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Short-term association of in-vehicle ultrafine particles and black carbon concentrations with respiratory health in Parisian taxi drivers

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16 **Abstract**

17 **Introduction**

18 Professional drivers are exposed inside their vehicles to high levels of air pollutants due to the
19 considerable time they spend close to motor vehicle emissions. Little is known about ultrafine
20 particles (UFP) or black carbon (BC) adverse respiratory health effects compared to the regulated
21 pollutants.

22 **Objectives**

23 We aimed to study the short-term associations between UFP and BC concentrations inside vehicles
24 and (1) the onset of mucosal irritation and (2) the acute changes in lung function of Parisian taxi
25 drivers during a working day.

26 **Methods**

27 An epidemiological study was carried out on 50 taxi drivers in Paris. UFP and BC were measured
28 inside their vehicles with DiSCmini® and microAeth®, respectively. On the same day, the
29 frequency and the severity of nose, eye, and throat irritations were self-reported by each participant
30 and a spirometry test was performed before and after the work shift. Multivariate analysis was used
31 to evaluate the associations between in-taxis UFP and BC concentrations and mucosal irritation and
32 lung function, after adjustment for potential confounders.

33 **Results**

34 In-taxis UFP concentrations ranged from 17.9 to 37.9 $\times 10^3$ particles/cm³ and BC concentrations
35 from 2.2 to 3.9 $\mu\text{g}/\text{m}^3$, during a mean of 9 ± 2 working hours. Significant dose-response
36 relationships were observed between in-taxis UFP concentrations and both nasal irritation and lung
37 function. The increase of in-taxis UFP (for an interquartile range of 20×10^3 particles/cm³) was
38 associated to an increase in nasal irritation (adjusted OR = 6.27 [95% CI: 1.02 to 38.62]) and to a
39 reduction in forced expiratory flow at 25–75 % by -7.44 % [95% CI: -12.63 to -2.24], forced
40 expiratory volume in one second by -4.46 % [95% CI: -6.99 to -1.93] and forced vital capacity by -
41 3.31 % [95% CI: -5.82 to -0.80]. Such associations were not found with BC. Incident throat and eye
42 irritations were not related to in-vehicle particles exposure; however, they were associated with
43 outdoor air quality (estimated by the Atmo index) and in-vehicle humidity, respectively.

44 **Conclusion**

45 To our knowledge, our study is the first to show a significant association, within a short-period of
46 time, between in-vehicle UFP exposure and acute respiratory effects in professional drivers.

47 **Keywords:** taxi drivers, ultrafine particles, black carbon, mucosal irritation, lung function

48 **1. Introduction**

49 Occupational respiratory diseases reached the third spot among the top three fatal work-related
50 illnesses, according to the Workplace Safety and Health Institute (WSHI, 2017). Outdoor workers
51 have been identified to be at high risk of developing respiratory health problems owing to their
52 continuous exposure to traffic related air pollutants (TRAP) during long period of time close to
53 vehicular emissions (HEI, 2010; Knibbs and Morawska, 2012). The respiratory health effects of
54 particulate matter with aerodynamic diameter ≤ 10 (PM_{10}) and ≤ 2.5 micrometers ($PM_{2.5}$), carbone
55 monoxide (CO), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2) on traffic policemen, bus drivers,
56 motorcycle taxi drivers, subway drivers are well documented in the literature (Arphorn et al., 2018;
57 Bener et al., 1997; Bigert et al., 2011; Brant et al., 2014; Choudhary and Tarlo, 2014; Jones et al.,
58 2006; Karita et al., 2004; Lawin et al., 2018; Mbelambela et al., 2017; Santos et al., 2016; Shakya et
59 al., 2016; Zhao et al., 2015; Zhou et al., 2001). Higher prevalence of respiratory symptoms (phlegm,
60 wheezing, short breath, chest pain, throat pain, cough) (Jones et al., 2006; Mbelambela et al., 2017;
61 Zhou et al., 2001) and lower lung function (FVC - forced vital capacity, FEV₁- forced expiratory
62 volume in one second) (Jones et al., 2006) are observed in outdoor workers compared to control
63 groups (non-exposed to TRAP). However, very little is known on the effect of TRAP on taxi
64 drivers' respiratory health, even though they are highly exposed to air pollutants inside their
65 vehicles during a significant proportion of their daily time (Hachem et al., 2019).

66 Recently, the focus has shifted towards ultrafine particles (UFP) and black carbon (BC), both
67 emitted by combustion processes, especially by combustion engines (particularly diesel) in urban
68 areas (Janssen et al., 2012; Morawska et al., 2008). UFP (≤ 100 nm) are small enough to reach
69 alveoli. They contribute to a large surface area with high deposition efficiency, which facilitates
70 their penetration through the epithelium and thus translocation to the circulatory system (Gulati and
71 Cullen, 2017; HEI, 2013; Leikauf et al., 2020; Morawska et al., 2019). BC is mainly harmful
72 through carrying a mix of toxic chemicals deeply into the lungs (Janssen et al., 2012).
73 Epidemiological studies investigating the link between short-term exposure either to UFP or BC
74 and respiratory health are still inconclusive. This is due to : (1) the absence of standard methods to
75 measure UFP, making results difficult to compare (Morawska et al., 2019); (2) the challenges
76 encountered in assessing TRAP exposure by considering the mixture of traffic pollutants (difficulty
77 to dissociate specific pollutant effect) and by taking into account all the determinants that may
78 affect their levels. However, there is some evidence of their adverse health effects on
79 cardiopulmonary hospital admissions, acute respiratory and cardiovascular morbidity, etc. (HEI,
80 2013; Janssen et al., 2012; Knibbs et al., 2011; Paunescu et al., 2019a; Paunescu et al., 2019b).

81 In this respect, the aim of this study is to investigate the short-term associations between in-vehicle
82 exposure of taxi drivers to UFP and BC during a working day and respiratory health, in particular
83 mucosal (nose, throat, and eye) irritation symptoms and lung function.

84 **2. Methods**

85 **2.1. Study design and participants**

86 As part of PUF-TAXI project, this observational study was carried out in Paris between 1st of
87 February 2019 and 10th of January 2020, on 50 volunteer taxi drivers recruited prospectively by two
88 taxi trade unions, and *via* advertising in taxi magazines/seminars. The taxi drivers included had to
89 be over 18 years of age and to work on full-time day shift with more than 6 months of experience in
90 their jobs.

91 At the first visit, all participants underwent a physical examination free of charge to evaluate their
92 general health status in the Occupational and Environmental Diseases Service at Hôtel-Dieu
93 Hospital in the city of Paris.

94 At the second visit, they were invited to participate in a measurement campaign which consisted of
95 (1) measuring UFP and BC inside their vehicles throughout a normal working day and (2)
96 evaluating the occurrence of nose/throat/eye irritation symptoms and the changes in lung function
97 parameters pre- and post- pollutant sampling period, during the same day (Figure A.1). One work
98 shift was monitored for each participant.

99 PUF-TAXI has been declared to the National Commission for Data Protection and Liberties
100 (2172757v0) and registered in ClinicalTrial.gov (NCT03839537). It was approved by the French
101 Institutional Review Board (Île-De-France III Ethics Committee 3593-RM; Research Ethics
102 Number: 2018-A00811-54). Informed written consent was obtained from all participants.

103 **2.2. Exposure measurements**

104 Particle pollutants and the comfort parameters (temperature, humidity, carbon dioxide (CO₂)) were
105 all measured inside taxi vehicles during a typical working day without any restrictions given to the
106 driver (ventilation settings, destinations, working hours, etc.). UFP count were recorded by the
107 Diffusion Size Classifier Miniature (DiSCmini®, Wohlen, Switzerland and commercialized by
108 Testo SE &Co. KGaA, Titisee-Neustadt, Germany); BC concentrations by the microAeth® Model
109 AE51 (Aethlabs, San Francisco, California, USA) and temperature, humidity, and CO₂
110 concentrations by CP11® (Michel Instruments, Lyon, France). All the devices were placed in a
111 carry case, on the shelf under the rear window of all the 50 taxi vehicles.

112 The outdoor air quality on the sampling day was estimated using the Atmo index from the Paris air
113 quality monitoring network “Airparif” (www.airparif.asso.fr). Atmo index is determined from four
114 sub-indices based on the ambient concentrations of SO₂, NO₂, ozone (O₃) and PM₁₀ measured by all
115 the background monitoring stations in Paris area (Paris and suburbs). In short, the Atmo index is
116 scaled from 1 (very good) to 10 (very bad) corresponding to the highest sub-index of the four
117 pollutants.

118 **2.3. Health data**

119 During the medical visit, a standardized examination was carried out by an occupational physician
120 at Hôtel-Dieu Hospital. A skin prick test (SPT) was performed to detect sensitization to the most
121 common inhalant allergens. The participant’s health data (chronic and current respiratory or allergic
122 diseases) was collected using a standardized medical questionnaire based on the European
123 Community Respiratory Health Survey II questionnaire (ECRHS II) and the Epidemiological Study
124 of the Genetics and Environment of Asthma questionnaire (EGEA).

125 On the sampling day – when UFP and BC were measured inside taxis, the occurrence of nose, eye,
126 and throat irritation symptoms was self-reported by each participant at the start and during the
127 working day and scored from 0 to 10 using a symptom intensity scale. A spirometry test was also
128 performed by the same experienced technician, pre- and post- pollutant sampling period in every
129 participant, unless contraindicated (hemoptysis, pneumothorax, unstable cardiovascular status,
130 thoracic, abdominal or cerebral aneurysms, recent eye/thoracic/abdominal surgery) (Graham et al.,
131 2019). A portable spirometer (Spirobank II®, MIR, Italy) was used according to the American
132 Thoracic Society and the European Respiratory Society (ATS/ERS) guidelines (Miller et al., 2005).
133 After explaining the appropriate technique of the test procedure, each driver performed in a sitting
134 position wearing a nose clip, at least three satisfactory maneuvers. Following these guidelines, the
135 lung function parameters of the best expiratory flow-volume curve were chosen. The predicted
136 values for FVC, FEV₁, forced expiratory flow at 25–75% (FEF₂₅₋₇₅) and peak expiratory flow (PEF)
137 were determined based on sex, age, height and ethnicity (Miller et al., 2005).

138 **2.4. Potential confounders and effect modifiers**

139 At the medical visit, sociodemographic data (age, sex); anthropometric data (height, weight);
140 smoking status (smokers/ex-smokers/never smokers); comorbidities (gastroesophageal reflux
141 disease (GERD), hypertension, diabetes, asthma, allergic rhinitis, atopy assessed by a positive SPT)
142 and work characteristics (job tenure, working hours per day, working hours per week, etc.) were
143 recorded on a standardized questionnaire by the physician.

144 All along the pollutant sampling day, details of each trip (duration, ventilation settings, smoking,
145 etc.) were self-reported by the participants on a standardized form.

146 **2.5. Statistical analyses**

147 The health and job-related characteristics of the taxi drivers were described, and the distribution of
148 particle pollutant concentrations was graphically presented by boxplots.

149 The prevalence and the intensity of the nose/throat/eye irritation reported by the taxi drivers were
150 compared pre- and post- working day using McNemar's test and paired sample t-test, respectively.
151 We should note that if the participant reported that he did not experience any symptom his response
152 was coded as 0. Therefore, an incident irritation was defined as the nasal, throat or eye irritation
153 occurring during the working day or getting worse compared to the start of the day (the symptom
154 intensity scale during the working day > the symptom intensity scale at the start of the working
155 day). Regarding lung function, all spirometry parameters measured at the start and at the end of the
156 working day were compared using paired sample t-test. The relative change in lung parameter was
157 calculated as the difference between the post- and pre-working values reported to the pre-working
158 parameter.

159 The short-term associations of in-vehicle UFP and BC concentrations with both incident irritation
160 (nose, throat and eye) and relative changes in lung function parameters during a working day were
161 studied using single- and multiple- pollutant logistic and linear regression models, respectively,
162 adjusted for potential confounders. Relevant covariates were chosen for each model according to
163 the literature, to the directed acyclic graphs (DAGs) version 3.0 (Figure A.2, Figure A.3) and to the
164 bivariate analysis (p-value of ≤ 0.20): age of the taxi driver (years); sex; body mass index (BMI)
165 (kg/m^2); having a GERD (yes/no); the outdoor air quality index (Atmo); exposure duration (hours);
166 temperature in-taxi ($^{\circ}\text{C}$); humidity in-taxi (%); ventilation settings (the duration in minutes of
167 opening windows and air-conditioning activation). Results were expressed as adjusted odd ratios
168 (ORa) or beta coefficients (βa) and their 95% confidence intervals (CI) for an interquartile range
169 (IQR) increase in UFP and BC concentrations.

170 Potential modification effects by comorbidities (atopic/respiratory diseases and GERD) were tested
171 by introducing multiplicative interaction terms in the models. All analyses were conducted using
172 STATA® /SE (version 15.1) (StataCorp, College Station, Texas, United-States). The statistical
173 significant level was $p < 0.05$.

174 **3. Results**

175 **3.1. Participants**

176 The mean age of the participants was 51.5 ± 7.3 years, the majority were men (92%) and less than a
 177 quarter of the drivers were current smokers (18%). Out of 50 taxi drivers, 20 (40%) reported having
 178 at least one chronic respiratory or allergic disease (29% allergic rhinitis, 16% asthma and 16%
 179 eczema) of whom 12 (60%) had a positive skin prick test (SPT) to at least one inhalant allergen
 180 (Table 1). Most of the taxi drivers (69%) declared experiencing nose (42%) and/or eye (38%)
 181 and/or throat irritation (36%) during the last 12 months. The job-related characteristics of the taxi
 182 drivers are presented in table 2.

183 **Table 1.** Baseline

Variables	Mean \pm SD or n (%)
General characteristics	
Age, years [min - max]	51.5 \pm 7.3 [37 - 73]
Sex	
Male	46 (92)
Female	4 (8)
Smoking status	
Smokers ^a	9 (18)
Ex-smokers ^b	19 (38)
Never smokers	22 (44)
Health data at physical examination	
Height (cm)	175.2 \pm 7.8
Weight (kg)	82 \pm 14.8
BMI (kg/m ²)	26.7 \pm 4.3
Skin prick tests (SPT) ^c	
Atopy by a positive SPT (N=38)	18 (47)
Reported respiratory and allergic diseases	
Asthma ever	8 (16)
Current ^d asthma	8 (16)
Allergic rhinitis ever	14 (29)
Current allergic rhinitis	4 (8)
Eczema ever	8 (16)
Current eczema	4 (8)
Atopy ever	12 (24)
Other reported diseases	
Hypertension	7 (14)
Diabetes	3 (6)
GERD	28 (56)
Reported respiratory and allergic symptoms in the past year	
Mucosal irritation	
Nose ^e	21 (42)
Eye ^f	19 (38)
Throat ^g	18 (36)
Wheezing	8 (16)
Breathing difficulties	14 (28)

184 characteristics of Parisian taxi drivers in PUF-TAXI study in Paris (N= 50)

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BMI: body mass index; **GERD:** gastroesophageal reflux disease; **SD:** standard deviation; **SPT:** skin prick test.

- a. **Smokers** current smokers or had quit smoking for less than twelve months.
- b. **Ex-smokers** have quit smoking for at least twelve months.
- c. **Skin prick test (SPT)** is considered positive if the wheal diameter ≥ 3 mm and at least half the size of the positive histamine control (Helaskoski et al., 2017).
- d. **Current** during the past 12 months.
- e. **Nose irritation** is defined as sneezing, stuffy or runny nose, itchy nose without any infectious triggers.
- f. **Eye irritation** is defined as redness, watery or itchy eyes without any infectious triggers.
- g. **Throat irritation** is defined as hoarseness, irritation, and itching without any infectious triggers.

driving-related
Parisian taxi
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Table 2. Job and characteristics of drivers in PUF-Paris (N= 50)

Occupational characteristics of taxi drivers	Mean \pm SD [min-max] or n (%)
Job tenure, years	16.1 \pm 7.7 [2 - 35]
Working hours per day	10 \pm 1.3 [7 - 12]
Working days per week	5.7 \pm 0.7 [4 - 7]
Taxi vehicles characteristics	
Car age, years	3.6 \pm 2.1 [1 - 10]
Fuel type	
Diesel	26 (52)
Petrol	24 (48)
During the measurement campaign	
Working hours per day	9.4 \pm 1.6 [5 - 13]
Smoking during the measurement day ^a	4 (8)
Number of trips per day	10 \pm 5 [2 - 29]
Duration of opening windows, minutes	105.4 \pm 134.5 [0 - 473]
Duration of activating AC, minutes	131.7 \pm 138.5 [0 - 603]
Duration of heating, minutes	79.8 \pm 136.2 [0 - 603]

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AC: air conditioning; **SD:** standard deviation

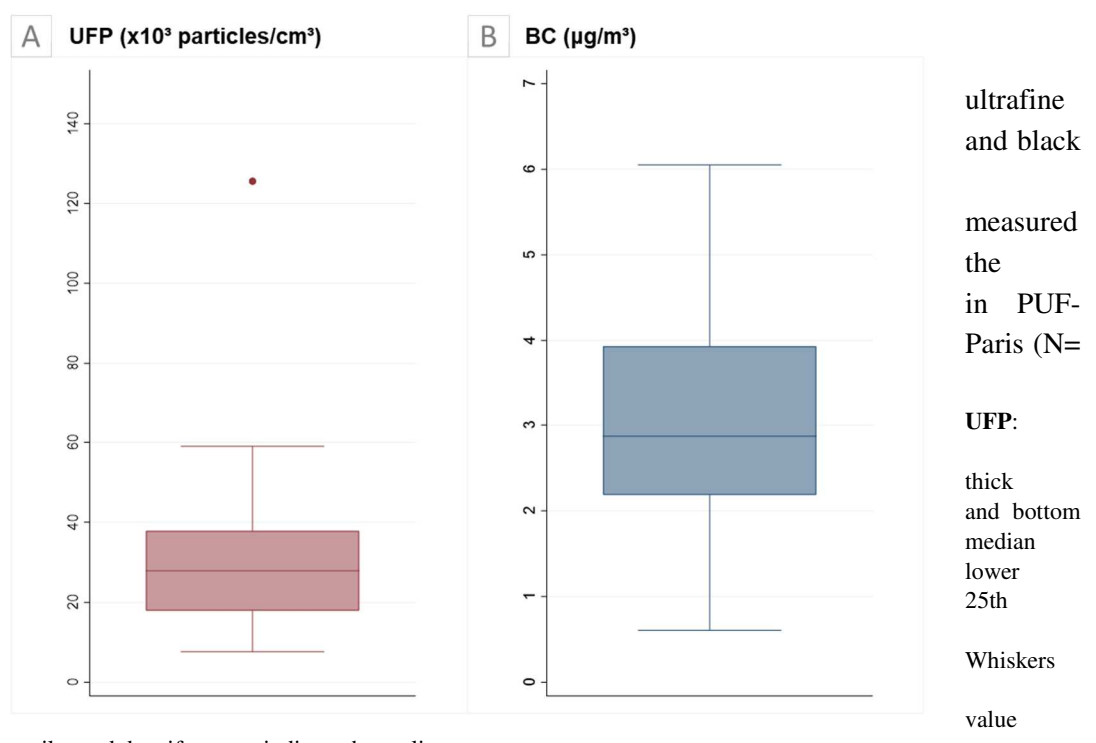
- a. Smoking during the measurement day if the driver or the client smoked inside the vehicle.

3.2. UFP and BC concentrations inside taxi vehicles

209 In-taxis concentrations ranged from 17.9 to 37.9 x10³ particles/cm³ for UFP and from 2.2 to 3.9
 210 µg/m³ for BC (Figure 1), during a mean of 9.4 ± 1.6 working hours. UFP and BC were moderately
 211 positively correlated (r= 0.43; p < 0.01). The average temperature, humidity and CO₂ levels
 212 recorded in taxis were 23.4 ± 3.7 °C, 41.6 ± 11.5 % and 1125 ± 603 ppm, respectively.

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Figure 1. Distribution of particles (A) carbon (B) concentrations in taxis during sampling days TAXI study in 50) BC: black carbon; ultrafine particles. In each box, the middle line, top represent the value, upper and quartile (75th and percentile), respectively. extend to the highest/lowest within 1.5 times the quartiles and dots if present indicate the outliers.



3.3. Association between in-taxis UFP and BC concentrations and mucosal irritation

252 Overall, the prevalence and the intensity of the reported eye/nose/throat irritation increased during
253 the working day significantly compared to the start of the day: 27 (54%) vs 17 (34%), $p = 0.01$;
254 geometric mean of the intensity irritation score: 4.1 vs 3.8, $p = 0.04$.

255 Incident nose irritation was significantly associated with UFP and BC concentrations inside taxis,
256 when tested in single pollutant models. However, in two-pollutants models only the association
257 with
258 in-taxis UFP concentrations remained statistically significant (Table 3A). In addition, results
259 showed significant positive association between nose irritation and working duration. In contrast,
260 nose irritation was inversely associated with temperature inside vehicles. No interaction was found
261 with respiratory/allergic diseases.

262 Incident throat irritation was not associated with in-taxis UFP and BC concentrations, but increased
263 with poor outdoor air quality (Table 3B), this association being modified by GERD (Table A.1).
264 Throat irritation in relation with outdoor air quality greatly increased in taxi drivers suffering from
265 GERD. Incident eye irritation was not associated to air pollutants (neither outdoor nor inside taxis)
266 and appeared to only depend on humidity levels inside taxis (Table 3C). Incident eye irritation
267 increased with the dryness of the atmosphere.

Table 3. Associations between in-taxis UFP (IQR of 20 x10³ pt/cm³) and BC (IQR of 1.75 µg/m³) concentrations and the incidence of nose (A), throat (B) and eye (C) irritation during the working day in PUF-TAXI project (N=50)

A Nose irritation ^a	UFP - single pollutant model		BC - single pollutant model		UFP&BC - multipollutant model	
	ORa [95% CI]	<i>P</i> - value	ORa [95% CI]	<i>P</i> - value	ORa [95% CI]	<i>P</i> - value
Exposure						
IQR of UFP (x10 ³ pt/cm ³)	8.32 [1.31 to 52.6]	0.024	---	---	6.27 [1.02 to 38.62]	0.048
IQR of BC (µg/m ³)	---	---	7.97 [1.11 to 57.03]	0.039	4.81 [0.63 to 36.62]	<i>0.129</i>
Outside air pollution index (Atmo index)	0.46 [0.16 to 1.37]	<i>0.163</i>	0.37 [0.11 to 1.22]	<i>0.102</i>	0.32 [0.09 to 1.13]	<i>0.077</i>
Working duration (hour)	3.32 [1.09 to 10.16]	0.035	3.09 [1.19 to 7.99]	0.020	3.51 [1.25 to 9.85]	0.017
Vehicle						
In-taxi temperature (°C)	0.47 [0.24 to 0.94]	0.032	0.61 [0.39 to 0.95]	0.034	0.49 [0.25 to 0.94]	0.032
In-taxi ventilation settings						
Air conditioning activation time (min)	1.01 [0.99 to 1.02]	<i>0.219</i>	1.01 [0.99 to 1.02]	<i>0.267</i>	1.01 [0.99 to 1.02]	<i>0.115</i>

a. Nose irritation defined as sneezing, stuffy or runny nose, itchy nose without any infectious triggers.

B Throat irritation ^b	UFP - single pollutant model		BC - single pollutant model		UFP&BC - multipollutant model	
	ORa [95% CI]	<i>P</i> - value	ORa [95% CI]	<i>P</i> - value	ORa [95% CI]	<i>P</i> - value
Exposure						
IQR of UFP (x10 ³ pt/cm ³)	1.24 [0.47 to 3.32]	<i>0.659</i>	---	---	1.50 [0.52 to 4.39]	<i>0.454</i>
IQR of BC (µg/m ³)	---	---	0.47 [0.11 to 2.09]	<i>0.324</i>	0.36 [0.07 to 2.00]	<i>0.224</i>
Outside air pollution index (Atmo index)	3.04 [1.22 to 7.63]	0.017	4.08 [1.35 to 12.30]	0.013	4.16 [1.32 to 13.07]	0.015
Working duration (hour)	1.26 [0.71 to 2.24]	<i>0.435</i>	1.16 [0.66 to 2.02]	<i>0.607</i>	1.24 [0.69 to 2.23]	<i>0.469</i>
Vehicle						
In-taxi ventilation settings						
Windows opening time (min)	0.99 [0.99 to 1.003]	<i>0.201</i>	0.99 [0.99 to 1.003]	<i>0.305</i>	0.99 [0.99 to 1.003]	<i>0.224</i>
Driver						
Gastroesophageal reflux disease						
No	Reference		Reference		Reference	
Yes	13.9 [1.3 to 149.4]	0.029	17.6 [1.6 to 197.13]	0.029	17.04 [1.5 to 198.9]	0.024

b. Throat irritation defined as hoarseness, irritation, and itching without any infectious triggers.

C Eye irritation ^c	UFP - single pollutant model		BC - single pollutant model		UFP&BC - multipollutant model	
	ORa [95% CI]	<i>P</i> - value	ORa [95% CI]	<i>P</i> - value	ORa [95% CI]	<i>P</i> - value
Exposure						
IQR of UFP (x10 ³ pt/cm ³)	1.16 [0.16 to 8.62]	<i>0.882</i>	---	---	2.49 [0.31 to 20.05]	<i>0.391</i>
IQR of BC (µg/m ³)	---	---	0.21 [0.01 to 3.21]	<i>0.262</i>	0.09 [0.002 to 4.74]	<i>0.237</i>
Outside air pollution index (Atmo index)	1.15 [0.38 to 3.35]	<i>0.801</i>	2.08 [0.48 to 9.09]	<i>0.331</i>	2.29 [0.41 to 12.84]	<i>0.345</i>
Working duration (hour)	1.34 [0.60 to 3.05]	<i>0.479</i>	1.47 [0.62 to 3.48]	<i>0.379</i>	1.71 [0.64 to 4.62]	<i>0.287</i>
Vehicle						
In-taxi humidity (%)	0.85 [0.74 to 0.98]	0.025	0.87 [0.74 to 1.01]	0.068	0.87 [0.75 to 1.00]	0.055
In-taxi temperature (°C)	0.84 [0.61 to 1.16]	<i>0.289</i>	0.83 [0.60 to 1.15]	<i>0.266</i>	0.79 [0.55 to 1.12]	<i>0.199</i>
Driver						
Body mass index (kg/m ²)	1.34 [0.98 to 1.85]	<i>0.070</i>	1.25 [0.95 to 1.67]	<i>0.111</i>	1.31 [0.94 to 1.82]	<i>0.106</i>

c. Eye irritation defined as redness, watery or itchy eyes without any infectious triggers.

BC: black carbon; IQR: interquartile range; ORa: adjusted odds ratio; UFP: ultrafine particles

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3.4. Associations between in-taxis UFP and BC concentrations and relative change in lung function parameters

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271 During the working day, increasing in-taxis UFP concentrations (for an IQR of 20×10^3

272 particles/cm³) were associated with a significant reduction in FEF₂₅₋₇₅ (-7,44 % [95% CI: -12.63 to -

273 2.24]), FEV₁ (-4,46 % [95% CI: -6.99 to -1.93]) and FVC (-3,31 % [95% CI: -5.82 to -0.80])

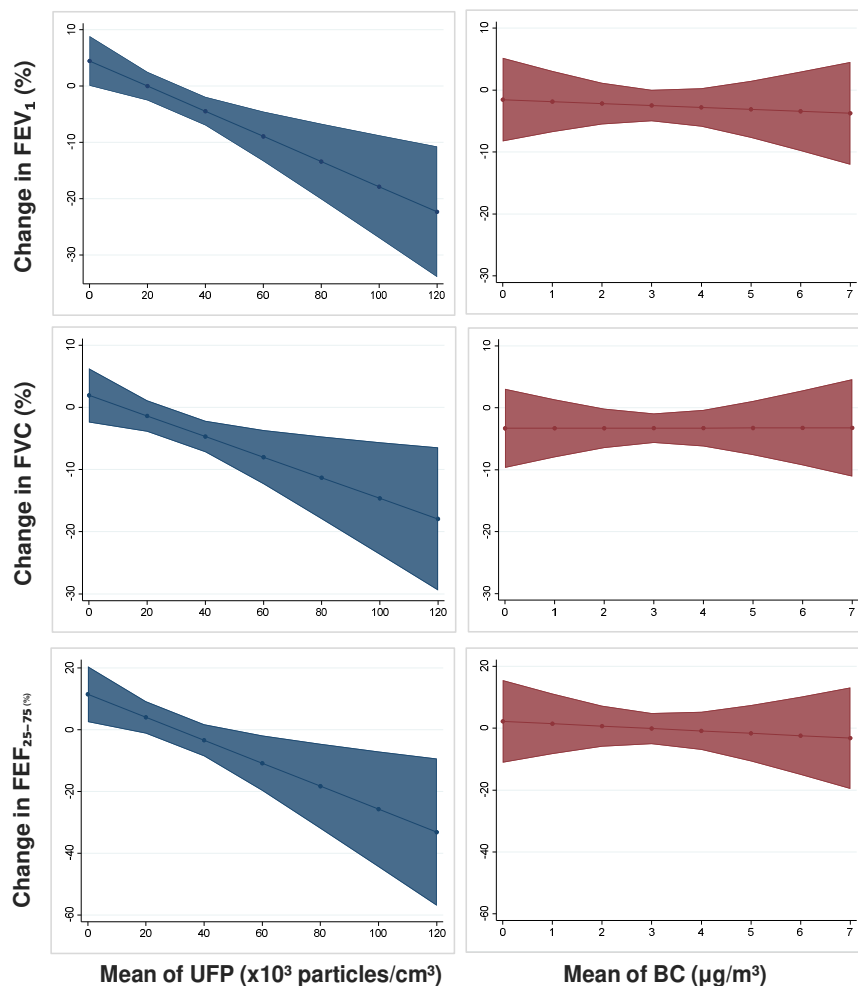
274 (Figure 2). At the end of the work shift, 21% (n=10) of the taxi drivers had a reduced FVC more

275 than 5%, 30% (n=14) a reduced FEV₁ more than 5% and 19% (n=9) a reduced FEF_{25-75%} more than

276 13% compared to at the start of the work shift. No significant association was found between in-

277 taxis BC concentrations and relative changes in lung function parameters measured pre- and post-

278 working day. No interaction was found with respiratory/allergic diseases.



279 **Figure 2.** Relative changes in FEV₁, FVC and FEF_{25-75%} before and after work shift according to in-taxis

280 UFP and BC concentrations measured throughout the working day in PUF-TAXI project (N=50)

281 **BC:** black carbon; **FEV₁:** forced expiratory volume in one second; **FEF_{25-75%}:** forced expiratory flow at 25-75% of the FVC; **FVC:**

282 forced vital capacity; **UFP:** ultrafine particles.

283 All models are adjusted for age (years), sex, body mass index, temperature inside taxi vehicles (°C) and the quality of the outdoor air

284 (Atmo index).

285 Blue and red dots represent adjusted β in percentage of change with its 95% confidence interval.

286 **4. Discussion**

287 **4.1. Key results**

288 This study offers new insights into the associations of short-term exposure to in-vehicle UFP and
289 BC concentrations with acute mucosal irritation and lung function variation of Parisian taxi drivers
290 during a working day. The most notable findings were the increase in incident nasal irritation and
291 the reduction of FEV₁, FVC and FEF₂₅₋₇₅ after short-term exposure to in-vehicle UFP. No
292 association was found with BC concentrations. Incident throat and eye irritations were not related to
293 in-vehicle particles exposure; however, they were associated with outdoor air quality and in-vehicle
294 humidity, respectively.

295 **4.2. Strengths and limitations**

296 To our knowledge, this is the first study to address the link between in-vehicles UFP and BC
297 exposure and acute respiratory effects. A major advantage of this research is to study real-world
298 working conditions, without any restrictions given to the taxi drivers, using individual
299 measurements of particle concentrations inside each taxicab during a working day. Pollutants were
300 recorded (every minute) for all participants using the same devices placed in the same position
301 inside taxis. As for health data, they were also carefully collected following precise standard
302 operating procedures. The medical examination was performed by a single physician and the
303 spirometry tests before and after work shift were carried out by the same investigator who
304 underwent a specific training prior to the study. The use of single and two-pollutant regression
305 models allowed to discern the specific association of each pollutant with the health outcomes.
306 However, this study has a few limitations. Randomization of taxi drivers was not possible due to the
307 inaccessibility to an exhaustive sampling frame. Therefore, the recruitment of participants was
308 based on volunteering resulting in a potential selection bias. Taxi drivers' motivation to participate
309 in the study might be related to their particular sensitivity to indoor air issues. Therefore, it was
310 important to complete the reporting of symptoms by objective measurements of lung function
311 parameters, each participant acting as his own control for health outcomes before and after work
312 shift comparisons. There were few women participants (n=4) which is somehow in line with their
313 low representation in this occupation, and we performed sensitivity analysis with and without
314 women. Results remained unchanged.

315 **4.3. Adverse short-term respiratory effects of in-vehicle exposure to traffic related air** 316 **pollutants**

317 We found that a significant proportion of taxi drivers (around 50%) reported having a least one
318 chronic respiratory/allergic disease and suffering from mucosal irritation during the last year (42%

319 nose irritation; 38% eye irritation; 36% throat irritation). Occupational epidemiological studies were
320 consistent with our findings. Professional drivers in Congo (Mbelambela et al., 2017), in Shanghai
321 (Zhou et al., 2001) and in the United Arab Emirates (Bener et al., 1997) (taxi drivers, bus drivers,
322 motorcycle taxi drivers) had significant higher prevalence of adverse respiratory effects (asthma,
323 allergic rhinitis, dyspnea, nasal catarrh, cough, phlegm, throat pain) than non-exposed groups
324 (manual/office/storage workers, high school teachers).

325 Regarding acute respiratory symptoms, this study showed significant dose-response relationships
326 between in-vehicle UFP and BC exposure and incident nasal irritation. However, when using the
327 two-pollutant models, it appears that the effect of UFP on nasal mucosa is more robust than that of
328 BC. Our results are biologically plausible. The major exposure route of particles is via inhalation.
329 Particles in the range of 1 to 10 μm , including BC $< 2.5 \mu\text{m}$, tend to deposit in the extra-thoracic
330 region (nose, pharynx, larynx). Smaller particles $< 1 \mu\text{m}$, in particular UFP, deposit in nasal and
331 alveolar regions due to diffusion (HEI, 2013; Oberdörster et al., 2005). Thus, during nasal
332 breathing, the nose mucosa plays a significant role in cleaning the inspired air by increasing mucus
333 production and ciliary beating, resulting in nasal discomfort (Brant et al., 2014; ICRP, 1994;
334 Oberdörster et al., 2005; Riechelmann et al., 2003). Furthermore, Brant et al. (2014) showed that
335 non-smoking commercial motorcyclists, in an urban city in Brazil, presented a decreased nasal
336 mucociliary clearance in relation with exposure to air pollutants (Brant et al., 2014). They also
337 found an increase in sino-nasal symptoms. Cole-Hunter et al. (2013) reported an increase in nasal
338 irritation related to high exposure to UFP ($29.5 \times 10^3 \text{ particles/cm}^3$) in healthy participants during
339 commuting by bicycle (Cole-Hunter et al., 2013), which is consistent with our results. Otherwise,
340 UFP appear to be cleared less quickly than larger particles. Indeed, UFP may penetrate through a
341 layer of relatively low viscosity surrounding the cilia or they deposit in areas in which mucous is
342 reduced or absent (HEI, 2013; Schürch et al., 1990). Consequently, the lack of UFP clearance may
343 lead to their accumulation, which may explain the robust association found between UFP and nasal
344 irritation but not with BC.

345 As for throat irritations, they were not associated with in-vehicle UFP and BC concentrations during
346 the working day. This outcome was expected given the deposition and the clearance mechanisms of
347 the corresponding pollutants in the respiratory tract. UFP tend to deposit either in the nose or in the
348 alveoli but not in the pharynx nor in the larynx. BC appears to be cleared easily from the upper
349 airways (Oberdörster et al., 2005). Conversely, throat irritation was related to outdoor air pollution.
350 This is consistent with the United States Environmental Protection Agency (US EPA) publication,
351 reporting that O_3 can cause sore or scratchy throat (EPA, 2020). Interestingly, we found that
352 outdoor air pollution may be differently associated with incident throat irritation depending on

353 whether the taxi driver is suffering from GERD or not. In fact, GERD refers to the passage of
354 gastric contents into the esophagus reaching the laryngeal and pharyngeal resulting in mucosal
355 injury, which manifests by extra-esophageal symptoms, including dry and sore throat (Issing and
356 Karkos, 2003; Tauber et al., 2002). In that respect, a possible explanation for our result is that
357 having an irritated mucosa could increase the effects of outdoor air pollutants.

358 Regarding eye irritation, it was not associated neither with in-vehicle particles nor with ambient air
359 pollution. Nevertheless, we found that taxi drivers experienced more eye irritation with the
360 decreasing in humidity inside cabs. The literature supports our result. There is a growing evidence
361 linking eye irritation to low relative humidity mainly by lacrimal hyper-osmolarity inducing
362 instability of the lacrimal film (2007; Doan, 2009; Hwang et al., 2016; Wolkoff, 2018). Sunwoo et
363 al. (2006) showed that under 30% of relative humidity, the subjects reported that their eyes became
364 drier (Sunwoo et al., 2006).

365 Most attention related to the lung function of professionals exposed to air pollution has focused on
366 its association with regulated pollutants (PM₁₀, PM_{2.5}, NO₂ and CO) (Bigert et al., 2011; Brant et
367 al., 2014; Jones et al., 2006; Zhao et al., 2015). In São Paulo, outdoor workers (including taxi
368 drivers) exposed to high concentrations of PM_{2.5} (> 39.6 µg/m³) had lower FVC (-12.2%; CI% 95: -
369 20% to -4.4%) and FEV₁ (-9.1 %; CI% 95: -19.1% to -0.9%) compared to those exposed to low
370 PM_{2.5} concentrations (< 25 µg/m³) (Santos et al., 2016). In Benin, motorcycle taxi drivers exposed
371 to CO concentrations above the US EPA air quality standard for 8 hours per day (9 ppm) had lower
372 PEF (-10%, p=0.02) compared to less exposed group < 9 ppm (Lawin et al., 2018). However, less is
373 known about UFP and BC. As far as we know, no team has assessed the effect of UFP on
374 professional drivers' health. Our main findings suggested that short-term exposure to in-vehicle
375 UFP concentrations during a working day reduced lung function in taxi drivers at the end of the
376 shift compared to its start. Hence, the association between respiratory effect and UFP exposure
377 might be considered as a continuum since it initiates with nasal irritation. Regarding BC, there was
378 no association with changes in lung function during a working day. Only Shayka et al. (2016)
379 investigated respiratory effect of BC exposure in traffic policemen (Shakya et al., 2016). Contrary
380 to our study, they found that personal occupational BC exposure was negatively correlated with
381 FEV₁ (r= - 0.36, p<0.05). This may be due to the high BC concentrations (range from 12.4 to 28.4
382 µgC/m³) traffic policemen were exposed to, much higher than those we measured inside Parisian
383 taxi vehicles (range from 2.2 to 3.9 µg/m³) (Shakya et al., 2016). Our results are biologically
384 plausible. In fact, larger particles appear to be cleared easily from the respiratory tract, whereas
385 smaller particles tend to remain longer, which may lead to their accumulation in airway tissues
386 (HEI, 2013; Oberdörster et al., 2005). This phenomenon may cause acute reduction in airway

387 caliber by increasing airway secretions or stimulating airway smooth muscle or pulmonary
388 vasoconstriction (Batalha et al., 2002; Brook et al., 2002; Pietropaoli et al., 2004). However, the
389 specific mechanism remains unknown (HEI, 2013). Nevertheless, this could explain the
390 deterioration of Parisian taxi driver's lung parameters (FVC, FEV₁, FEF_{25-75%}) associated with UFP
391 but not with BC, at the end of the working day, although the circadian rhythm of lungs improves the
392 pulmonary function in the late afternoon (Medarov et al., 2008; Nosal et al., 2020). Hence, the
393 associations we observed might have been underestimated.

394 Lastly, the clinical significance of lung function results must be questioned. According to the
395 ATS/ERS publication, a real change in lung function is significant if FVC and FEV₁ varied $\geq 5\%$
396 and FEF_{25-75%} $\geq 13\%$ within a day in normal subjects (Pellegrino et al., 2005). In our study, the
397 mean variations of lung parameters were below these thresholds. However, 36% of drivers
398 presented significant changes of at least one of the lung parameters. We should note, though, that
399 reduction in FEF₂₅₋₇₅ and in FEV₁ suggest obstruction in the small and central airways (Pellegrino et
400 al., 2005; Pietropaoli et al., 2004). Porsbjerg et al. (2015) reported that decline in FEV₁ is associated
401 with incident asthma in adults (Porsbjerg et al., 2015). Moreover, some evidence has shown that
402 exposure to air pollutants can trigger the adult onset of asthma or exacerbate existing asthma
403 (Guarnieri and Balmes, 2014). Our results need to be confirmed by further studies.

404 **5. Conclusion**

405 In conclusion, this study has shown a significant association, within a short period of time, between
406 in-vehicle UFP exposure and acute respiratory effects (nasal irritation, lung function) of
407 professional drivers. Given the considerable time professional drivers spend inside vehicle, further
408 studies are needed to investigate the adverse respiratory effects of UFP and BC in occupational
409 population. Such research could further help policy makers to define appropriate limit values for
410 UFP and BC, not regulated to this day.

411 **Patient consent**

412 Written.

413 **CRedit authorship contribution statement**

414 **Melissa HACHEM**: Validation, Formal analysis, Investigation, Writing – Original Draft. **Maxime**
415 **LOIZEAU**: Investigation, Writing - Review & Editing. **Nadine SALEH**: Validation, Supervision,
416 Writing - Review & Editing. **Isabelle MOMAS**: Conceptualization, Methodology, Validation,
417 Resources, Writing - Review & Editing, Supervision, Project administration. **Lynda BENSEFA-**

418 **COLAS:** Conceptualization, Methodology, Validation, Investigation, Supervision, Project
419 administration, Writing - Review & Editing.

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429 The authors declare no competing financial interest.

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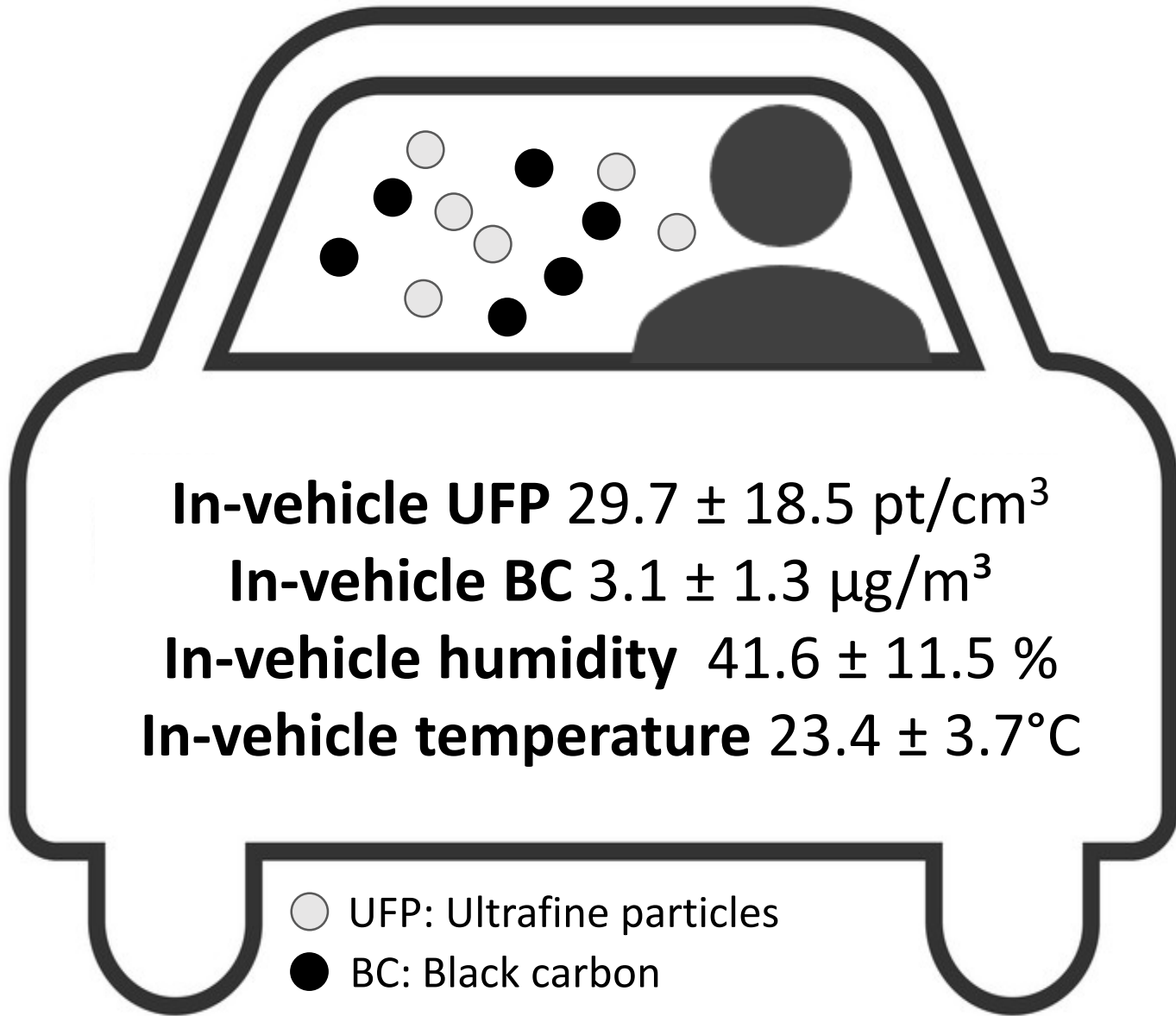
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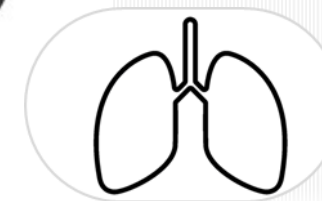
Incident eye irritation related to in-vehicle **humidity**



Incident nasal irritation related to **in-vehicle UFP** concentrations



Incident throat irritation related to **outdoor air quality (Atmo index)**



Decrease in lung function related to **in-vehicle UFP** concentrations