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Original Contribution

Public Transport Strikes and Their Relationships With Air Pollution, Mortality, and Hospital Admissions

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There is limited suggestive evidence of relationships between public transport strikes and either increased air pollution or worse population health. In this study we aimed to assess whether public transport strikes were associated with increases in health events (overall, cardiovascular and respiratory mortality, and cardiovascular and respiratory hospitalizations). We also explored whether air pollution mediated those associations. We used data from the city of Barcelona (Spain) for the period 2005–2016 on strikes, health events, and ambient air pollution (nitrogen dioxide, nitrogen monoxide, particulate matter (PM) with an aerodynamic diameter $\leq$10 μm, PM with an aerodynamic diameter $\leq$2.5μm, PM with an aerodynamic diameter $\leq$1μm, number of particles with a diameter greater than 5 nm per cm^3 (particle number concentration), and black carbon). We used linear and quasi-Poisson regression models to explore the associations between air pollution and public transport strikes and between public transport strikes and health outcomes. We also investigated potential causal mediation by air pollution. Overall, this study suggested that public transport strikes are associated with increased overall mortality, respiratory mortality, and respiratory hospitalizations. However, our findings suggest that such increases are not mediated by the increase in air pollution. Our results indicate the need to further investigate these relationships and potential mechanisms.

air pollution; hospitalization; mortality; public transport; strike; transit

Abbreviations: BC, black carbon; NO, nitrogen monoxide; NO_2, nitrogen dioxide; PM_1, particulate matter with an aerodynamic diameter $\leq$1μm; PM_{10}, particulate matter with an aerodynamic diameter $\leq$10 μm; $PM_{2.5}$, particulate matter with an aerodynamic diameter $\leq$2.5μm.

Public transport is usually seen as a key tool to reduce air pollution in cities. Despite the thin literature on public transport strikes, the existing work suggests some relationships between public transport strikes and either increased air pollution (particulate matter with an aerodynamic diameter $\leq$10 μm (PM_{10}), nitrogen oxides, or black carbon (BC)) or worse population health (1–4). Recently, we quantified that air pollution levels increased by 4%–7% during public transport strikes in Barcelona (Spain) and by 45% during strikes of the metro system (1). Here, we aim to assess whether public transport strikes are associated with increases in mortality or hospital admissions, and we hypothesize that, if such increases exist, they will be mediated by increases in air pollution.

METHODS

As described in detail elsewhere (1), government records were used to compile data about strikes for the period of January 2005 through June 2016. The study was restricted to the city of Barcelona (Spain), which has a population of approximately 1.6 million inhabitants. The health information system services (Barcelona Public Health Agency) together with the Spanish National Institute of Statistics provided data on daily hospitalizations for the period of January 2006 through June 2016 and on mortality for the period of January 2005 through December 2014. We included in our analyses only unscheduled hospital admissions. Multiple hospitalizations from the same individual were included if

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they had a different diagnosis or, when the diagnoses were the same, if the hospitalizations were more than 15 days apart. Daily counts of overall mortality and cardiovascular and respiratory mortality and hospitalizations were considered as response variables. We obtained ambient levels of air pollutants (nitrogen dioxide (NO_2), nitrogen monoxide (NO), PM_{10}, particulate matter with an aerodynamic diameter smaller than 2.5μm, ($PM_{2.5}$), particulate matter with an aerodynamic diameter ≤1μm (PM_1), number of particles with a diameter greater than 5 nm per cm^3 (particle number concentration), and BC) from real-time monitoring stations located in Barcelona city (1). Different air pollutants were collected at different stations and during different time periods (Web Table 1 and Web Table 2, available at https://academic.oup.com/aje). For NO and NO_2, we derived city concentrations by averaging the concentrations of various monitoring stations (i.e., Poblenou (background), Ciutadella (background), Gràcia (traffic), Eixample (traffic)). For PM_{10}, $PM_{2.5}$, and PM_1, as well as particle number concentration and BC, we considered the data from a single, urban background, air-quality monitoring supersite (Palau Reial, Institute of Environmental Assessment and Water Research (IDAEA-CSIC)) as representative of the city concentration levels. These different considerations between air pollutants were used because only NO and NO_2 had enough completeness and overlap between stations for the entire period to compute citywide averages. Meanwhile, for the other pollutants, only the Palau Reial IDAEA-CSIC station had the maximum data completeness. Specifically, at this station, data were available for the entire period for all PM fractions, and particle number concentration and BC were available for 2009–2016.

To describe the changes in air pollution during public transport strikes, we fitted linear regression models for each air pollutant, with strike occurrence as the explanatory variable. These linear models adjusted for month, year, day of the week, and a holiday indicator. To explore the associations between public transport strikes and health outcomes, we fitted quasi-Poisson regression models to the daily time series for each health outcome, with strike occurrence as the explanatory variable. Models adjusted for day of the week, holiday indicators at lag 0 and lag 1, and temporal trend and seasonality using a natural spline of time with 6 degrees of freedom per year. Moreover, we conducted several sensitivity analyses by considering: 1) strike in the previous day as the explanatory variable; 2) strike occurrence as the explanatory variable and adjusting for strike in the previous day as well; 3) using a natural spline of time with 4 degrees of freedom per year to account for temporal and seasonal trends; 4) using a natural spline of 5 degrees of freedom per year to account for temporal and seasonal trends; 5) adjusting for influenza hospitalizations; or 6) adjusting for mean temperature.

We also explored the potential mediation of the association between public transport strikes and health outcomes by air pollution levels. We applied the regression approach for mediation with multiple mediators described by VanderWeele and Vansteelandt (5). In particular, we fitted the outcome model, including the strike indicator, the different pollutants (potential mediators), and confounders, with a mediator model for each mediator, including as predictors the strike indicator and confounders. Confounders in both the outcome and mediator models were the same as those described above plus average temperature, which was introduced using the distributed lag nonlinear model framework, with a cross-basis in which the exposure-response association was modeled using a quadratic B-spline with 3 internal knots placed at the 10th, 75th, and 90th percentiles of temperature, and the lag-response association up to lag 21 was modeled using a natural cubic B-spline with an intercept and 3 internal knots placed at equally spaced values in the log scale (6). The natural direct association was estimated using the regression coefficient of the strike indicator in the outcome model. The natural indirect association was estimated as the sum over all mediators of the product of the regression coefficient for the strike indicator in the ith ($i = 1, \ldots, K$, where K is the number of mediators) mediator model and the regression coefficient for the ith mediator in the outcome model. We used bootstrap to calculate 95% confidence intervals. In order to test whether collinearity between pollutants could alter the results of mediation analyses, we conducted a sensitivity analysis in which we included only PM_{10}, NO, and BC as potential mediators.

RESULTS

During the study period, there were 208 days (5%) affected by a strike of the metro (28), train (106), or bus (91) systems (Web Table 3). There was a median of 42 deaths per day, 13 from cardiovascular and 4 from respiratory causes (Web Table 4 and Web Table 5). There was a median of 74 cardiovascular or respiratory daily hospitalizations (equally distributed between the 2 causes). During strike days, air pollution levels were 1%–46% higher than during days without strikes. Those increases were more marked during metro strikes and for BC and NO (Web Table 6 and Web Table 7).

Respiratory mortality was higher during public transport strikes, with an increase by 9% (95% confidence interval: 1, 18) (Table 1). Stronger associations were found for metro strikes (increased by 53%, 95% confidence interval: 24, 89) (Table 1). For the other outcomes, there was no indication of increased number of events during strikes. Associations with respiratory mortality were stronger during full-day strikes (vs. part-day strikes) and for multiday strikes (vs. single-day strikes) (Web Table 8). In multiday or full-day strike days, more events were also detected for overall mortality and respiratory hospitalizations, with increases by up to 18% (Web Table 8).

The strongest associations of strikes with health outcomes were observed on the same day of the strike (indicating no shifts in hospitalizations or mortality following a strike). Results did not vary when changing the degrees of freedom of the temporal spline, including other potential confounders (influenza hospitalizations or temperature) in the models (excluding year 2005), or when restricting the associations to the period with air pollution data (Web Table 9 and Web Table 10).

When conducting mediation analyses, all indirect associations were close to 1, indicating that the associations detected for public transport strikes were not mediated

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Table 1. Association Between Health Outcomes and Public Transport Strikes in Barcelona, Spain, 2005–2016

Health Outcome[a]	All Strikes		Metro Strikes		Train Strikes		Bus Strikes	
	RR	95% CI	RR	95% CI	RR	95% CI	RR	95% CI
Overall mortality	1.01	0.99, 1.04	1.08	0.99, 1.18	1.02	0.98, 1.06	1.02	0.98, 1.06
Cardiovascular mortality	1.02	0.97, 1.06	0.94	0.80, 1.10	1.04	0.98, 1.11	0.99	0.93, 1.06
Respiratory mortality	1.09	1.01, 1.18	1.53	1.24, 1.89	1.12	1.01, 1.26	1.11	1.00, 1.23
Cardiovascular hospitalizations	0.99	0.96, 1.02	0.99	0.93, 1.06	1.00	0.96, 1.04	0.99	0.95, 1.02
Respiratory hospitalizations	0.99	0.96, 1.02	0.99	0.92, 1.06	1.00	0.95, 1.04	1.01	0.97, 1.05

Abbreviations: CI, confidence interval; RR, relative risk.
[a] Models adjusted for day of the week and 2 variables indicating whether the same or the previous day was a holiday, and temporal and seasonal trends were accounted for with natural spline of time with 6 degrees of freedom per year, apart from the inclusion of the strike indicator.

by indirect pathways through air pollution concentrations (Table 2). When we repeated the analyses considering only PM_{10}, NO, and BC as potential mediators, results were practically unchanged (data not shown).

DISCUSSION

Overall, this study suggests that public transport strikes are associated with increased overall mortality and respiratory events (both mortality and hospitalizations). However, our findings suggest that such increases are not mediated by the increase in air pollution.

Our findings on respiratory events are in line with the study by Bauernschuster et al. (2) in 5 German cities, the only study that previously examined these associations. Bauernschuster et al. reported that strike days were associated with increases in hospital admissions for respiratory diseases and breathing abnormalities, particularly among young children. To our knowledge, no previous studies have explored the potential associations between strikes and other health outcomes (mortality or cardiovascular hospitalizations).

Increases in air pollution during strikes did not explain the increases in health events. The identification of

Table 2. Estimated Natural Direct Associations and Natural Indirect Associations for the Association Between Health Outcomes and Public Transport Strikes in Barcelona, Spain, 2005–2016

Health Outcome and Association	All Strikes		Metro Strikes		Train Strikes		Bus Strikes	
	RR	95% CI	RR	95% CI	RR	95% CI	RR	95% CI
Overall mortality								
NDA	1.002	0.974, 1.032	1.071	0.967, 1.187	1.013	0.976, 1.052	1.003	0.966, 1.042
NIA[a]	1.000	0.997, 1.002	1.001	0.993, 1.009	1.000	0.997, 1.003	0.999	0.996, 1.003
Cardiovascular mortality								
NDA	0.999	0.951, 1.049	0.939	0.787, 1.121	1.036	0.974, 1.102	0.966	0.900, 1.037
NIA[a]	0.999	0.995, 1.003	1.002	0.988, 1.016	0.998	0.993, 1.004	1.000	0.994, 1.006
Respiratory mortality								
NDA	1.076	0.987, 1.171	1.474	1.154, 1.884	1.115	0.996, 1.248	1.081	0.962, 1.216
NIA[a]	1.001	0.994, 1.008	1.004	0.981, 1.027	1.000	0.992, 1.009	1.002	0.993, 1.012
Cardiovascular hospitalizations								
NDA	0.991	0.964, 1.018	0.992	0.937, 1.051	1.002	0.963, 1.043	0.988	0.950, 1.028
NIA[a]	1.001	0.998, 1.003	1.003	0.997, 1.009	1.001	0.998, 1.003	1.001	0.997, 1.005
Respiratory hospitalizations								
NDA	0.987	0.956, 1.019	0.976	0.885, 1.076	1.000	0.955, 1.046	0.994	0.955, 1.034
NIA[a]	1.000	0.997, 1.002	0.999	0.993, 1.006	1.000	0.997, 1.003	1.000	0.996, 1.004

Abbreviations: CI, confidence interval; NDA, natural direct associations; NIA, natural indirect associations; RR, relative risk.
[a] Indirect associations refer to those explained by changes in air pollution levels during public transport strikes.

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direct and indirect associations requires several assumptions: 1) no unmeasured confounding of the exposure-outcome association, 2) no unmeasured confounding for the mediator-outcome relationship, 3) no unmeasured confounding of the exposure-mediator relationship and 4) no exposure effects that confound the mediator-outcome relationship (5). We controlled for temporal trends, day of the week, and holiday periods to try to achieve the first. We adjusted for temperature to accomplish the second because, even though temperature is not expected to be a confounder of the exposure-outcome association, it can be a confounder of the mediator-outcome association. Regarding the third, we do not expect that factors that determine the occurrence of a strike are related to air pollution levels, apart from those that can affect the choice of a specific date (e.g., day of the week, holiday periods, or other temporal trends), which were already adjusted for. Finally, public transport strikes (exposure) might affect the concentrations of several pollutants (mediators), and each pollutant can affect the concentration of other pollutants and the health outcomes considered. Conducting mediation analysis separately for each pollutant would violate the fourth assumption, because the pollutants not included in the analysis will act as omitted mediator-outcome confounders affected by the exposure. This is why we used a method that allows for examining the mediating effects of multiple mediators. Despite all these considerations, we cannot guarantee that all assumptions were met. We further assumed that there were no interactions between strikes and pollution levels (exposure-mediator interactions) or between different pollutants (mediator-mediator interactions).

An alternative hypothesis could be that days with strikes of the public transport system increase stress levels because of having to change routines, increased congestion, or overcrowding in stations and trains. Episodes of anxiety have been reported in the press in overcrowded metro trains during strikes (7). Previous studies have shown links between stress and cardiovascular outcomes (8) and that psychological stress can alter the magnitude of the airway's inflammatory response to irritants and susceptibility to respiratory illness (9). However, we cannot discard the possibility that the associations we detected are due to chance. Considering the low number of respiratory deaths per day and the low number of strike days (particularly metro strike days), our results should be considered cautiously. This could also explain the lack of mediation by air pollution. Our study could also be affected by measurement error in air pollution exposure, although we expect that the main component would be Berkson error, which is not expected to bias the exposure-outcome associations (10). However, measurement error could result in some bias towards the null in the indirect associations estimated in the mediation analysis (11). Future research might shed more light on these relationships and potential pathways. It would be interesting in these future studies to explore the associations according to population subgroup, according to both sociodemographic characteristics and residential area.

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Conflicts of interest: none declared.

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