Did air pollution continue to affect bike share usage in Seoul during the COVID-19 pandemic?

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ABSTRACT

Introduction

The role of cycling has become more important in the urban transport system during the Covid-19 pandemic. As public transport passengers have tried to avoid crowded vehicles due to safety concerns, a rapid surge of cycling activities has been noted in many countries. This implies that more cyclists might be exposed to air pollution, potentially leading to health problems in cities like Seoul where the level of air pollution is high.

Methods

We utilised three years of bike sharing programme (Ddareungi) data in Seoul and time series models to examine the changes in the relationship between particulate concentration ($PM_{2.5}$) and daily cycling duration before and during the pandemic.

Results

We find that cyclists reacted less to the $PM_{2.5}$ level during the pandemic, potentially due to the lack of covid-secure travel modes. Specifically, our results showed significant negative associations between concentrations of $PM_{2.5}$ and daily cycling duration before the pandemic (year 2018 and 2019). However, this association became insignificant in 2020.

Conclusions

Building comprehensive cycling infrastructure that can reduce air pollution exposure of cyclists and improving air quality alert systems could help build a more resilient city for the future.

1. INTRODUCTION

Cycling has played an important role in urban transport systems during the coronavirus pandemic. A rapid surge of cycling activities has been noted in many countries, and several cities have utilised this opportunity to improve their cycling infrastructure (Adkins, 2021, Buehler and Pucher, 2021, Hong et al., 2020). As public transport passengers have tried to avoid crowded vehicles due to concerns over the transmission of the virus, cycling seems to have been a viable alternative to private cars during the pandemic.

Cycling has been a key research topic for several decades due to its substantial health and environment benefits (Oja et al., 2011, Götschi et al., 2016, Pucher and Buehler, 2008, Unwin, 1995). Increased levels of cycling could reduce car-dependency and improve public health. However, cyclists are vulnerable to traffic collisions and air pollution, potentially reducing the health benefits of cycling. Although several studies have shown that the health benefits of cycling outweigh the negative effects of air pollution exposure or traffic collisions (Tainio et al., 2016, Schepers et al., 2015, Hartog et al., 2010, Mueller et al., 2015), a body of research on the air pollution exposure of cyclists has continued to grow due to the potential health impacts (Krecl et al., 2020, Raza et al., 2018, Bergmann et al., 2021).

Seoul, South Korea, has suffered from a high level of air pollution for several years, and has adopted various policies and regulations to improve the air quality (Kim et al., 2020). For example, the government introduced ambient air quality standards updated in 2015. In addition, an air pollutant emission cap management system was implemented in Seoul in 2008 (Trnka, 2020). Health concerns over air pollution have grown continuously, and have become a key political issue (McCurry, 2019). During the pandemic, cycling activities have increased while public transport ridership has decreased substantially in Seoul. Car traffic has also decreased but to a much lesser extent than public transport ridership (see Table1)[1]. This indicates that a substantial portion of the increase in cycling could be

[1] It is worth noting that cycling activities have increased as shown in Figure 2.

explained by the shift from public transport to cycling, leading to little environment improvement. It also implies that more cyclists might be exposed to air pollution due to a relatively high level of inhalation doses compared to drivers or public transport passengers (Dons et al., 2019, Apparicio et al., 2018, Kim et al., 2009). In addition, the health benefits of increased physical activities in highly-polluted areas like Seoul could be negligible for certain groups of people (Kim et al., 2021).

Cyclists could modify their travel behaviour according to the air pollution level to mitigate adverse health effects (e.g., shift to other travel modes on days with poor air quality). However, it may not be the case during the pandemic due to the lack of safe travel options, potentially resulting in adverse health effects. We could face more outbreaks in the future, and planners should understand their potential effects on cycling and related health issues to build a more resilient city. Unfortunately, empirical studies, especially for highly-polluted Asian cities, are scarce, limiting our knowledge.

In this paper, we examined how the total volume of trips on shared bicycles changes in response to the level of particulate matter ($PM_{2.5}$) before and during the pandemic. Specifically, we investigated the relationship between the level of $PM_{2.5}$ and total daily cycling duration between 2018 and 2020 by utilising bike sharing programme (Ddareungi) data from Seoul, South Korea and time series regression models. The results will provide empirical evidence for environmental and transport planners for making better plans in the future.

Table 1 Changes in vehicles and public transport usage

	2019	2020	Reduction
Motorised vehicles*	10,586	10,091	-495 (-4.7%)
Public transport passengers**	10,445	7,767	-2,678 (-34.5%)

Unit: thousand vehicles/people per day

* Daily average (0 to 24hr) traffic collected at 135 common points in 2019 and 2020 (https://topis.seoul.go.kr/refRoom/openRefRoom_2.do)

** Passengers of mass public transport modes (subway lines 1-9 and Wui New Line, local buses, and community buses (https://news.seoul.go.kr/traffic/archives/31616.))

2. LITERATURE REVIEW

The health and economic benefits of cycling have been well documented in various studies (Fishman et al., 2015, Blondiau et al., 2016, Maizlish et al., 2017). Several studies showed the net positive health benefits of cycling despite the air pollution exposure. Some argued that the level of air pollution exposure of cyclists or pedestrians is not as high as that of drivers or public transport passengers (de Nazelle et al., 2012, Cepeda et al., 2017) while other studies showed the opposite results (Vouitsis et al., 2014, Wang et al., 2021, Briggs et al., 2008). Importantly, the high inhalation doses of cyclists compared to drivers or public transport passengers (Apparicio et al., 2018, Borghi et al., 2021) were reported in several studies, potentially resulting in relatively worse health effects on cyclists compared to other travellers. Moreover, short and long-term exposure to air pollution causes serious health issues (Kampa and Castanas, 2008), leading to active research on cycling and air pollution exposure (Weichenthal et al., 2011, Lu et al., 2019, Raza et al., 2018, Tran et al., 2020). It is also worth noting that these health effects studies rely heavily on dose-response function assumptions, which could result in substantial variations in results.

A limited number of studies have examined how cyclists change their travel behaviour to mitigate the adverse effects of air pollution. For example, using their own survey, Zhao et al. (2018) investigated the reactions to air pollution ($PM_{2.5}$) across different groups of cyclists. Their result showed that female cyclists are more sensitive to air pollution than males. In addition, income and the perception of safety and comfort are important determinants of cycling in hazy weather. Anowar et al. (2017) examined the extent to which cyclists are willing to trade-off air pollution exposure with other factors such as travel time. Their results indicated that cyclists would change to routes with a low level of air pollution if it added only a small amount of time (less than 4 minutes). Other studies also provide evidence of behavioural changes (e.g., reduction in outdoor activities) in response to high levels of air pollution (An et al., 2017, Roberts et al., 2014, Cole-Hunter et al., 2015). These studies imply that cyclists are likely to change their behaviour (e.g., shift to other transport modes) to avoid or reduce their exposure to air pollution. Some research also showed that the behavioural response may be stronger in highly polluted areas such as Seoul (Jun and Min, 2019).

Other studies have emphasized the importance of information/knowledge for influencing environmental behaviours (Tan and Xu, 2019, Radisic et al., 2016, Delmas and Kohli, 2020, Wen et al., 2009). Some acknowledged that disseminating information on air pollution through smartphone apps or other air pollution alert systems could be an effective way to promote behaviour change. Saberian et al. (2017), for instance, evaluated the effectiveness of air pollution alert programmes on the reduction of cycling volumes, and found a reduction of between 14% and 35% when an alert was issued.

A body of research has examined the relationship between the built environment and air pollution exposure for active travel users (Hankey et al., 2012, Farrell et al., 2016). Air pollution dispersal depends on various factors such as meteorological conditions, geographic features and the characteristics of sources. Built environments and traffic conditions are also important factors, leading to variations in the level of air pollution exposure within a city (Zhou et al., 2018, Miskell et al., 2015). Jarjour et al. (2013) showed that cyclists could reduce traffic-related air pollution exposure by choosing low-traffic bicycle boulevards. Weichenthal et al. (2014) argued that traffic conditions and built environment factors are the most important determinants of ultrafine particles and black carbon concentrations in a city. Gilliland et al. (2018) also showed the substantial variations in the air pollution exposure level within routes, and land use factors are closely associated with air pollution exposure. Interestingly, street trees and high residential land use have negative relationships with $PM_{2.5}$ concentrations.

In sum, previous studies provide evidence that travellers will adapt their travel behaviour to lower their exposure to air pollution although there are still limited empirical studies, especially for developing countries (Zhao et al., 2018). This trend can be reinforced through information/knowledge dissemination strategies. In South Korea, air pollution issues have been a key political issue, and the effect of making real-time air quality information available on outdoor activities has already been evaluated (Yoo, 2021). However, there is a lack of empirical studies about how cyclists react to high levels of air pollution in South Korea, and how this relationship changes before and during the pandemic. In this study, we utilised three years of bike sharing programme data and time series models to examine the relationship between $PM_{2.5}$ concentrations and total daily cycling duration before and during the pandemic. It is worth nothing that the intention of this study is to investigate the overall relationship between $PM_{2.5}$ concentrations and total daily cycling duration rather than examining individual level behaviour with detailed characteristics of cyclists. The overall relationship represents the sum of individual relationships. This approach does not require information of individual characteristics and these are not included in the bike sharing programme data. In addition, the chosen approach is appropriate to answer our key research question (i.e., how does the overall relationship between PM2.5 concentration and total daily cycling duration change before and during the pandemic?).

3. DATA AND ANALYTICAL MODEL

Seoul is the capital of South Korea with a population of approximately 10 million inhabitants. It is considered as a global city and has a comprehensive public transport network. For example, the subway system has 9 lines, 302 stations and about 327 km of track (Railway Technology, 2020). More than 10 million passengers per day have used the public transport system in Seoul since 2013 except in 2020 (about a 34% reduction due to COVID-19)[2]. Total modal shares of buses and subway in 2019 were about 24% and 41.6%, respectively[3]. During the pandemic, several government interventions (e.g., social distancing, reduction of public transport services, work from home/study for some government workers and university students) have been introduced although there was no

[2] https://news.seoul.go.kr/traffic/archives/31616
[3] https://news.seoul.go.kr/traffic/archives/285

lockdown in Seoul. The government also urged companies to adopt flexible work hours and work from home to reduce the transmission rate of the virus at the workplaces (Cha, 2020). These interventions reduced total traffic volumes. However, the public transport ridership reduced significantly (Cho and Yoon, 2020) while coping with these new interventions. In addition, the frequency of public transport services has dropped for certain times of day (e.g., after 10pm), potentially increasing the use of other transport modes (e.g., cars or cycling).

Ddareungi is the official bike rental service provided by the Seoul metropolitan government since 2015. In 2021, there were 3,040 bike stations[4] in Seoul, and they are well connected with the public transport system. Figure 1 shows a map of Ddareungi stations and the subway system in Seoul. We can easily see that most Ddareungi stations are located along the subway lines and near stations. The number of registered users has increased substantially. During the Pandemic, rentals increased by about 24% compared to 2019. For the analysis, we utilised three-years of Ddareungi data (2018-2020). Data are publicly available (http://data.seoul.go.kr/dataList/OA-15246/F/1/datasetView.do). Since there is only one bike rental service in Seoul, the data include all rental cycling activities in Seoul. In addition, three years of data allow us to consider a time trend in rental cycling activities while examining the changes caused by the COVID-19 pandemic with a time series model. Data include aggregated information on total rentals, distances, and durations according to date, station, age, gender and membership. After processing, we have total 1,092 observations (2018: 363 days; 2019: 363 days; and 2020: 366 days). For the main analysis, we calculated daily total cycling duration (the daily sum of the time each bike was rented for) and used it as a dependent variable since it is the most relevant measure for air pollution exposure. We took a square-root transformation[5] due to the skewed distribution of daily total cycling durations. It is worth noting that the characteristics of bikeshare users may be different from the general cyclists. For example, Buck et al. (2013) compared personal and travel characteristics of bikeshare users in Washington D.C. (from two bikeshare

[4] https://news.seoul.go.kr/traffic/archives/504919. About 900 new bike stations were installed in 2021.
[5] It is worth noting that square-root transformation seems to perform better than log-transformation based on residual analyses.

member surveys) with those of area cyclists (from the regional travel survey). Their results showed that bikeshare users are more likely to be female, younger and have fewer bicycles than general cyclists. In addition, they tend to cycle for utilitarian purposes more than general cyclists. Therefore, our results should be interpreted with care.

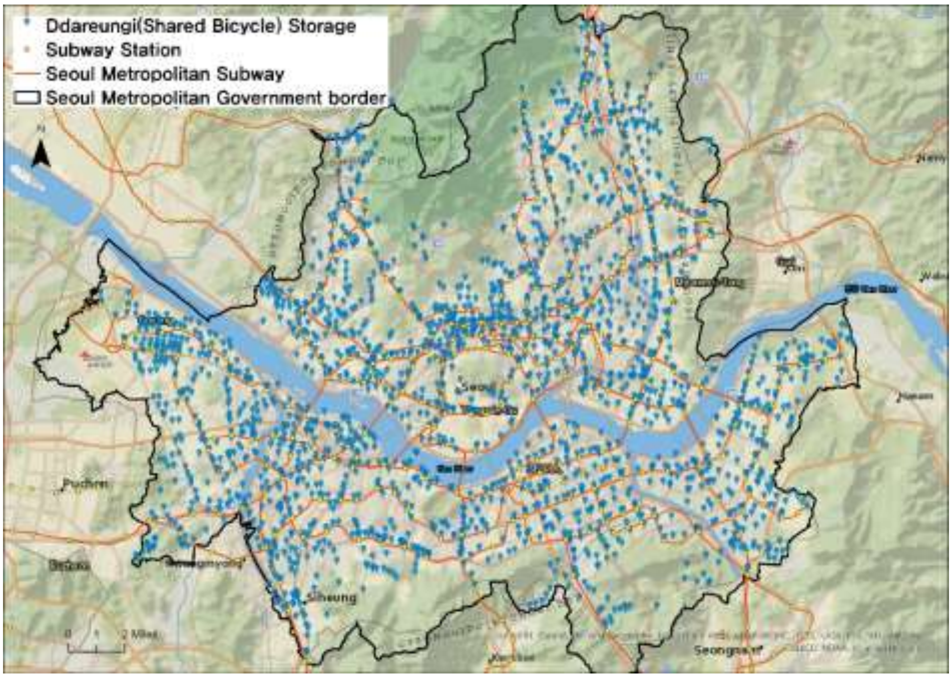

Figure 1 Map of Ddareungi stations and the subway system in Seoul, South Korea

Figure 2 shows the average daily total number of bicycle rentals and trip durations across the days of week between 2018 and 2020. We can see the substantial increases in total rentals and durations since 2018. Average total rentals show that people used Ddareungi more on weekdays compared to weekends. This implies that Ddareungi served as an effective travel mode for daily activities and potentially first-last mile connection based on its excellent connections to the public transport system. Interestingly, people spent more time cycling during the weekend than weekdays even though the number of rentals is lower. This could be due to leisure and exercise activities during the weekend, and most weekdays trips (e.g., first-last mile of commute or connection) are short ones.

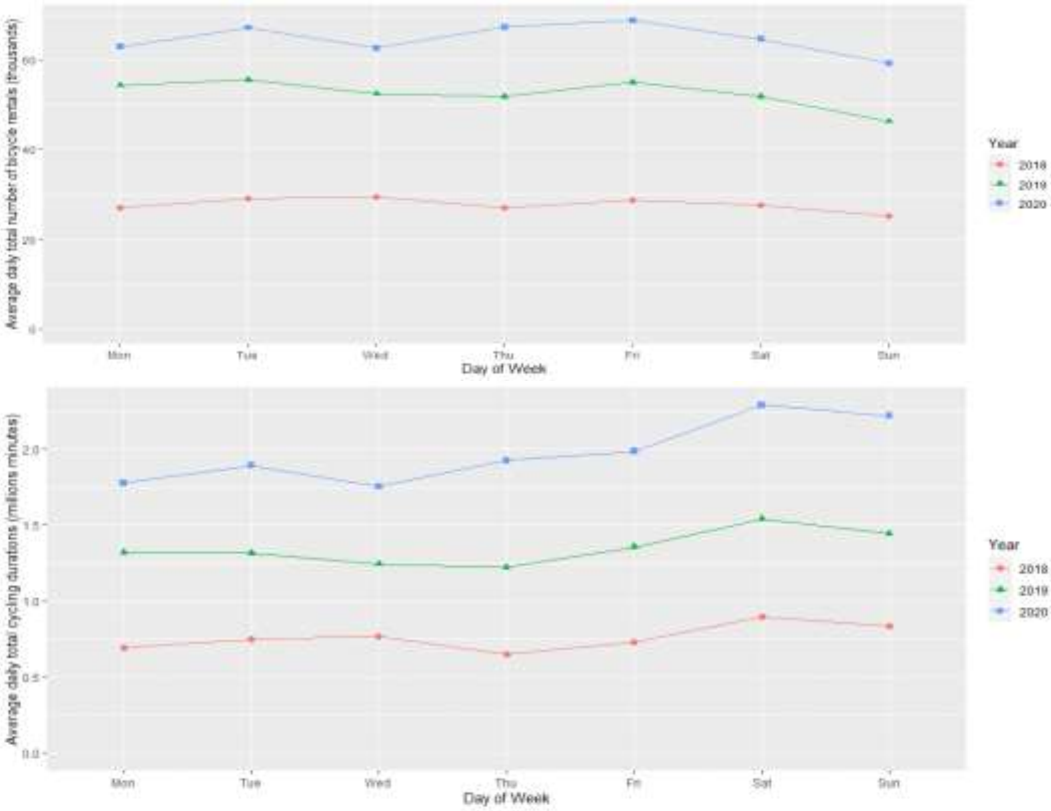

Figure 2 Average daily total rental cases and durations across the day of week

The seven-day moving averages of daily total cycling durations are shown in Figure 3. The cycling durations increased in spring and autumn but decreased rapidly during the middle of summer. This could be due to the high temperature and typhoons in summer in Seoul. This indicates that seasonal effects and weather conditions should be controlled in the main analyses.

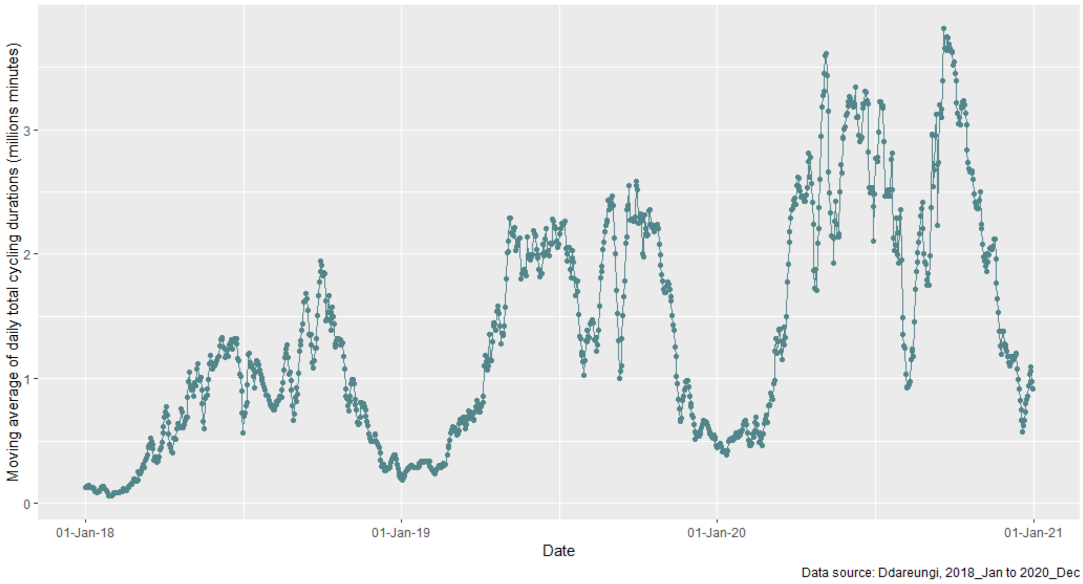

Figure 3 Moving average of daily total cycling durations (2018-2020)

We chose to quantify air pollution using the concentration of fine particulates ($PM_{2.5}$ i.e., particles with a diameter of 2.5 µm or less). $PM_{2.5}$ data for Seoul can be downloaded from the Seoul government website (https://cleanair.seoul.go.kr/statistics/dayAverage). Data provide the $PM_{2.5}$ level of 25 Gu (administrative districts) in Seoul. We calculated daily average $PM_{2.5}$ levels across 25 districts from 2018 to 2020, and used it as the key independent variable. Figure 4 shows the average levels of $PM_{2.5}$ varied across years. There were significantly higher levels of $PM_{2.5}$ in winter in 2019. In general, $PM_{2.5}$ levels are high during winter and spring. Although the average level of $PM_{2.5}$ in 2020 is lower than that of 2019 (possibly due to the Covid-19 effects), a significant number of days in 2020 has much higher level of $PM_{2.5}$ against global standards (i.e., 35 µg/$m^3$and 25 µg/m^3). It implies that cyclists in Seoul, as in other developing countries, are more at risk of being affected by the harmful air pollutants than those in developed countries. Weather information was obtained from the NOAA Integrated Surface Database by using the worldmet package in R.

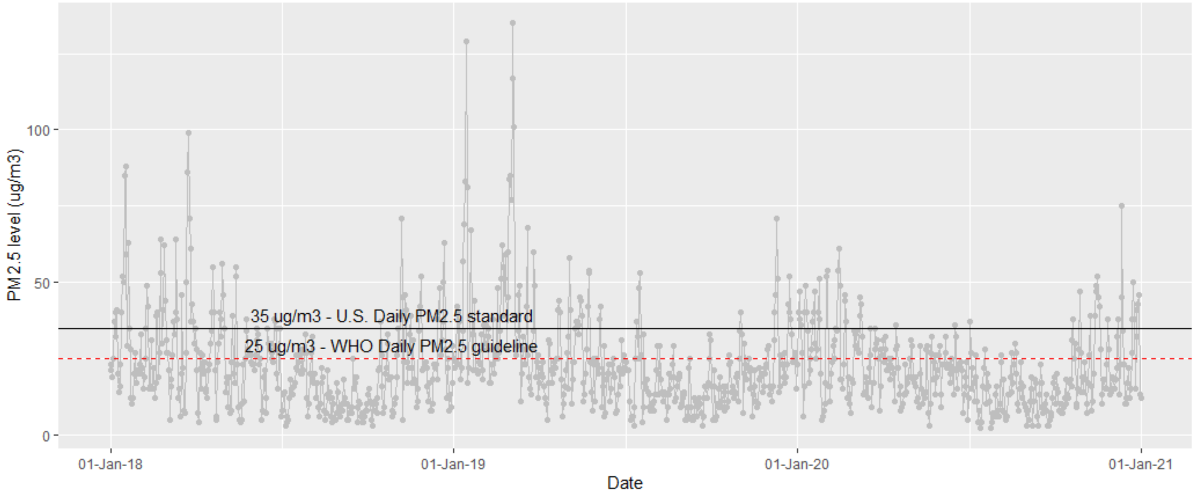

Figure 4 $PM_{2.5}$ levels between 2018 and 2020

For the main analyses, we utilised a linear regression model with an auto regressive moving average (ARMA) error term. The lag structure was selected using the auto.arima function from the forecast package in R (Hyndman and Khandakar, 2008). It searches for the best ARIMA model based on several measures of model fit such as AIC and BIC. First, we examined how $PM_{2.5}$ levels are related to the daily total cycling duration with an interaction term of *Year* and $PM_{2.5}$. The year variable (X_{year_t}) represents the pandemic period (2020), and the interaction term ($X_{year\_t} * X_{PM2.5\_t}$) indicates how the relationship between daily total cycling duration and $PM_{2.5}$ varies before and during the pandemic.

$$\sqrt{Y_{daily\ total\ cycling\ duration\_t}} = F(X_{dayofweek\_t}, X_{season\_t}, X_{weather\_t}, X_{year\_t}, X_{PM2.5\_t})$$

$$t = 1, \ldots, 1092 \text{ days} \qquad (1)$$

where, $X_{dayofweek\_t}, X_{season\_t}, X_{weather\_t}, X_{year\_t}$ *and* $X_{PM2.5\_t}$ represents day of the week (i.e., Monday to Sunday), season (i.e., spring, summer, autumn and winter), weather (i.e., max wind speed (m/s), average temperature (°C) and total precipitation (mm)), year of 2020 and $PM_{2.5}$ level, respectively.

Secondly, we modelled the relationship between $PM_{2.5}$ levels and daily total cycling duration for each year while controlling for day of week, season, and weather factors. The results will confirm how people reacted to the $PM_{2.5}$ level for each year, and how this relationship changed before and during the pandemic.

4. RESULTS

Table 2 shows the empirical results for the relationship between $PM_{2.5}$ levels and daily total cycling duration with an interaction of *Year* and $PM_{2.5}$. It shows that more time was spent cycling during weekends compared to Monday. This confirms what we saw in Figure 2. Although there are fewer rentals during the weekends compared to weekdays, people might use Ddareungi for leisure or exercise purposes during the weekends, resulting in longer trips. In addition, shorter duration trips on weekdays compared to weekends supports the hypothesis that Ddareungi was used as a feeder transport mode. Seasonal variables show that people used Ddareungi for more time in autumn compared to winter while controlling for other factors including weather conditions. In addition, all three weather variables are statistically significant at the 0.05 level of significance, and results are consistent with previous studies. As maximum wind speed or total precipitation increases, daily total cycling duration decreases significantly. On the other hand, daily total cycling duration increases as average temperature increases.

Table 2 Result of the relationship between $PM_{2.5}$ level and daily total cycling duration with the full sample (ARIMA (1,1,2)).

	Estimate	Standard errors	p-value	
Day of week (ref: Monday)				
Tuesday	9.312	17.792	0.589	
Wednesday	-6.682	18.522	0.704	
Thursday	-3.676	18.313	0.824	
Friday	5.132	18.396	0.765	
Saturday	87.340	18.581	0.000	**
Sunday	60.648	17.825	0.001	**
Season (ref: Winter)				

Spring	49.221	50.404	0.322	
Summer	15.937	58.539	0.770	
Autumn	96.097	50.501	0.056	.
Weather				
Max wind speed (m/s)	-13.151	5.533	0.017	*
Total precipitation (mm)	-11.970	0.510	0.000	**
Avg. temperature (°C)	24.098	1.921	0.000	**
Pandemic (Year 2020)				
Year (ref: 2018+2019)	-76.144	105.057	0.459	
Air pollution				
$PM_{2.5}$ ($\mu g/m^3$)	-1.844	0.506	0.000	**
Interaction of Year and $PM_{2.5}$	2.507	1.009	0.013	*
ar1	-0.760	0.089	0.000	**
ma1	0.006	0.079	0.918	
ma2	-0.692	0.061	0.000	**
Sample size	1092			

. significant at the 0.1 level; * significant at the 0.05 level; ** significant at the 0.01 level.

Year was not statistically significant. This is not a surprising result. Our testing procedure suggested that the dependent variable should be differenced to induce stationarity. This has the effect of removing a trend from the data. After this procedure, and controlling for our other variables, it seems 2020 was not different from previous years. $PM_{2.5}$ shows a negative and statistically significant association with daily total cycling duration before the year of 2020 (i.e., reference group). It implies that cyclists adopted behavioural changes to mitigate harmful effects of air pollution exposure before the pandemic. Interestingly, the coefficient of interaction between *Year* and $PM_{2.5}$ is positive and statistically significant at the 0.05 level of significance. It means that cyclists did not react to the $PM_{2.5}$ level to the same extent during the pandemic compared to pre-pandemic periods (i.e., 2018 and 2019) while all other factors were constant.

Table 3 Result of the relationship between $PM_{2.5}$ level and daily total cycling duration for each year.

	2018		2019		2020	
	Estimate	P-Value	Estimate	P-Value	Estimate	P-Value
Day of week (ref: Monday)						
Tuesday	35.634	0.122	-0.450	0.967	-15.934	0.667

Wednesday	23.348	0.340	-25.140	0.370	-28.808	0.452
Thursday	-10.962	0.641	-6.353	0.808	-5.791	0.865
Friday	15.313	0.516	-21.686	0.443	7.664	0.829
Saturday	88.181	0.000**	46.485	0.103	108.476	0.006**
Sunday	67.307	0.004**	24.228	0.360	90.444	0.019 *
Season (ref: Winter)						
Spring	15.450	0.793	95.592	0.213	85.867	0.376
Summer	3.802	0.940	198.987	0.027 *	-146.144	0.197
Autumn	185.239	0.005**	117.310	0.159	97.978	0.315
Weather						
Max wind speed (m/s)	0.428	0.935	2.333	0.795	-35.270	0.001**
Total precipitation (mm)	-10.585	0.000**	-15.602	0.000**	-11.652	0.000**
Avg. temperature (°C)	20.657	0.000**	24.626	0.000**	30.548	0.000**
Air pollution						
$PM_{2.5}$ (μg/m^3)	-1.655	0.006**	-1.637	0.011 *	-0.783	0.504
ar1	0.237	0.074 ·	0.972	0.000**	-0.858	0.000**
ar2	0.711	0.000**				
ma1	0.046	0.679	-0.707	0.000**	0.069	0.273
ma2	-0.689	0.000**	-0.088	0.101	-0.786	0.000**
Model	ARIMA (2,0,2)		ARIMA (1,0,2)		ARIMA (1,1,2)	
Sample size	363		363		366	

. significant at the 0.1 level; * significant at the 0.05 level; ** significant at the 0.01 level.

We modelled each year separately to examine the changes in the relationship between $PM_{2.5}$ level and daily total cycling duration more explicitly. The results are presented in Table 3. Although there are some variations, results are consistent. Weather conditions are important determinants of daily total cycling duration. Statistically significant relationships between $PM_{2.5}$ level and daily total cycling duration are found in pre-pandemic periods (2018 and 2019). However, it becomes insignificant in 2020. This implies that cyclists' reactions to air pollution changed during the pandemic. As shown in Table 1, a significant reduction in the public transport ridership compared to car trips implies the potential impacts of the fear of virus on people's travel choices towards safer private transport modes. It is also supported by the increased use of cycling. Although overall travel demand reduced due to government policies (e.g., work from home/study for some government workers and university students), most people still travelled for various activities in South Korea during the pandemic. Therefore, the result implies that people cycle more during the pandemic to reduce the risk of Covid-

19 virus exposure for their daily activities even on days when the air quality is not good.

5. CONCLUSIONS

Air pollution has become one of the key life concerns in South Korea. Various policies, including the deployment of an air quality forecasting system, have been implemented, and people have changed their behaviour to minimise harmful effects of air pollution. For instance, people limit their outdoor activities when the level of air pollution is high. This also applies to the use of active travel modes.

Cycling has become more popular during the pandemic in part because the transmission of the virus is less likely outdoors compared to on crowded public transport. People were reluctant to use public transport (e.g., bus and subway) during the pandemic, and cycling became a feasible option that could compete with private cars. Considering the health benefits of cycling through the increased level of physical activity, this is potentially beneficial for society. However, cyclists are often exposed to air pollution that will result in negative health outcomes, especially in developing countries like South Korea where the level of air pollution is high. The lack of covid-secure travel options for daily activities during the pandemic limits the scope for people to change their travel behaviour. People might cycle even when the air quality is bad in Seoul during the pandemic because it is preferable to the alternatives. In this study, we examined how cyclists reacted to the $PM_{2.5}$ level before and during the pandemic by utilising three-year bike sharing programme data and time series regression models.

Our results show that there were more Ddareungi trips, but with shorter durations, on weekdays compared to weekends. This supports a hypothesis that people used Ddareungi for their first and last mile of commute or connection. Seoul is one of the world's mega cities and has an extensive public transport system. This result suggests that the bike sharing programme in Seoul helps support sustainable urban transport.

Second, weather conditions are very important determinants of cycling use. Specifically, our result shows that daily total cycling duration increases as average temperature increases while it decreases as the level of precipitation increases. Seoul has a very hot and humid summer with a high level of precipitation. This is the reason why the cycling activities reduced during the middle of summer. Recently, several abnormal weather events were recorded in Seoul. Planners may need to consider that such events will become more frequent due to climate change and adopt appropriate mitigation measures where possible.

Lastly, we found that people reacted more to the $PM_{2.5}$ level prior to the pandemic. That is, daily total cycling duration decreases significantly as the $PM_{2.5}$ level increases. However, this significant association became insignificant in 2020. This could be due to the lack of covid-secure travel modes during the pandemic, possibly leading to harmful health effects. As shown in the literature, the level of air pollutant concentration varies across roads. This indicates that planners should consider air pollution levels when they build new cycling infrastructure. For example, they can avoid building cycling lanes along roads with heavy traffic (Cole-Hunter et al., 2012) and plant trees on the roads. More work could be done to reduce the overall level of car use in the city. Some health experts have argued that we are highly likely to face more outbreaks in the future (Whiting, 2020). Building comprehensive cycling infrastructure that can reduce air pollution exposure of cyclists could help build a more resilient city for the future.

For future work, it will be important to evaluate the net health benefits of cycling in the highly polluted mega cites during this unexpected time with more detailed cycling and air quality data. In addition, more detailed analyses about the spatial variations in the air quality across different areas (e.g., residential areas, sidewalk trees, park, etc) would be useful for planners. Finally, robust analyses of cycling behaviour depending on individual characteristics (e.g., travel habit, attitudes, socio-demographic factors, etc) could complement our study to provide more useful information to planners. For example, future studies could examine how the reaction to the level of air pollutants varies according to individual attitudes or habits by using disaggregated data (e.g., survey). The results can be useful for making more effective policies (e.g., public information campaigns, free bikes rentals, etc).

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