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COVID-19 impact on teleactivities: Role of built environment and implications for mobility

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ABSTRACT

This paper presents new evidence on changes in a broad range of teleactivities due to the Coronavirus disease (COVID-19) pandemic and investigates how the built environment relates to these changes. The paper relies on survey and geospatial data from Oslo and its surrounding Viken region in Norway. Findings suggest that most teleactivities increased due to COVID-19. Telework, teleconferencing, online learning, telehealth, and virtual meetings with friends and family all increased during COVID-19 compared to the pre-COVID-19 period. The next step in the analysis examined relationships between built environment characteristics and teleactivities before and during COVID-19. Telework and virtual meetings increased to a greater extent in denser neighborhoods than in lower-density neighborhoods. A larger increase in online learning was associated with lower neighborhood density, lower accessibility to public transport, and more local facilities. Numerous local facilities were associated with more frequent telework and virtual meetings both before and during COVID-19. The substantial COVID-19-induced increase in teleactivities found in the study highlights the potential of information and communications technology (ICT) for replacing travel for various activities.

1. Introduction

The adoption and frequency of teleactivities – activities that are performed remotely – have been increasing rapidly with the development in information and communications technology (ICT). Teleactivities have implications for various life domains, including mobility as they can influence travel behavior and transport systems (e.g. Andreev, Salomon, & Pliskin, 2010; Gössling, 2018; Kwan, Dijst, & Schwanen, 2007; Levinson & Krizek, 2017; Line, Jain, & Lyons, 2011; Mokhtarian, Salomon, & Handy, 2006; van Wee, 2015; van Wee, Geurs, & Chorus, 2013). The coronavirus disease (COVID-19) pandemic has provided an additional strong boost to the widespread global application of certain teleactivities (Eurofound, 2020; Nguyen et al., 2020; Pierce, Perrin, Tyler, McKee, & Watson, 2021; Wijesooriya, Mishra, Brand, & Rubin, 2020). During COVID-19, citizens, worldwide, were encouraged or forced to perform, whenever possible, an extensive range of activities remotely with the help of ICT. When possible, physical presence at work was replaced by telework, meetings and conferences were conducted virtually, physical attendance at schools was replaced by online courses, and in-store shopping was replaced by online shopping. New forms of teleactivities also emerged or became more popular during this period. These include online live concerts, virtual celebrations, virtual traveling, virtual weddings, and virtual funerals. All these changes in how activities were performed during COVID-19 had substantial effects on mobility during that period (de Haas et al., 2020; Mouratidis, 2021; Shamshiripour et al., 2020), but may also have important long-term implications for mobility in the future.

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To better understand all these changes and their implications for mobility, we first need to systematically study how COVID-19 has affected and will affect the adoption of a wide range of teleactivities. Most existing studies focus on specific types of teleactivities in specific contexts, discussing implications and post-COVID-19 development for each type. To understand the implications for travel behavior, however, there is a need to compile an overview of all different types of teleactivities and to assess to what extent COVID-19 has affected them in different contexts (see e.g. Mouratidis & Papagiannakis, 2021). Evidence on trends in the frequency of a broad range of teleactivities before and during COVID-19 from various contexts will be particularly useful for this purpose.

In this paper, we aim to address this need and provide new empirical evidence on whether and how a wide range of teleactivities changed due to COVID-19. We then explore links between the built environment and teleactivities before and during COVID-19. The characteristics of the built environment may influence the level of adoption of teleactivities since living in certain types of environments may favor performing activities from distance (Kim, Mokhtarian, & Ahn, 2012; Vilhelmson & Thulin, 2016). These links between the built environment and teleactivities might in turn influence how cities are shaped and whether and how residents travel to access destinations (Gössling, 2018; Mouratidis, Peters, & van Wee, 2021). We anticipate, therefore, that knowledge about how the built environment influences the frequency of teleactivities due to COVID-19 can shed additional light on implications for mobility.

This is the first attempt, as far as we are aware, to evaluate changes in the frequency of various teleactivities due to COVID-19 and then investigate how the built environment relates to these changes. The paper addresses two research questions: (1) "how has the frequency of engaging in teleactivities changed before and during COVID-19?" and (2) "how do built environment characteristics relate to teleactivities before and during COVID-19?" Based on the findings from the two research questions, we also discuss short- and long-term implications of these changes for mobility. The following teleactivities are examined: telework, teleconferencing for work, virtual meetings with friends or family, online shopping, online learning, telehealth, and online dating. Built environment characteristics examined in the study are: distance to city center, neighborhood density, public transport accessibility, local facilities, and green space. The paper relies on survey and geospatial data from Oslo and its surrounding Viken region in Norway. Changes in the frequency of teleactivities due to COVID-19 were evaluated with data on the frequency of teleactivities of the same participants before and during COVID-19. The survey was conducted during June-August 2020. The data were analyzed with descriptive statistics, Wilcoxon signed-rank tests, and ordered logistic regression.

2. Literature review

2.1. Teleactivities before and during COVID-19

During health crises and other crises that disrupt personal contact, technological means are employed for the continuation of activities and communication in human societies (Ahmad, Krumkamp, & Reintjes, 2009; Denstadli, Julsrud, & Hjorthol, 2011). Changes in teleactivities due to COVID-19 have been radical and continuous. Highly relevant for understanding the impacts of COVID-19 on society and mobility seems the study of changes in working life.

Telework (also called *telecommuting*) increased during COVID-19 in several parts of the world (e.g. Eurofound, 2020; Mouratidis & Papagiannakis, 2021; Okubo, 2020). De Haas et al. (2020) examined, through a Dutch nationwide survey study, the possibility of considerable structural changes after COVID-19. They found a strong increase in home workers during pandemic conditions and many of those who were able to work from home during the pandemic expected to work more from home also in the future. Participants in that study did not only report positively about individual working tasks but also about having formal meetings and occasional meetings in daily working life with colleagues. Jenelius and Cebecauer (2020) do not directly focus on teleactivities but investigate the impact of the recommendation to "stay at home", including working from home if possible, in Stockholm. They found a severe decrease in public transport ridership in the city during the pandemic and related it strongly to the "stay at home" advice from the Swedish government. It should be noted that these studies capture the earlier stages of the pandemic, when massive telework was a new phenomenon. In later stages of the pandemic, teleworking may have caused fatigue and feelings of isolation to people working remotely for a prolonged period (for possible negative impacts of teleworking see e.g. Golden, Veiga, & Dino, 2008). Changes in working life during the pandemic also included the sharp rise in *teleconferencing* for work purposes. Teleconferencing largely replaced face-to-face meetings when this was possible (Mouratidis & Papagiannakis, 2021). Daily work meetings, seminars, conferences, and social meetings between colleagues were performed via online platforms.

Online learning (also called *e-learning* or *online education*) increased during COVID-19 in several contexts (Favale, Soro, Trevisan, Drago, & Mellia, 2020; Hilburg, Patel, Ambruso, Biewald, & Farouk, 2020; Mouratidis & Papagiannakis, 2021) due to temporary closing of educational facilities, restrictions and social distancing measures in educational facilities, and travel restrictions. It is noteworthy that some studies report negative experiences with online learning, if overused, due to physical and mental risks of online teaching and studying (e.g. de Haas et al., 2020; Mladenova, Kalmukov, & Valova, 2020). As in the case of teleworking, continuous use of online learning throughout the pandemic might have had negative outcomes for students such as lower satisfaction with the learning process and lack of social connectedness (for possible negative impacts of online learning see e.g. Bulu, 2012; Summers, Waigandt, & Whittaker, 2005).

Certain types of *online shopping* (also called *e-shopping*) seemed to be on the rise during COVID-19. With stores being closed or unsafe during the pandemic, online shopping provided an alternative to traditional in-store shopping. Shamshiripour et al. (2020) conducted a study based on survey data in Chicago investigating possible post-pandemic behavior of online shopping of meals and groceries. They concluded that this teleactivity would certainly remain post-COVID-19 and "expect that a considerable portion of this notable increase in online shopping for both groceries and meals during the pandemic will sustain in the future" (p. 10). Alaimo, Fiore, and Galati (2020) also reported findings indicating that online food shopping has experienced a boost during COVID-19. Changes in online

shopping, but also other teleactivities, due to COVID-19 have been affected by both changes in demand and changes in supply. The demand for certain activities (e.g. shopping for clothes) may have decreased due to the economic crisis followed by the pandemic at least in some contexts, therefore the expected increase in online shopping due to closed stores may not be as large. At the same time, the supply of other activities such as tourism or cultural activities has been reduced due to lockdown measures and mobility restrictions, thus online shopping of flight tickets or tickets for cultural events has declined (Gössling, Scott, & Hall, 2021).

As the pandemic is particularly severe for vulnerable populations due to age or health issues, many studies, if not most, examine implications for *telehealth* or *telemedicine*. Remote health consultation, for example, is experiencing extraordinary growth, and the literature on the implications of COVID-19 for different types of health services and treatments is vast. The health sector in particular is, by many, expected to change permanently and strongly towards an increase in telehealth services (North, 2020; Perrin, Pierce, & Elliott, 2020; Pierce et al., 2021; Wijesooriya et al., 2020).

Even though the above-mentioned studies give valuable insights into impacts of COVID-19 on specific teleactivities, they only represent cases where teleactivities and travel restrictions are a possibility. Mogaji (2020) and Pawar, Yadav, Akolekar, and Velaga (2020) state that large parts of the world's population do not have the possibility to work from home or engage in other teleactivities, due to the lack of personal resources or/and infrastructure. Regarding assumptions about future changes in travel patterns due to COVID-19, they also raise the issue that large parts of the population do not have the option to choose among different travel modes. Claims about changed behavior based on COVID-19 impacts can thus only be valid for specific contexts with certain conditions.

Based on our review of relevant literature, there seems to be a lack of studies comprehensively linking COVID-19 to all the different types of teleactivities. Rather, most studies focus either only on certain types of teleactivities and trends during COVID-19 or on certain travel behavior changes due to COVID-19. A recent overview of changes in different types of teleactivities due to COVID-19 in Greece reported a growth in most teleactivities: telework, online learning, and video calls were the activities with the steepest increase, while telehealth and online shopping increased more modestly (Mouratidis & Papagiannakis, 2021). Telework, online learning, and video calls can substitute daily-life activities: work, learning, and meeting. Replacing these in-person activities with their equivalent teleactivities reasonably results in sharp increases in telework, online learning, and video calls. Some forms of online shopping (e.g. food shopping) increased but others decreased (e.g. ticket shopping) during the pandemic, so the change for overall online shopping is likely to be smaller than other teleactivities and also largely depends on ways of measurement. Telehealth could be reasonably expected to increase. Nevertheless, since telehealth options are exercised more sparingly than potential daily-life activities such as telework, online learning, and video calls for work or socializing, telehealth is expected to increase to a lesser extent overall than these activities.

2.2. Built environment and teleactivities

Teleactivities provide opportunities for performing tasks without the need to physically travel. The built environment is related to teleactivities as individuals living in certain types of environments might be more likely to engage in certain types of teleactivities. There are two contrasting mechanisms to be considered. First, teleactivities such as online learning, telehealth, and online meetings offer access to education, healthcare, and people respectively without the need to physically travel (Dorsey and Topol, 2016; Xanthidis et al., 2016), thus may be more attractive for inhabitants of remote locations where there are limited educational, healthcare, and meeting facilities. Second, the characteristics of urban residents (age, education level, computer literacy, cosmopolitan attitudes) and of cities themselves (better ICT infrastructure) might encourage teleactivities (Cao, Chen, & Choo, 2013; Farag, Weltevreden, van Rietbergen, Dijst, & van Oort, 2006). Telework facilitates working from distance (Hill, Ferris, & Märtinson, 2003), therefore, in certain contexts, teleworkers are more likely to live far from work and to live in suburban or exurban locations (Kim et al., 2012; Tayyaran, Khan, & Anderson, 2003). The rise in telework has led to new types of co-working spaces and laptop-friendly cafés (Di Marino, Lilius, & Lapintie, 2018), thus teleworkers might be encouraged to live in areas with proximity to such facilities. Online shopping is more frequent in urban areas, in some contexts, since urban residents may have better computer skills and access to better ICT infrastructure (Cao et al., 2013; Farag et al., 2006). This trend however is changing, and online shopping is becoming prevalent in rural areas as well. In some contexts, research suggests that there is no urban–rural difference in the frequency of online shopping (De Blasio, 2008). Accessibility to shops may also play a role in online shopping. Residents who live far from shops are in higher need of online shopping (Cao et al., 2013; Freathy & Calderwood, 2013) so they might purchase online certain items such as clothing and leisure and cultural items more frequently than city dwellers (De Blasio, 2008; Farag et al., 2006; Zhen, Du, Cao, & Mokhtarian, 2018). Other items such as flight tickets are bought more frequently in urban centers due to the cosmopolitan attitudes commonly found in these locations (Farag et al., 2006).

Overall, evidence on the relationship between the built environment and teleactivities is quite limited and inconclusive, and a number of factors need to be considered depending on the context (Clarke, Thompson, & Birkin, 2015). Urban residents who live close to workplaces, educational facilities, meeting places, and shops have, in theory, lower need to engage in teleactivities as they can more easily travel to perform activities in person. Suburban or rural residents might have a greater need to work, shop, learn, and meet via the use of ICT. However, in certain contexts, urban residents may have, on average, higher education level, better computer skills and access to ICT infrastructure, and possibly different attitudes to ICT, which altogether may encourage teleactivity.

In this paper, new evidence is provided on the relationship between built environment and different teleactivities both before and during COVID-19. Whether COVID-19 changed the relationship between the built environment and teleactivities remains unexplored. Two relatively contrasting hypotheses are discussed here.

(a)Urban residents living in proximity to city centers are typically more reliant on public transport and might have been unable or discouraged to travel medium or long distances, since public transport was associated with a higher risk of infection than other travel modes (Hu, Roberts, Azevedo, & Milner, 2021; Zheng, Xu, Wang, Ning, & Bi, 2020). Suburban, exurban, and rural residents, on the

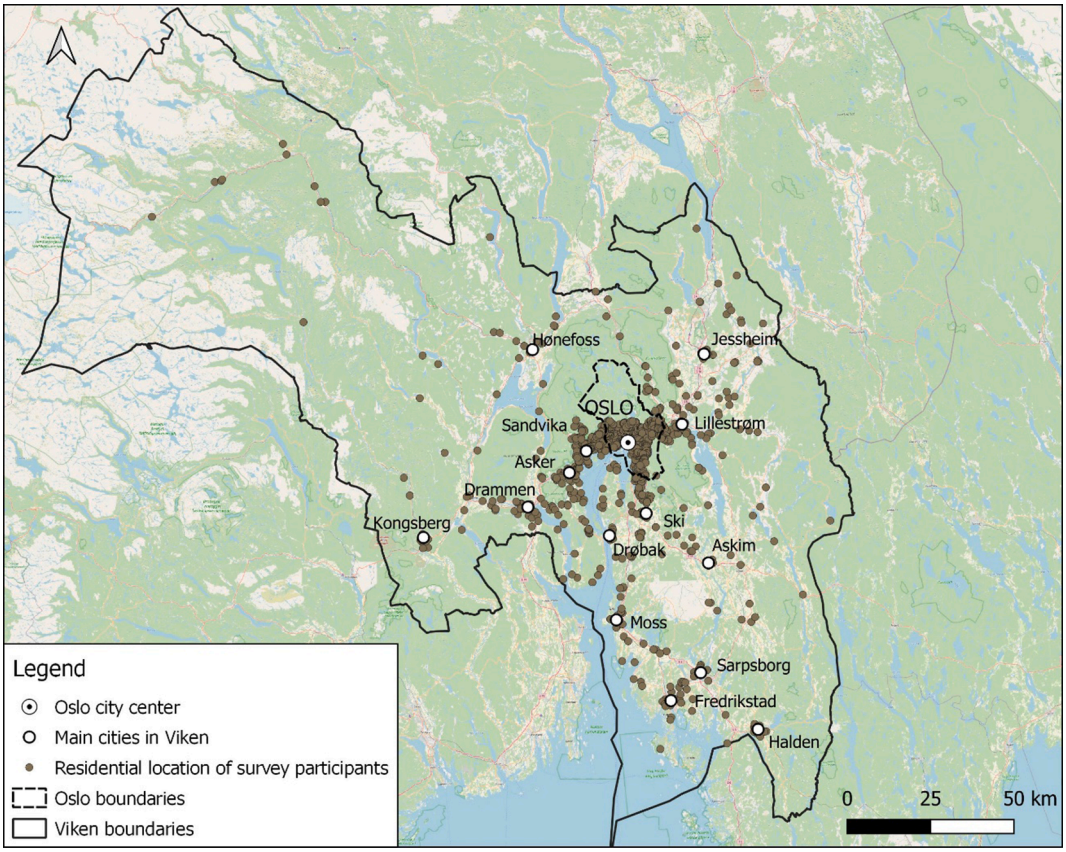

Fig. 1. Map of Oslo and Viken counties showing the residential location of survey participants.

other hand, are typically more dependent on car travel and own more cars (Cao, Næss, & Wolday, 2019), therefore they could have traveled more safely to perform activities physically. Our hypothesis is that the public transport reliance of urban dwellers might have forced them to engage in teleactivities to a greater extent than suburban dwellers.

(b)In cases where some facilities (offices, shops, healthcare, education, and meeting places) remained open during COVID-19 lockdowns, urban dwellers who live close to such facilities might have had more opportunities to perform activities in person (Litman, 2020), as they could more easily walk and cycle to access facilities. Conversely, the lack of facilities in close proximity, for example in strictly monofunctional residential areas, might have encouraged more frequent engagement in teleactivities since teleactivities became the norm during the pandemic (e.g. telework was adopted by several businesses, telehealth was encouraged when possible, physical presence in education was optional if not discontinued). Therefore, our hypothesis is that proximity to facilities, often associated with inner-city living, might have resulted in a less dramatic rise in teleactivities.

In the analysis, we explore changes in the relationship between the built environment and different teleactivities and later discuss findings considering the theoretical background and the hypotheses presented here. It should be however noted that the analysis presented in this paper is exploratory and not confirmatory, as theory on built environment and teleactivities is still rather immature.

3. Data and methods

3.1. Case area

The study is part of a research project on emerging mobility, travel behavior, and quality of life (Mouratidis & Peters, 2020). Data collection was carried out in the counties of Oslo and Viken in Norway (see also Mouratidis, 2022). The county of Viken is an administrative region surrounding the county of Oslo, the capital of Norway. In 2019, the population of Oslo county was approximately 670,000 and the population of Viken was approximately 1,230,000. The urban area and the metropolitan area of Oslo – both of which include Oslo county as well as parts of Viken county – had a population of approximately 1,000,000 and 1,500,000 respectively. The area of Oslo and Viken is to a large extent monocentric and is characterized by a center-periphery gradient. Oslo city center is the main center of economic and cultural activity, and population densities tend to increase closer to Oslo city center. Residents of the metropolitan area of Oslo as well as other parts of Viken may travel to central locations in Oslo for work, education, and cultural or commercial activities. A map of Oslo and Viken counties is presented in Fig. 1.

Table 1
Measurement of frequency of teleactivities and general online activities.

Variables	Question	Scale
Teleactivities and general online activities	*Consider your life during the lockdown (the period with the most restrictions) due to the coronavirus pandemic (COVID-19) (During COVID-19). Also consider your life right before the COVID-19 pandemic (Before COVID-19).*	
	How often do you do (or use) the following…?	
Telework	Work remotely using laptop/internet (during COVID-19) Work remotely using laptop/internet (before COVID-19)	"never" (1), "sporadically (less than once a month)" (2), "occasionally (sometimes a month)" (3), "often (sometimes a week)" (4), and "every day" (5).
Teleconferencing for work	Online meetings for work (e.g. with Skype) (during COVID-19)Online meetings for work (e.g. with Skype) (before COVID-19)	
Online learning	Online learning (e.g. online courses) (during COVID-19) Online learning (e.g. online courses) (before COVID-19)	
Telehealth	Online consultation (e.g. with doctor, therapist, coach) (during COVID-19)Online consultation (e.g. with doctor, therapist, coach) (before COVID-19)	
Online shopping	Online shopping/booking/tickets (during COVID-19)Online shopping/booking/tickets (before COVID-19)	
Online dating	Online dating (e.g. Tinder) (during COVID-19)Online dating (e.g. Tinder) (before COVID-19)	
Internet use	The internet in general (during COVID-19) The internet in general (before COVID-19)	
Social media use	Social media (during COVID-19)Social media (before COVID-19)	
Smart phone use	Smart phones (during COVID-19) Smart phones (before COVID-19)	
Virtual meetings with friends and family	*Consider your life during the lockdown (the period with the most restrictions) due to the coronavirus pandemic (COVID-19) (During COVID-19). Also consider your life right before the COVID-19 pandemic (Before COVID-19).*	
Virtual meetings with friends and family[1]	How often do you meet friends and relatives virtually with video calls (during COVID-19)? (Do not consider friends/relatives who live within your household.) How often do you meet friends and relatives virtually with video calls (before COVID-19)? (Do not consider friends/relatives who live within your household.)	"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)

Note: [1]The question used to obtain this variable was adapted from a similar question in the European Social Survey (2012) and this is why the scale differs from the one used for the other teleactivities.

3.2. Data sources

The study is based on data from a population-based questionnaire survey and geospatial data collected with geographic information systems (GIS). The survey was carried out in Oslo and Viken counties in June-August 2020. This time period was a few months after COVID-19 was declared a pandemic by the World Health Organization in March 2020. It coincided with the first wave of the pandemic and was just after the period with the most restrictions in Oslo and Viken that was March-May 2020. Survey participants were asked to consider the period with the most restrictions when answering questions related to COVID-19 (see section 3.3 below). Norway had an early, but less strict lockdown compared to some other European countries. While restrictions and measures had a strong impact on society, culture, and economy, they were in many cases less radical than in other countries. Several establishments were temporarily closed – several businesses, restaurants, fitness centers, and cultural venues – but certain businesses and shops remained open. This is important to consider when analyzing data and drawing conclusions about the impact of COVID-19 on teleactivities and mobility. During the period with the most restrictions that the survey respondents were asked to consider (March-May 2020), schools, kindergartens, universities, offices, fitness centers, hair salons, and other facilities were closed, sports and cultural events were banned, gatherings were restricted, offices closed, and restrictions were applied to cafés and restaurants. Telework was implemented when possible and the use of public transport was discouraged.

The final sample of the survey consists of 1796 adults aged 19–95 years and residing in various locations of Oslo and Viken (Fig. 1). Prior to the survey, we submitted an application to the Norwegian Tax Administration in order to get access to a list of the residential addresses of all the residents of Oslo and Viken. We then distributed 20,000 letters by post inviting randomly selected residents to participate in an online survey. Only adult residents and only one member per household were invited to participate in the survey. We divided the case area into different zones and then performed random sample selection within each of these zones. We sent 12,000 letters in Oslo county (8,000 in the inner city and 4,000 in the outer city) and 8,000 letters in Viken county (4,000 in suburbs of Oslo and 4,000 in peripheral towns and rural areas). This selection was made to achieve a high representation of diverse urban forms (high

Table 2
Descriptive statistics of independent variables.

Variables	N	Min/Max	Mean	s.d.
Built environment				
Distance to city center (km)	1796	0.40/217.17	17.56	27.13
Neighborhood density (persons/hectare within 1 km radius)	1796	0.43/173.66	64.36	51.04
Public transport (number of stops within 1 km radius)	1796	0/233	48.08	43.69
Local facilities (number of facilities within 1 km radius)	1796	0/1523	263.19	310.51
Green space (% within 1 km radius)	1796	1.46/73.83	25.24	14.37
Sociodemographic variables				
Age (years)	1796	19/95	49.67	16.50
Female	1796	0/1	0.50	0.50
Unemployed	1796	0/1	0.04	0.20
Living with partner/spouse	1796	0/1	0.69	0.46
Non-Norwegian	1796	0/1	0.10	0.30
Adjusted household income (1000 s NOK)[1]	1796	0/4899	735.96	411.25
College degree or higher	1796	0/1	0.70	0.46
Household with children	1796	0/1	0.33	0.47
Disability	1796	0/1	0.16	0.36

Note: [1]Annual household income divided by the square root of household size.

density, medium density, low density) and locations (urban, suburban, peripheral, rural) among the sample. The invitation letter and the survey questions were in both Norwegian and English to facilitate the participation of persons who do not speak the Norwegian language. The survey was pilot-tested and revised, before its final distribution. No monetary or other incentives were offered to the participants. Excluding the letters that were sent to invalid addresses, the final response rate was approximately 9%-10%. Therefore, non-response bias might be relevant for the dataset. Table A1 in Appendix suggests that several of the survey sample's sociodemographic characteristics are relatively similar to those of the population, while there are differences in terms of citizenship, education, and cohabitation status. Ethics approval for this research was received by the Norwegian Center for Research Data (NSD), with reference number 869419.

3.3. Variable descriptions

Data on the frequency of teleactivities and general online activities were obtained via the survey. Table 1 shows how these variables were measured. As shown in Table 1, retrospective questions were asked in order to obtain before and during COVID-19 measurements. The following teleactivities were measured: telework, teleconferencing for work, online learning, telehealth, online shopping, online dating, and virtual meetings with friends and family. The following general online activities were also measured: internet use, social media use, and smart phone use.

Individual sociodemographic variables were also measured via the survey. Sociodemographic variables included: age, gender, cohabitation status (living with partner or spouse), citizenship, household income, presence of children in the household, employment status, and level of education. Having a disability or important health issue was considered as a control variable in the study and was measured with the question: "Are you hampered in your daily activities in any way by any longstanding illness, or disability, infirmity or mental health problem?" Table 2 shows descriptive statistics for all the sociodemographic variables used in the study.

Built environment characteristics were captured with geospatial data in GIS. The following built environment characteristics were measured: distance to city center, neighborhood density, public transport accessibility, local facilities, and green space. These characteristics were measured for each survey participant individually based on the residential address. *Distance to city center* assessed the location of each participant's residence in relation to the city center of Oslo. It was calculated in kilometers along walking routes. *Neighborhood density* was measured in persons per hectare as the population density within a 1000 m radius from each participant's residence. The 2019 population dataset for statistical grids (250 m × 250 m) from Statistics Norway was used for this analysis. *Public transport* accessibility was measured as the number of public transport stops (bus, tram, metro, train) within a 1000 m radius from each participant's residence. OpenStreetMap data were used for this analysis. *Local facilities* were measured as the number of facilities within a 1000 m radius from each participant's residence. This analysis used data from OpenStreetMap on the "amenity" category. All different types of facilities in this category were included in the analysis, for example: school, cinema, theater, post office, café, restaurant, bank, library, and hospital. *Green space* was calculated as the mean percentage of green space area within 1000 m radius from each participant's residence. Data from 2019 by Hansen et al. (2013) were used. Table 2 shows descriptive statistics for all built environment variables.

4. Results

4.1. Teleactivities before-during COVID-19

The first part of the analysis compares the frequency of teleactivities before and during COVID-19. Fig. A1, Fig. A2, and Fig. A3 (Appendix) present the distribution of frequencies of teleactivities and general online activities before and during COVID-19. Telework

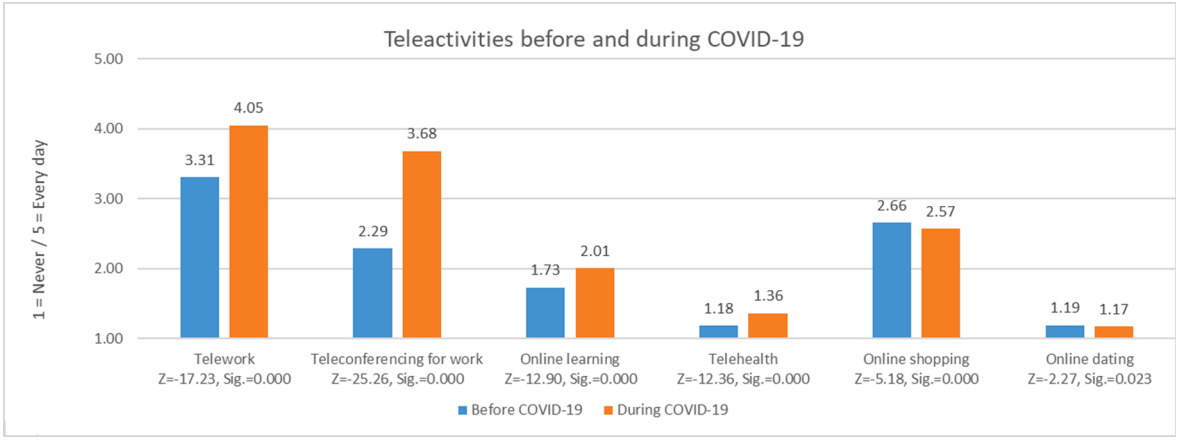

Fig. 2. Mean frequency of teleactivities before and during COVID-19 and Wilcoxon signed-rank tests comparing frequencies before and during COVID-19. *Notes*: Telework and teleconferencing for work were analyzed only for workforce participants and students among the sample (N = 1300). For the other teleactivities, the whole sample was analyzed (N = 1796). Z scores for online shopping and online dating are based on positive ranks, while for the other teleactivities they are based on negative ranks.

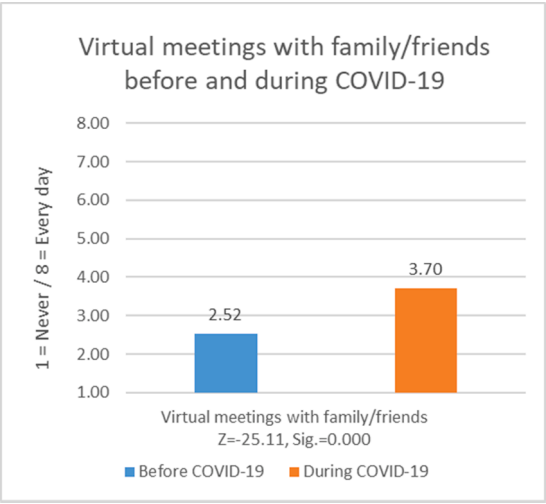

Fig. 3. Mean frequency of virtual meetings with family or friends before and during COVID-19 and Wilcoxon signed-rank tests comparing frequencies before and during COVID-19 (Sample size: N = 1796). *Note:* Z score is based on negative ranks.

and teleconferencing for work were analyzed only for workforce participants and students among the sample (N = 1300). For the other activities, the whole sample was analyzed (N = 1796).

Fig. A1 and Fig. A2 show that, overall, most teleactivities substantially increased during COVID-19. Approximately 30% of the workforce participants used to work remotely every day before COVID-19, while this increased to approximately 60% during COVID-19. Approximately 8% of the workforce participants used teleconferencing for work purposes every day before COVID-19, while this increased to approximately 37% during COVID-19. The percentage of respondents who engaged in online learning sometimes per week or every day doubled during COVID-19. The percentage of respondents who engaged in telehealth sometimes per month or per week rose from around 2% before COVID-19 to around 7% during COVID-19. The frequency of online shopping increased for some respondents, while it decreased for others. No substantial change in online dating before and during COVID-19 can be observed. Around 50% of the sample never had virtual meetings with friends/family before COVID-19, while during COVID-19 around 25% never had such meetings, indicating a substantial increase of virtual meetings during COVID-19. Fig. A3 shows that general online activities remained relatively stable before and during COVID-19. Most survey participants, approximately 90%, used the internet and a smart phone almost every day both before and during COVID-19. Social media use was also high both before and during COVID-19.

Next, Wilcoxon signed-rank tests were conducted to test for significant differences in the frequency of each teleactivity and general online activity before and during COVID-19. Wilcoxon signed-rank test is a non-parametric test suitable for ordinal variables such as the frequency variables used in the study. This test is preferred for such variables since differences between each point in the frequency scales are not necessarily equal.

Table 3
Ordered logistic regression models examining how built environment relates to telework before and during COVID-19.

Variables	Telework					
	Before COVID-19		During COVID-19		During COVID-19 accounting for Before COVID-19	
	1	2	1	2	1	2
Built environment						
Distance to city center	−0.031	−0.062	−0.036	−0.055	−0.003	0.009
Neighborhood density	−0.007	−0.050	0.092[a]	−0.012	0.118*	0.060
Public transport		−0.149*		−0.050		0.096
Local facilities		0.187*		0.198*		0.012
Green space		0.031		0.052		0.028
Sociodemographic variables						
Age	0.081*	0.077*	0.048	0.047	0.026	0.027
Female	0.020	0.017	0.030	0.029	0.040	0.042
Living with partner/spouse	−0.005	−0.007	0.053	0.053	0.054	0.055
Non-Norwegian	−0.068*	−0.074*	−0.059	−0.064[a]	−0.038	−0.038
Adjusted household income	0.241***	0.236***	0.232***	0.233***	0.104[a]	0.111[a]
College degree or higher	0.062[a]	0.059[a]	0.205***	0.203***	0.189***	0.190***
Household with children	0.090*	0.089*	0.071[a]	0.076[a]	0.031	0.037
Disability	−0.036	−0.038	−0.078*	−0.081*	−0.085*	−0.086*
Telework Before COVID-19						
Never					−4.787***	−4.795***
Sporadically					−2.179***	−2.193***
Occasionally					−1.570***	−1.587***
Often					−1.367***	−1.378***
Every day (ref.)						
Summary statistics						
N	1300	1300	1300	1300	1300	1300
Nagelkerke R-squared	0.063	0.069	0.083	0.087	0.408	0.409

Notes: [a]$p < 0.10$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. All coefficients shown are standardized.
Telework was analyzed only for workforce participants and students among the sample.

Table 4
Ordered logistic regression models examining how built environment relates to teleconferencing for work before and during COVID-19.

Variables	Teleconferencing for work					
	Before COVID-19		During COVID-19		During COVID-19 accounting for Before COVID-19	
	1	2	1	2	1	2
Built environment						
Distance to city center	−0.072	−0.076	−0.066	−0.078[a]	−0.047	−0.059
Neighborhood density	−0.076	−0.163[a]	−0.002	−0.154[a]	0.043	−0.097
Public transport		0.008		−0.003		−0.006
Local facilities		0.060		0.147[a]		0.140
Green space		−0.039		−0.031		−0.028
Sociodemographic variables						
Age	0.006	0.007	0.015	0.016	0.003	0.003
Female	−0.248***	−0.246***	−0.007	−0.003	0.143***	0.147***
Living with partner/spouse	−0.037	−0.036	0.015	0.018	0.060	0.062
Non-Norwegian	0.119**	0.119**	−0.025	−0.027	−0.102**	−0.104**
Adjusted household income	0.411***	0.411***	0.340***	0.342***	0.160**	0.162**
College degree or higher	0.307***	0.307***	0.334***	0.333***	0.228***	0.227***
Household with children	0.169***	0.173***	0.115**	0.124**	0.060	0.067
Disability	−0.077[a]	−0.079[a]	−0.074*	−0.077*	−0.042	−0.046
Teleconferencing for work Before COVID-19						
Never					−3.748***	−4.190***
Sporadically					−2.231***	−2.500***
Occasionally					−1.707***	−1.915***
Often					−1.096***	−1.233***
Every day (ref.)						
Summary statistics						
N	1300	1300	1300	1300	1300	1300
Nagelkerke R-squared	0.183	0.184	0.152	0.156	0.394	0.396

Notes: [a]$p < 0.10$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. All coefficients shown are standardized.
Teleconferencing for work was analyzed only for workforce participants and students among the sample.

Table 5
Ordered logistic regression models examining how built environment relates to virtual meetings with friends/family before and during COVID-19.

Variables	Virtual meetings with friends/family					
	Before COVID-19		During COVID-19		During COVID-19 accounting for Before COVID-19	
	1	2	1	2	1	2
Built environment						
Distance to city center	−0.026	−0.052[a]	−0.026	−0.041	−0.013	−0.008
Neighborhood density	0.016	−0.179**	0.055*	−0.036	0.058*	0.096*
Public transport		−0.047		−0.033		0.008
Local facilities		0.251***		0.137**		−0.032
Green space		0.000		0.013		0.020
Sociodemographic variables						
Age	−0.070**	−0.072**	−0.156***	−0.157***	−0.162***	−0.162***
Female	0.022	0.025	0.089***	0.091***	0.128***	0.128***
Unemployed	0.016	0.013	−0.013	−0.016	−0.041[a]	−0.041[a]
Living with partner/spouse	−0.051*	−0.052*	−0.021	−0.019	0.013	0.013
Non-Norwegian	0.176***	0.170***	0.087***	0.083***	−0.031	−0.031
Adjusted household income	0.017	0.012	0.061**	0.059**	0.083***	0.084***
College degree or higher	0.035	0.034	0.055**	0.053*	0.052*	0.052*
Household with children	0.019	0.026	0.025	0.028	0.023	0.022
Disability	−0.020	−0.022	−0.042*	−0.043*	−0.048*	−0.047*
Virtual meetings with friends/family Before COVID-19						
Never					−8.684***	−8.703***
Less than once a month					−7.238***	−7.252***
Once a month					−6.641***	−6.653***
2–3 times a month					−6.143***	−6.159***
Once a week					−5.525***	−5.535***
2–3 times a week					−4.758***	−4.767***
4–6 times a week					−3.355***	−3.348***
Every day (ref.)						
Summary statistics						
N	1796	1796	1796	1796	1796	1796
Nagelkerke R-squared	0.052	0.065	0.103	0.108	0.556	0.556

Notes: [a]$p < 0.10$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. All coefficients shown are standardized.

Table 6
Ordered logistic regression models examining how built environment relates to online learning before and during COVID-19.

Variables	Online learning					
	Before COVID-19		During COVID-19		During COVID-19 accounting for Before COVID-19	
	1	2	1	2	1	2
Built environment						
Distance to city center	−0.017	−0.028	−0.016	−0.052	0.003	−0.039
Neighborhood density	−0.098	−0.243*	−0.130*	−0.219*	−0.098[a]	−0.119
Public transport		0.005		−0.141[a]		−0.198*
Local facilities		0.134		0.204*		0.180[a]
Green space		−0.030		−0.006		0.004
Sociodemographic variables						
Age	−0.588***	−0.586***	−0.637***	−0.643***	−0.437***	−0.447***
Female	−0.234***	−0.231***	−0.011	−0.011	0.144**	0.141**
Unemployed	−0.036	−0.038	−0.068[a]	−0.072[a]	−0.041	−0.048
Living with partner/spouse	−0.108	−0.107[a]	−0.128**	−0.127**	−0.073	−0.072
Non-Norwegian	0.192***	0.188***	0.155***	0.148***	0.080[a]	0.072[a]
Adjusted household income	0.283***	0.282***	0.152***	0.145***	0.020	0.012
College degree or higher	0.324***	0.323***	0.210***	0.205***	0.098*	0.093[a]
Household with children	0.059	0.066	0.039	0.038	0.030	0.027
Disability	−0.186**	−0.189**	−0.119**	−0.121**	−0.045	−0.048
Online learning Before COVID-19						
Never					−6.395***	−6.437***
Sporadically					−4.541***	−4.581***
Occasionally					−3.363***	−3.398***
Often					−2.413***	−2.459***
Every day (ref.)						
Summary statistics						
N	1796	1796	1796	1796	1796	1796
Nagelkerke R-squared	0.152	0.153	0.175	0.177	0.519	0.520

Notes: [a]$p < 0.10$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. All coefficients shown are standardized.

The results in Fig. 2 and Fig. 3 show that the frequency of most teleactivities increased during COVID-19. Telework, teleconferencing for work, online learning, telehealth, and virtual meetings with friends/family all increased during COVID-19. The most substantial increases are observed for teleconferencing for work, virtual meetings with friends/family, and telework. On the other hand, the frequency of online shopping and online dating slightly decreased on average. The decrease in online shopping is small, but statistically significant. The decrease in online dating is negligible, and it could be suggested that online dating remained relatively stable.

Fig. A4 (Appendix) shows that general online activities slightly increased during COVID-19, although this increase is negligible. Internet use and smart phone use were substantially the same before and during COVID-19 and continued to be performed close to every day on average. Social media use was also high both before and during COVID-19.

4.2. Built environment and teleactivities before-during COVID-19

The analyses presented in Tables 3-6 below examine associations between built environment characteristics and teleactivities, with each table focusing on a different type of teleactivity. As shown in Fig. A1, the distributions of different teleactivities differ significantly so a factor synthesizing all the variables would not be reliable. Moreover, telework and teleconferencing are examined only for workforce participants and students, while for the other teleactivities the whole sample is used. Therefore, independent models for each teleactivity are applied. Ordered logistic regression analysis was used, in which built environment characteristics and sociodemographic characteristics were treated as independent variables and the frequency of teleactivities was treated as the dependent variable. Variables on the frequency of teleactivities are measured on 1–5 and 1–8 scales. These variables are ordinal, thus suitable for ordered logistic regression. The analysis was conducted for the frequency of teleactivities: before COVID-19, during COVID-19, and during COVID-19 accounting for before COVID-19. The last type of analysis examines whether and how the built environment relates to a teleactivity during COVID-19 accounting for the extent to which individuals performed this teleactivity before COVID-19.

Built environment variables were included in the models in two steps based on relevant theoretical considerations (Mouratidis & Poortinga, 2020; Næss, Strand, Wolday, & Stefansdottir, 2019). The first step includes the variables distance to city center and neighborhood density, while the second step additionally includes the variables public transport, local facilities, and green space, all of which are influenced by distance to city center and neighborhood density especially for the case area which is largely monocentric. In models of the second step, distance to city center and neighborhood density function as control variables. Therefore, we focus on distance to city center and neighborhood density in the results of models of the first step, and on public transport, local facilities, and green space in the results of models of the second step.

Table 3 displays associations between the built environment and telework. Neighborhood density is positively associated with telework during COVID-19 but not before COVID-19. When accounting for telework before COVID-19, the association between neighborhood density and telework during COVID-19 becomes stronger. Results indicate that the increase in telework due to COVID-19 has been larger in denser neighborhoods. Public transport accessibility is found to be negatively related to telework before COVID-19. The negative association between public transport and telework disappeared during COVID-19. Local facilities are positively related to telework before COVID-19. The positive association between local facilities and telework remained similar during COVID-19, and therefore local facilities are not associated with telework during COVID-19 when accounting for before COVID-19. The other built environment characteristics – distance to city center and green space – did not yield statistically significant relationships with telework. Regarding sociodemographic characteristics, age is found to be positively related to telework before COVID-19, while it is not associated with telework during COVID-19. Non-Norwegian citizenship is negatively associated with telework before COVID-19 and, less strongly, during COVID-19. Household income and higher education are positively associated with telework before and during COVID-19. The association between higher education and telework becomes considerably stronger during COVID-19. Households with children are positively associated with telework before and during COVID-19. Disability is negatively associated with telework during COVID-19. Telework before COVID-19 is strongly associated with telework during COVID-19.

Table 4 presents associations between built environment characteristics and teleconferencing for work. Local facilities are positively related to teleconferencing for work during COVID-19, while this relationship becomes weaker when accounting for telework before COVID-19. Regarding sociodemographic characteristics, being female is negatively associated with teleconferencing before COVID-19, but not during COVID-19. Non-Norwegian citizenship is positively related to teleconferencing before COVID-19, but not during COVID-19. Household income, higher education, and having children in the household are positively associated with teleconferencing both before and during COVID-19. Disability is negatively associated with teleconferencing both before and during COVID-19. Teleconferencing before COVID-19 is strongly associated with teleconferencing during COVID-19.

Table 5 displays associations between the built environment and virtual meetings with friends/family. Neighborhood density is positively associated with virtual meetings during COVID-19, even when accounting for virtual meetings before COVID-19. Results indicate that the increase in virtual meetings due to COVID-19 has been larger in denser neighborhoods. Local facilities are strongly associated with virtual meetings before COVID-19. The positive association between local facilities and virtual meetings is less strong (but still significant) during COVID-19. Regarding sociodemographic variables, age is negatively associated with virtual meetings before COVID-19, and even more strongly during COVID-19. Being female is positively related to virtual meetings during COVID-19, but not before COVID-19. Non-Norwegian citizenship is positively related to virtual meetings both before and during COVID-19. Household income and higher education are positively related to virtual meetings only during COVID-19. Disability is negatively related to virtual meetings only during COVID-19. Virtual meetings before COVID-19 are strongly related to virtual meetings during COVID-19.

Table 6 presents models examining how built environment characteristics relate to online learning. A negative relationship

between neighborhood density and online learning during COVID-19 is observed. This relationship persists even when accounting for online learning before COVID-19. Therefore, the increase in online learning due to COVID-19 has been smaller in denser neighborhoods. Public transport is negatively associated with online learning during COVID-19, even when accounting for online learning before COVID-19. The increase in online learning due to COVID-19 has been smaller in neighborhoods with high accessibility to public transport. Local facilities are positively associated with online learning during COVID-19, even when accounting for online learning before COVID-19. The increase in online learning due to COVID-19 has been larger in neighborhoods with numerous local facilities. Regarding sociodemographic variables, age and disability are negatively associated with online learning both before and during COVID-19. Being female is negatively associated with online learning only before COVID-19. Being unemployed is negatively associated with online learning during COVID-19. Living with a partner/spouse is negatively related to online learning only during COVID-19. Non-Norwegian citizenship, household income, and higher education are positively related to online learning both before and during COVID-19. Online learning before COVID-19 strongly relates to online learning during COVID-19.

Table A2, Table A3, and Table A4 (Appendix) present models examining how the built environment relates to telehealth, online shopping, and online dating respectively. As the tables show, no significant associations between the built environment and these teleactivities were observed. Regarding sociodemographic variables, Table A2 shows that age and living without partner or spouse are positively associated with telehealth before COVID-19, but not during COVID-19. Being female and having higher education are related to telehealth only during COVID-19. Disability is positively associated with telehealth both before and during COVID-19. Telehealth before COVID-19 is strongly related to telehealth during COVID-19. As reported in Table A3, age and living with a partner/spouse are negatively related to online shopping both before and during COVID-19. Household income, higher education, and having children in the household are positively related to online shopping both before and during COVID-19. Online shopping before COVID-19 strongly relates to online shopping during COVID-19. Table A4 indicates that being older, being female, living with a partner/spouse, and having a disability are all negatively associated with online dating both before and during COVID-19. Having higher education is positively related to online dating before and during COVID-19, while income is positively related to online dating before COVID-19. Online dating before COVID-19 is strongly related to online dating during COVID-19.

5. Discussion

5.1. Changes in teleactivities due to COVID-19

Findings show that the frequency of most teleactivities increased during COVID-19. Telework, teleconferencing for work, online learning, telehealth, and virtual meetings with friends/family all increased during COVID-19, compared to the period just before COVID-19. The most substantial increases were reported for telework, teleconferencing, and virtual meetings with friends or family.

The increase in *telework* due to COVID-19 found here is in line with findings from Europe (Eurofound, 2020; Mouratidis & Papagiannakis, 2021), Japan (Okubo, 2020), and United States (Shamshiripour et al., 2020). *Teleconferencing* and *virtual meetings with friends and family* were found to be increased during COVID-19, supporting evidence of increased digital communication due to COVID-19 (de Haas et al., 2020; Mouratidis & Papagiannakis, 2021; Nguyen et al., 2020). *Online learning* increased during COVID-19 for adult populations in the study's sample, as also suggested by previous relevant studies (Favale et al., 2020; Hilburg et al., 2020). *Telehealth* – measured as online consultation with a doctor, therapist, or coach – was found to have increased during COVID-19, in line with previous evidence on increased adoption of telehealth (Mouratidis & Papagiannakis, 2021; Wijesooriya et al., 2020) and telepsychology (Pierce et al., 2021) during COVID-19.

On the other hand, the frequency of *online shopping* among the study participants slightly decreased on average during COVID-19. This finding contradicts studies suggesting an increase in online shopping during COVID-19 (Alaimo et al., 2020; Shamshiripour et al., 2020). Some online shopping activities may have increased (e.g. food delivery, online clothes shopping) but others may have decreased (e.g. online shopping of flight tickets, tickets for cultural events, tickets for sports events) during COVID-19. To better understand changes in online shopping due to COVID-19, distinct measures of different online shopping activities should be used in future studies. The context of Norway should also be considered when interpreting the present study's finding. As mentioned in section 3.2 above, COVID-19 restrictions in Norway were less radical compared to those applied in some other countries. Several stores remained open during the lockdowns. Therefore, certain in-store shopping activities were still possible. The context of the study is not representative of countries where people were more or less forced to shop online (e.g. Mouratidis & Papagiannakis, 2021). Moreover, the pandemic has led to economic instability and loss of income for some households, thus affecting their overall shopping activity.

The frequency of *online dating* was not found to have meaningfully changed before and during COVID-19 in the present study. General online activities like *internet use*, *smart phone use*, and *social media use* remained relatively similar before and during COVID-19. These general online activities were used daily even before COVID-19, so there was little room for a further increase in their frequency.

5.2. Built environment and teleactivities before-during COVID-19

The analysis on built environment characteristics and teleactivities indicates associations between *neighborhood density* and certain teleactivities. Neighborhood density was associated with more frequent telework during COVID-19 and more virtual meetings with friends and family during COVID-19. COVID-19-induced increase in telework and virtual meetings was larger in denser neighborhoods. These results confirm our expectations discussed in Section 2.2 above, suggesting that urban residents may not wish or be able to physically travel to perform certain activities because they may not have (easy) access to a car, which was safer during COVID-19 than public transport. They might then prefer or be forced to work remotely or virtually meet friends and family. Moreover, before

COVID-19, residents of denser neighborhoods tended to socialize with acquaintances that reside all over the city region, while residents of low-density neighborhoods tended to socialize more locally (Mouratidis, 2018). Restrictions in travel might inhibit residents of denser neighborhoods to socially meet their acquaintances that are dispersed in various areas, so they might be forced to use virtual meetings to a larger extent. Neighborhood density, on the other hand, was found to be related to less frequent online learning during COVID-19 and a smaller increase in online learning, which is a result contrasting to the aforementioned theoretical considerations. This result seems difficult to interpret but might be attributed to colleges, universities, and schools offering some necessary in-person teaching (e.g. labs or teaching support for vulnerable students) during lockdowns. Since some educational facilities are often located in dense urban areas, residents living in such areas were more likely to attend in-person teaching and less likely to attend online courses.

Results also display positive associations between *local facilities* and several teleactivities during COVID-19. Based on the theoretical considerations presented in section 2.2 above, we hypothesized the exact opposite relationship: that living in an area with plenty of local facilities might be related to less frequent teleactivities during COVID-19. Facilities that remained open during COVID-19 in the case area included stores and healthcare establishments. Residents who could easily access such facilities locally would have lower need to engage in relevant teleactivities. However, we found positive relationships between local facilities and four teleactivities (telework, teleconferencing, virtual meetings with friends and family, and online learning) during COVID-19, suggesting that residents living in areas with many facilities teleworked and participated in online meetings and courses more frequently.

Findings show that local facilities were associated with increased telework both before and during COVID-19. This might indicate that the presence of certain facilities (when open) in the local area could enable some people to work remotely. Such facilities include cafes, libraries, and co-working spaces (Di Marino et al., 2018). Paradoxically, although several of these local facilities were closed or restricted during COVID-19, the association with telework remains similar. This could be due to some local facilities remaining open and/or due to habits and attitudes of residents living in areas with a high presence of such facilities. Local facilities were also associated with teleconferencing, virtual meetings with friends and family, and online learning. Local facilities were associated with teleconferencing and online learning only during COVID-19, while they were associated with virtual meetings with friends and family both before and during COVID-19. In addition, local facilities were associated with a larger COVID-19-induced increase in online learning. As already mentioned, some facilities remained open during COVID-19 lockdowns in Norway. However, it seems unlikely that such facilities enabled residents to do more online courses or online meetings. These findings could then be attributed to the personal characteristics of residents living in areas with many facilities, e.g. attitudes or type of profession. These characteristics have not been captured by the analysis in this study and should be examined in future research.

Public transport was associated with reduced telework but only before COVID-19. It is likely that residents of areas with good access to public transport also have better access to their workplace – especially considering the several car restrictions and relevant policies in Oslo – so they telework less than residents with worse access to public transport. Similar to neighborhood density, public transport was associated with reduced online learning during COVID-19. This finding is again difficult to interpret but might be attributed to the same factor as in the case of neighborhood density. Transit-oriented, dense, urban areas may include educational facilities that offered some necessary in-person teaching during lockdowns, thus residents living in such areas were less likely to replace in-person teaching with online courses.

The frequency of teleactivities was not found to be linked to *distance to the city center*, in contrast with studies from other contexts that find that residential location is linked to engagement in teleactivities such as telework and online shopping (Cao et al., 2013; Kim et al., 2012; Tayyaran et al., 2003; Yousefi & Dadashpoor, 2019). Residents of inner-city neighborhoods were as likely to engage in teleactivities as residents of suburbs and peripheral towns were. Finally, *green space* in the local area of the residence was not found to be related to the adoption of teleactivities neither before COVID-19 nor during COVID-19.

5.3. Implications for mobility

Findings from this paper indicate an important increase in most teleactivities due to COVID-19. The replacement of traditional activities with teleactivities is expected to have contributed – together with travel restrictions, social distancing measures, and temporary closing of workplaces, facilities, and services – to people traveling less during COVID-19 compared to before COVID-19. This increase in teleactivities may contribute to substantial effects of COVID-19 on travel behavior, suggested by earlier studies (de Haas et al., 2020; De Vos, 2020; Liu et al., 2020; Shamshiripour et al., 2020). Travel has been substantially reduced both in terms of daily life travel but also in terms of international travel. This reduction in total travel might have not been possible or might have been less significant if ICT did not offer opportunities to perform a wide range of activities remotely.

The study's findings also provide insights into the role of the built environment in the relationship between teleactivities and mobility before and during COVID-19. A finding that stands out is that areas with plenty of local facilities were associated with more frequent teleactivities (telework, teleconferencing, virtual meetings with friends/family, online learning) during COVID-19. This could be attributed to certain facilities themselves (perhaps for the case of telework) or to self-selection and personal characteristics – that may have not been captured by the control variables in the study – of residents choosing to live in these areas. If self-selection is not the main driver of this finding, and local facilities have enabled certain teleactivities during COVID-19, the potential of local facilities and mixed land use development to enable replacing trips with remote activities should be explored.

The significant increases in teleactivities during COVID-19 might have important long-term implications for mobility. People and organizations have become more familiar with teleactivities and their potential during COVID-19. The attitudes of users, as well as employers and decision makers are expected to be more positive due to this increased familiarity (de Haas et al., 2020; Shamshiripour et al., 2020). Skills and competences in ICT might have also been improved. At the same time, infrastructure and systems have been rapidly improved, extended, or created from scratch to support a number of different teleactivities during restrictions and lockdowns

due to COVID-19. The "dematerialization" of certain categories of goods and the emergence of online businesses (Circella & Mokhtarian, 2017; Pawlak, Circella, Mahmassani, & Mokhtarian, 2019) are likely to occur even faster due to the temporary or even permanent closing of "bricks and mortar" shops and businesses during COVID-19.

All these changes in attitudes, skills, competences, infrastructure, and systems in relation to teleactivities are expected to contribute to more engagement in teleactivities post-COVID-19 compared to pre-COVID-19. Naturally, teleactivities are likely to decrease post-COVID-19, compared to the COVID-19 period. But they are likely to substantially increase compared to pre-COVID-19 and at a higher rate than they would have increased if COVID-19 never occurred (Conway, Salon, da Silva, & Mirtich, 2020).

This may contribute to changed travel routines in post-COVID-19 times compared to pre-COVID-19. Travel to work or travel for other daily activities such as socializing, shopping, learning, and visiting a doctor or coach may be reduced and be partly replaced by teleactivities. Rebound effects could however occur (Mokhtarian & Chen, 2004). The time and money saved from this reduced travel enabled by teleactivities could be spent on traveling for other purposes. People may also adapt their trip destination, residential choices, and trip frequencies. For example, people might relocate to a more remote location or they might increase their international travel (Czepkiewicz, Heinonen, & Ottelin, 2018). It remains to be seen however whether the reduced travel enabled by teleactivities will be larger than possible rebound effects. It is still unclear whether total travel will be reduced in the post-COVID-19 times and whether teleactivities will have an important contribution to sustainable mobility.

6. Conclusions

This study has provided new insights into changes in the frequency of teleactivities due to COVID-19 and into the role of the built environment in these changes. It is one of the first studies to examine trends in a wide range of teleactivities before-during COVID-19 and to shed light on the role of the built environment in these trends. Although there are studies focusing on trends in specific teleactivities during COVID-19, empirical evidence synthesizing a wide spectrum of teleactivities has been scarce. Furthermore, this is one of the first attempts to explore the relationship between built environment characteristics and teleactivities both before and during COVID-19.

The paper has tried to address these gaps by examining two main research questions, one focusing on COVID-19 related changes in teleactivities and another linking teleactivities to certain aspects of the built environment. Findings addressing the first question suggest that most teleactivities significantly increased due to COVID-19. Telework, teleconferencing for work, online learning, telehealth, and virtual meetings with friends/family all increased in frequency during COVID-19 compared to pre-COVID-19. The most important findings helping to answer the second question are as follows. First, COVID-19-induced increases in telework and virtual meetings with friends and family were larger in denser neighborhoods than in lower-density neighborhoods. Second, lower neighborhood density, lower accessibility to public transport, and more local facilities were all associated with a larger increase in online learning due to COVID-19. Finally, local facilities were associated with more frequent telework and virtual meetings both before and during COVID-19.

The paper's findings shed light on short and long-term implications for mobility. The significant increase in teleactivities found in the present study may contribute to substantial effects of COVID-19 on travel behavior. Reduced travel during COVID-19 might have not been possible to this extent if ICT did not offer opportunities to perform a wide range of activities remotely. Moreover, the study on the role of the built environment suggests that certain environmental characteristics might have enabled or discouraged teleactivities during COVID-19, and, thereby, possibly contributing to changes in travel behavior. Finally, changes in attitudes, skills, competences, infrastructure, and systems concerning teleactivities that occurred during COVID-19 may contribute to more engagement in teleactivities post-COVID-19 compared to pre-COVID-19.

Future research could explore this topic in different contexts. Social, cultural, and spatial characteristics may contribute to differences in engagement with teleactivities. The spreading of COVID-19 and subsequent social distancing measures might also significantly affect the frequency of teleactivities in different contexts. The role of the built environment in the adoption of teleactivities might also significantly differ in other contexts. The study has used univariate measures of the frequency of teleactivities. Latent constructs might have produced more reliable outcomes. Moreover, retrospective measurements were used for the analysis in the present paper. A prospective longitudinal design would probably have reduced the risk of biases and confounding issues, resulting in even more robust outcomes. An important sociodemographic variable that is missing from the survey employed in this study concerns the description of the individual's occupation. Occupation information is critical for two reasons: the ability to work from home and the "critical worker" status. These characteristics should be considered in future studies as they play an important role in whether and how often individuals are able to engage in teleactivities such as teleworking and teleconferencing. Finally, based on the study's results on changes in teleactivities before and during COVID-19 and the role of built environment characteristics in these changes, we have theoretically discussed implications for mobility (Section 5.3 above). Empirical research is needed to explore how the increased adoption of teleactivities due to COVID-19 may influence travel behavior and transport systems and whether and how it could contribute to sustainable mobility in the future.

CRediT authorship contribution statement

Kostas Mouratidis: Conceptualization, Methodology, Investigation, Formal analysis, Visualization, Writing – original draft, Writing – review & editing, Funding acquisition, Project administration. **Sebastian Peters:** Conceptualization, Writing – original draft, Writing – review & editing, Funding acquisition.

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

Table A1
Sociodemographic characteristics of survey participants.

	Survey participants (N = 1796)	Population
	Mean	Mean
Age (for aged 18 or older)[1]	49.67	46.30
Female[1]	50.20%	50.30%
Living with partner/spouse[1]	69%	48%
Unemployed[2]	4.20%	2.50%
Adjusted household income (1000 s NOK)[1]	735.96	582.98
Non-Norwegian[1]	10%	21%
College degree or higher[2]	70%	50%
Household size (persons)[1]	2.38	1.94
Household with children[1]	33%	26%

Notes: [1]Population mean for Oslo and Akershus. [2]Population mean for Oslo Municipality. *Source*: Statistics Norway (2019).

Table A2
Ordered logistic regression models examining how built environment relates to telehealth before and during COVID-19.

Variables	Telehealth					
	Before COVID-19		During COVID-19		During COVID-19 accounting for Before COVID-19	
	1	2	1	2	1	2
Built environment						
Distance to city center	−0.295	−0.323	−0.016	−0.037	0.061	0.050
Neighborhood density	−0.177	−0.428	0.007	−0.246	0.064	−0.164
Public transport		−0.029		−0.001		0.037
Local facilities		0.074		0.267		0.270
Green space		−0.289		−0.017		0.061
Sociodemographic variables						
Age	0.338*	0.342*	−0.044	−0.039	−0.161[a]	−0.157
Female	0.077	0.078	0.218**	0.224**	0.230*	0.238**
Unemployed	0.098	0.097	0.082	0.079	0.052	0.050
Living with partner/spouse	−0.308*	−0.306*	−0.018	−0.018	0.072	0.070
Non-Norwegian	−0.097	−0.091	0.089	0.082	0.140	0.132
Adjusted household income	0.002	−0.009	−0.120	−0.121	−0.147	−0.145
College degree or higher	0.206	0.207	0.220*	0.217*	0.173[a]	0.171[a]
Household with children	0.059	0.068	0.054	0.068	0.072	0.086
Disability	0.340*	0.334*	0.489***	0.484***	0.440***	0.438***
Telehealth Before COVID-19						
Never					12.133***	12.072***
Sporadically					13.698***	13.635***
Occasionally					14.973***	14.932***
Often					16.602[na]	16.534[na]
Every day (ref.)						
Summary statistics						
N	1796	1796	1796	1796	1796	1796
Nagelkerke R-squared	0.019	0.021	0.040	0.042	0.266	0.268

Notes: [a]$p < 0.10$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. na: not applicable because estimate tends to infinity. All coefficients shown are standardized.

Table A3
Ordered logistic regression models examining how built environment relates to online shopping before and during COVID-19.

Variables	Online shopping					
	Before COVID-19		During COVID-19		During COVID-19 accounting for Before COVID-19	
	1	2	1	2	1	2
Built environment						
Distance to city center	−0.102	−0.108	−0.085	−0.075	−0.051	−0.032
Neighborhood density	0.092	0.104	0.087	0.163	0.050	0.143
Public transport		−0.031		0.022		0.064
Local facilities		−0.080		−0.102		−0.088
Green space		−0.114		−0.001		0.081
Sociodemographic variables						
Age	−0.406***	−0.406***	−0.587***	−0.587***	−0.478***	−0.477***
Female	0.062	0.060	0.057	0.057	0.041	0.042
Unemployed	0.092	0.092	−0.022	−0.021	−0.103*	−0.101[a]
Living with partner/spouse	−0.179**	−0.180**	−0.093[a]	−0.095[a]	0.001	0.000
Non-Norwegian	−0.070	−0.065	−0.066	−0.063	−0.035	−0.034
Adjusted household income	0.448***	0.444***	0.414***	0.416***	0.233***	0.237***
College degree or higher	0.338***	0.340***	0.233***	0.235***	0.089	0.089[a]
Household with children	0.201**	0.200**	0.202***	0.199***	0.120*	0.118*
Disability	0.016	0.012	0.000	0.002	−0.011	−0.008
Online shopping Before COVID-19						
Never					−10.090***	−10.101***
Sporadically					−8.360***	−8.372***
Occasionally					−6.519***	−6.525***
Often					−4.190***	−4.194***
Every day (ref.)						
Summary statistics						
N	1796	1796	1796	1796	1796	1796
Nagelkerke R-squared	0.121	0.123	0.179	0.179	0.556	0.557

Notes: [a]$p < 0.10$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. All coefficients shown are standardized.

Table A4
Ordered logistic regression models examining how built environment relates to online dating before and during COVID-19.

Variables	Online dating					
	Before COVID-19		During COVID-19		During COVID-19 accounting for Before COVID-19	
	1	2	1	2	1	2
Built environment						
Distance to city center	−0.236	−0.260	−0.270	−0.269	−0.131	−0.029
Neighborhood density	0.061	0.082	−0.139	0.022	−0.368	−0.231
Public transport		−0.112		0.011		0.306
Local facilities		−0.026		−0.091		−0.009
Green space		−0.111		0.135		0.476
Sociodemographic variables						
Age	−1.083***	−1.083***	−1.070***	−1.077***	−0.314	−0.310
Female	−0.447**	−0.446**	−0.334*	−0.348*	0.043	0.032
Unemployed	0.222*	0.220*	0.073	0.068	−0.153	−0.174
Living with partner/spouse	−2.475***	−2.475***	−2.203***	−2.206***	−0.421	−0.446
Non-Norwegian	−0.108	−0.105	−0.045	−0.047	0.110	0.117
Adjusted household income	0.315*	0.312*	0.112	0.110	−0.305	−0.291
College degree or higher	0.402**	0.398*	0.331*	0.333*	−0.166	−0.176
Household with children	−0.207	−0.218	−0.240	−0.247	−0.029	−0.002
Disability	−0.306[a]	−0.308[a]	−0.317[a]	−0.315[a]	−0.270	−0.323
Online dating Before COVID-19						
Never					−12.633***	−12.701***
Sporadically					−8.000***	−8.026***
Occasionally					−6.371***	−6.353***
Often					−4.318***	−4.330***
Every day (ref.)						
Summary statistics						
N	1796	1796	1796	1796	1796	1796
Nagelkerke R-squared	0.352	0.352	0.295	0.295	0.677	0.679

Notes: [a]$p < 0.10$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. All coefficients shown are standardized.

Fig. A1. Teleactivities before and during COVID-19. *Notes*: Telework and teleconferencing for work were analyzed only for workforce participants and students among the sample (N = 1300). For the other activities, the whole sample was analyzed (N = 1796).

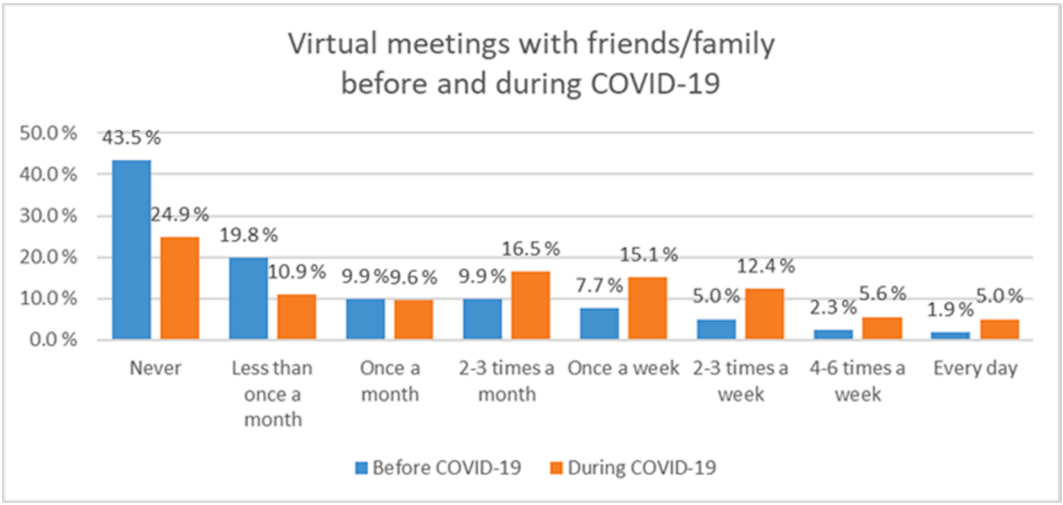

Fig. A2. Virtual meetings with friends/family before and during COVID-19 (sample size N = 1796).

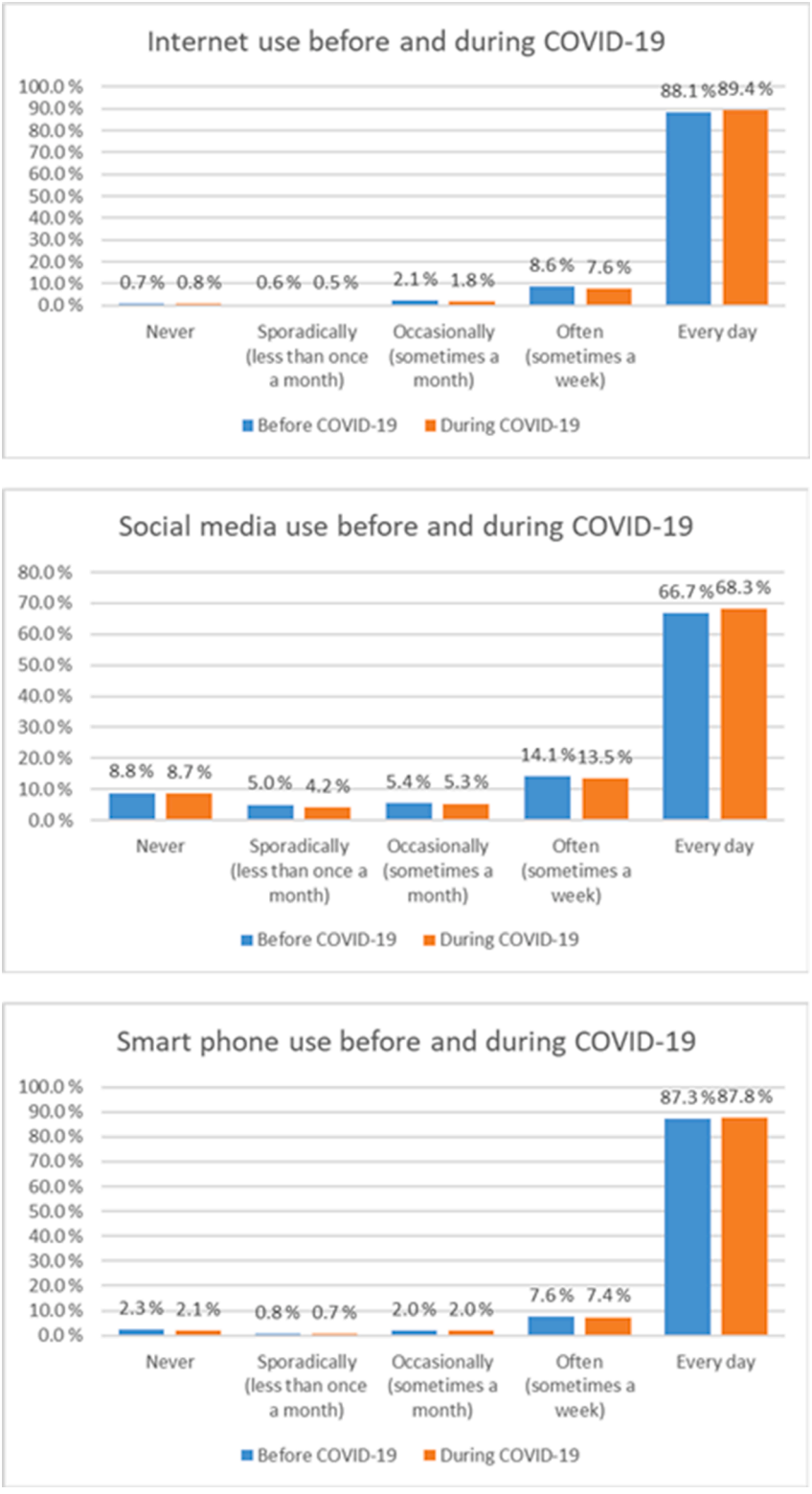

Fig. A3. Use of internet, social media, and smart phone before and during COVID-19 (sample size N = 1796).

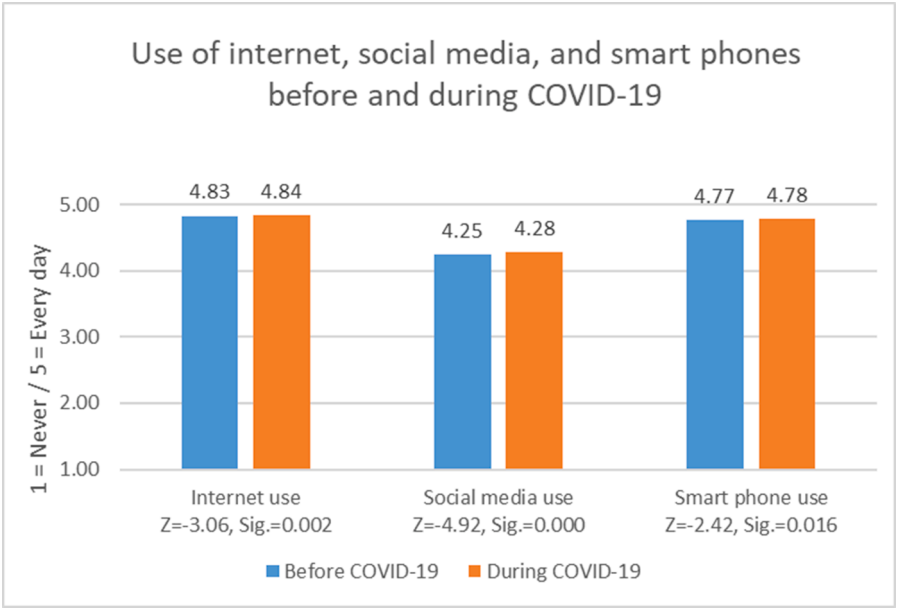

Fig. A4. Mean frequency of online activities before and during COVID-19 and Wilcoxon signed-rank tests comparing frequencies before and during COVID-19 (Sample size: N = 1796). *Note:* Z scores are based on negative ranks.

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