Addressing confounding by air pollution in studies of noise and health: the relationship of noise and ultra-fine particles

John Gulliver[1], Gerard Hoek[2], Erik van Nunen[2], Paolo Vineis[1], David Morley[1]

[1] UK Small Area Health Statistics Unit, MRC-PHE Centre for Environment and Health, Imperial College London, UK

[2] Institute for Risk Assessment Sciences (IRAS), division of Environmental Epidemiology (EEPI), Utrecht University, Utrecht, the Netherlands

corresponding author's email: j.gulliver@imperial.ac.uk

ABSTRACT

If the relationship of noise and air pollution exposure is strong it may be difficult to distinguish the effects of noise on health, and vice versa. We aimed to establish a spatially dense network of measurement sites to assess the relationship of urban noise and ultrafine particles (UFP).

We made repeated (3) 30-minute measurements of noise levels, UFP number, and vehicle counts at 145 sites in Norwich, UK (55 traffic; 90 urban background sites) and produced averaged values of each metric per site. We assessed the correlation of noise, UFP and vehicle counts overall and by site type.

For all sites, traffic sites, and urban background sites, respectively, mean UFP number (cm^{-3}) is 10806, 15063, and 8204; mean values of LAeq (dB) are 65.2, 70.0, and 62.3. Correlations of noise and UFP are overall moderate ($r = 0.60$; $p < 0.001$) and also moderate for traffic ($r = 0.51$; $p < 0.001$) and urban background sites ($r = 0.52$; $p < 0.001$). Moderate correlations suggest that epidemiological studies should be able to separate the effects of noise and UFP number.

INTRODUCTION

There is a need in studies of traffic noise pollution and health to evaluate the robustness of associations in order to distinguish the effects from other factors such as air pollution. If the relationship of noise and air pollution is strong it may be difficult to distinguish the effects of noise. A number of studies have compared the relationship of different noise metrics (L_{day}, L_{eve}, L_{night}, L_{Aeq16}) and air pollutants (e.g. NO_2, $PM_{2.5}$, PM_{10}, ozone) from measurements [1,2,3,4] and estimates from models [5,6,7] over different averaging periods. Less is known about the relationship of noise and novel pollutants such as ultra-fine particles (UFP). We aimed to use a spatially dense network of measurement sites to assess the relationship of urban noise and UFP number.

METHODS

Measurements of UFP, noise, and vehicle counts

We contemporaneously measured noise levels (Optimus CR:171B), UFP (TSI-3007 condensation particle counter), and manually counted vehicles, for 30 minutes on 3 occasions (covering different seasons), at 161 sites (55 traffic; 90 urban background (i.e. residential); 4 regional background; 10 urban green space; 1 industrial; 1 reference site) during 2014/15, in the city of Norwich, UK (Figure 1). For this presentation we only used the traffic and urban background sites due to the low numbers of other site types; total N = 145.

Traffic sites were defined using information from a traffic model, supplied by Norwich City Council, as roads with > 10,000 annual average daily traffic (AADT). Other sites were defined using GIS data on land cover using open street maps and field visits. A reference site was established in an urban background location to continuously measure UFP levels (discMini) over the study period to adjust each of the short-term UFP measurements (relative to a long-term average) for the influence of regional-background sources (i.e. those outside the study area). Figure 1 shows the spatial distribution of site types in relation to major roads (traffic) and built-up land in Norwich.

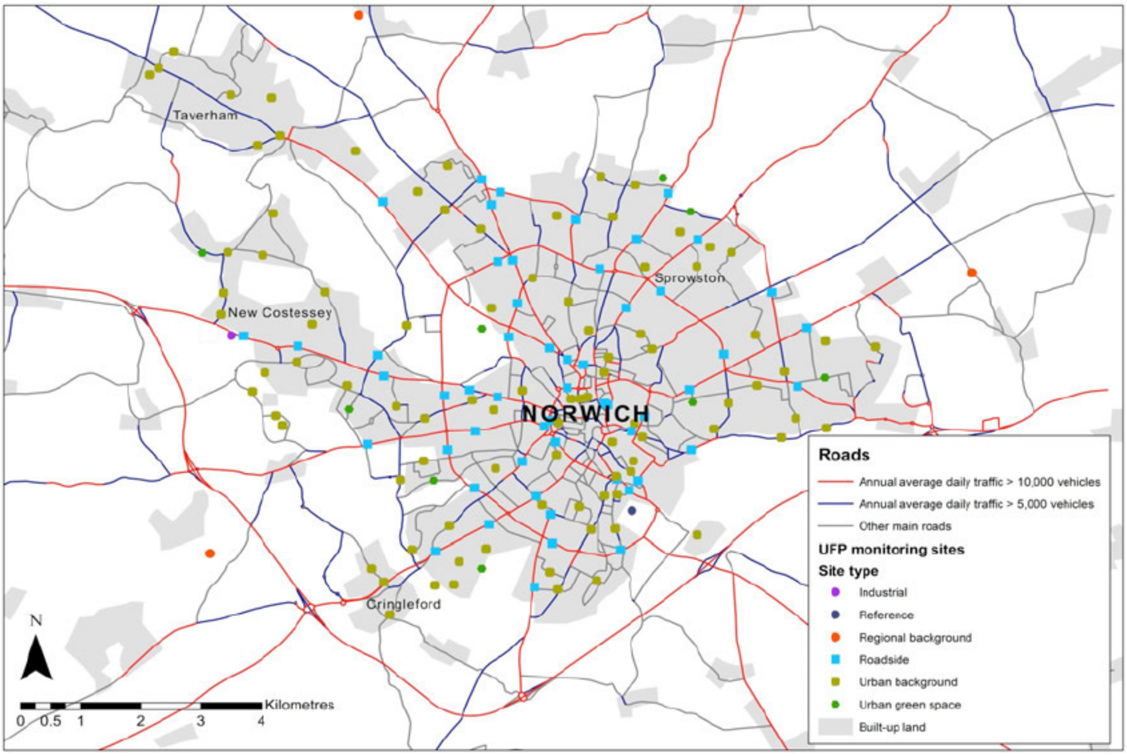

Figure1: location of measurements sites in relation to major roads and land cover

UFP short-term and reference site measurements were made following a standard protocol developed in the EU-funded EXPOsOMICS project [8]. Measurements were made in a total of six areas (Basel, Heraklion, Norwich, The Netherlands, Sabadell, Turin) in order to develop land use regression models (a statistical method using spatial predictors) for use in exposure assessment [9]. Up to 8 measurements were made per day, with all measurements taking place during off-peak, daytime periods (0900-1600). We used this protocol for UFP measurements and allied our noise and vehicle measurements to it. Co-located measurements of UFP and noise were made as close as possible to the nearest dwelling as the focus was on residential exposures (Figure 2). Vehicle counts were made by the accompanying researcher in close proximity to the UFP and noise instruments.

Following an instrument warm-up, and then a zeroing filter to mark the start of the measurement, UFP was continuously measured at 1Hz resolution for a period of 30-minutes. Prior to the first noise measurements each day an acoustic calibrator was used to provide a reference calibration (93.7 dB) and record any offset for later calibration of the collected measurements. Noise measurements were made using A-weighting at 1 Hz resolution with audio recording switched off. All vehicles, in one or two directions, were manually counted with a tally counter for the two consecutive fifteen-minute periods, and then these values were summed to create a 30-minute total.

Figure 2: Typical setup for noise and UFP measurements

Data processing

UFP measurements were processed using a script developed within EXPOsOMICS to produce a single average particle number count (cm^{-3}) for each period. UFP measurements were temporally adjusted using measurements from the reference site [9]. Noise measurements were processed using the manufacturer's software (NoiseTools™) to produce a single average noise level (dB) for each 30-minute period. All measurements from the three periods were subsequently averaged to provide a single "long-term" estimate for each metric (noise, UFP, vehicle counts). Thus, LAeq,30-min is an estimate of annual average 30-minute A-weighted noise level for off-peak, daytime periods. Extensive comparisons were made between the different technologies for UFP (CPC and discMini for the reference site) in the abovementioned six areas and were shown have a good level of correspondence [9].

Statistical analysis

We used intra-class correlation (ICC) for comparisons of values from the three measurements of noise, UFP, and vehicles. Due to the skewed nature of each metric, we used non-parametric (Mann-Whitney U) tests to assess whether noise, UFP, and vehicle counts varied by site type. We produced correlations between measurements of noise, UFP and vehicle counts using Pearson’s ‘r’ with a significance threshold of 95% (i.e. p > 0.05). We define correlations as weak (< 0.3), moderate (>= 0.3 and <=0.7) and strong (> 0.7); a correlation of 0.7 represents about 50% of the explained variability, hence the upper limit of a moderate relationship. We used LOWESS (LOcally-WEighted Scatterplot Smoother) curves on 95% of the data to estimate the linearity of the relationship between noise and UFP for all sites, and then separately for traffic and background sites. All statistical tests were undertaken in IBM SPSS v23.

We also assessed the strength of correlation for the same sites between annual average UFP from the land use regression model [9] and LAeq, 24hour from our own implementation of CNOSSOS-EU noise methodology [10], and compared it to correlation between measured UFP and noise.

RESULTS

Mean UFP number is 10806, 15063, and 8204 for all sites, traffic sites, and urban background sites, respectively. Mean values of noise (dB) are 65.2, 70.0, and 62.3 for all sites, traffic sites, and urban background sites, respectively. The ICCs for the three noise measurement are 0.93 - 0.95, with an average range of 3.1 dB(A). ICCs for vehicle counts are 0.97 - 0.98 and for temporally adjusted UFP are 0.44 - 0.55.

Average values of LAeq, UFP, and vehicle counts vary significantly (p<0.001) by site type (Figure 3). Noise levels are more variable across urban background sites than traffic sites, whereas this reverses for UFP.

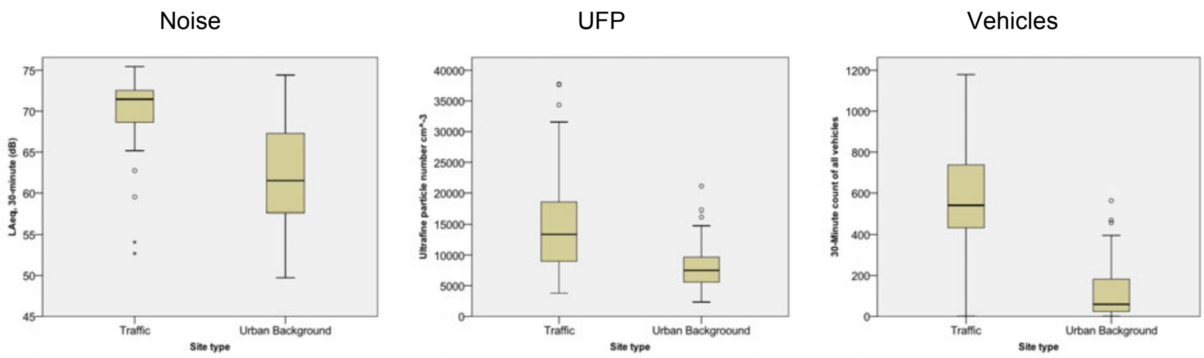

Figure 3: Variability in noise, UFP and vehicle counts between traffic and urban background measurement sites

Noise and UFP are overall moderately (r = 0.60; p < 0.001) and non-linearly (Figure 4) correlated. Noise and UFP are also moderately correlated for traffic (r = 0.51; p < 0.001) and urban background sites (r = 0.52; p < 0.001). Vehicles counts are more strongly related to noise (r = 0.71; p < 0.001) than UFP (r = 0.57; p < 0.001) and the relationship is stronger at background sites than at traffic sites. There is a non-significant relationship of UFP and vehicle counts at traffic sites. The correlation between modelled noise and UFP is also moderate ($r = 0.62$; $p < 0.001$).

Table 1: Pearson's (R) correlations between noise level (dB), ultra-fine particle number, and vehicle counts

	All (N = 145)			Traffic (N = 55)			Urban Background (N=90)		
	Noise[a]	UFP[b]	Veh.[c]	Noise[a]	UFP[b]	Veh.[c]	Noise[a]	UFP[b]	Veh.[c]
Noise[a]	1	.60	.71	1	.51	.30	1	.52	.82
UFP[b]	.60	1	.57	.51	1	.25*	.52	1	.54
Veh.[c]	.71	.57	1	.30	.25*	1	.82	.54	1

*not significant (p>0.05)

[a]30-min, A-weighted noise (LAeq,1hr) (dB); [b]ultra-fine particle number; [c]30-minute count of all vehicles.

The relationship of noise and UFP is approaching linearity (LOWESS) when traffic sites are isolated. LOWESS slopes are different between traffic (average = ~10%) and urban background sites (average = ~45%), hence the overall non-linear relationship (Figure 4).

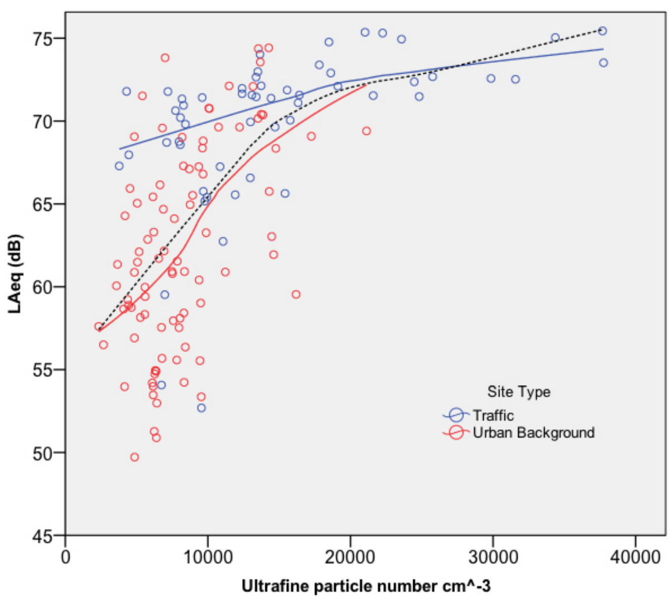

Figure 4: Relationship of measured noise and UFP, separately and in combination for traffic and urban background sites (LOWESS curves estimated using 95% of data in each case; curve for all data shown by the dashed black-line)

DISCUSSION AND CONCLUSIONS

We found moderate and non-linear correlations between measured noise and UFP across 145 sites in Norwich, UK. After temporal adjustment for background UFP, noise levels had stronger correlation with co-located vehicles counts than UFP. The relationship of vehicle counts and UFP is weak and non-significant in traffic locations. In further work we will look at the proximity of specific traffic sites to other sources; for example, UFP number may be affected by meteorology and contributions from other sources such as restaurants/cafes that predominate in traffic locations [15].

The challenge of using short-term environmental noise measurements is that they may be confounded by the presence of one or more other noise sources (e.g. animals such as dogs and birds, human voices, sirens, construction work etc.). For this reason, we made measurements on three occasions at each site, but still our data at some sites may have raised average noise levels due to other sources. This is more likely to be an issue at background sites, as values of LAeq at traffic sites tend to be dominated by vehicle noise; noise from other sources, perhaps with the exception of sirens and heavy construction/industry, has less influence on overall noise levels. Conversely we may have unknowingly measured noise on occasions with especially low levels of traffic at specific sites. Some of our vehicle counts (N = 2) were low (< 50 vehicles in 30-minutes) at sites previously determined as roadside sites (Figure 3), based on information from a traffic model, thus we may have misclassified site types in these instances. Although we found high ICCs for noise and much lower ICCs for UFP from short-term measurements, we also compared long-term modelled noise and UFP and found the correlation also to be moderate (r = 0.62).

A few other studies have compared noise and UFP in urban settings. A similar methodology to ours (three 20-minute paired UFP number and noise level measurements at 141 sites) was applied in three European cities (Basel, Girona, Grenoble) [11]; Pearson's correlation of UFP and noise is in the range 0.43 - 0.55 depending on the city. Correlations between noise and vehicle counts are stronger (0.54 - 0.72) than between UFP and vehicle counts (0.15 - 0.37), as we also found. In 11 cities in The Netherlands a moderate (median r = 0.34) relationship was found between noise and UFP number during cycling and driving [12]. A maximum correlation of 0.74 was found between UFP number and noise measured in a mobile campaign traversing major roads into background areas in Essen, Germany [13]. Noise levels and UFP were measured in a street canyon over three weeks alongside information on other pollutants, meteorology and detailed characterization of traffic composition, producing a maximum correlation between noise indicators UFP of 0.62 [14].

Based on information from this and other studies, the correlation between noise levels and various air pollutants is overall moderate but variable. Based on the limited analysis in our study, UFP is not different from other pollutants (e.g. NO_2, $PM_{2.5}$, ozone) in its strength of relationship with noise. Moderate correlations in our study and those reported in the scientific literature suggest that epidemiological studies should be able to control for UFP in studies of noise and vice versa.

Acknowledgements

The research was supported by funding from the European Community's Seventh Framework Program EXPOsOMICS study under grant agreement number FP7 308610. We thank Norwich City Council for providing information on traffic composition for major roads in Norwich.

REFERENCES

[1] Allen, R. W., Davies, H., Cohen, M. A., Mallach, G., Kaufman, J. D., & Adar, S. D. (2009). The spatial relationship between traffic-generated air pollution and noise in 2 US cities. *Environmental Research, 109*(3), 334-342. doi:http://dx.doi.org/10.1016/j.envres.2008.12.006

[2] Apparicio, P., Carrier, M., Gelb, J., Séguin, A.-M., & Kingham, S. (2016). Cyclists' exposure to air pollution and road traffic noise in central city neighbourhoods of Montreal. *Journal of Transport Geography, 57*, 63-69. doi:http://dx.doi.org/10.1016/j.jtrangeo.2016.09.014

[3] Davies, H. W., Vlaanderen, J. J., Henderson, S. B., & Brauer, M. (2009). Correlation between co-exposures to noise and air pollution from traffic sources. *Occupational and Environmental Medicine, 66*(5), 347-350. doi:10.1136/oem.2008.041764

[4] Vlaanderen, J., Davies, H., Henderson, S., & Brauer, M. (2006). Correlation Between Co-Exposures to Noise and Air Pollution From Traffic Sources. *Epidemiology, 17*(6), S251-S252.

[5] Fecht, D., Hansell, A. L., Morley, D., Dajnak, D., Vienneau, D., Beevers, S., . . . Gulliver, J. (2016). Spatial and temporal associations of road traffic noise and air pollution in London: Implications for epidemiological studies. *Environ Int, 88*, 235-242. doi:10.1016/j.envint.2015.12.001

[6] Foraster, M., Deltell, A., Basagana, X., Medina-Ramon, M., Aguilera, I., Bouso, L., . . . Kunzli, N. (2011). Local determinants of road traffic noise levels versus determinants of air pollution levels in a Mediterranean city. *Environ Res, 111*(1), 177-183. doi:10.1016/j.envres.2010.10.013

[7] Kheirbek, I., Ito, K., Neitzel, R., Kim, J., Johnson, S., Ross, Z., . . . Matte, T. (2014). Spatial variation in environmental noise and air pollution in New York City. *J Urban Health, 91*(3), 415-431. doi:10.1007/s11524-013-9857-0

[8] van Nunen, E., Vermeulen, R., Tsai, M. Y., Probst-Hensch, N., Ineichen, A., Davey, M., . . . Hoek, G. (2017). Land Use Regression Models for Ultrafine Particles in Six European Areas. *Environ Sci Technol*. doi:10.1021/acs.est.6b05920

[9] Vineis, P., Chadeau-Hyam, M., Gmuender, H., Gulliver, J., Herceg, Z., Kleinjans, J., . . . Consortium, E. X. (2016). The exposome in practice: Design of the EXPOsOMICS project. *Int J Hyg Environ Health*. doi:10.1016/j.ijheh.2016.08.001

[10] Morley, D. W., de Hoogh, K., Fecht, D., Fabbri, F., Bell, M., Goodman, P. S., . . . Gulliver, J. (2015). International scale implementation of the CNOSSOS-EU road traffic noise prediction model for epidemiological studies. *Environ Pollut, 206*, 332-341. doi:10.1016/j.envpol.2015.07.031

[11] Boogaard, H., Borgman, F., Kamminga, J., & Hoek, G. (2009). Exposure to ultrafine and fine particles and noise during cycling and driving in 11 Dutch cities. *Atmospheric Environment, 43*(27), 4234-4242. doi:http://dx.doi.org/10.1016/j.atmosenv.2009.05.035

[12] Morelli, X., Foraster, M., Aguilera, I., Basagana, X., Corradi, E., Deltell, A., . . . Slama, R. (2015). Short-term associations between traffic-related noise, particle number and traffic flow in three European cities. *Atmospheric Environment, 103*, 25-33. doi:http://dx.doi.org/10.1016/j.atmosenv.2014.12.012

[13] Weber, S. (2009). Spatio-temporal covariation of urban particle number concentration and ambient noise. *Atmospheric Environment, 43*(34), 5518-5525. doi:http://dx.doi.org/10.1016/j.atmosenv.2009.06.055

[14] Can, A., Rademaker, M., Van Renterghem, T., Mishra, V., Van Poppel, M., Touhafi, A., . . . Botteldooren, D. (2011). Correlation analysis of noise and ultrafine particle counts in a street canyon. *Science of The Total Environment, 409*(3), 564-572. doi:http://dx.doi.org/10.1016/j.scitotenv.2010.10.037

[15] Vert, C., Meliefste, K., & Hoek, G. (2016). Outdoor ultrafine particle concentrations in front of fast food restaurants. *J Expos Sci Environ Epidemiol, 26*(1), 35-41. doi:10.1038/jes.2015.64