



Studying the Interrelationship between Telecommuting during COVID-19, residential local accessibility, and active travel: a panel study in Montréal, Canada

Rodrigo Victoriano-Habit¹ · Ahmed El-Geneidy¹

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Abstract

The COVID-19 pandemic led to a substantial increase in the number of people working from home (*telecommuting*), in turn leading to unprecedented changes in mobility patterns worldwide. Due to the changing context of the pandemic, there is still a significant gap in knowledge regarding the effects of working from home on workers' travel patterns. The main goal of this work is to unravel the interrelationship between telecommuting during the COVID-19 pandemic, the frequency of active travel for non-work utilitarian purposes, and local accessibility levels around workers' homes. This study uses a longitudinal approach by analyzing travel and telecommuting behavior data from a two-wave survey administered in Montreal in 2019, pre-pandemic, and 2021, during COVID-19 (n=452). Through a set of weighted multi-level linear regressions, we study the effects of telecommuting on the frequency of active travel for non-work utilitarian purposes, mediated by local accessibility around the household. Results show that the effect of telecommuting on non-work active travel for utilitarian purposes is highly dependent on local accessibility levels around the person's household. For workers living in high local accessibility areas, an increase in telecommuting during the pandemic has induced an increase in active trips for non-work utilitarian purposes. On the other hand, for workers residing in low local accessibility neighborhoods, the effect is the opposite. This research provides insights into the effects of telecommuting on non-work active travel, an area that is currently of interest to policy-makers and practitioners working towards increasing the level of physical activity among individuals through travel.

Keywords Telecommuting · Telework · Active travel · Local accessibility · COVID-19 · Panel analysis

✉ Ahmed El-Geneidy
ahmed.elgeneidy@mcgill.ca

Rodrigo Victoriano-Habit
rodrigo.victoriano@mail.mcgill.ca

¹ McGillUniversity, Quebec, Canada

Introduction

The COVID-19 pandemic has led to unprecedented changes in mobility patterns worldwide due to lockdowns and various health intervention measures. Almost all regions around the world experienced a substantial increase in the number of people working from home (*telecommuting*) and participating in various activities remotely (Reuschke and Felstead 2020). Since the beginning of the pandemic, it has been speculated that these large impacts on travel patterns can be a pivotal point for the renaissance of active modes of travel (Nurse and Dunning 2020). Although nowadays there is considerably less travel to work, with many employers still encouraging telecommuting, the use of private vehicles for various purposes has nearly recovered compared to pre-pandemic levels (Melo 2022). In this context, it is still not clear if the large increase in telecommuting during the lockdown periods has truly led to more use of active modes of travel for non-work purposes or the opposite.

Due to the changing context of the pandemic and the different manner in which telecommuting affects several dimensions of workers' lives, there is still a significant gap in knowledge regarding the effects of working from home on workers' general well-being (Lunde et al. 2022). While pre-COVID-19 studies have linked telecommuting to an increase in the likelihood of walking and cycling (Chakrabarti 2018), it is not yet clear what the impact of telework on active travel is in the context of increased telecommuting during the pandemic. This is of particular relevance since active travel has been shown to be a good way to increase people's physical activity and mental health (Kroesen and De Vos 2020; Panik et al. 2019).

While some studies suggest that the higher levels of telecommuting during COVID-19 have increased active travel for leisure (Doubleday et al. 2021), to our knowledge there are no studies that focus on non-work utilitarian purposes. Moreover, since active travel has been shown to be highly dependent on local accessibility levels (Ewing and Cervero 2010; Saelens and Handy 2008), we hypothesize that residential local accessibility acts as a moderator variable in the effects of telecommuting on active mode use. In this context, the main goal of this work is to unravel the interrelationship between telecommuting, frequency of active travel for non-work utilitarian purposes, and local accessibility levels around workers' homes, specifically during the COVID-19 pandemic.

To achieve this goal, we take a panel approach using a two-wave survey administered in the Greater Montreal Area. To unravel the interrelationship between active travel, telecommuting, and local accessibility, while also taking the specific context of increased telecommuting during COVID-19 into account, we estimate three weighted multi-level linear regressions. With a first set of two models, we study the frequency of travel for non-work utilitarian purposes as a response to (i) the frequency of telecommuting, and (ii) the interrelated effect of telecommuting and local accessibility. Subsequently, we use a third model to study (iii) the interrelated effect of telecommuting and local accessibility on the frequency of travel for non-work utilitarian purposes, specifically in the context of increased telecommuting during the COVID-19 pandemic.

Literature review

In a matter of weeks, the spread of COVID-19 and the imposition of non-pharmaceutical measures to combat the pandemic changed mobility patterns worldwide. One of the most relevant aspects in the evolution of mobility patterns throughout the pandemic is that reduction in travel flows has not been uniformly distributed across transport modes (Pereira et al. 2021). While public transit has suffered steep declines in ridership (Tirachini and Cats 2020), the use of private vehicles for various purposes has nearly recovered compared to pre-pandemic levels (Melo 2022). Within this context, since the beginning of the pandemic, it has been speculated that COVID's impacts on mode split can be an opportunity for increasing the use of active modes, such as walking and cycling (Nurse and Dunning 2020).

Active modes of transport have been a relevant topic for travel behavior research and urban planning alike, as their use has been shown to beget several benefits for people's general well-being. For instance, when compared to motorized mode use, the use of active modes is known to have a positive impact on physical health (Panik et al. 2019), mental health (Kroesen and De Vos 2020), general quality of life (Fordham et al. 2018), and trip satisfaction levels (St-Louis et al. 2014). For these reasons, promoting active travel is widely seen as a desirable outcome of transport planning. However, there is still no general consensus on the effect of the pandemic on current and future mode share for active modes. For instance, Doubleday et al. (2021) have shown that the pandemic has had a reduction effect on walking and cycling, except for the purpose of leisure, for which active mode use has increased. On the other hand, Thombre and Agarwal (2021) showed that, although active mode use has presented a relative decrease due to the pandemic, the effect hasn't been as steep due to mode switching as a result of public transport avoidance.

The changes in urban mobility patterns brought about by the pandemic are largely related to changes in activity patterns, with an increase in the frequency of remote activities (Rahman et al. 2021; Reuschke and Felstead 2020). In this context, the popularity of remote working (or *telecommuting*) has largely increased and is expected to persist even after the COVID-19 pandemic is over (Mohammadi et al. 2022). However, even before the pandemic, there has been an interest in the effect of telecommuting on mobility patterns, as well as on mental and physical health (Mokhtarian 1991). Previous research has shown that telecommuting has positive impacts on workers performing it, such as increased perceived quality of life (O'Keefe et al. 2016). On the other hand, other studies have shown that telecommuting can also result in negative impacts on physical health, as it increases time spent sitting and reduces the frequency of physical activities (Kooshari et al. 2021). Moreover, due to the changing context of the pandemic and the different manner in which telecommuting affects several dimensions of workers' lives, there is still a significant gap in knowledge regarding the effects of working from home on workers' physical activity and health (Lunde et al. 2022).

A relevant way in which telecommuting can affect workers' health is through its impact on the use of active modes of transport, given the multiple benefits that their use has been shown to beget (Fordham et al. 2018; Kroesen and De Vos 2020; Panik et al. 2019). What past studies have shown in the pre-pandemic context, when telecommuting was restricted to a more limited fraction of workers (Mokhtarian 2009; Reuschke and Felstead 2020), is that teleworkers have a higher probability of using active modes (Chakrabarti 2018), which is also linked to the performance of shorter trips (Elldér 2020). While telecommut-

ing eliminates the necessity to travel to work, it has been shown that teleworkers have an increased frequency of travel for non-work purposes (Caldarola and Sorrell 2022). It is this context that has led to the speculation that the increasing frequency of telecommuting due to the COVID-19 pandemic can result in a more frequent use of active modes of transport (Nurse and Dunning 2020). However, studies during the COVID-19 pandemic have associated higher telework frequency with a potential increase in car use once the pandemic is over (Javadinasr et al. 2022). Thus, given that the pandemic context may have changed the relationship between teleworking and mode choice, analyses of the relationship between active travel and telecommuting need to be revisited.

Previous analyses have shown that factors related to the built environment are key predictors of active mode use frequency (Ewing and Cervero 2010). Improving local accessibility of an urban area has been linked to an increased likelihood of incurring in active travel (Saelens and Handy 2008), as well as an increase in equity in active travel among genders and age groups (Althoff et al. 2017). One popular measure of local accessibility is WalkScore, which focuses on the number and diversity of activities that can be reached within walking distance, has been tested repeatedly in the land use and transport literature (Hall and Ram 2018) showing reliability in predicting active travel behavior (Manaugh and El-Geneidy 2011).

While local accessibility has been shown to be a highly relevant factor in predicting levels of active travel, to our knowledge no previous studies have inquired into the interaction between telecommuting and local accessibility, and its joint effect on active mode use. Additionally, since eliminating the commute to work changes peoples' activity spaces, then telework also has the potential to influence telecommuters' experienced accessibility levels throughout the day (Tribby et al. 2016). This can, in turn, affect their active travel behavior. For this reason, this work tests the hypothesis that the impact of telecommuting on active non-work utilitarian trips is mediated by residential local accessibility within the specific context of increased telecommuting due to the COVID-19 pandemic.

This paper contributes to the existing literature in several ways. First, given the large changes brought by the COVID-19 pandemic to activity participation and travel behavior, analyses of the relationship between telecommuting and mode choices need to be revisited. Specifically, this work focuses on active mode use for utilitarian purposes, as this can mitigate the sedentary lifestyle that teleworking may promote (Kooshari et al. 2021). In this way, this paper addresses the impacts of increased telecommuting during COVID-19 on both workers' travel behavior and physical health. Additionally, this work helps unravel the effect of telecommuting on active mode use while taking the effect of residential local accessibility into account as a moderator variable. To the best of our knowledge, this has not yet been tested in the existing literature. Finally, this paper contributes to the literature by unraveling complex interrelationships in travel behavior through a longitudinal approach. This kind of approach has been strongly recommended for unraveling causal links in travel behavior but is seldomly used due to high costs and complexity (van de Coevering et al. 2015).

Data

This study uses data collected through a two-wave online survey administered in the Greater Montreal Area to participants 18 years of age and older. The first wave of the survey collected 3,533 valid responses between October and November of 2019 (pre-pandemic), while the second wave collected 4,063 valid responses between October and November of 2021 (during the pandemic). All those who participated in wave 1 and provided their email address received an invitation to participate in wave 2. Through this process, we received 1,541 responses in wave 2 from participants who had previously answered wave 1.

To ensure the representativeness of the sample, in both waves we employed various recruitment techniques recommended by Dillman et al. (2014). These techniques included the distribution of flyers at various residences and downtown transport hubs, as well as targeted online recruitment through paid and unpaid advertisements on various social media platforms. Incentives were included in the survey such as the possibility of winning a prize based on a draw. A public opinion survey company was also hired in both waves to help in recruiting part of the sample.

The same data-cleaning process was applied to both waves of the survey to ensure consistency in the exclusion criteria of unreliable responses. Some of these exclusion criteria were related to responders' time in filling out the survey, multiple responses being filled by the same e-mail or IP address, and invalid age and height changes between 2019 and 2021. In terms of the time in which the respondent filled the survey, the fastest 5% were excluded from the sample depending on the number of questions answered in each wave. It must be noted that different groups of respondents, depending on their answers, got different sets of questions. Each of these groups was cleaned according to their own respective top 5% speed. Those who placed a pin representing their home, school, and/or work location outside the Montreal metropolitan region were also excluded. This led to a final sample of 870 valid and complete responses answering both waves, out of which 452 were working in both waves of the survey and indicated a valid primary work location.

The two waves of the survey included the same questions pertaining to travel behavior information such as frequency of travel, telecommuting, and mode choices. Respondents' sociodemographic and economic characteristics, as well as residential choice factors, which allow us to control for residential self-selection, were collected in both waves. For each person in the sample, we know their individual pre-pandemic behavior, as well as their current behavior (during the pandemic). This allows to assess the impacts of new telecommuting that respondents adopted due to the pandemic on travel behavior for non-work utilitarian purposes, namely grocery shopping and attending healthcare facilities. Since this work focuses on the effect of telecommuting, we only analyze and model the responses of the 452 workers in the sample with a valid primary work location, excluding students and retirees.

To account for residential local accessibility levels, we retrieved the WalkScore for each respondent's home from *walkscore.com*. WalkScore is a popular measure of local accessibility which has been repeatedly tested in the land use and transport literature (Hall and Ram 2018), and has shown reliability in predicting active travel patterns (Manaugh and El-Geneidy 2011). The WalkScore index is produced through a gravity-based assessment of amenities within a 30-minute walk of a location (Walk Score, 2022). The index considers several types of amenities, including grocery stores, schools, parks, restaurants, and coffee shops. The value of WalkScore ranges from 0 to 100 and is typically classified into one of

four categories: car-dependent (0–49), somewhat walkable (50–69), very walkable (70–89), and walker’s paradise (90–100) (Walk Score, 2022). For the first-wave sample, WalkScore was retrieved in 2019, while for the second-wave sample it was retrieved in 2021. Thus, our data accounts for changes in residential local accessibility both in the case of respondents moving house or due to changes in time.

Methods

To achieve this work’s main goal of unraveling the interrelationship between active travel for non-work utilitarian purposes, telecommuting, and local accessibility in the context of increased telecommuting during COVID-19, we estimate three weighted multi-level linear regressions. The methodological framework followed in this work is summarized in Fig. 1. In our first model, we use a panel three-level linear regression with the number of weekly trips conducted by an active mode for non-work utilitarian purposes. In this context, active modes include walking and cycling, and non-work utilitarian purposes include grocery shopping and going to healthcare facilities. The main independent variables of Model 1 are the frequency of telecommuting and the home-location local accessibility measured through WalkScore. Since Model 1 assumes that the effects of telecommuting frequency and home-location local accessibility are independent, in Model 2 we consider the interaction between these two effects. In this context, Model 2 is identical to Model 1 except for the inclusion of the interaction variable constructed from multiplying weekly telecommuting frequency by home-location WalkScore.

Model 1 and Model 2 use a three-level approach in which we use the census tract of the home location as the higher level. This allows to control for characteristics shared by a neighborhood that are otherwise unaccounted for. The second and lowest levels of the models, person-level and person-wave-level respectively, give the model its longitudinal component. That is to say, this model takes the dataset in long format (i.e., each row is one time point per person) and the second-level random effects control for the fact that observations in different waves can correspond to the same respondent. However, it must be noted that when using this three-level panel format, we assume that the effect of telecommuting on non-work utilitarian active travel frequency is the same in 2019 as it is in 2021.

To study the effect of the frequency of telecommuting on non-work utilitarian active travel specifically in the context of COVID-19, our third model uses a different modeling approach. In this third model, we use the number of weekly trips conducted for non-work utilitarian purposes by an active mode in 2021 as the dependent variable. In this context, the model is specified as a two-level weighted linear regression, where the higher level is the census tract of the home location, and the dataset is introduced in its wide format (i.e., each row consists of a person’s repeated responses). Here, the longitudinal component is considered by predicting behavior in 2021 by factors from both 2019 and 2021.

To evaluate the effect of increased telecommuting during the pandemic, we used the difference in weekly telecommuting between 2021 and 2019 to measure its impacts on non-work utilitarian active travel. The relevance of using this difference in telecommuting between the two survey waves is that it allows us to measure the impact of telecommuting specifically during the COVID-19 pandemic, as opposed to most previous research on telecommuting (e.g., Caldarola and Sorrell 2022; Ell  r 2020). Since, in this third model, the

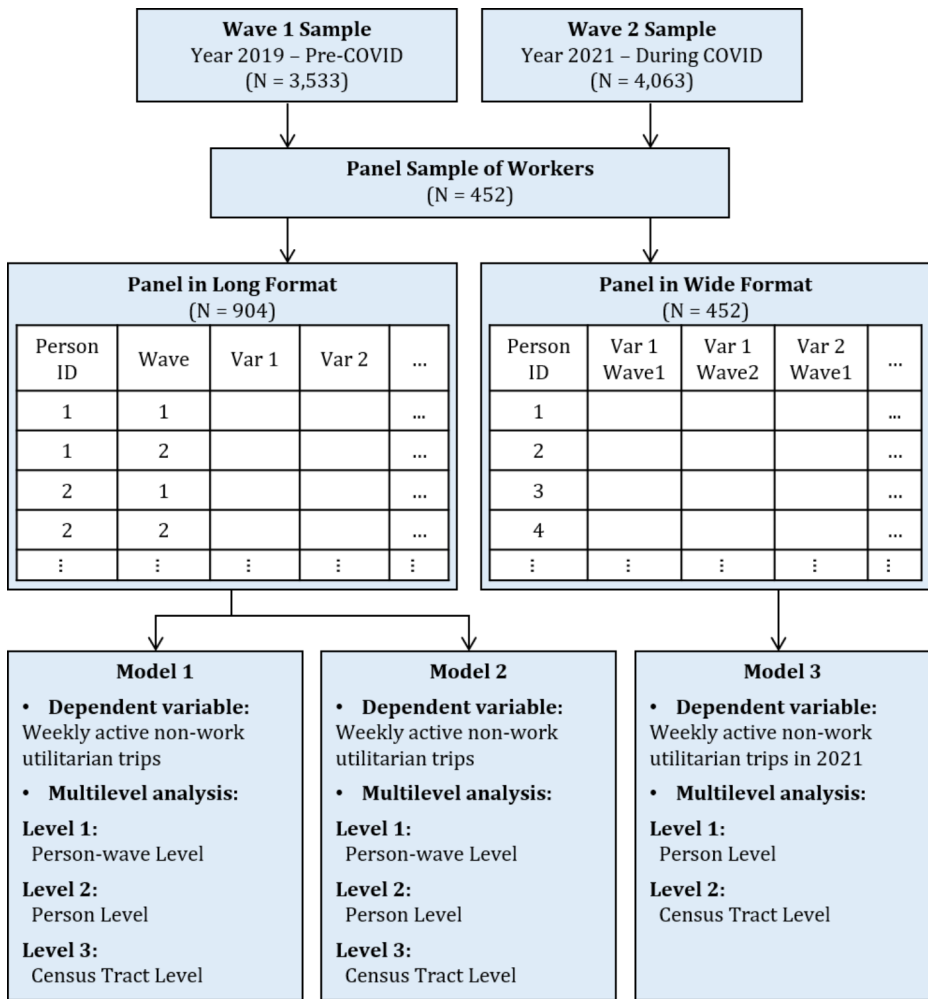


Fig. 1 Methodological framework

dependent variable relates to behavior in 2021 and is being predicted by factors that relate to both current and pre-pandemic behavior, in order to control for past active mode use, we also introduced the number of weekly non-work utilitarian active trips reported in 2019.

Each model considered additional independent variables to control for sociodemographic characteristics and residential self-selection. In the case of sociodemographic characteristics, gender, age, and household income were tested but were not statistically significant in any of the models. Car ownership at the household level was also tested and included in the models in which it had statistical significance. To control for residential self-selection, we incorporate respondents' reported importance factors for neighborhood choice. These factors were reported in a five-level Likert scale and are also described in Table 1. Moreover, to assess non-linear effects of local accessibility, we tested the squared value of the home-

location WalkScore as an independent variable. This variable was only included in model 3 as it was not statistically significant for other models.

The weighted multilevel linear regression was the method selected for all three models estimated as it responds to several requirements of this work's objective. First, for models 1 and 2, the second level of the random-effects structure (person level) accounts for the longitudinal component of the dataset when it is taken in its long format (Fig. 1). Second, for all three models, the highest level (census-tract level) allows to control for common characteristics shared in a neighborhood that are otherwise unaccounted for, such as the quality of active transport infrastructure and frequency of crime. Third, the weighting process is key to ensure that the resulting effects of telecommuting and local accessibility on active travel are not biased by the sampling of the survey. Lastly, the coefficients of this type of model are easily interpretable as the marginal effect of independent variables on the explained variable, reason for which this method has been widely used in the travel behavior literature (El-Assi et al. 2017; El-Geneidy et al. 2014; Faghih-Imani et al. 2014; Grisé and El-Geneidy 2017).

All of the weighted multilevel linear regressions were estimated using the lme4 R package (Bates et al. 2015). The weightings in the model were calculated for all valid responses in the panel using the anesrake R package (Pasek 2018). The weights were calculated to match our sample to census tract information of age, income, and gender from the Statistics Canada 2016 Census (Statistics Canada, 2016), retrieved through the cancensus R package (von Bergmann et al. 2021).

Results and discussion

Data description

Table 1 includes the description of the sample in terms of their sociodemographic characteristics and modelling variables, and Fig. 2 presents the geographical location of the respondents' households within the Greater Montreal Area in 2021. Our two-wave sample of 452 workers is composed of 53.3% of participants identifying as men. Because this sample focuses only on workers, it can be seen that most respondents are between 30 and 64 years of age. The sample presents variability among income groups, and there is a general tendency of income levels increasing from 2019 to 2021. Residential local accessibility presents large variability, with a good representation of all WalkScore groups. This is also seen in Fig. 2, showing that there is a large spatial representation of the sample over the Greater Montreal Area. Moreover, the sample's local accessibility levels seem to have remained stable over time between 2019 and 2021.

As expected, telecommuting frequency suffered a large increase from the first to the second wave of the survey. While 78.7% of the sample did not telecommute in 2019, this percentage went down to 31.5% in 2021. Moreover, while only 4.9% of the sample were telecommuting 5 days per week in 2019, this number increased to 42.6% in 2021. In terms of non-work active trips for utilitarian purposes, the share of people with zero weekly trips suffered a slight decrease, from 54.3% to 2019 to 50.8% in 2021. However, there is also a slight decrease in the number of people doing five or more non-work active weekly trips,

Table 1 Sample description by survey wave

Variable		Wave 1 (2019)	Wave 2 (2021)
		Mean (std. dev.)	Mean (std. dev.)
N		452	
Sociodemographic			
Gender	<i>[1=man]</i>	53.3%	
Age	<i>[years]</i>		
<i>[18–29]</i>		16.2%	10.0%
<i>[30–44]</i>		42.1%	42.6%
<i>[45–64]</i>		39.9%	45.2%
<i>[65–80]</i>		1.8%	2.2%
Household Income	<i>[\$/year]</i>		
<i>\$120,001 or more</i>		33.3%	40.1%
<i>\$60,001 - \$120,000</i>		42.4%	44.6%
<i>\$60,000 or less</i>		24.4%	15.3%
Local accessibility			
Neighborhood WalkScore	<i>[1-100]</i>		
<i>[0–49]</i>		37.9%	39.2%
<i>[50–69]</i>		23.1%	21.3%
<i>[70–89]</i>		28.2%	29.3%
<i>[90–100]</i>		10.9%	10.2%
Telecommuting			
Weekly days telecommuted	<i>[days/week]</i>		
<i>No telecommuting</i>		78.7%	31.5%
<i>1 to 4 days per week</i>		16.4%	25.9%
<i>5 days per week</i>		4.9%	42.6%
Non-work travel			
Non-work active trips	<i>[trips/week]</i>		
<i>None</i>		54.3%	50.8%
<i>1 to 2 trips per week</i>		23.3%	27.1%
<i>3 to 4 trips per week</i>		14.2%	15.5%
<i>5 or more trips per week</i>		8.2%	6.7%
Residential Self-Selection			
Neighborhood car-friendliness	<i>[5 levels]</i>	3.33 (1.42)	3.24 (1.44)
Familiarity with the neighborhood	<i>[5 levels]</i>	3.66 (1.13)	3.72 (1.07)
Near the work/school of HH member	<i>[5 levels]</i>	3.48 (1.28)	3.44 (1.23)
Being near family and friends	<i>[5 levels]</i>	3.25 (1.21)	3.38 (1.16)
Being near cycling infrastructure	<i>[5 levels]</i>	3.25 (1.22)	3.20 (1.23)

from 8.2% to 2019 to 6.7% in 2021. Finally, it can be seen that attitudes towards residential selection remain stable over time between 2019 and 2021.

Modelling results

The results for models 1 and 2 are presented in Table 2, in which the dependent variable is the weekly number of active trips for non-work utilitarian purposes. In Model 1, from the wave 2 coefficient we can conclude that, when keeping all else constant, people had a lower frequency of active travel for non-work utilitarian purposes, with 0.21 trips less in 2021

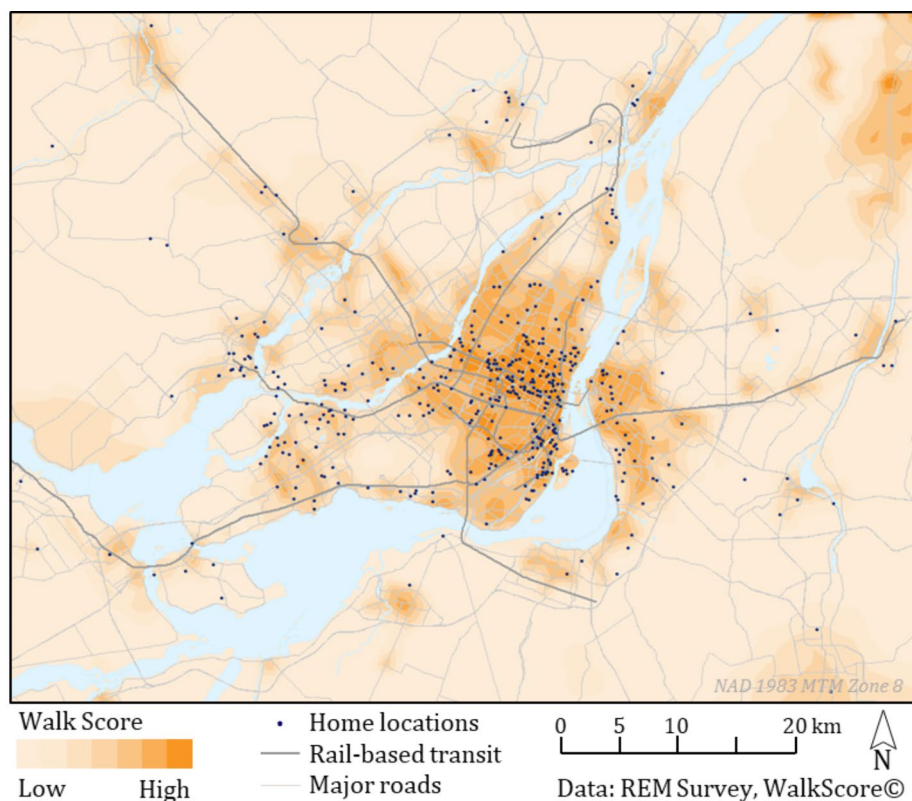


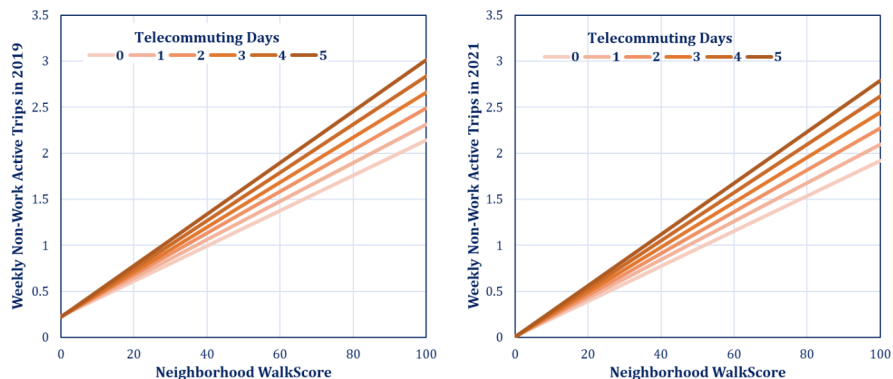
Fig. 2 Home location of survey participants and WalkScore levels in 2021

than in 2019. From this model, we can also conclude that telecommuting has a small but statistically significant positive effect of 0.1 additional non-work utilitarian active trips for each additional day of telecommuting. In terms of the effect of local accessibility, for every 10-point increase in WalkScore, weekly active trips performed for non-work utilitarian purposes increase by 0.2 trips. Having at least one private vehicle in the household reduces the dependent variable in 0.4 weekly trips, *ceteris paribus*. The residential self-selection factors in Model 1 show that a preference for car-friendly environments decreases non-work utilitarian travel by 0.23 trips, while the preference for neighborhoods that are near to the respondent's family and friends increases the frequency of active travel for non-work utilitarian purposes. Similarly, a preference for proximity to cycling infrastructure also has a positive effect on our dependent variable.

Model 2, which is identical to Model 1 except for the inclusion of the interaction between telecommuting frequency and local accessibility, shows nearly identical results to Model 1. The effect of telecommuting frequency is not statistically significant, yet the interaction term with local accessibility is statistically significant. The best way to understand these results is through a sensitivity analysis shown in Fig. 3. We calculated the number of weekly non-work utilitarian active trips for 2019 and 2021 separately, by fixing every independent variable to the sample's mean except for local accessibility and the number of telecommut-

Table 2 Models 1 and 2: Weekly non-work utilitarian active trips as the dependent variable

Variable	Model 1		Model 2	
	Coefficient	95% C.I.	Coefficient	95% C.I.
Intercept	0.23	[-0.46; 0.92]	0.40	[-0.31; 1.11]
Wave 2 (Year 2021)	-0.21**	[-0.41; -0.01]	-0.22**	[-0.42; -0.02]
Telecommuting				
Weekly days telecommuted	0.10***	[0.04; 0.16]	-0.001	[-0.11; 0.11]
Local accessibility				
Home location WalkScore	0.02***	[0.02; 0.03]	0.02***	[0.01; 0.03]
Telecommuting-WalkScore interaction				
Telecommuting days * WalkScore	--	--	0.002**	[0.000; 0.003]
Car ownership				
At least 1 car in the household	-0.40**	[-0.72; -0.08]	-0.40**	[-0.72; -0.08]
Residential self-selection factors				
Neighborhood car-friendliness	-0.23***	[-0.33; -0.13]	-0.23***	[-0.32; -0.13]
Being near family and friends	0.14***	[0.04; 0.24]	0.14***	[0.04; 0.24]
Being near cycling infrastructure	0.13**	[0.03; 0.23]	0.13**	[0.03; 0.23]
Observations	904		904	
N_{PEOPLE} / N_{CT}	452 / 374		452 / 374	
ICC_{PEOPLE} / ICC_{CT}	0.45 / 0.15		0.45 / 0.15	
σ^2	1.15		1.14	
$\tau_{00\text{ PEOPLE}} / \tau_{00\text{ CT}}$	1.29 / 0.43		1.28 / 0.44	
AIC	3524.8		3534.8	
BIC	3577.6		3592.5	
Pseudo-R2 (fixed effects / total)	0.25 / 0.70		0.25 / 0.70	

** $p < 0.05$ *** $p < 0.01$ **Fig. 3** Model 2 telecommuting-WalkScore sensitivity analysis for 2019 and 2021

ing days. We varied these two key variables within their possible ranges: 0 through 100 in the case of WalkScore, and 0 to 5 telecommuting days a week.

The analysis in Fig. 3 shows that the effect of increasing telecommuting frequency on the number of active trips for non-work utilitarian purposes depends strongly on the worker's home-location local accessibility levels. For workers living in higher local accessibility

Table 3 Model 3: Weekly non-work utilitarian active trips in 2021 as dependent variable

Variable	Model 3	
	Coefficient	95% C.I.
Intercept	0.65	[-0.22; 1.52]
Telecommuting		
Changes in telecommuting	-0.06	[-0.19; 0.08]
Local accessibility		
Home location WalkScore	-0.02**	[-0.04; 0.00]
WalkScore squared	0.0003***	[0.0000; 0.0005]
Telecommuting-WalkScore interaction		
Change in telecommuting * WalkScore	0.002**	[0.000; 0.004]
Pre-pandemic travel behavior		
2019 Non-work active trips	0.40***	[0.34; 0.47]
Residential self-selection factors		
Neighborhood car-friendliness	-0.24***	[-0.35; -0.14]
Familiarity with the neighborhood	0.11**	[0.02; 0.28]
Near the work/school of HH member	0.15**	[0.00; 0.22]
Observations	452	
N _{CT}	315	
ICC _{CT}	0.10	
σ^2	1.58	
$\tau_{00\text{ CT}}$	0.17	
AIC	1711.5	
BIC	1756.8	
Pseudo-R2 (fixed effects / total)	0.47 / 0.53	

** p<0.05 *** p<0.01

areas, the effect of telecommuting is positive and larger than that predicted by Model 1. In fact, for workers living in an area with a maximum WalkScore of 100, each additional telecommuting day results in 0.2 additional weekly active trips for non-work utilitarian purposes, assuming all else remains constant. This is double the value predicted by Model 1. For workers in low local accessibility areas, the effect of increasing telecommuting frequency is almost negligible.

Table 3 presents the results of Model 3, with weekly non-work utilitarian active trips in 2021, during COVID-19, as the dependent variable. Similar to results in Model 2, while the effect of change in telecommuting from 2019 to 2021 is not statistically significant, other coefficients in the model allow to understand the effect of telecommuting on active travel. In this model, both home-location WalkScore and WalkScore squared are statistically significant, indicating a non-linear effect of local accessibility on non-work utilitarian active trips during COVID-19. Additionally, the interaction between telecommuting and local accessibility implies that the effect of telecommuting is strongly dependent on the worker's home-location local accessibility levels in the pandemic context.

A good way to illustrate these interrelated effects and how they differ from the results from Model 2 is through the sensitivity analysis shown in Fig. 4. We calculated the number of weekly non-work utilitarian active trips in 2021 by fixing every independent variable to the sample's mean, except for local accessibility and the number of additional telecommuting days during the pandemic, which we varied within their respective ranges. Through the results in Fig. 4, we can conclude that home-location local accessibility acts as an important

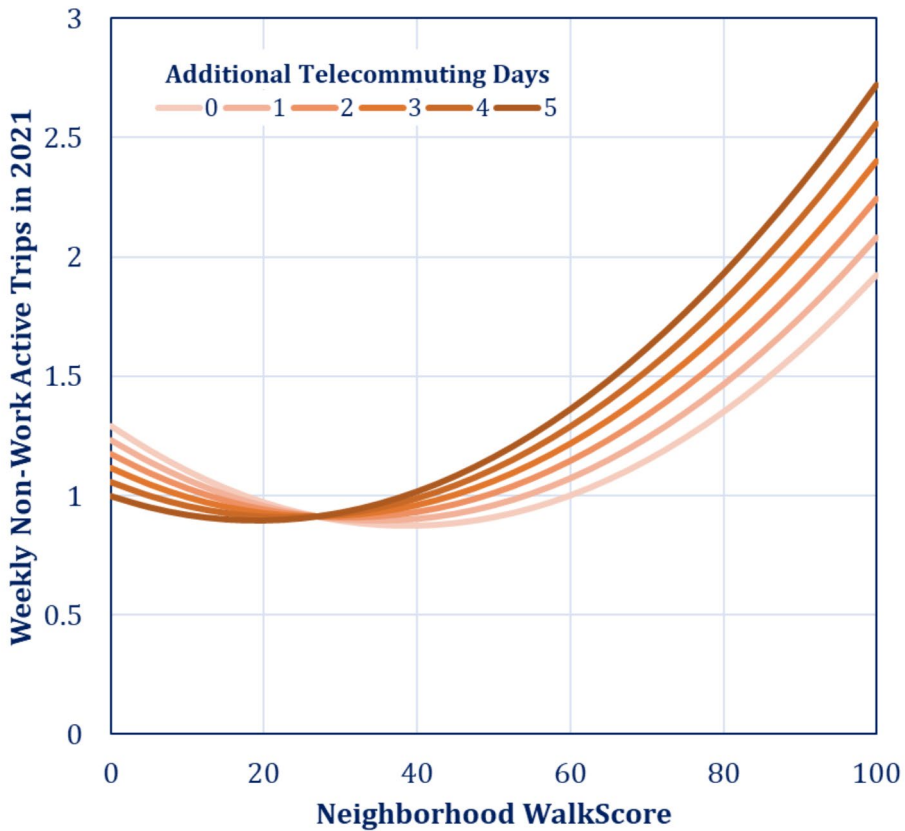


Fig. 4 Model 3 telecommuting-local accessibility sensitivity analysis

moderator variable in the effect of increased telecommuting due to COVID-19 on active travel. Workers living in high local accessibility areas experienced an increase in active trips for non-work utilitarian purposes during the COVID-19 period. The results show that the effect is the opposite for workers in the lowest local accessibility areas, who decrease their active travel for non-work utilitarian purposes. Thus, while Model 2 showed that telecommuting has no statistically significant effect on the active mode use of workers in the lowest local accessibility areas, Model 3 shows that additional telecommuting days during COVID-19 has had a negative effect on the active mobility of these workers.

Model 3 also controls for residential self-selection, showing that a preference for car-friendly environments has a negative and statistically significant effect on non-work utilitarian travel, *ceteris paribus*. A preference for neighborhoods that were previously familiar to the respondent increases the frequency of active travel for non-work utilitarian purposes, similar to the preference for proximity to the workplace or school of a household member.

It is relevant to note that, while there is no explicit control of sociodemographic variables in the models, we estimated versions of all three regressions which included several sociodemographic characteristics as independent variables, none of which showed to be statistically significant. Among the tested variables were age, income, number of children

in the household, marital status, and environment while growing up (urban, suburban, or rural), all of which showed no significant effects. A binary variable indicating if a worker was employed full-time or part-time was tested as well, showing no significant effect.

Discussion and policy implication

The results from this work allow to draw relevant conclusions regarding travel behavior during the pandemic through a multi-period design. In turn, many of these conclusions can help policy-making in a post-pandemic context, as well as provide methodological insights for longitudinal analyses of travel behavior in the future.

Our results from models 1 and 2 yield interesting results with respect to the effects of telecommuting on active non-work trips. First, both of these models allow to conclude that active trips for non-work utilitarian purposes have suffered a small decrease which is not related to telecommuting. This suggests that a renaissance of active modes due to the pandemic (Nurse and Dunning 2020) may not be the case, at least for workers in the Canadian context. Moreover, this result highlights the necessity of promoting public policies that encourage active-mode use which are specifically designed for the post-pandemic context.

The results from Model 2 show that the effect of telecommuting is strongly dependent on the worker's home-location local accessibility levels. This means that eliminating the necessity of commuting to a workplace only results in more non-work utilitarian active travel when there is a potential for reaching a destination within a small distance from home. From this, it can be concluded that ignoring the interrelated effect of telecommuting and local accessibility results in an inaccurate estimation of non-work utilitarian active trips. More specifically, ignoring the effect of local accessibility as a moderator variable results in an underestimation of non-work utilitarian active trips for workers in high local accessibility areas, and an overestimation for workers in low local accessibility areas.

The results of Model 3 provide an interesting complement to models 1 and 2. While this model's specification does not allow the conclusion that, keeping all else constant, there has been a reduction in non-work active utilitarian trips, it allows for other relevant insights. First, this model specification does not assume that the effect of telecommuting on active travel was the same pre-pandemic as it was during the pandemic. With this specification, active-travel behavior in 2021 is considered a result of active-travel behavior in 2019, as well as a result of the change in telecommuting frequency. Most importantly, this allows to unravel the fact that the effect of increased telecommuting frequency during the pandemic results in fewer active trips for non-work purposes for workers living in the most car-dependent areas.

In the long term, these results suggest that the best intervention for increasing active mobility for non-work purposes can be achieved through increasing local accessibility in car-dependent areas. That is, increasing the number and diversity of amenities that can be reached from residential areas within walking or cycling distance. While the importance of local accessibility in promoting active travel has been widely shown by previous literature (Ewing and Cervero 2010; Saelens and Handy 2008), to our knowledge, this is the first study that shows the effect of local accessibility as a moderator variable in the effect of telecommuting on active travel. In this context, this study shows that local accessibility has taken a heightened role during the pandemic given the increase in telecommuting frequency.

Moreover, this heightened relevance of local accessibility can be expected to remain, at least partially, once the pandemic is over, as post-pandemic frequencies of telecommuting are expected to be higher than pre-pandemic levels (Javadinasr et al. 2022).

This work complements past studies which have concluded that teleworkers have a higher frequency of active travel (Chakrabarti 2018; Elldér 2020). As these previous studies, our results suggest that telecommuting may be encouraged as a public policy to increase active mode use. However, our results also show that, if policies are designed by analyzing the effect of telecommuting on active mobility on its own, ignoring the mediating effect of local accessibility, the expected positive outcomes in active mobility could be largely overestimated. In this context, this work highlights the relevance of designing transport policy that correctly adapts to the post-pandemic context. Considering the interaction between the increase in telecommuting due to the pandemic with local accessibility is key for effective policy design, which clearly shows the relevance of local accessibility and its positive impacts on active travel.

In our model estimations, we found that no individual or household sociodemographic characteristics of the respondent are significant to explain workers' active mode use when accounting for telecommuting and local accessibility. This indicates that the effect of telecommuting is influenced significantly more by the worker's neighborhood characteristics than their personal characteristics. This goes against the results of Elldér (2017), which suggested that telework would decouple travel behavior from urban form, making only personal characteristics relevant.

Conclusion

In this work, we inquired into the interrelationship between telecommuting during the COVID-19 pandemic, the frequency of active travel for non-work utilitarian purposes, and local accessibility levels around workers' homes. Using a set of weighted multi-level linear regressions, we analyze a two-wave survey administered in the Greater Montreal Area in the years 2019 and 2021, allowing us to study the specific context of increased telecommuting frequency due to the COVID-19 pandemic.

Through our first model, we conclude that increasing telecommuting frequency has a positive average effect on the frequency of active travel for non-work utilitarian purposes. However, through our second model, we conclude that this positive effect is strongly dependent on the local accessibility levels of workers' home locations. More specifically, we conclude that this effect increases with higher local accessibility levels and that there is no effect of telecommuting on non-work utilitarian active trip frequency for workers living in the lowest local accessibility areas. The results of these two models lead us to conclude that ignoring the interrelationship between telecommuting frequency and local accessibility levels results in an overestimation of the effect of telecommuting on active travel for workers in low local accessibility areas, and an underestimation for workers in high local accessibility areas.

Through our third and final model, we study the interrelated effect of change in telecommuting during the COVID-19 period and local accessibility levels on active travel. For this specific context, we corroborate that the effect of telecommuting on non-work active travel for utilitarian purposes is highly dependent on workers' home-location local accessibility

levels. More specifically, for workers living in high local accessibility areas, our modelling results suggest that an increase in telecommuting during the pandemic has also induced an increase in the number of active trips for non-work utilitarian purposes. On the other hand, for workers who live in low local accessibility neighborhoods, results suggest that the effect is the opposite. We speculate that, for workers living in higher local accessibility areas, not having to travel to work gave them more time to interact with their local context.

Our results can be of value to the travel behavior literature. To our knowledge, these are the first results to incorporate local accessibility as a moderating variable of the effect of telecommuting on active travel. This work shows that, for the case of utilitarian purposes, telecommuting increases active mode use when the worker's home has available destinations by active modes. Additionally, these results' conclusions suggest that, at least for active non-work utilitarian purposes, neighborhood local accessibility showed to be more relevant than sociodemographic characteristics.

In terms of policymaking, the two main implications of our results are that, first, if telecommuting is meant to be promoted with the goal of increasing active travel, then it should be mostly incentivized for people living in higher local accessibility areas, while for people living in lower local accessibility areas it should be accompanied by land-use policies that encourage positive changes in local accessibility. Secondly, improving neighborhood local accessibility increases the likelihood that people will incur in active travel, which goes in line with past results (Ewing and Cervero 2010; Saelens and Handy 2008). Our results suggest that this is especially the case in a context of increased telecommuting. Thus, our results additionally suggest that the benefits of increasing local accessibility in the COVID-19 context are larger than in pre-pandemic years.

One limitation of this work is that we assume a linear effect of every telecommuted day on non-work utilitarian active trips. However, previous works have shown that there could be an exponential effect, as more telecommuting allows for larger changes in mobility strategies and lifestyle (Asgari et al. 2019). Another limitation is that we don't take into account trip-chaining behavior, which has been shown to be more prevalent in workers living in lower accessibility areas (Chowdhury and Scott 2020).

As a future line of work, it would be interesting to inquire into a similar analysis for active trips for non-utilitarian purposes, i.e., recreation and socialization. The effects of telecommuting and the moderating effect of local accessibility on these purposes are not intuitive, since walking and cycling for recreation are not as dependent on the availability of destinations as utilitarian purposes, or even socializing. Another possibility for future work would be to corroborate the effects found in this work in the future, as COVID-19's effect on daily behavior starts to decrease, including a wider time gap and potentially more survey waves in future studies. Future results will depend on the prevalence of telecommuting in a post-COVID world, as well as on workers' adjustments towards voluntary telecommuting.

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