancing policy measures and mobility restrictions will develop in the long run after the end of the health crisis. The most crucial question is whether the development of alternative and soft transport modes will be reinforced, or if car use will be boosted due to the sense of security it generates. Changes forced by COVID-19 and lessons learned during the pandemic period provide the opportunity for a shift towards sustainable mobility that will be characterized by improved conditions for active travel, improved public transport services, reduction of unnecessary travel, and, when possible, replacement of trips with remote online activities (virtual mobility) (Benita, 2021; Conway et al., 2020; Hasselwander et al., 2021). The negative scenario is the operational and financial collapse of public transport that consequently leads to negative sustainability-related outcomes including increased traffic, atmospheric pollution, and social inequalities regarding accessibility issues (Honey-Rosés et al., 2020). Thus, the critical challenge faced by cities at this point is whether after the end of the pandemic they will return to a car-oriented normality, or jump at the chance of creating a more sustainable, just, and resilient urban mobility and urban environment (Barbarossa, 2020; Lak, Asl, & Maher, 2020; Sharifi & Khavarian-Garmsir, 2020).

The answer to the above challenge depends on the strategic guidelines that will be provided by an integrated, urban and transport planning framework, the market penetration and the degree of social acceptance of remote activities (teleworking, online shopping, teleeducation, etc.), and the political will of the local governance system combined with the efforts of civil society to promote sustainable and resilient mobility.

Transit-oriented development could contribute to dealing with the effects of the pandemic, even though it promotes a compact urban form, and requires relatively high densities and mixed land uses. This is because it forms an opportunity for cities with poor public transport and a lack of open and green spaces (e.g. Thessaloniki), to create functional, comfortable, and high aesthetic pedestrian paths, by implementing traffic calming measures, forming pedestrian zones, and widening the sidewalks in the stations' catchment areas (Papagiannakis, Vitopoulou, & Yiannakou, 2021). What is more, in cities with the above characteristics, the development of a multimodal and integrated mass transit system is deemed highly necessary; built around track-based modes (urban rail, metro, tram) and dedicated bus lanes (BRT), it will be able to regain the trust of the citizens by offering high-quality services in terms of reliability, frequency, capacity, comfort, and safety.

The reinvention of the form of the city and the redesign of the urban environment based on the new mobility conditions that the pandemic created (Barbarossa, 2020) could ensure the "right to mobility for all" and, in the end, the "right to the city" (Lefebvre, 1967). Active mobility and micromobility, that promote a healthy, ecological, and safe travel behavior, should be supported and protected (Campisi, Basbas, Skoufas, Akgün, Ticali & Tesoriere, 2020). The recovery and expansion of urban public space, through the creation of coherent and extensive networks of pedestrian and bicycle routes, shared space, and traffic calming areas, form the preconditions of transport resilience. Several cities around the globe, like Auckland, Barcelona, Bogota, Brussels, Lima, Milan, New York, Paris, and Rome, are planning and constructing emergency cycling and pedestrian infrastructure to accommodate social distancing and offer an alternative to public transport use (ITF-International Transport Forum, 2020).

In the long run, the adoption of innovative smart mobility applications will allow for the optimization of personal mobility planning (Mobility as a Service) and the creation of novel, flexible, or demand-responsive transport services that will be tailored to the users' preferences, needs, and perceptions (So, An, & Lee, 2020). In conclusion, an anthropocentric, integrated, multimodal, intelligent, and sustainable transport system is more likely to absorb the shocks of climate, environmental, financial, or health crises, and to adequately meet the emergency and long-term needs of mobility and accessibility of citizens.

5.3. Limitations and future research

The study has reported some clear results but also has certain limitations. The trends in online activities before and during the COVID-19 pandemic are examined in a South European context, and more specifically the context of Greece. Future studies providing overviews of COVID-19-related changes in online activities in other contexts should be compared with the present findings. The sample used for the

empirical analysis is characterized by certain deviations from the general population, typical for samples in questionnaire surveys and non-probability sampling. Retrospective data on online activities for the pre-COVID-19 period were used to address the research questions of the study. Individual recall in retrospective questions might be less precise and subject to biases. Nevertheless, the sample's deviations from the population, the larger sample of Thessaloniki compared to that of Athens relative to their population, and possible biases from retrospective measurements are not expected to influence the general trends of the results, but only their magnitude. Future studies with prospective longitudinal designs and representative samples can provide more accurate estimates. Studies of COVID-19-related changes in online activities at later time points than the one in this study would be particularly useful, as the importance and frequency of online activities may have increased to a greater extent later during the pandemic. Finally, future studies could investigate factors driving changes to online activity behavior using relevant survey data and applying regression or structural equation models.

6. Conclusions

This study has provided new evidence on changes in a range of online activities due to COVID-19 that replaced physical participation in activities and contributed to changes in mobility. Overviews of changes in a wide spectrum of online activities before and during COVID-19 have been scarce. Evidence from this study compiles such an overview, providing essential input on how COVD-19 boosted the phenomenon of "virtual mobility" and a platform for further discussion on ongoing and future changes in transportation and their implications for human societies and sustainability. Using nationwide survey data from Greece, the paper has addressed this gap by investigating two main research questions. The first focused on the importance of engaging in online activities before and during COVID-19 and the second focused on the frequency of engaging in online activities before and during COVID-19. (1) The importance of engaging in online activities significantly increased due to COVID-19. The importance of telework, teleconferencing, online learning, and telehealth substantially grew during COVID-19 compared to pre-COVID-19 times. The importance of online shopping increased but to a lesser degree, while the importance of online dating remained stable. Internet use, social media use, and smartphone use were considered very important both before and during COVID-19. (2) The frequency of engaging in online activities significantly increased due to COVID-19. The frequency of telework, teleconferencing, online learning, and video calls substantially increased during COVID-19. Telehealth and online shopping modestly increased during COVID-19, while online dating remained stable. The internet, social media, and smartphones were used almost every day both before and during COVID-19.

The short-term impacts of COVID-19 on urban mobility were the trips' decrease for all transport purposes and modes, the reduction in the frequency of transit use, and the increase of the modal share for cycling and walking. It seems that a significant part of mandatory and optional travel has been replaced by teleworking and other remote online activities. More research is needed to determine the possibility of maintaining the observed shift towards soft mobility in the long term and capitalizing on the health crisis experience on the use of public space to enhance urban resilience and sustainability. The mobility behavior perspectives for the post-COVID-19 period depend on a set of complex and interconnected factors which are related to the degree of prevalence and acceptance of remote online activities in daily life, urban form, the spatial planning and decision-making system, and the social awareness about the future of cities.

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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