Environment International 103 (2017) 30–38

Contents lists available at ScienceDirect

Environment International

journal homepage: www.elsevier.com/locate/envint

Associations of long-term exposure to air pollution and road traffic noise with cognitive function—An analysis of effect measure modification

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ARTICLE INFO

Article history:
Received 30 November 2016
Received in revised form 21 March 2017
Accepted 21 March 2017
Available online xxxx

Keywords:
Cognitive function
Air pollution
Traffic noise
Effect modification

ABSTRACT

Background: Adverse effects of traffic-related air pollution (AP) and noise on cognitive functions have been proposed, but little is known about their interactions and the combined effect of co-exposure.
Methods: Cognitive assessment was completed by 4086 participants of the population-based Heinz Nixdorf Recall cohort study using five neuropsychological subtests and an additively calculated global cognitive score (GCS). We assessed long-term residential concentrations for size-fractioned particulate matter (PM) and nitrogen oxides with land use regression. Road traffic noise (weighted 24-h (L_{DEN}) and night-time (L_{NIGHT}) means) was assessed according to the EU directive 2002/49/EC. Linear regression models adjusted for individual-level characteristics were calculated to estimate effect modification of associations between AP and noise with cognitive function. We used multiplicative interaction terms and categories of single or double high exposure, dichotomizing the potential effect modifier at the median (AP) or at an a priori defined threshold (road traffic noise).
Results: In fully adjusted models, high noise exposure increased the association of AP with cognitive function. For example, for an interquartile range increase of $PM_{2.5}$ (IQR 1.43), association s with GCS were: estimate (β) $= -0.16$ [95% confidence interval: -0.33; 0.01] and $\beta = -0.48$ [-0.72; -0.23] for low and high L_{DEN}, respectively. The association of noise with GCS was restricted to highly AP-exposed participants. We observed stronger negative associations in those participants with double exposure compared to the addition of effect estimates of each single exposure.
Conclusions: Our study suggests that AP and road traffic noise might act synergistically on cognitive function in adults.

1. Introduction

Even though many studies show effects of either ambient air pollution (AP) or noise on health (Basner et al., 2014; WHO, 2013), few studies have investigated both environmental exposures together. However, for effective prevention of adverse health effects it is important to know, whether environmental exposures are affecting health outcomes independently, and whether effects of AP and noise are additive or even synergistic, specifically because they often occur simultaneously (Foraster, 2013).

One of the outcomes that have been proposed to be affected by both, AP and traffic noise, is cognitive function (Clark and Stansfeld, 2007; Oberdörster and Utell, 2002). Age-related decline of cognitive function and development of dementia are an important topic due to aging populations in developed countries and the resulting burden of disease on these aging societies (Prince et al., 2013; Sousa et al., 2009). Since no effective treatments for dementia exist, prevention through identification and mitigation of factors causally related to cognitive decline is paramount.

Most of the existing studies generally support the hypothesis that ambient AP is negatively associated with cognitive function in adults (Guxens and Sunyer, 2012; Block et al., 2012). In the recently published

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http://dx.doi.org/10.1016/j.envint.2017.03.018
0160-4120/© 2017 Published by Elsevier Ltd.

longitudinal study by Chen et al. (2017), living < 50 m to major traffic increased incidence of dementia, but not of Parkinson's disease, in adults aged 55–85 living in Ontario, Canada. In a recent cohort study in USA, Loop et al. (2013) found a slight increase (1.40 [1.06–1.85] per 10 μg/m^3 $PM_{2.5}$) in incidence of cognitive impairment in participants living in urban areas. In Taiwan, Jung et al. (2014) that found that raised concentrations of O_3 and $PM_{2.5}$ increased the risk for Alzheimer's disease in 10-years of follow-up. For long-term noise exposure, the evidence from studies investigating effects on cognitive function in adult populations is scarce (Tzivian et al., 2014), suggesting worse cognitive function in a highly noise-exposed population (Tzivian et al., 2016a).

Studies investigating simultaneous exposures of AP and traffic noise on cognitive function are few, mostly limited to children (Clark et al., 2012; van Kempen et al., 2012) and show partly inconsistent results regarding the independency of these two potential risk factors. In the cross-sectional study by Clark et al. (2012) of children aged 9–10 years, no association between nitrogen dioxide (NO_2) and reading comprehension, recognition memory, information recall, conceptual recall, and working memory was found either before or after adjustment for aircraft and road traffic noise. On the other hand, associations between aircraft noise and cognitive function remained stable after adjustment for AP. In the cross-sectional study by van Kempen et al. (2012), NO_2 was significantly associated with a decrease in memory in 9–11 years old children, independent of adjustment for transport noise. In our previous cross-sectional study (Tzivian et al., 2016a), investigating confounding between AP and noise, associations between AP and mild cognitive impairment (MCI) became non-significant after adjustment for noise in two-exposure models, whereas association between road traffic noise and MCI remained stable after adjustment for AP (Tzivian et al., 2016a). While these studies have examined confounding between AP and noise, there are no studies to date that have investigated the interaction between AP and noise and the potential for synergistic effects.

Therefore, the aim of this study was to investigate whether long-term AP and road traffic noise exposure modify each other in their associations with cognitive functions in middle-aged and older adults, using cross-sectional data from the first follow-up examination of the population-based Heinz Nixdorf Recall cohort study in Germany.

2. Methods

2.1. Study population

This study is a cross-sectional analysis based on data from the first follow-up examination (2006–2008) of the Heinz Nixdorf Recall (Risk factors, Evaluation of Coronary Calcium and Lifestyle) study, a prospective population-based cohort study located in three adjacent cities (Bochum, Essen and Mülheim/Ruhr) in the highly urbanized German Ruhr Area. The study design has been described in detail before (Schmermund et al., 2002). In short, 4814 randomly chosen men and women aged between 45 and 75 years at baseline were enrolled between December 2000 and August 2003 (response rate 55.8%). A detailed analysis of the non-responders has previously been published (Stang et al., 2005). Briefly, there was no age difference between the participants and the non-participants, but elderly women were less likely to participate. Furthermore, a school degree at university entrance qualification level was more often reported among participants than among non-participants.

After five years (2006–2008), the first follow-up examination was conducted (response rate of 90.2% of original study population), including a standardized assessment of neurocognitive function. The Heinz Nixdorf Recall study was approved by the ethics committee of the University Hospital Essen. All participants gave their written informed consent.

2.2. Cognitive assessment

At the 5 year follow-up examination, a cognitive performance assessment was completed in 4086 participants. The cognitive performance assessment has been previously described in detail (Dlugaj et al., 2010; Wege et al., 2011). Briefly, it consists of established measures of verbal fluency (semantic category “animals”, number of recalled words within one minute), immediate and delayed verbal memory (eight word list, performance measured as number of words recalled in each trial), problem solving/speed of processing (labyrinth test, time in seconds needed to complete the task), and abstraction (as an executive function)/visual-spatial organization (clock-drawing test, performance was rated from 1 (perfect clock) to 6 (poor performance; was not reached in our sample (maximum value was 5)). The short cognitive performance assessment reached a good accuracy (area under the curve = 0.82 [95% confidence interval (CI) = 0.78; 0.85]) against a detailed neuropsychological and neurological examination in a previous study (Wege et al., 2011). The raw data for each subtest was z-transformed (mean = 0, standard deviation (SD) ± 1) according to three age groups (50–59 years, 60–69 years, and 70–80 years) and within every age group according to three education groups (≤10 years, 11–13 years, ≥14 years). A global cognitive score (GCS) was calculated as a sum of all five age- and education-specific z-scores of individual cognitive subtests, where higher GCS means better performance in cognitive tests. Due to the construction of the GCS as the sum of individual z-scores, the GCS is not a z-score and therefore, while still having an expected mean of 0, the expected SD of the GCS is higher than 1.

2.3. Exposure assessment

We used the land use regression (LUR) model according to the European Study of Cohorts for Air Pollution Effects (ESCAPE) standardized procedure (ESCAPE-LUR) to estimate traffic-related long-term air pollution (De Hoogh et al., 2013). Briefly, particulate matter of varying sizes in aerodynamic diameter measured in μm - that is <10 μm (PM_{10}), >2.5 to <10 μm (PM_{coarse}), <2.5 μm ($PM_{2.5}$), and $PM_{2.5}$ absorbance (blackness of the $PM_{2.5}$ exposed filter, determined by measurement of light reflectance as a marker for soot and black carbon) - was measured at 20 sites, and nitrogen oxides (NOx and NO_2) were measured at 40 sites in three separate two week periods (to cover different seasons) over one year (Beelen et al., 2013; Eeftens et al., 2012). Air pollution measurements were performed between October, 2008, and October, 2009, and resulting LUR models were applied to estimate long-term exposure of concentrations at the baseline year of the study. Annual averages of measured pollutant concentrations at the monitoring sites and predictor variables, derived from Europe-wide and local Geographic Information System databases were used to develop the study-specific LUR model and to predict concentrations at each participant's baseline address. Background NO_2 was modeled including the data from background measurement stations only while excluding traffic stations from the model (http://www.escapeproject.eu/manuals/ESCAPE_Exposure-manualv9.pdf). In the Ruhr Area, the models explained 88% of the variability in the annual concentrations of $PM_{2.5}$, 69% of that for PM_{10}, 66% of that for PM_{coarse}, 97% of that for $PM_{2.5}$ absorbance, 89% of that for NO_2, and 88% of that for NOx (Beelen et al., 2013; Eeftens et al., 2012).

Long-term exposure to traffic noise was modeled according to the European Directive 2002/49/EC (European Commission, 2002), stage 1, year 2007, as weighted 24-h mean (L_{DEN}) and night-time (22–6 h) mean (L_{NIGHT}) at the baseline address, with consideration of the following determinants: small-scale topography of the area, dimensions of buildings, noise barriers, street axis, vehicle type specific traffic density, speed limit, and type of street surface. Models were performed on behalf of the cities for road traffic noise, industrial noise, and aircraft noise, and were supplied as source-specific facade values from local city