Concern over health effects of air pollution is associated to NO2 in seven European cities
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Concern over health effects of air pollution is associated to NO₂ in seven European cities

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Abstract

Subjective perception of air pollution is important, and can have impacts on health in its own rights, lead to protective behaviour, or it can be leveraged to engage citizens and stakeholders in support of cleaner air policies. The aim of the current analysis was to examine associations between level of concern over health effects of air pollution and personal and environmental factors.

In 7 European cities, 7622 adult participants were recruited to complete an online questionnaire on travel and physical activity behaviour, perceptions and attitudes on active mobility and the environment, and sociodemographics. Air pollution at the home address was determined using Europe-wide $PM_{2.5}$ and NO_2 land use regression models. Mixed effects logistic regression was used to model concern over air pollution (worried versus not-worried; city as random effect).

Fifty-eight percent of participants were worried over health effects of air pollution with large differences across cities (Antwerp 78%; Barcelona 81%; London 64%; Oerebro 11%; Rome 72%; Vienna 43%; Zurich 33%). Linking mean modelled air pollution to mean level of concern per city, gave a good correlation for NO_2 ($r^2=0.75$), and a lower correlation for $PM_{2.5}$ ($r^2=0.49$). In the regression model sex, having children in the household, levels of physical activity, and NO_2 at the home address were significantly linked to individual concern over health effects of air pollution.

We found that NO_2 but not $PM_{2.5}$ at the home address was associated with concern over health effects of air pollution.

Introduction

Air pollution has been identified as an important cause of disease, responsible for an estimated 6.5 million deaths worldwide (Cohen et al. 2017). The problem is especially critical in rapidly growing urban areas that currently contain 55% of the world's population, and up to 75% in Europe (Khreis et al. 2016). Many air pollutants peak in urban areas, for instance pollution from traffic and from wood burning (Beelen et al. 2013). Epidemiological studies believe there is no safe threshold for exposure to air pollution: the lower the air pollution levels, the better for public health (WHO 2013). Citizen awareness of the air pollution problem (including their understanding that they are part of the problem – as drivers, as householders, etc.) is key to put pressure on governments and mobilize resources needed to improve air quality and reduce the health burden (Landrigan et al. 2017).

Risk perception is a complex issue (Backer-Grøndahl and Fyhri 2009; Gatersleben and Uzzell 2000). Air pollution is in many countries perceived as an important public health risk for many reasons. Firstly, exposure to air pollution is to a large extent not voluntary: you cannot choose not to be exposed to air pollution; moreover air pollution tends to affect disadvantaged groups more often (Kim et al. 2010; O'Neill et al. 2003). Secondly, when a risk is more visible (e.g. sensory awareness of smoke, visible smog) or more familiar, people are usually more concerned (Gatersleben and Uzzell 2000). Thirdly, when the risk has known or observable consequences (e.g. frequent news coverage on health impact of air pollution, having a child with asthma), and has more immediate physiological effects, concern scores will be higher (Bickerstaff 2004). The subjective perception of the risks of air pollution may in itself play a role in health and quality of life, possibly even to a larger extent than the purely physical effects (Deguen et al. 2012; Kim et al. 2012). This may especially be the case when the lay public's perceptions of risk are larger than those of scientific and policy experts (Bickerstaff 2004). This is often linked to broader social norms and attitudes toward air pollution, and trust in the central government or in the communicator, and it may differ between cities and countries (Bickerstaff 2004; Gatersleben and Uzzell 2000).

Annoyance due to air pollution is incorporated into the National Environmental monitoring in some countries (Jacquemin et al. 2007). In some epidemiological studies, an assessment of air pollution annoyance is used as a proxy for actual exposure (Oglesby et al. 2000). In this study, we assessed whether there is an association between (objective) exposure and (subjective) annoyance/concern over health effects of air pollution in seven European cities.

We first tested this association at the city-scale. Individual factors that influence the association between air pollution levels and subjective scoring may be levelled out on a population average scale (Oglesby et al. 2000). A disadvantage of such an ecological approach is that it prevents the establishment of any direct link between objective measures of air pollution surrounding people's homes and individual subjective air pollution concerns.

Secondly, we associated concern over health effects of air pollution to air pollution at home on an individual level, while taking into account a number of covariates. Previous studies have illustrated the complexity of individual scoring: other factors than measured/modelled air pollution, have been found to affect perceptions. Socioeconomic characteristics such as age, sex, race, income, or education level may impact subjective scoring of air pollution (Johnson 2002). Also characteristics of the local setting are important: proximity of roads, density of traffic, neighbourhood characteristics (urban vs. rural) (Brody et al. 2004; Pattinson et al. 2015). Increased susceptibility for health effects of air pollution may lead to higher concern levels with good reason (having a respiratory condition, being pregnant, elderly people) (Fernandez-Somoano et al. 2015; Llop et al. 2008; Piro et al. 2008). Being exposed to tobacco smoke in your neighbourhood, or living close to a high emitting factory have also been shown to impact concern over health effects of air pollution (Brody et al. 2004; Forsberg et al. 1997; Jacquemin et al. 2007).

A subjective assessment of concern lacks pollutant-specific information. Therefore it is difficult to use this information for policy evaluation, in epidemiologic inference, or for regulatory purposes. As a last research objective, we investigated whether some pollutants correlate better to concern levels than others.

Materials & methods

In seven urban areas around Europe, over 10,000 adults were recruited to participate in a survey on transport, physical activity, and health. The survey was part of the PASTA project (Physical Activity through Sustainable Transport Approaches) and has as a general aim to investigate correlates and interrelations of active mobility, physical activity, air pollution and crash risk (Dons et al. 2015; Gerike et al. 2016). Participants to the survey had to live, work, or go to school in Antwerp (Belgium), Barcelona (Spain), London (UK), Oerebro (Sweden), Rome (Italy), Vienna (Austria) or Zurich (Switzerland). They had to be 18 or older (16 in Zurich), and had to give informed consent prior to starting the survey. Participants were recruited continuously between November 2014 and December 2016, through a myriad of opportunistic recruitment methods, with one overall strategy combined with local actions. Most participants were recruited through workplaces, project outreach activities like street recruiting or presence at events, and social media activity (Twitter and Facebook). The survey was fully administered online on a dedicated website custom-built for this project. Data was stored and managed in one central database; data were cleaned and restructured in a collaborative effort using R software ensuring transparency and reproducibility. The baseline questionnaire that took about 30 minutes to complete was followed by a set of shorter questionnaires, always two weeks apart, in a longitudinal design.

As part of the online survey, concern over the health effects of air pollution was assessed in the baseline questionnaire using the question "Are you worried that air pollution in the neighbourhood of either your home or work can lead to health problems?" (similar to Deguen et al. (2012)). A standard five point Likert scale response was applied, ranging from 'Not worried at all' (score=1) to 'Extremely worried' (score=5). Through the survey, a number of sociodemographic variables were available (sex, age, education level, children at home), as well as variables indicating whether participants had access to a car (1=always/sometimes; 0=never), their physical activity level (based on the GPAQ questionnaire that was integrated in the survey (Laeremans et al. 2017)), and coordinates of the home location. Participants providing an address outside country borders, and participants that did not change the default coordinate value (as was the case for participants that did not move the pinpoint on the online map component) were excluded from further analysis. Air pollution at the residence was derived from Europe-wide NO_2 and $PM_{2.5}$ maps with a 100m resolution and available for base year 2010 (Figure 1) (de Hoogh et al. 2016). The NO_2 model explained 58.2% of spatial variation in measured concentrations, while the $PM_{2.5}$ model performed slightly better with

63.3%. The European main road network was used to determine the distance of each residence to the nearest primary road (OpenStreetMap; roads tagged as 'highway', 'motorway', 'trunk', or 'primary').
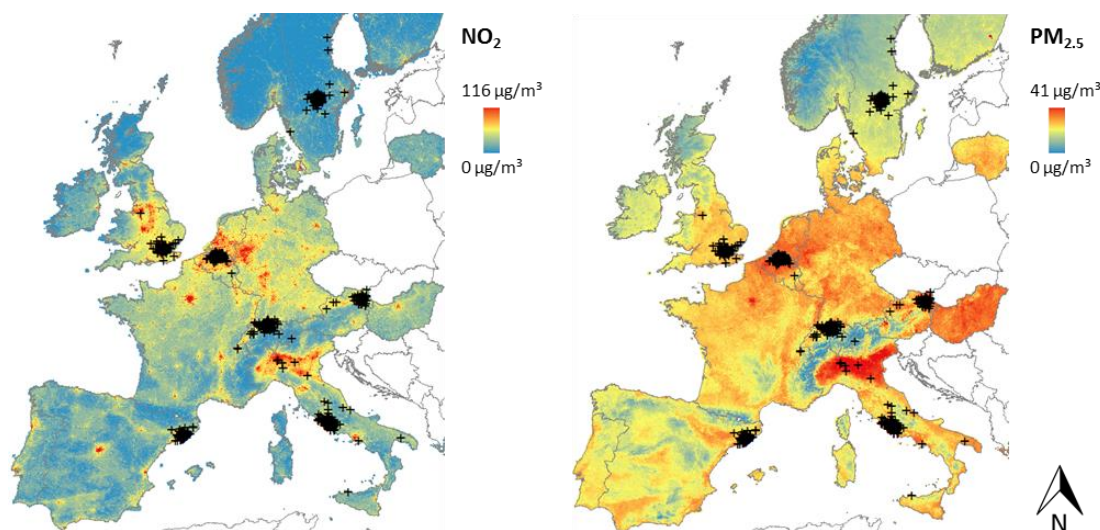
Figure 1: An overlay of the home locations of the participants to the PASTA survey, clustered around the seven participating cities (Antwerp, Barcelona, London, Oerebro, Rome, Vienna, Zurich), and air pollution maps from *de Hoogh et al., 2016*.

We associated the responses of concern over health effects of air pollution to modelled air pollution at the geocoded residence of each individual. Firstly, the average concern level per city was associated to average air pollution across participants' homes by city. Secondly, on an individual participant level, concern over health effects of air pollution was associated to modelled air pollution at home and to a number of other variables that might explain concern levels. A bivariate analysis was performed linking each factor individually to levels of concern (significance level 0.05). Bivariate associations between the individual concern level and potential confounders were assessed with Spearman's rank correlation (continuous variables), Mann-Whitney U test (dichotomous variables), and Kruskal–Wallis test (categorical variables). Afterwards a mixed effects logistic regression model was applied, with city as a random effect, and adjusted for variables that were found statistically significant in bivariate analyses. A dichotomized concern rating was used as outcome variable in the models: worried (score 4-5) versus not-worried (score 1-3). City was included as a random effect as the relationship between exposure and concern levels may depend on the study area, more specifically on background air pollution levels or on social acceptance of local environmental conditions (Fernandez-Somoano et al. 2015). We performed a complete case analysis keeping only participants with valid data for all variables. All analyses were conducted using R statistical software.

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Results

In total, 7622 participants had complete data for all the variables considered in this analysis (Table 1). Participants were almost equally distributed between cities. On average, 58% of the participants were worried over health effects of air pollution with large differences across cities (Antwerp 78%; Barcelona 81%; London 64%; Oerebro 11%; Rome 72%; Vienna 43%; Zurich 33%). 48% of the participants were male. There was a bias towards higher education, and participants were more physically active compared to the general population. Most participants reported good to excellent health (87%). 13% of all participants were current smokers, and 26% used to smoke in the past. 35% of all participants had children under the age of 18. The majority of the participants had at least sometimes access to a car (78%). In Barcelona, the nearest primary road was on average 262±293 meter from the homes of the participants, this distance was larger for all other cities; over all cities the average distance to the nearest primary road was 736±977 meter. There was a wide range in modelled air pollution concentrations at the residential address of participants, both within and between cities. The highest average NO_2 concentration at homes of participants was in Barcelona, while for $PM_{2.5}$ this was in Vienna. WHO annual guideline values (WHO 2016) for $PM_{2.5}$ were only met for the majority of home addresses in Oerebro; all of the other cities exceeded the guideline on nearly all locations. For NO_2, the guideline was exceeded on average for 37% of the homes (from 1 home in Oerebro, to 90% of all homes in Barcelona).

Table 1: Sample characteristics.

	Antwerp	Barcelona	London	Oerebro	Rome	Vienna	Zurich	All
N	1163	1283	937	863	1320	1049	1007	7622
Age [mean (SD)]	42 (12)	36 (12)	39 (13)	44 (14)	39 (11)	38 (13)	39 (13)	40 (13)
Sex – Male [N (%)]	569 (49)	541 (42)	399 (43)	329 (38)	851 (64)	505 (48)	438 (43)	3632 (48)
Concern over health effects of air pollution [N (%)]								
Extremely worried	341 (29)	208 (16)	141 (15)	12 (1)	274 (21)	68 (6)	45 (4)	1089 (14)
Worried	567 (49)	829 (65)	459 (49)	87 (10)	684 (52)	387 (37)	290 (29)	3303 (43)
Neither worried nor not worried	151 (13)	186 (14)	199 (21)	269 (31)	242 (18)	263 (25)	226 (22)	1536 (20)
Not worried	86 (7)	54 (4)	99 (11)	258 (30)	96 (7)	260 (25)	317 (31)	1170 (15)
Not worried at all	18 (2)	6 (0)	39 (4)	237 (27)	24 (2)	71 (7)	129 (13)	524 (7)
Modelled air pollution at residences [mean (SD)]								
NO_2	40 (8)	46 (6)	42 (5)	17 (6)	34 (7)	36 (6)	31 (7)	36 (11)
$PM_{2.5}$	21 (1)	19 (1)	16 (1)	9 (1)	17 (1)	21 (1)	16 (1)	17 (4)
Air pollution above WHO guideline values [N (%)]								
NO_2 (guideline value of 40 µg/m³)	594 (51)	1152 (90)	620 (66)	1 (0)	161 (12)	206 (20)	73 (7)	2807 (37)
$PM_{2.5}$ (guideline value of 10 µg/m³)	1163 (100)	1283 (100)	937 (100)	103 (12)	1320 (100)	1049 (100)	1006 (100)	6861 (90)

Linking mean modelled air pollution near the homes of participants directly to mean level of concern per city, gave a good correlation for NO_2 (r^2=0.75), and a lower correlation for $PM_{2.5}$

(r²=0.49) (Figure 2). For NO_2, this would lead to a concern score that is 0.58 points higher per 10 µg/m³ NO_2.
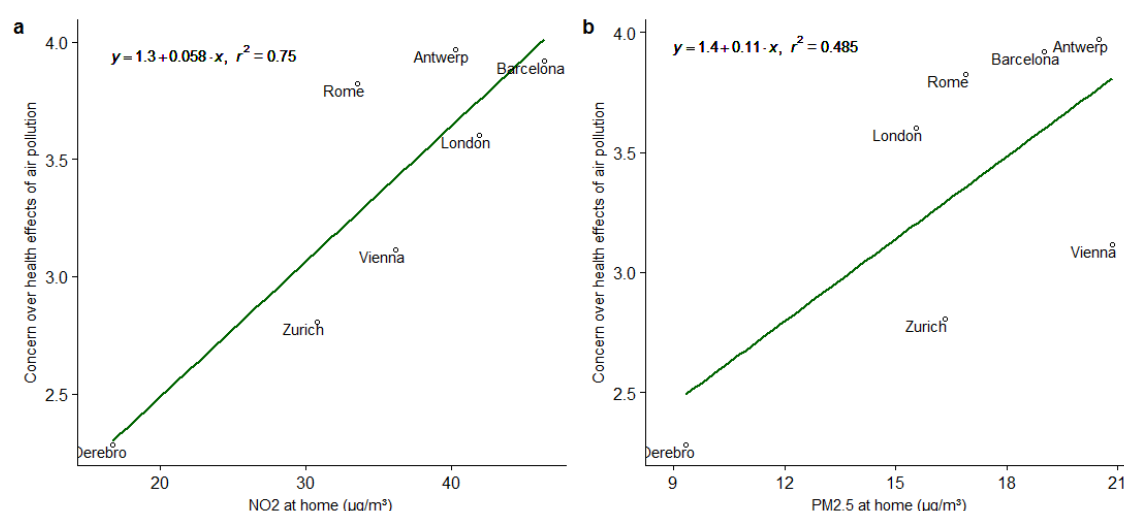
Figure 2: Average concern over health effects of air pollution by city compared to the average concentration near the home of the participants in each city [(a) NO_2; (b) $PM_{2.5}$].

In bivariate analyses, city, sex, level of education, self-reported health status, having children in the household, distance to the nearest major road, level of physical activity, and NO_2 and $PM_{2.5}$ at the home address were statistically significantly linked to concern over health effects of air pollution. Age (p=0.07), car access (p=0.19), and smoking behaviour (p=0.24) were not associated to the outcome variable. In the mixed effects logistic regression model sex, having children in the household, level of physical activity, and NO_2 at the home address remained statistically significant (Table 2). Females were 13% less likely to be worried over health effects of air pollution. Each extra µg of NO_2 increased the odds of being worried over the health effects of air pollution by about 2% (Table 2). When there were children in the household, people were 25% more worried over the health effects of air pollution than participants without children; and also participants that were more physically active, for example through active mobility, were more likely to be worried over air pollution. If distance to the nearest primary road increased, participants were less likely to be worried over air pollution, independent of modelled NO_2 at home (p=0.06). Figure 3 further illustrates the large difference in concern between the seven cities and at different levels of exposure to NO_2 in the form of predicted probabilities.

Table 2: Results from the mixed effects logistic regression to model concern over health effects of air pollution (worried (score 4-5) versus not-worried (score 1-3); city as random effect).

		Estimate	Std. Error	OR	95% CI (OR)		p value
Sex	Female	-0.14	0.0540	0.87	0.78	0.97	0.0095 **
Education level	Higher education / University education	0.11	0.0615	1.11	0.99	1.26	0.0778 .
Health status	Very good	0.22	0.0948	1.25	1.04	1.51	0.0178 *
	Good	0.29	0.0956	1.34	1.11	1.62	0.0021 **
	Fair	0.20	0.1179	1.22	0.97	1.54	0.0864 .
	Poor	0.28	0.2377	1.32	0.83	2.11	0.2373
Children in the household	1 or more children	0.22	0.0570	1.25	1.12	1.40	0.0001 ***
Distance to primary road [†]		-0.06	0.0326	0.94	0.88	1.00	0.0640 .
METs [†]		0.19	0.0294	1.21	1.14	1.28	0.0000 ***
NO_2		0.02	0.0054	1.02	1.01	1.03	0.0002 ***
$PM_{2.5}$		0.05	0.0327	1.05	0.99	1.12	0.1205

[†] rescaled (z-transformed)

Statistical significance: 0 *** 0.001 ** 0.01 * 0.05 . 0.1

METs = Metabolic Equivalents of Task (measure for physical activity expressed as METminutes per week); CI = Confidence Interval; OR = Odds ratio
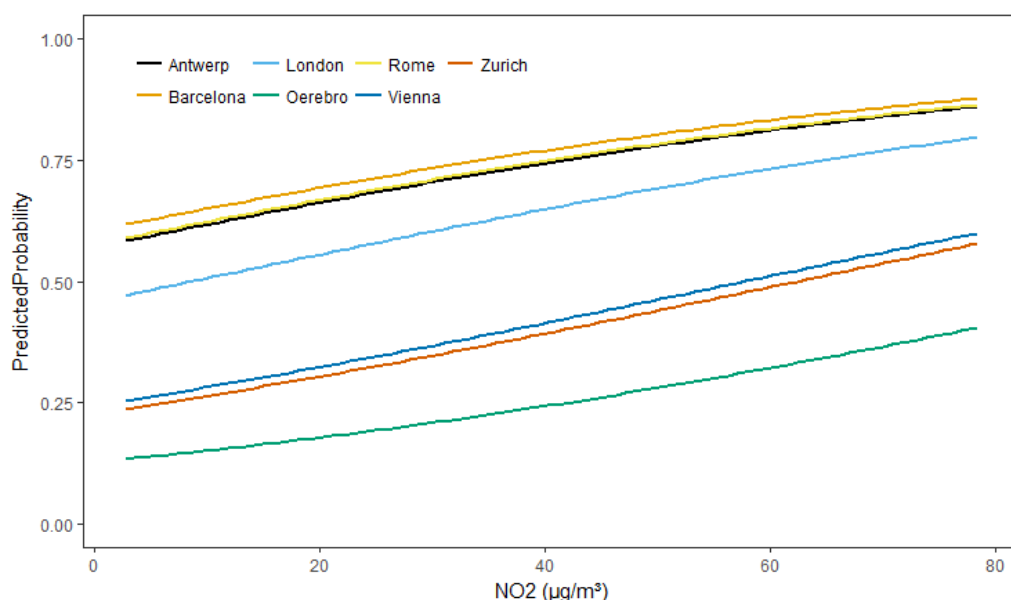
Figure 3: Predicted probability of being worried (worried (score 4-5) versus not-worried (score 1-3)) over health effects of air pollution by different levels of modelled NO_2 at a participant's residential address by city (model adjusted for sex, education level, health status, children in the household, distance to primary road, METs, and $PM_{2.5}$).

Discussion

In this study, we associated concern over the health effects of air pollution with modelled air pollution at the geocoded residence of each individual. We found that indeed level of concern is linked to NO_2 at the home address in the fully-adjusted model. However, level of concern was not statistically significantly linked to $PM_{2.5}$ at the home address. Other factors that were identified to impact concern over health effects of air pollution were sex (females were less concerned), having children in the household (participants with children were more concerned), and level of physical activity (the higher the level of physical activity, the more participants were concerned).

Previous studies often studied annoyance by air pollution, rather than concern over health effects of air pollution. In our study, we went one step further and assessed whether participants were worried over the health effects of air pollution near their living environment. This included both an assessment of the actual levels of ambient air pollution (~annoyance), and an assessment of how much participants think this could affect their health. Annoyance caused by air pollution is usually assessed on an 11-point scale (from no annoyance, to strong and unbearable); in our study we used a 5-point scale to assess concern over health effects of air pollution. Our study revealed a high prevalence of concern (11-81%; 57% on average; score ≥4 on a 5-point scale) when compared to previous studies. In the EXPOLIS study only 2.7%-7.1% was highly annoyed, except in Prague where 25.3% was highly annoyed (score ≥7 on an 11-point scale) (Rotko et al. 2002). A European wide study (ECRHS) from 1999-2001 also assessed disturbance to air pollution on an 11-point scale; only 14% was highly annoyed (score ≥6) (Jacquemin et al. 2007). In the SAPALDIA study in Switzerland, 18.1% reported high annoyance levels (score ≥8 on an 11-point scale), but this number was higher when only considering the urban areas (12.1%-36.8%) (Oglesby et al. 2000). In our study most participants lived in urban areas; also our study may have attracted a biased sample of environmentally aware and highly educated people that may explain higher concern scores. Also growing awareness of and media attention for the air pollution problem in recent years may have increased the concern levels.

Population level concern scores correlated with $PM_{2.5}$ and NO_2 levels averaged across participants' homes by city. A higher correlation was found between average concern over health effects of air pollution and average NO_2, compared to $PM_{2.5}$. In the cities that lie above the trendline in Figure 2 (Antwerp, Barcelona, London, Rome), low social acceptance of local

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environmental conditions (i.e. air pollution) may explain higher concern scores. Also participants may be worried less over ambient air pollution in cities with a colder climate because they keep their windows closed most of the time; however this does not seem to hold for Antwerp or London in our study. In Jacquemin et al. (2007), a very similar regression slope (0.06) compared to our study was found for $PM_{2.5}$ concentration at home and air pollution annoyance in multiple European cities; however the correlation was low. Rotko and colleagues (2002) found a slightly higher correlation for $PM_{2.5}$ in 6 EU cities. Oglesby and colleagues (2000) found a high correlation for NO_2 in Swiss cities. Because of the modifiable areal unit problem (Fotheringham and Wong 1991) the association between modelled air pollution at home and levels of concern over cities may not be transferable to other spatial scales, therefore we also did an individual level analysis.

NO_2 and $PM_{2.5}$ have both been associated to reported individual annoyance to air pollution in previous studies (Fernandez-Somoano et al. 2015; Heinrich et al. 2005; Oglesby et al. 2000; Persson et al. 2007; Rotko et al. 2002; Sass et al. 2017). As in previous studies, modelled air pollution in our study cannot fully explain concern over health effects of air pollution, showing only a low or medium correlation. In our study, NO_2 at home was statistically significantly associated with levels of concern over health effects of air pollution, while $PM_{2.5}$ was not. NO_2 tends to be rather heterogeneous in urban areas coming mainly from traffic, while $PM_{2.5}$ is more similar across larger areas. Since traffic is easily perceptible, it makes sense that level of concern of the population is more associated to NO_2 than to $PM_{2.5}$ (Lercher et al. 1995).

Other variables in our study that could be associated to individual concern over health effects of air pollution were sex (males were more concerned), children in the household (participants with children were more concerned), and level of physical activity (physically active participants were more concerned). Females report higher annoyance in most studies, although it is unclear why – there may be a difference in risk perception, but the reverse has also been observed in some studies (Gustafson 1998; Jacquemin et al. 2007; Johnson 2002). Children in the household and level of physical activity are only sporadically included as influencers (Sass et al. 2017; Stenlund et al. 2009). We included these variables as we believe that parents could be more concerned over the health of their children than over their own health; moreover children are more susceptible to air pollution. Participants who were physically active may be inhaling more pollution because of their increased breathing, thus may be more worried about the health effects of air pollution (Dons et al. 2017). They may also be more health-conscious in general, hence more worried about air pollution (Tormo et al.

2003). In multiple other studies, current smoking behaviour was identified as a determinant in the association between air pollution at home and concern scores. Smoking behaviour was not a statistically significant factor in the bivariate analysis in our study and was not included in the mixed effects logistic regression model; current and former smokers were even slightly more worried than never smokers. Self-reported health in general, or more specifically respiratory health (asthma, chronic obstructive pulmonary disease) or chronic diseases, are variables that are often linked to annoyance to air pollution since these people are more susceptible to the health effects of air pollution (Forsberg et al. 1997; Jacquemin et al. 2007; Piro et al. 2008; Rotko et al. 2002). In our study, we only had information on self-reported health status on a 5-point scale (from Poor to Excellent), but the results were mostly non-significant and inconclusive. People who are most concerned about air pollution may choose to live further away from traffic hence attenuating the relationship between home-base air pollution and concern levels; this may have lowered the explanatory power of our model as well. We had no information on time living at the current address so we could not exclude reverse causality.

Our study had a number of strengths. It was a multicentre study in seven European cities; these cities differed in size, geographical region, and in air pollution levels. We had samples of similar sizes in the different cities; and the samples were well balanced between male and female. The same question was asked in all cities; and participants could complete the questionnaire in their preferred language (8 languages available). Air pollution was estimated at the home address using Europe-wide land use regression models through which we could estimate NO_2 and $PM_{2.5}$ in a harmonized way over the country borders. This very much limited the bias associated with the use of local air pollution models, or the bias when using measurements from fixed monitoring sites only. Since NO_2 was associated with concern over health effects of air pollution, concern scores could be used as an indicator of actual NO_2 levels; however other factors also played a role in the association. Rather than being an exposure indicator in epidemiological studies, concern over health effects of air pollution may increase vulnerability, or lead to actual health effects (Hicken et al. 2014). Concern may lead to a feeling of discomfort and stress, producing stress hormones, or leading to high blood pressure (Llop et al. 2008; Pitchika et al. 2017).

The study has some limitations as well. Since the survey was not specifically designed to answer the current research question, some variables that could have been confounders in the association were not available and might have contributed to residual confounding (e.g. presence of respiratory or chronic diseases, general risk perception). The air pollution model

was estimated for base year 2010, while the survey took place from 2014 until 2016. Previous studies have shown that the spatial distribution of traffic-related air pollution is generally stable over periods 10-15 years, supporting the use of an annual average of a single year preceding our questionnaire to assess long-term exposure (Eeftens et al. 2011; Gulliver et al. 2011). Also the air pollution model was raster-based (100mx100m) and this may have led to exposure misclassification and lower correlations (Dionisio et al. 2016). The question on subjective perception of air pollution in the questionnaire referred to air pollution in the neighbourhood of home or work, yet we only tested out the relationship at the home address, which again may have blurred the results. Brody and Zahran (2007) postulated that people have a tendency to recall events by their highest point of intensity or how they end: the so-called peak-end rule in psychometric research. This would have favoured the use of a peak-hour air pollution model, rather than an annual average model. Concern levels may also be associated to concentrations on the day participants completed the questionnaire; therefore we could have tested out the use of an air pollution model with a high temporal resolution. Unfortunately neither of these models were available. Most studies, including ours, use a cross-sectional design making it very difficult to evaluate causality; we identified only one longitudinal study (Sass et al. 2017), and one intervention study (Stenlund et al. 2009) studying concern or annoyance over air pollution.

We studied the association between actual air pollution levels and levels of concern over health effects of air pollution near the living environment of participants. A statistically significant association was found for NO_2, but not for $PM_{2.5}$ at the geocoded home address. Subjective perception of air pollution can be as important as looking at the objective air pollution concentrations as it can: have impacts on health in its own rights; lead to protective behaviour (e.g. minimizing exposures through travel route choices or residential location decisions); be leveraged to engage stakeholders and members of the public in support of cleaner air policies.

Additional files

The full questionnaire of the PASTA longitudinal survey is available from:

http://pastaproject.eu/fileadmin/editor-upload/sitecontent/City_survey/PASTA-questionnaires.pdf. (PDF 3792 kb)

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