Cyclists' Exposure to Road Traffic Noise: A Comparison of Three North American and European Cities

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Abstract: According to the World Health Organization, high levels of exposure to road traffic noise are associated with adverse health effects. Earlier studies suggest that cyclists are exposed to higher noise levels than motorists. Other studies have demonstrated that cyclists' exposure to noise could vary significantly according to their routes. The aim of this study is to compare cyclists' exposure to noise and their determinants in three cities. Three participants cycled equipped with noise dosimeters and GPS watches: 1823, 967, and 1362 km in Copenhagen, Paris, and Montreal, respectively. We fitted three generalized additive mixed model with an autoregressive term models to predict the cyclists' exposure to noise according to the type of route and bicycle infrastructure after controlling for the day of the week, as well as spatial and temporal trends. The overall noise means were 73.4, 70.7, and 68.4 dB(A) in Paris, Montreal, and Copenhagen, respectively. The exposure to road traffic noise is strongly associated with the type of bicycle infrastructure taken by the cyclist; riding on a cycleway significantly decreases it, while riding in a shared lane has no impact. Our findings demonstrate that it is possible to achieve a substantial reduction in cyclists' exposure by adopting new practices that include noise exposure in the planning of future cycling infrastructure.

Keywords: noise exposure; cycling; GAM; Bayesian modeling; Copenhagen; Montreal; Paris

1. Introduction

Cycling is becoming an increasingly popular mode of transportation in many North American and European cities. In the last few years, we have seen a revival of bicycling in North America and elsewhere in the world. Some authors even speak of a "bicycle renaissance" [1]. This is not surprising because this active means of transportation has numerous benefits for people's health and well-being (improving cardiovascular fitness, reducing the risk of chronic diseases, overweight and obesity, and so on) [2–6]. Collectively, travelling by bicycle also has positive effects on reducing traffic congestion, greenhouse gas emissions, and noise, but also on reducing health care costs [7]. Despite these widely documented benefits, cycling in urban areas is associated with health and safety risks owing to potentially high levels of traffic density [8,9], as well as high levels of exposure to air pollution and road traffic noise [5], as cyclists travel on roads shared with motor vehicles or on cycling routes adjacent to or near main roads [10,11].

Over the last two decades, cyclists' individual exposure to air pollution—more specifically, their inhalation of pollutants [2]—has been, and continues to be, studied extensively (e.g., [12–26]). In contrast, during the same period, cyclists' noise exposure is, however, less often examined. First, some studies have compared the individual exposure to noise by mode of transportation [26–31]. For example, a recent study conducted during rush hours in Montreal (Canada) has demonstrated

that cyclists' levels of exposure to noise ($L_{Aeq, 1min}$) are significantly greater than motorists' exposure, but lower than public transit commuters' (68.8, 66.8, and 74.0 dB(A), respectively). Even rarer are the urban studies that examine the variations of cyclists' exposure to road traffic noise according to characteristics of the route taken by the cyclists [26,28,32]. The present work falls within this stream of studies. For example, a recent study based on data collection by bicycle through the streets of Ho Chi Minh City (1035 km) has shown that the levels of cyclists' exposure were particularly high (mean = 78.8 dB(A)). This study also demonstrated that these noise levels vary significantly according to the type of road taken by cyclists; compared with a residential street, spending one minute on a trunk, primary, secondary, or tertiary road increases mean noise exposure (5.1, 3.4, 3.1, and 2.2 dB(A), respectively) [32].

1.1. Research Objectives

The aim of this study is to compare cyclists' exposure to road traffic noise, as well as their determinants, in three cities: Copenhagen, Montreal, and Paris. To do this, three sub-objectives are defined. First, we want to identify in which city exposure levels are the highest. Second, we want to determine the factors associated with a significant increase or decrease in exposure to noise: time of day, day of the week, types of roads (primary, secondary, or tertiary roads; residential street; and so on) and bicycle infrastructures (cycleway, cycle track, bike lane, shared bike lane) taken by the cyclist, and number of intersections crossed. Third, we want to identify which factors are consistent across the three cities. Identifying these factors allows us to formulate recommendations in terms of the planning and development of bicycle infrastructure.

1.2. Description and Justification for the Selection of Cities

The three study areas are the urban agglomerations of Montreal and Copenhagen, and the City of Paris. Although they share relatively comparable population sizes, they have different urban forms and, in particular, Paris has a very high population density: Copenhagen (1.6 million, 293 km^2, population density per km^2: 5400), Montreal (1.9 million, 499 km^2, population density per km^2: 3890), City of Paris (2.2 million, 105 km^2, population density per km^2: 20,781). Owing to this high density of population and human activities, Paris is one of Europe's most congested cities [33].

There are several ranking indexes that classify cities by their level of bicycle-friendliness. The most popular is the Copenhagenize Index [34], where, in 2019, Copenhagen is ranked as a world leader, followed closely by Amsterdam and Utrecht, while Paris and Montreal rank eighth and eighteenth, respectively. Montreal is the only North American city to have been included in this Top 20 Index every year since 2011 [34]. It is worth mentioning that, over the past decades, European cities (in particular, Dutch, Danish, German, and Swedish cities) and North American cities have had opposing visions of cycling infrastructure policies [35,36]. The first vision applied par excellence in Copenhagen is characterized by "the cyclists' need for separation from fast, heavy traffic [that] is considered a fundamental principle of a road safety" [35]. Conversely, the North American vision has "mainly pursued a policy of integrating bikes with traffic, so that getting places by bike usually requires riding in streets with heavy traffic" [35]. For example, a recent study has shown the length of the cycling network increased from 270 to 732 km (171%) in the urban agglomeration of Montreal over 25 years (1991–2016) [37]. However, this extension is mainly because of a large increase of on-street bike lanes because of their low cost (i.e., bike lane and shared bike lane), particularly in the Central City [37].

2. Materials and Methods

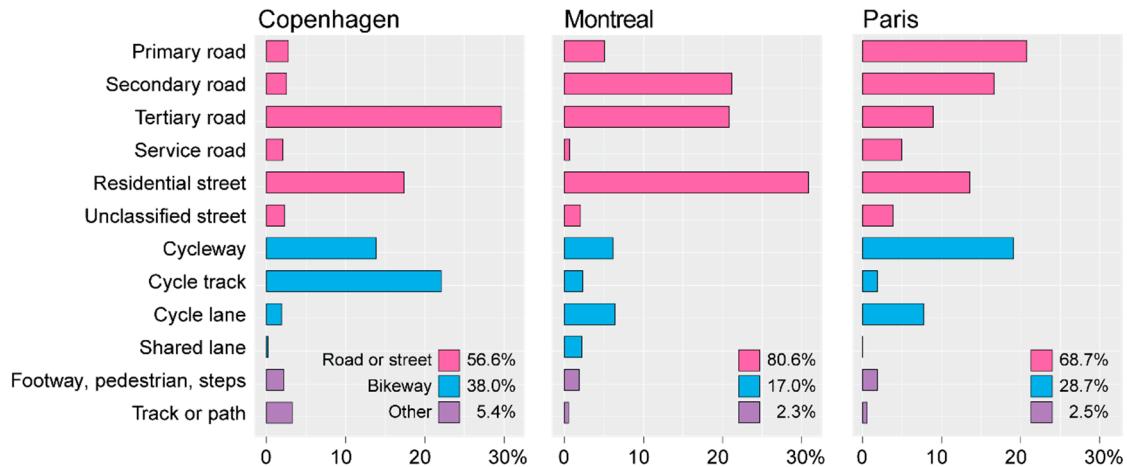### 2.1. Data Collection and Design

For each city, three students (Master or PhD candidates in Urban Studies) and one professor were involved in the data collection. The study was conducted during three weeks: four dry days in Paris (2017-09-04 to 2017-09-07), four dry days in Montreal (2018-06-19 to 2018-06-22), and six dry

days in Copenhagen (2018-09-01 to 2018-09-06). During these data collections, each participant cycled between eighty and one hundred kilometres per day. In total, 1823 km (103 h) were travelled through Copenhagen, 1362 km (78 h) in Montreal, and 967 km (63 h) in Paris. The routes were previously defined using GoogleMyMaps. The goal was to maximize the coverage of each city (Figure 1), as well as the diversity of types of route and cycling infrastructure taken by the cyclist (Figure 2). In terms of route and bike infrastructure diversity, it should be noted that we proportionally cycled more time on bikeways in Copenhagen (38%) than in Paris (29%) and Montreal (17%). The reason is twofold: the cycling network is denser in Copenhagen, and more segregated from the road network. Nevertheless, we had sufficient observations for each of the types of road or bicycle paths and bike lanes in order to estimate their impacts on noise exposure in regression models.
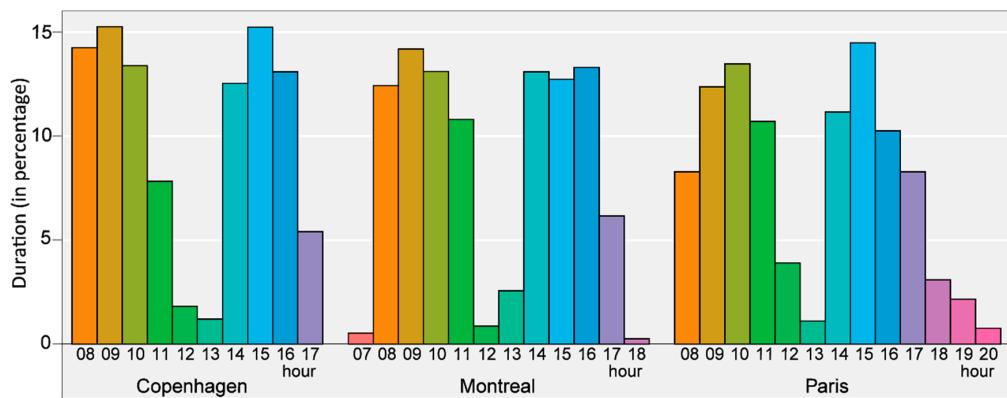

Figure 1. Study areas and sample routes for the three cities.

The routes were cycled between 07:00 and 20:00 (Figure 3). There are fewer observations between 12:00 and 13:00 because of the team members' lunch break and the recharging of device batteries for data collection. In the field, the participants followed the determined routes on a cellphone attached to the handlebars.

Figure 2. Time spent on each type of road or bicycle infrastructure.

Figure 3. Time of data collection.

Data collection was based on the use of two types of devices: three Brüel and Kjaer personal noise dose meters (Type 4448—class 1, Narum, Denmark), and three Garmin GPS watches (Forerunner 920 XT, Olathe, KA, USA). The Bruel and Kjaer devices record the average decibel level (dB(A)) every minute ($L_{Aeq, 1min}$). As recommended by the manufacturer, the three personal noise dose meters were calibrated once a day using the sound calibrator type 4231. A temporal resolution of one minute is sufficiently detailed considering that, with a mean speed of 15 km/h, a cyclist can ride only 250 m. More specifically, the 3 dB(A) exchange rate is used, which means that an increase of 3 dB(A) corresponds to a doubled noise intensity. The Garmin watch records the GPS coordinates every second. The GPS points are map-matched with the Open Street Map network [38,39], which allows us to use the same typology of street and bike network for the three cities. By merging the data collected by the dosimeter and the map-matched points, a GPS trace of each trip was obtained and then divided into one-minute segments for which the average noise exposure level is known ($L_{Aeq, 1min}$).

2.2. Statistical Analyses

Three types of statistical analyses were conducted using the R software [40]. Summary statistics and analysis of variance (ANOVA) were calculated to determine whether the cyclists' exposure to road traffic noise is significantly different for each of the three cities (Objective 1). Violin plots were also used to graphically illustrate these differences. For the second and third objectives, three Bayesian models—one for each city—were built using the *brms* package [41,42], in which the dependent variable is the level of noise (dB(A)) $L_{Aeq, 1min}$) and observations are the number of one-minute segments (N = 6212, 4723, and 3793 for Copenhagen, Montreal, and Paris, respectively).

The model proposed here is largely based on a recent study [32]. First, we used GAMMAR models (generalized additive mixed model with an autoregressive term) with a scaled t-distribution for the dependent variable [43]. Consequently, four types of terms were introduced into each city model: random effects terms, fixed linear terms, non-linear terms, and an autoregressive term.

As the noise could vary according to the day of the week, it was introduced as a random effect. Next, the number of intersections crossed and the time spent in minutes on twelve types of road and bicycle infrastructures were introduced as fixed effects (1. primary road, 2. secondary road, 3. tertiary road, 4. residential street, 5. service, 6. unclassified road, 7. cycleway, 8. cycle track, 9. cycle lane, 10 shared lane, 11. footway, pedestrian or steps, 12. track or path). Overall, we expected that noise levels would decrease from primary road to residential street and cycleway. Moreover, a greater number of intersections crossed by the cyclist may mean slower and possibly less noisy traffic.
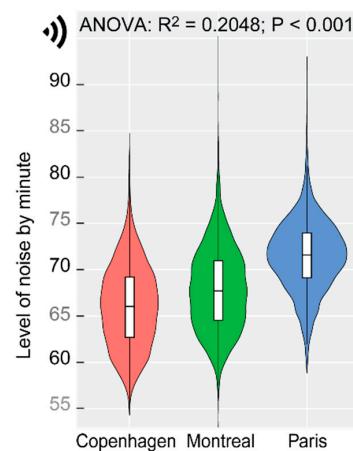
As done by Gelb and Apparicio [32], to take the temporal and spatial variabilities of traffic into account, the time of day (number of minutes passed since 07:00) and the geographic coordinates were introduced as non-linear terms (i.e., splines). Therefore, we expected to observe peaks of noise during the morning and evening rush hour periods, and in the central districts of each city. We introduced a moving average term (MA = 3) to control the temporal autocorrelation of noise.

We fitted our three Bayesian models using four chains, each with 4000 iterations, where the first 1000 were used as a warm-up for sampling [41]. Samples were implemented using the No-U-Turn Sampler (NUTS), which is an extension of a Hamiltonian Monte Carlo method, to increase the effectiveness in performing tasks related to the optimal number in each iteration [44]. The used priors are described in the Supplementary Materials.

3. Results

3.1. Descriptive Statistics

The overall noise means were 73.4 dB(A) in Paris, 70.7 dB(A) in Montreal, and 68.4 dB(A) in Copenhagen (Table 1). Given the logarithmic scale of the noise and the exchange rate of 3, the difference of 4.9 dB(A) between the noise mean values of Copenhagen and Paris (during our data collections) can be considered as a multiplication of the noise energy by more than 3. In other words, on the basis of the data collected, Paris is by far the noisiest city (Figure 4), which may be explained by a greater degree of traffic congestion, population density, and a larger presence of two- or three-wheeled mopeds or scooters than in Copenhagen and Montreal. Finally, during 67.8% of cycling time in Paris (versus 32.7% in Montreal and 19.6% in Copenhagen), the noise level was higher 70 dB(A).

Figure 4. Cyclists' exposure to road traffic noise by city. ANOVA, analysis of variance.

Table 1. Distribution of 1 min averages of noise levels (in dB(A)) during cycling routes per city.

	Copenhagen	Montreal	Paris
N	6212	4723	3793
Percentiles			
1	57.5	59.2	62.3
5	59.1	61.1	65.0
10	60.3	62.3	66.5
25 (first quartile)	62.7	64.5	69.1
50 (median)	66.0	67.7	71.6
75 (third quartile)	69.2	71.0	74.0
90	71.9	73.7	76.0
95	73.3	75.2	77.2
99	76.5	78.9	81.0
Standard deviation	4.4	4.4	3.8
Bootstrapped statistics (8000 replications)			
Arithmetic mean	66.1 [66.0–66.2]	67.9 [67.8–68.0]	71.5 [71.4–71.6]
Noise mean	68.4 [68.3–68.6]	70.7 [70.2–72.5]	73.4 [71.3–71.8]
Median	66.0 [65.9–66.2]	67.1 [67.6–67.9]	71.6 [71.5–71.8]

3.2. GAMMAR Models

3.2.1. Assessment of the Models

All models' parameters converged (Rhat = 1.0) and all the trace plots display import mixing (four chains) (Figures S1–S3 in Supplementary Materials). Also, the posterior predictive checks demonstrate that the three models are well fitted (Figure S4 in Supplementary Materials). The obtained Bayes R-squared are relatively similar among the three models: 0.491, 0.505, and 0.439 for Copenhagen, Montreal, and Paris, respectively, when keeping only the fixed effects, and 0.507, 0.516, and 0.441, respectively, with the random effects. To measure the temporal dependence of the residuals' models, we calculated the autocorrelation function (ACF) index [32]. The obtained values suggest there is no temporal dependency in the residuals for the Copenhagen model (ACF at lag 2 = −0.024, lag 3 = 0.023, lag 4 = 0.063), Montreal model (ACF at lag 2 = −0.031, lag 3 = 0.006, lag 4 = 0.045), and Paris model (ACF at lag 2 = −0.016, lag 3 = 0.016, lag 4 = 0.002). The values of Bayes marginal R-squared and Bayes conditional R-squared are a very close for each model. This implies that fixed effects play a major role in the noise exposure prediction.

3.2.2. Analysis of the Random Linear Terms

The coefficients of the random effects show that the road traffic noise level could vary according to the day of the week in Copenhagen, Montreal, and Paris (Table 2). Because the data collections lasted only 4–6 days in each city, we cannot state if a particular weekday is systematically more or less noisy for each city all year round. However, these results demonstrate the relevance of introducing the day of the week as a random-effect term in order to obtain unbiased coefficients for the fixed effects predictors.

Table 2. Results of the Bayesian models for the three cities. MA, moving average; CI, confidence interval.

	Copenhagen		Montreal		Paris	
	Est.	95% CI	Est.	95% CI	Est.	95% CI
Fixed effects						
(Intercept)	68.10	[66.83 69.36]	70.95	[69.48 72.41]	73.11	[72.25 74.00]
Intersections crossed	−0.05	[−0.09 −0.01]	−0.03	[−0.12 −0.02]	0.04	[0.01 0.07]
Primary road	Ref		Ref		Ref	
Secondary road	0.37	[−0.56 1.30]	−1.12	[−1.77 −0.46]	−1.02	[−1.42 −0.63]
Tertiary road	−1.11	[−1.76 −0.46]	−2.97	[−3.64 −2.32]	−2.27	[−2.74 v1.79]
Service	−2.82	[−3.80 −1.84]	−4.27	[−5.67 −2.88]	−1.66	[−2.27 −1.06]
Residential street	−3.11	[−3.82 −2.41]	−4.68	[−5.35 −4.02]	−4.95	[−5.38 −4.52]

Table 2. *Cont.*

	Copenhagen		Montreal		Paris	
	Est.	95% CI	Est.	95% CI	Est.	95% CI
Footway, pedestrian or steps	−3.14	[−4.05 −2.25]	−3.81	[−4.84 −2.76]	−3.93	[−4.91 −2.95]
Track or path	−2.79	[−3.63 −1.95]	−6.32	[−8.01 −4.63]	−2.16	[−3.79 −0.49]
Unclassified	−3.27	[−4.17 −2.38]	−3.38	[−4.33 −2.40]	−3.10	[−3.72 −2.48]
Cycleway	−2.56	[−3.27 −1.85]	−4.01	[−4.84 −3.19]	−2.07	[−2.47 −1.67]
Cycle track	0.03	[−0.29 0.34]	−0.89	[−1.74 −0.03]	0.41	[−0.48 1.28]
Cycle lane	−0.60	[−1.28 0.08]	−0.17	[−0.68 0.34]	0.09	[−0.34 0.52]
Shared lane	1.45	[−0.64 3.52]	−1.26	[−2.10 −0.43]	0.95	[−4.13 6.01]
Random effects (intercept)						
Monday	−0.02	[−1.16 1.14]	–	–	−0.43	[−1.33 0.42]
Tuesday	−0.50	[−1.64 0.64]	−0.12	[−152 1.27]	0.35	[−0.48 1.29]
Wednesday	−0.32	[−1.46 0.84]	0.82	[−0.52 2.23]	0.04	[−0.81 0.95]
Thursday	0.95	[−0.16 2.16]	0.04	[−1.32 1.42]	0.08	[−0.76 1.02]
Friday	1.07	[−0.05 2.28]	−0.76	[−2.16 0.60]	–	–
Saturday	−1.20	[−2.35 −0.06]	–	–	–	–
Moving average						
MA [1]	0.71	[0.68 0.73]	0.62	[0.59 0.65]	0.47	[0.44 0.51]
MA [2]	0.34	[0.31 0.37]	0.25	[0.21 0.28]	0.16	[0.12 0.19]
MA [3]	0.15	[0.13 0.18]	0.09	[0.06 0.12]	0.04	[0.01 0.07]
Bayes marginal R-squared	0.491	[0.479 0.501]	0.505	[0.492 0.517]	0.439	[0.422 0.455]
Bayes conditional R-squared	0.507	[0.497 0.518]	0.516	[0.504 0.528]	0.441	[0.424 0.457]
WAIC	31,550		23,832		18,513	

WAIC: widely applicable information criterion.

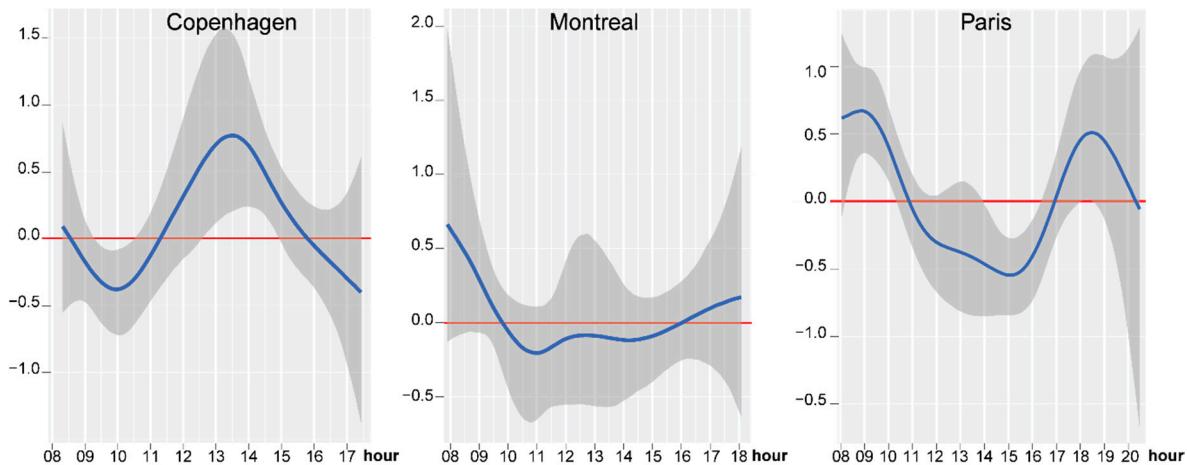### 3.2.3. Analysis of the Fixed Linear Terms

Table 2 (fixed terms) presents the results of the predictors linearly added to the models. First, the number of intersections crossed by the cyclist during a one-minute segment is associated with a decrease in noise levels in Montreal and Copenhagen (−0.03 and −0.05 dB(A)), and conversely an increase in Paris (0.04 dB(A)). Within the latter, we hypothesize that several scooters on the intersection, sometimes on the advanced stop box for bicycles, contribute to a significant increase in noise levels when the traffic light turns green.

Second, the exposure to road traffic noise is strongly associated with the type of road or bicycle infrastructure taken by the cyclist in the three cities. For example, compared with a primary road, spending one minute on a residential street decreases mean noise exposure by 3.1 dB(A) in Copenhagen, 4.7 dB(A) in Montreal, and 4.9 dB(A) in Paris. Not surprisingly, these decreases are lower for secondary, tertiary, and service roads. Third, riding on a cycleway significantly decreases her/his exposure to road traffic noise in Montreal, Copenhagen, and Paris (−4.0, −2.6, and −2.1 dB(A), respectively). In contrast, taking a track or a shared lane has no impact on reducing the exposure to road traffic noise.
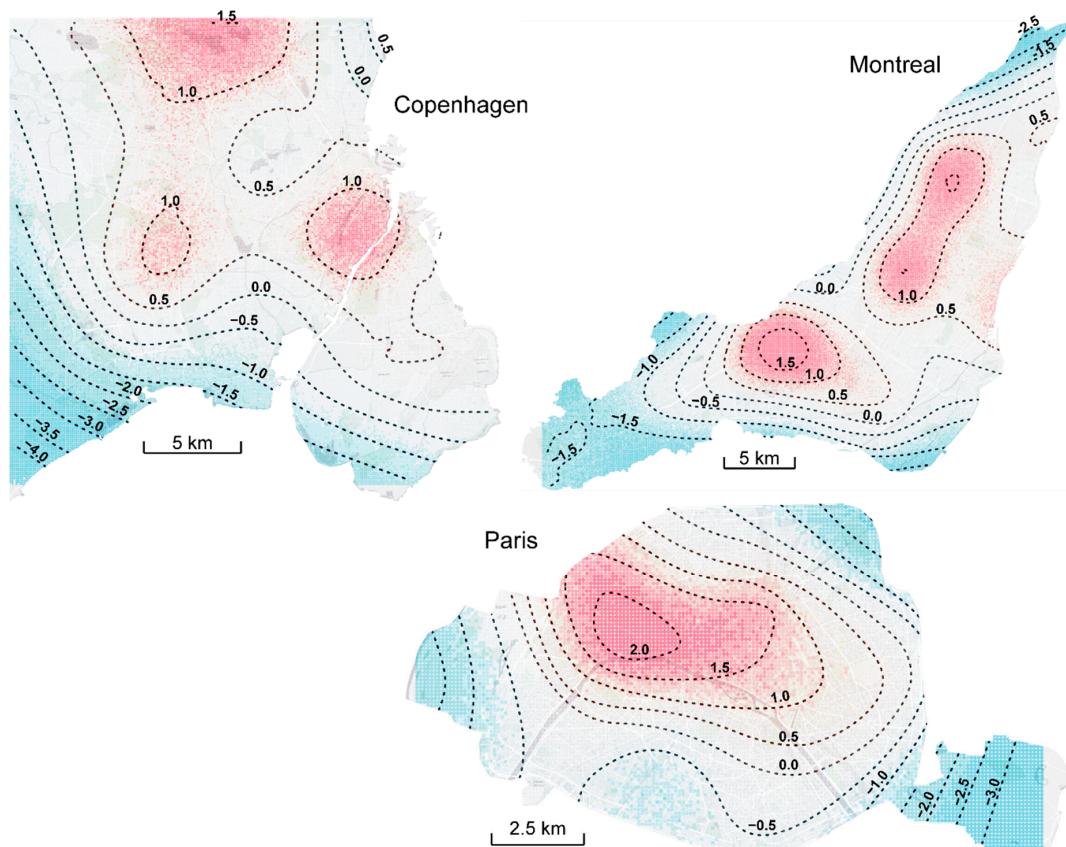
3.2.4. Analysis of the Non-Linear Terms

Figures 5 and 6 display the marginal effects of time and space, respectively, introduced as splines in three models. Concerning the temporal trends for noise exposure, there is an important effect in Copenhagen and Paris, but a weak one in Montreal. The patterns of noise exposure in Paris and Copenhagen are reversed. Conventionally, we observed higher levels during the rush hours (08:00 to 10:00 and 17:00 to 19:00) and lower levels between 12:00 and 15:00, whereas in Copenhagen, this last period shows the lowest values. In Montreal, there are slightly higher levels only in the morning (08:00 to 10:00). Concerning the spatial patterns, the extent of the effect between the places with the higher and lower concentration levels reaches 5.5 dB(A) in Copenhagen versus 5 dB(A) in Paris and 4 dB(A) in Montreal (Figure 6). Overall, the central parts of the three cities have the highest noise levels, while the suburban areas have the lowest. However, these temporal and spatial trends could be characterized by strong variability and uncertainty, and thus must be interpreted with caution. These spatial and temporal trends are valid only for the data collection periods, as mentioned before for the

random linear term (day of the week). In other words, they cannot be generalized over all weeks of the year. Nevertheless, this underlines the need to control the spatial and temporal effects in a model of exposure to noise in order to obtain more robust coefficients for the fixed effects predictors.

Figure 5. Marginal effects of time on noise exposure prediction for the three cities. The red horizontal line represents the daily mean and allows us to observe when the exposure values are higher and lower during the day, all other things being equal.

Figure 6. Marginal effects of space on noise exposure prediction for the three cities. The marginal effect represents the spatial deviation from the overall mean. These maps allow to identify places where noise exposure levels are lower or higher through space, all other things being equal.

4. Discussion

4.1. Limitations of the Study

Even though we cycled over 1823 km in Copenhagen, 1362 km in Montreal, and 967 km in Paris, some sectors of each city were less well covered or little covered. Concerning the modelling, we did not introduce predictors related to the urban morphology such as street canyons and streets bordering an open space (e.g., parks and green spaces), which could have an impact on the noise propagation. Finally, the models presented are Bayesian models, and thus are influenced by the definition of the priors (presented in the Supplementary Materials). At present, we do not have enough knowledge to define informative priors, so we decided to use weakly informative and conservative priors that might temper the results.

4.2. Comparison with Previous Studies

It is interesting to compare the mean noise levels recorded here—68.4, 70.7, and 73.4 dB(A) in Copenhagen, Montreal, and Paris, respectively—to those found in other European and North American cities: from 63 to 65 dB(A) in eleven Dutch cities [28], 70 in Rotterdam, 73 in Helsinki, 75 in Thessaloniki [29], and 70.5 and 68.8 in Montreal [25,26].

4.3. Potential Health Implications

It would be risky to conclude categorically that these noise levels, especially in Paris, are harmful to cyclists' health. The World Health Organization (WHO) recommends the guideline value of 53 dB for the average road traffic noise exposure during the day (L_{den}), "as road traffic noise above this level is associated with adverse health effects" [45]. The WHO guideline development group also reports two priority health outcome evidences at 53.3 and 59.3 dB L_{den}. First, "the 5% relevant risk increase occurs at a noise level of 59.3 dB L_{den}" for the incidence of ischaemic heart disease [45]. Second, "there was an absolute risk of 10% at a noise exposure level of 53.3 dB L_{den}" for the prevalence of a highly annoyed population [45]. This last cutoff value is based on a systemic review on environmental noise and annoyance [46]. The authors propose a quadratic regression equation to resume the association between road traffic noise (L_{den}) and the percentage of the population highly annoyed (%HA) [46]:

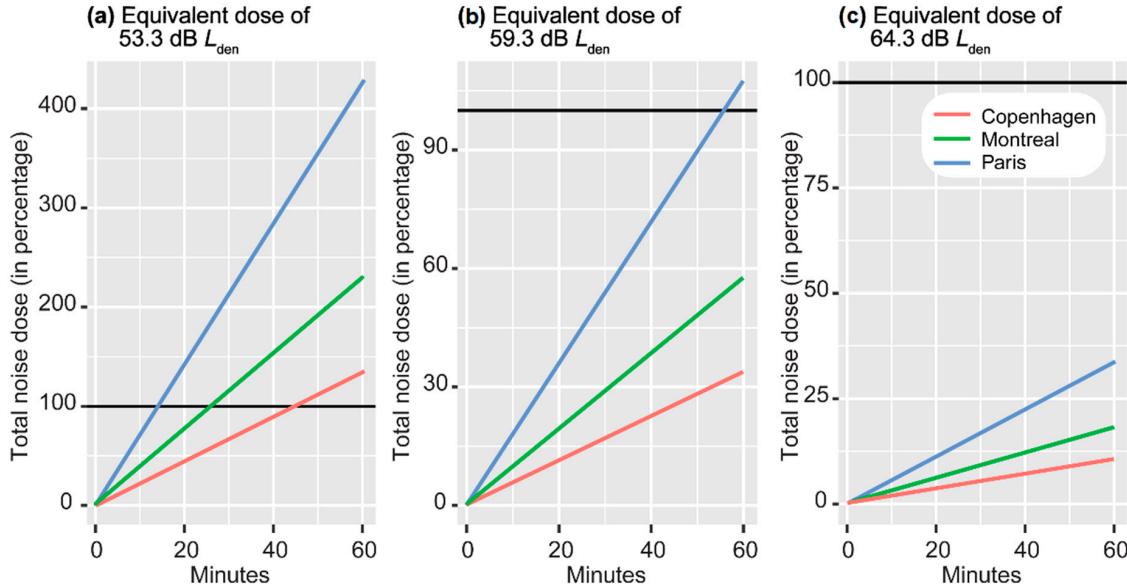$$\%HA = 78.9270 - 3.1162 \times L_{den} + 0.0342 \times L_{den}{}^2 \tag{1}$$

Using this equation, we can estimate 10% and 20% of the population are highly annoyed by the traffic noise when it reaches 53.3 and 64.3 dB L_{den}, respectively. Consequently, we decided to select three cutoff values: 53.3, 59.3, and 64.3 dB L_{den}. However, it is not possible to directly compare a one-minute mean exposure ($L_{Aeq,\,1min}$) and daily mean exposure (L_{den}). We thus propose to compare these values in terms of doses. According to Berger [47], the noise dose is the cumulative exposure to noise over time. It is presented as a percentage of a reference dose, which enables us to calculate the daily maximum acceptable dose. Classically, it is calculated as follows [47]:

$$D = \frac{100}{T_c} T_i 10^{\left(\frac{L_i - L_c}{q}\right)}, \tag{2}$$

where D is the total noise dose (in percentage), T_c is the criterion sound duration (e.g., 24 h), T_i is the time exposure spent in the ith interval in hours, L_c is the criterion sound level (e.g., 53.3 dB(A)), L_i is the noise exposure intensity during the ith time interval, and q is the exchange rate parameter (dB)) (e.g., 10 for an exchange rate of 3 dB).

As illustrated in Figure 7, for each city, we estimated the total noise dose for the three selected noise cutoff values using Equation (2) and the noise mean values reported in Table 1 (68.4, 70.7, and 73.4 dB(A) for Copenhagen, Montreal, and Paris, respectively). In this figure, the horizontal axis

represents duration of the cycling activity (between 0 and 60 min). For example, a duration of 60 min could mean regular trips to and from work of 30 min for a cyclist throughout one of the three cities.

Figure 7. Total noise dose (in percentage) according to cycling duration (in minutes) for three cutoff values ((**a**) 53.3 db L_{den}, (**b**) 59.3 db L_{den}, and (**c**) 64.3 db L_{den}) by city. The black horizontal line represents the 100% dose with an exposure of 53.3 dB (**a**), 59.3 dB (**b**), and 64.3 dB (**c**) during 24 h.

With the mean noise exposure observed in Paris (73.4 dB(A) $L_{Aeq, 1min}$), after only 14 min, a cyclist would cumulate the equivalent dose than someone exposed at 53.3 dB(A) during 24 h (versus 26 and 45 min in Montreal and Copenhagen, respectively). With the second cutoff value (59.3 dB L_{den}), associated with a 5% relevant risk for the incidence of ischaemic heart disease [45], a Parisian cyclist potentially reaches 100% of the total dose after 56 min versus 105 min in Montreal and 177 in Copenhagen. That means the high levels of road traffic noise recorded in Paris could be considered as problematic from a public health perspective.

4.4. Implications for Policy

As mentioned before, the cycling network in Copenhagen provides physical separation from motor vehicles. Conversely, in Montreal and Paris, cyclists are more integrated into traffic, in particular when they ride on streets, but also bike lanes and shared bike lanes. This certainly contributes to explaining why the noise levels of cyclists' exposure found here are significantly lower in Copenhagen than in Montreal and Paris.

Concerning the fit of the model, we found that fixed effects have a major contribution to noise exposure prediction (low differences between marginal and conditional R-squared). That means the characteristics of the road taken by the cyclist have more impact on noise exposure than spatial and temporal trends. This is good news for two reasons. First, when possible, the cyclists could significantly reduce their noise exposure by modifying their routes. Second, the bicycle infrastructure planners could have a significant impact on cyclists' noise exposure by implementing new cycling routes in a less noisy urban environment.

Indeed, the exposure to road traffic noise is strongly associated with the type of bicycle infrastructure taken by the cyclist; riding on a cycleway significantly decreases it, while riding in a shared lane has no impact. Therefore, it would be preferable to place less emphasis on the development of bike lanes and shared bike lanes. It has also been widely shown that the risks of accidents involving cyclists are greater on these types of bike lanes because cyclists share the road with motor vehicles [48,49].

Therefore, cyclists' exposure to noise is an important issue in Montreal and Paris that might discourage bicycle use. Indeed, an interesting study on 73 motivators and deterrents of bicycling in Vancouver—based on a survey of 1402 potential cyclists—has shown that the first motivator is "routes away from traffic noise and pollution" [50].

For some years now, urban planners in Montreal and Paris are increasingly in favour of bicycle use, as seen in the desire to extend cycling networks and in the setting up of bike-sharing schemes. Their political intent is to increase the modal share of cycling trips for reducing traffic congestion, greenhouse gas emissions, and noise. It is also worth pointing out that the shares of cycling trips for Montreal and Paris are diametrically opposed (2.4% and 3%) to that of Copenhagen (38%) [51]. Our findings support that noise is an important dimension that should be integrated into the future bicycle infrastructure planning in Paris and Montreal, in the same way as the safety and connectivity. These new bicycle routes should physically separate bicycles from motor vehicles to reduce their exposure to traffic noise [52].

5. Conclusions

It was not surprising to find that cyclists' levels of noise exposure in Paris and Montreal are higher than in Copenhagen (noise mean: 73.4 and 70.7 versus 68.4 dB(A)) in part because of two opposite visions of cycling infrastructure policies. After controlling for the day of the week, as well as temporal and spatial trends, we identified several similarities in the three cities. First, compared with a primary road, cycling on a residential street significantly decreases noise exposure. Second, the type of bicycle infrastructure is also strongly associated with exposure to road traffic noise; compared with a primary road, riding on a cycleway has a negative impact, while taking a track or a shared lane has no impact. Our findings demonstrate that it is possible to achieve a substantial reduction in cyclists' exposure by adopting new practices that include noise exposure in the planning of future cycling infrastructure in Paris and Montreal. That means, where possible, urban planners should prioritize cycling infrastructures that physically separate cyclists from motor vehicles. Concretely, this can be accomplished in two ways: by placing less emphasis on the development of bike lanes and shared bike lanes and focusing on off-street bicycle paths, and by developing cycling infrastructures on residential streets that are much quieter.

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