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COMPETING FINANCIAL INTERESTS

There are no competing financial interests.

ABSTRACT

Background: By 2050, almost 70% of people globally are projected to live in urban areas. As the environments we inhabit affect our health, urban and transport designs that promote healthy living are needed.

Objective: We estimated the number of premature deaths preventable under compliance with international exposure recommendations for physical activity (PA), air pollution, noise, heat, and access to green spaces.

Methods: We developed and applied the Urban and TranspOrt Planning Health Impact Assessment (UTOPHIA) tool to Barcelona. Exposure estimates and mortality data were available for 1357361 residents. We compared recommended with current exposure levels. We quantified the associations between exposures and mortality and calculated population attributable fractions to estimate the number of premature deaths preventable. We also modeled life-expectancy and economic impacts.

Results: We estimated that annually almost 20% of mortality could be prevented if international recommendations for performance of PA, exposure to air pollution, noise, heat, and access to green space were complied with. Estimations showed that the biggest share in preventable deaths was attributable to increases in PA, followed by exposure reductions in air pollution, traffic noise and heat. Access to green spaces had smaller effects on mortality. Compliance was estimated to increase the average life expectancy by 360 (95% CI: 219, 493) days and result in economic savings of 9.3 (95% CI: 4.9; 13.2) billion € per year.

Conclusions: PA factors and environmental exposures can be modified by changes in urban and transport planning. We emphasize the need for (1) the reduction of motorized traffic through the promotion of active and public transport and (2) the provision of green infrastructure, which are both suggested to provide PA opportunities and mitigation of air pollution, noise, and heat.

INTRODUCTION

By 2050 almost 70% of people globally are projected to live in urban environments (United Nations 2014). Cities can be beneficial for people's well-being as they provide innovation, access to goods and services, and facilitate social interaction (United Nations 2014). Some aspects of urban life, however, such as a sedentary lifestyle, increased exposure to air pollution, noise, heat, and a lack of green space can have detrimental effects on health and increase premature mortality (Gascon et al. 2016; Guo et al. 2014; Halonen et al. 2015; Woodcock et al. 2011; World Health Organization 2014b).

Physical inactivity and ambient air pollution are estimated to cause more than five million premature deaths each year worldwide, ranking them among the leading risk factors in the global burden of disease study (Forouzanfar et al. 2015). Car-centric city designs typical of preceding decades have little space assigned for green infrastructure, despite increasingly-known benefits for physical and mental health (Gascon et al. 2016).

Further to being the main source of air pollution in urban areas, motorized road traffic exposes an estimated 40% of Europeans to day time noise levels exceeding the WHO recommended threshold of 55 dB (World Health Organization 1999) as well as produces anthropogenic heat that together with re-radiation effects of dense urban structures can amplify urban summer temperatures resulting in urban heat islands (Zhao et al. 2014). Reducing exposure to urban environmental hazards, increasing exposure to green spaces and promoting physical activity (PA) may be achievable through community-level interventions such as health-promoting urban and transport planning.

We aimed to estimate the mortality burden associated with exposures related to current urban and transport planning. Thereto, we developed the 'Urban and TranspOrt Planning Health Impact Assessment' (UTOPHIA) model and conducted a health impact assessment (HIA) for Barcelona. We estimated the impact of meeting the international recommendations for performance of PA, exposure to air pollution, noise and heat, and access to green spaces on preventable natural all-cause mortality, life expectancy, and economic savings.

METHODS

Study setting

Barcelona, located on the Spanish northeastern coast, as of 2012 had 1620943 inhabitants living in an area of 101 km^2 (Barcelona City Council 2012). Barcelona has a Mediterranean climate with an annual mean temperature of 18 ºC through mild winters and hot, humid summers (Barcelona City Council 2012). Temperature levels in the densely-inhabited center of Barcelona can be up to 8 ºC higher compared to spacious surrounding areas, because of the urban heat island effect (Moreno-Garcia 1994). Air pollution and noise levels are amongst the highest in Europe, due to Barcelona's high population and traffic density, large share of diesel-powered vehicles, low precipitation and an urban design of narrow street canyons framed by semi-tall buildings of 5-6 stories (Nieuwenhuijsen et al. 2014). In turn, green space is mainly located at the hilly west side of Barcelona and only 6.8 m^2 is available on a city-wide average per resident (Barcelona City Council 2012).

HIA methodology: UTOPHIA

We conducted a HIA analysis at the Barcelona census tract level (N=1061) using data from 2012. The analysis estimated the impact on natural-cause mortality for Barcelona residents ≥20 years (N=1357361), under compliance with international exposure level recommendations. The 2012 natural all-cause mortality rate for Barcelona residents ≥20 years was 1108 deaths/ 100000 persons, after excluding external causes of death (Supplemental Material A) (Agència de Salut Pública de Barcelona 2012).

We developed the UTOPHIA tool following quantitative HIA methodology (Figure 1) (World Health Organization 2015) (1) We obtained recommended exposure levels ('counterfactual exposure´); and (2) current exposure levels; (3) we determined the difference between recommended and current exposure levels ('exposure difference'); (4) we obtained the exposure response functions (ERF) quantifying the association between exposure and mortality from the literature (Table 1); (5) we calculated the relative risk (RR) and (6) the population attributable fraction (PAF) for each 'exposure difference' (Supplemental Material A).

Life expectancy and economic evaluations were also carried out. We estimated average change in life expectancy based on age-specific all-cause mortality rates for Barcelona (2011) (Institut d'Estadística de Catalunya (IDESCAT) 2011), following standard life table methods (Miller and Hurley 2003). The economic evaluation was based on the value of statistical life (VoSL) approach (3202968 € for Spain, 2012) (World Health Organization 2014a).

International exposure recommendations

1. Physical activity

The World Health Organization (WHO) recommends adults ≥18 years to achieve 150 minutes of moderate-intensity aerobic PA or 75 minutes of vigorous-intensity aerobic PA weekly (Table 2) (World Health Organization 2010).

2. Air pollution

Particulate matter with a diameter ≤2.5 µm ($PM_{2.5}$) is a commonly-used proxy for exposure to all fossil fuel combustion sources (Mueller et al. 2015). The WHO recommends that annual mean $PM_{2.5}$ exposure concentrations should not exceed 10 µg/m^3 (World Health Organization 2006).

3. Noise

The WHO recommends that day time (7:00-23:00 hr) outdoor noise levels should not exceed equivalent sound pressure levels above 55 dB(A) (World Health Organization 1999).

4. Heat

Although there are no guidelines, increasing greenery and urban albedo while reducing traffic and impermeable surfaces in cities may provide cooling in the summer months by up to 4 ºC (Doick et al. 2014; Zhao et al. 2014).

5. Green spaces

A European Commission working group, as well as the WHO, recommend universal access to a green space defined as living within a 300 m linear distance of a green space ≥0.5 ha (European Commission 2001; World Health Organization 2016 forthcoming).

Exposure data

1. Physical activity

PA data were available for 3279 Barcelona residents (N=2486, 20-64 years; N=793, ≥65 years) through the 2011 Barcelona Health Survey, a population-based randomized sample studying the health status of Barcelona residents (Bartoll et al. 2013). PA data were extrapolated to all Barcelona residents ≥20 years (Table 2).

WHO guidelines for adults 18-64 years/ ≥65 years, were translated into 600/ 450 metabolic equivalent of task (MET) minutes/ week, respectively (Supplemental Material B) (IPAQ Webpage 2005). The association between PA and mortality was quantified using a curvilinear exposure response function (ERF), applying a 0.25 power transformation to PA (Woodcock et al. 2011). As health benefits occur already at low levels of PA, the RR and PAF were calculated for both the current and the recommended MET minutes/ week. Estimated preventable deaths for current PA levels were subtracted from estimated preventable deaths for recommended PA levels.

Sensitivity analyses using (1) a linear ERF and (2) including METs accumulated by walking as part of total PA were carried out (Supplemental Material B).

2. Air pollution

Annual mean $PM_{2.5}$ data (2012) were available for Barcelona on census tract level through the European Study of Cohorts for Air Pollution Effects Land Use Regression (ESCAPE LUR) model (Eeftens et al. 2012). The 'exposure difference' in annual mean $PM_{2.5}$ concentrations necessary to comply with the recommendation of 10 μg/m^3 was estimated for each census tract. The association between $PM_{2.5}$ and mortality was quantified using a linear ERF (World Health Organization 2014b). The RR and PAF corresponding to the 'exposure difference' were calculated on census tract level.

Sensitivity analyses assuming achievement of (1) the WHO interim target of 15 μg/m^3 $PM_{2.5}$ annual mean (World Health Organization 2006) and (2) the lowest measured $PM_{2.5}$ level of 5.8 μg/m^3 were carried out (Supplemental Material C) (Krewski et al. 2009).

3. Noise

Day time traffic noise levels were calculated on census tract level through Barcelona's strategic noise map (7:00-23:00 hr; $L_{Aeq,16hr}$) (Generalitat de Catalunya 2006). The ERF for Barcelona traffic noise exposure and mortality was predicted based on available risk categories (Halonen et al. 2015), assuming a logarithmic relationship (Supplemental Material D).

The 'exposure difference' was determined for each census tract exceeding $L_{Aeq,16hr}$ 55 dB(A). The corresponding RR and PAF were calculated, based on the predicted ERF.

As sensitivity analysis, the PAF was calculated exclusively for the proportion of people in each census tract that self-reported noise annoyance (Supplemental Material D) (Gobierno de España 2012).

4. Heat

Daily mean temperature (2009-2014) were available through a central monitor in Barcelona (Klein Tank 2002). Drawing on a temperature raster map (2007, resolution 1 km) (Grupo de Investigación Kraken. Universidad Extremadura 2007) and using QGIS (v2.6.1), monthly mean temperatures on census tract level were calculated.

2009-2014 daily mean temperatures available through the monitor were averaged to obtain typical temperatures for one calendar year. Following an empirical model, the 74th daily mean temperature percentile, defining the 'minimum mortality temperature percentile' for Spain, was determined at 21.8 ºC (Supplemental Material E) (Guo et al. 2014). Between the 74th and 99th temperature percentiles, a linear mortality ERF was assumed. Monitor data and raster map data were combined to estimate daily mean temperature on census tract level for 2011 (Supplemental Material E).

For those days exceeding 21.8 ºC the 'exposure difference' in daily mean temperature was calculated on census tract level. The corresponding RR and PAF were calculated. Temperatures were theoretically reduced by 4 ºC and the 'exposure difference' for those days still exceeding 21.8 ºC was calculated. The corresponding RR and PAF were calculated. The number of deaths attributable to 4 ºC reduced temperatures was subtracted from the number of deaths attributable to estimated temperatures in 2011.

A sensitivity analysis of 1 ºC temperature reduction was carried out (Supplemental Material E).

5. Green space

In order to provide universal access to a green space ≥0.5 ha within a 300 m linear distance, we estimated how much green space surface (%GS) each census tract needs to have.

Green space data were available through Urban Atlas (2007, resolution 1:10000) (European Environment Agency 2007) and the Barcelona Health Survey. Using ArcGIS the current %GS was calculated for each census tract. Quintiles of the %GS distribution were calculated (Supplemental Material F). Using GIS derived green space data of the Barcelona Health Survey respondents (N=3417), for each %GS quintile the proportion of Health Survey respondents living within 300 m of a green space ≥0.5 ha was determined. A logarithmic function was fitted to predict the %GS needed to provide universal access to a green space ≥0.5 ha within 300 m (Supplemental Material F). It was predicted that each census tract would need to have 25.6% greenness (%GS) in order to provide universal access to a green space ≥0.5 ha within 300 m.

The 'exposure difference' between the current %GS of each quintile and the necessary 25.6% was determined. A linear ERF was used to quantify the association between green space and mortality (Gascon et al. 2016). For each 'exposure difference' by %GS quintile the RR and the corresponding PAF were calculated.

RESULTS

More than 70% of adults in Barcelona were insufficiently active (Table 2). Air pollution and traffic noise levels exceeded recommended values by far (Figure 2). Barcelona's summer months were too hot, and one third of the population did not live within the recommended distance of 300 m to a green space ≥0.5 ha.

Annually, 2904 (95% CI: 1568; 4098) deaths were estimated to be preventable if Barcelona complied with international exposure recommendations (Table 2). Estimations showed that the biggest share in preventable deaths was attributable to increases in PA (1154 deaths; 95% CI: 858, 1577) followed by exposure reductions in air pollution (659 deaths; 95% CI: 386, 834), traffic noise (599 deaths; 95% CI: 0, 1009) and heat (376 deaths; 95% CI: 324, 442) (Figure 3). Access to a green space was estimated to have smaller impacts on mortality (116 deaths; 95% CI: 0, 236).

Under compliance with international exposure recommendations, Barcelona's residents were estimated to live on average 360 (95% CI: 219, 493) days longer and an estimated 9.3 (95% CI: 4.9, 13.2) billion € could be saved annually.

Results of sensitivity analyses are presented in the Supplemental Material (B-F) and show that our estimates are generally robust.

DISCUSSION

We developed and implemented the UTOPHIA model for Barcelona and estimated that 2904 (i.e. almost 20%) of all annual natural deaths in Barcelona could be prevented if international recommendations for performance of PA, exposure to air pollution, noise, heat, and access to green space were complied with. The present study is the first study to quantify the effects of multiple urban and transport planning related exposures in a city for which we showed considerable impacts on health.

Other HIA have estimated the impacts of some of these exposures in cities and found comparable results to ours. A HIA in Madrid, with twice as many residents and similar environmental conditions, found almost 470 deaths attributable to a theoretical traffic noise exposure decrease by solely 1 dB(A) (Tobías et al. 2014). Other HIA looking at mortality effects of increases in active transport found considerable reductions in premature deaths with most benefits attributable to increases in PA (Rojas-Rueda et al. 2011; Woodcock et al. 2014). A recent HIA for Basel found that expected $PM_{2.5}$ reductions with implementation of proposed transport policy measures would result in a reduction of premature mortality by 3% (Perez et al. 2015).

Limitations and strengths

We have estimated a considerable impact on all-cause mortality of Barcelona complying with international exposure recommendations. However, HIA involves multiple assumptions that carry uncertainties in estimating health impacts and of which we could quantify only a limited extent.

The ERFs for PA, air pollution and green spaces were obtained from the most recent meta-analyses. The strength of evidence of mortality effects of PA and air pollution is stronger than of the other exposures, simply because more research has been done on these exposures. The estimates of noise and green spaces are only suggestive, as reflected by the wide confidence intervals. Despite emerging evidence on green spaces providing general health benefits (Dadvand et al. 2016; Triguero-Mas et al. 2015), so far only a few studies have looked at the association between green space and mortality. Moreover, the exposure definition of 'greenness' implies uncertainties due to heterogeneity in exposure assessment. For noise and heat we are unaware of existing meta-analyses or quantitative reviews. The ERF for noise came from the currently-only existing ecological study and the ERF for heat from a population-level time-series study, which limits the strength of evidence. For noise, the WHO recommends that night time (23:00-7:00 hr) outdoor noise levels should not exceed equivalent sound pressure levels above 40 dB(A) (World Health Organization 1999). However, no evidence exists on the association between night time noise and all-cause mortality (Halonen et al. 2015). For heat, the exposure indicator used was daily mean temperature. This indicator, however, only is limited in its reflection of heat-stress as it does not consider other important determinants such as humidity, solar radiation or wind force.

Generally, benefit estimations are sensitive to the contextual setting and underlying population parameters. Estimations of health impacts depend largely on baseline exposure to the health pathways considered and the general health status of the population, thus varying results can be expected in different settings. Moreover, personal choices and intrinsic motivations for behavior change (e.g. choosing the bicycle over the car), and thus exposure alterations, are unquantifiable but determine health impacts largely. Generalizability and causal inference of our results may thus be uncertain.

In addition, time-lags in benefit estimations and thus delayed receipt of health benefits can significantly alter benefit estimations. As we were interested in long-term effects of exposure alterations, a delay in benefit reception is expected. Practical implications of this delay may be that changes to urban and transport planning practices are less relevant for younger people in terms of mortality impacts, but its importance is reinforced for older people. In times of demographic change and increasing ageing populations, this is important to keep in mind. In this regard, the estimated economic impact is most likely overestimated, as time discounting applies because benefits occurring in the future are less valuable than benefits occurring immediately.

The present study focused on mortality. Assessing the associated morbidity burden was outside the scope of this study. A further concern is the double-counting of deaths, as air pollution, noise, and heat share a common source (i.e. motorized traffic) and a common mitigator (i.e. green spaces). Estimated effects might interact and synergies may exist between the exposures. Currently, evidence on the independence of mortality effects is only available for air pollution and noise (Tétreault et al. 2013). Therefore, the results presented herein need to be interpreted with caution, as effect modification cannot be ruled out. Nevertheless, on the other hand, we might have underestimated the air pollution burden, as we only considered $PM_{2.5}$ mortality effects. Other traffic-related air pollutants, which we did not consider, such as nitrogen dioxides (NO_2) show to have independent mortality associations (Faustini et al. 2014).

The strength of this study is its novelty in terms of linking urban and transport planning related exposures and health in an integrated way, which highlighted the considerable impacts on mortality by non-compliant exposure levels. The detailed exposure data on the same spatial scale strengthen internal validity of the study. The census tract level and exposure models were of fairly refined resolution. The sensitivity analyses showed that our estimates were fairly robust. Despite being unable to show to what extent improvements of the urban environment could actually contribute towards achieving recommended exposure levels, it is believed that PA factors and environmental exposures would greatly be impacted by reconsideration of urban and transport policies. Therefore, HIA is a valuable tool to enhance the understanding of the interrelationship between the environment and health, and can assist policy makers in optimizing health gains.

Solutions

Solutions to the considerable burden of environmental exposures on mortality can be found, at least in part, in changes to urban and transport planning. Despite the estimated number of preventable deaths being much larger than annual numbers of traffic fatalities in Barcelona (N=30, 2012) (Barcelona City Council 2013), traffic safety is receiving most attention in terms of health impacts of urban and transport planning (Figure 4).

A paradigm shift in urban and transport planning is needed that provides a multidimensional approach to urban environmental quality and associated public health benefits (Brauer and Hystad 2014). Increasing public and active transport (walking and cycling for transport) while simultaneously facilitating urban greening can provide multiple health benefits.

1. Physical activity

Insufficient PA was associated with the largest excess mortality in Barcelona. This highlights the urgency of integrating PA into daily life. Active and public transport provide a great opportunity to do so, as both forms of transport provide coincidental health gains by increases in PA. While public transport is estimated to provide an additional ten minutes of walking per day (Rojas-Rueda et al. 2012), a longitudinal study showed significant contributions of PA from active transport to overall PA as participants who increased their active transport levels had an additional 135 minutes of total PA per week (Sahlqvist et al. 2013).

The proportion of trips made by walking and cycling is increasing in Barcelona (+0.7%; +5.6% in 2012/ 2011) (Barcelona City Council 2013), but further efforts are needed to reinforce these positive trends. Investment in active and public transport infrastructure and safety measures are economically justified and yield high return (Gössling and Choi 2015).

Reinforcement of green infrastructure may also facilitate PA engagement (i.e. active transport) as exercise in green spaces is associated with higher intensity exercising and higher enjoyment (Gladwell et al. 2013).

2. Air pollution, noise and heat

Exposure to air pollution, noise, and heat resulted in large contributions to the estimated mortality burden. Barcelona's vehicle fleet of more than 500000 cars and almost 300000 scooters and motorcycles, plus a daily suburban commuter fleet result in high motorized traffic volume and associated emissions (Barcelona City Council 2013).

Air pollution and noise are amplified in the narrow, built-up streets typical of Barcelona, due to reduced air mass exchange within these street canyons (Marini et al. 2015) and multiple interactions of noise waves with building facades (Van Renterghem et al. 2015). A systematic review supports our findings with the conclusion that noise and air pollution have similar but independent mortality effects (Tétreault et al. 2013).

Barcelona's summer temperatures are reinforced by anthropogenic heat due to combustion by motorized traffic, re-radiation by urban construction, and a shortage of green and open spaces for dissipation (Ahmen Memon et al. 2008).

Key strategies for air pollution, noise and heat mitigation are the reduction of motorized traffic through the replacement by zero and low-emitting modes of transport (i.e. active and public transport) and the provision of urban greening. Taking opportunities with urban renewal, densely-constructed grey infrastructure could be loosened-up and replaced by non-radiating and green infrastructure. Vegetation can be a passive control of air pollution exposure (Abhijith and Gokhale 2015), is a natural noise barrier (Van Renterghem et al. 2015) and provides shading and cooling of the surroundings through evapo-transpiration of water (Raji et al. 2015).

3. Green space

Despite the minor suggested impact of green spaces on natural all-cause mortality, the co-benefits of PA engagement and refuge from harmful environmental exposures (i.e. air pollution, noise, and heat) make green spaces an important urban and traffic management tool.

The present study evaluated mortality effects of 'access' to green spaces. The recommendation of a 300 m linear distance is supported by research findings suggesting that green space use declines after 300-400 m (Annerstedt et al. 2012). For active use (i.e. PA), however, green space attractiveness and maintenance appear more important than distance or size (Sugiyama et al.

2010). Furthermore, aesthetically pleasing 'surrounding greenness' such as street trees or greenways may also be important and have been associated with a wide range of health indicators (Triguero-Mas et al. 2015).

Additional pathways that may help in explaining the beneficial effects of green space on mortality are: (1) mitigation (of air pollution, noise, and heat) (Gascon et al. 2016); (2) 'visual access' to green spaces as associated with stress relief, positive affect and restoration (Wolf and Robbins 2015); (3) improved mental health (Triguero-Mas et al. 2015); (4) enriched biodiversity that strengthens immune function (Rook 2013); and, (5) increased safety perception and social cohesion (Garvin et al. 2013; Wolf and Robbins 2015).

CONCLUSIONS

In Barcelona each year, almost 20% of mortality was estimated to be attributable to non-compliance of recommended levels to PA, air pollution, noise, heat and access to green spaces. Environmental exposures and PA factors can be modified by changes in urban and transport planning. We appeal to further consider health impacts when designing cities and emphasize the importance of (1) the reduction of motorized traffic through the promotion of active and public transport; and (2) the provision of urban greening, which are both suggested to provide opportunities for PA engagement as well as mitigation for air pollution, noise, and heat.

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Table 1. Risk estimates for all-cause mortality by exposure domain

Exposure domain	**Relative Risk (95% CI)**	**Exposure**	**Age group**	**Study design**	**Reference**
Physical activity[a]	0.81 (0.76, 0.85)	11 vs 0 MET hours/ week	≥20 years	Meta-analysis	Woodcock et al. 2011
Air pollution[b]	1.07 (1.04, 1.09)	per 10 μg/m^3 increase in $PM_{2.5}$ exposure	≥20 years	Meta-analysis	WHO 2014
Noise[c]	1.04 (1.00, 1.07)	Day time traffic noise $L_{Aeq,16hr}$ >60 dB(A) vs <55 dB(A)	≥25 years	Ecological study	Halonen et al. 2015
Heat[d]	1.19 (1.16, 1.23)	99th vs 74th temperature percentile	NA	Time-series study	Guo et al. 2014
Green space[e]	0.99 (0.98, 1.01)	per 10% increase in greenness	≥18 years	Meta-analysis	Gascon et al. 2015

CVD=cardiovascular disease; dB(A)=A-weighted average sound pressure decibel levels; MET=metabolic equivalent of task (1 MET=1 kcal * kg^{-1} * h^{-1}); NA=not available; $PM_{2.5}$=particulate matter ≤2.5 μg; 95% CI=95% confidence interval.

[a] Mortality effect of physical activity modeled with a curvilinear exposure response function, applying a 0.25 power transformation.

[b] Mortality effect of air pollution modeled with a linear exposure response function

[c] Mortality effect of noise modeled with a logarithmic exposure response function.

[d] Mortality effect of heat modeled with a linear exposure response function, after determining the minimum mortality percentile (74th temperature percentile) of daily mean temperature at 21.8 ºC.

[e] Mortality effect of greenness (defined as green space surface in % (%GS)) modeled with a linear exposure response function.

Table 2. Estimated premature all-cause mortality preventable under compliance with international exposure recommendations in Barcelona

Exposure	Recommendation[a]	Current exposure[b]	Deaths (95% CI)[c]	Life expectancy in days (95% CI)[d]	Economic savings in billion € (95% CI)[e]
Physical activity Adults 18-64 years Adults ≥65 years	 600 MET minutes/ week 450 MET minutes/ week	 77.7 MET minutes/ week 36.7 MET minutes/ week	1154 (858, 1577)	204 (161, 259)	3.7 (2.7, 5.1)
Air pollution Annual mean $PM_{2.5}$	10 μg/ m^3	16.6 μg/ m^3	659 (386, 834)	52 (29, 67)	2.1 (1.2, 2.7)
Noise Day time (7:00-23:00 hr) outdoor activity noise ($L_{Aeq,16hr}$)	55 dB(A)	65.1dB(A)	599 (0, 1009)	47 (0, 81)	1.9 (0, 3.2)
Heat	Changes to urban plan may provide cooling of 4 ºC	>21.8 ºC on 101 days ('minimum mortality percentile')	376 (324, 442)	34 (29, 40)	1.2 (1.0, 1.4)
Green spaces	Access to green space ≥0.5 ha within 300 m linear distance	31% of residents without access to green space ≥0.5 ha within 300 m linear distance	116 (0, 236))	23 (0, 46)	0.4 (0, 0.8)
Total			**2904 (1568, 4098)**	**360 (219, 493)**	**9.3 (4.9, 13.2)**

L_{Aeq}=A-weighted equivalent sound pressure levels in decibels, dB(A); MET=metabolic equivalent of task (1 MET=1 kcal * kg^{-1} * h^{-1}); PA=physical activity; $PM_{2.5}$=particulate matter ≤2.5 µg; %GS=green space surface in %.

[a] International exposure recommendation by exposure domain.

[b] Current exposure level in Barcelona by exposure domain (2012).

[c] Estimated annual premature deaths due to non-compliance with international exposure recommendations.

[d] Estimated increase in life expectancy under compliance with international exposure recommendations.

[e] Estimated economic saving under compliance with international exposure recommendations; based on value of statistical life (VoSL) approach (3202968 € for Spain, 2012).

Figure 1. Conceptual framework of the Urban and TranspOrt Planning Health Impact Assessment (UTOPHIA) tool.

(1) Recommended exposure level; (2) current exposure level; (3) exposure difference between recommended and current exposure level; (4) exposure response function (ERF) quantifying association between exposure and mortality; (5) relative risk (RR) corresponding to 'exposure difference'; (6) population attributable fraction (PAF) corresponding to 'exposure difference'.

Figure 2. Environmental exposure maps for Barcelona on census tract level (N=1061).

(A) air pollution, $PM_{2.5}$ annual mean; (B) day time road traffic noise, $LA_{eq,16hr}$ (7:00-23:00 hr); (C) heat, daily mean temperature for 01.07.2011; (D) green spaces, green space surface in % (GS%) of green spaces ≥0.5 ha.

Figure 3. Estimated preventable deaths under compliance with exposure recommendations by exposure domain.

95% CI= 95% confidence interval

The exposure response functions (ERF) for physical activity, air pollution and green spaces were obtained from meta-analyses. The ERF for noise was taken from an ecological study. The ERF for heat was taken from a population-level time-series study.

Figure 4. Mortality pathways of urban and transport policies.

Health effects of urban and transport planning are most likely considered in terms of traffic safety. However, health pathways of physical activity, air pollution, traffic noise, heat, and green spaces show considerable impacts on natural all-cause mortality.

Figure 1.

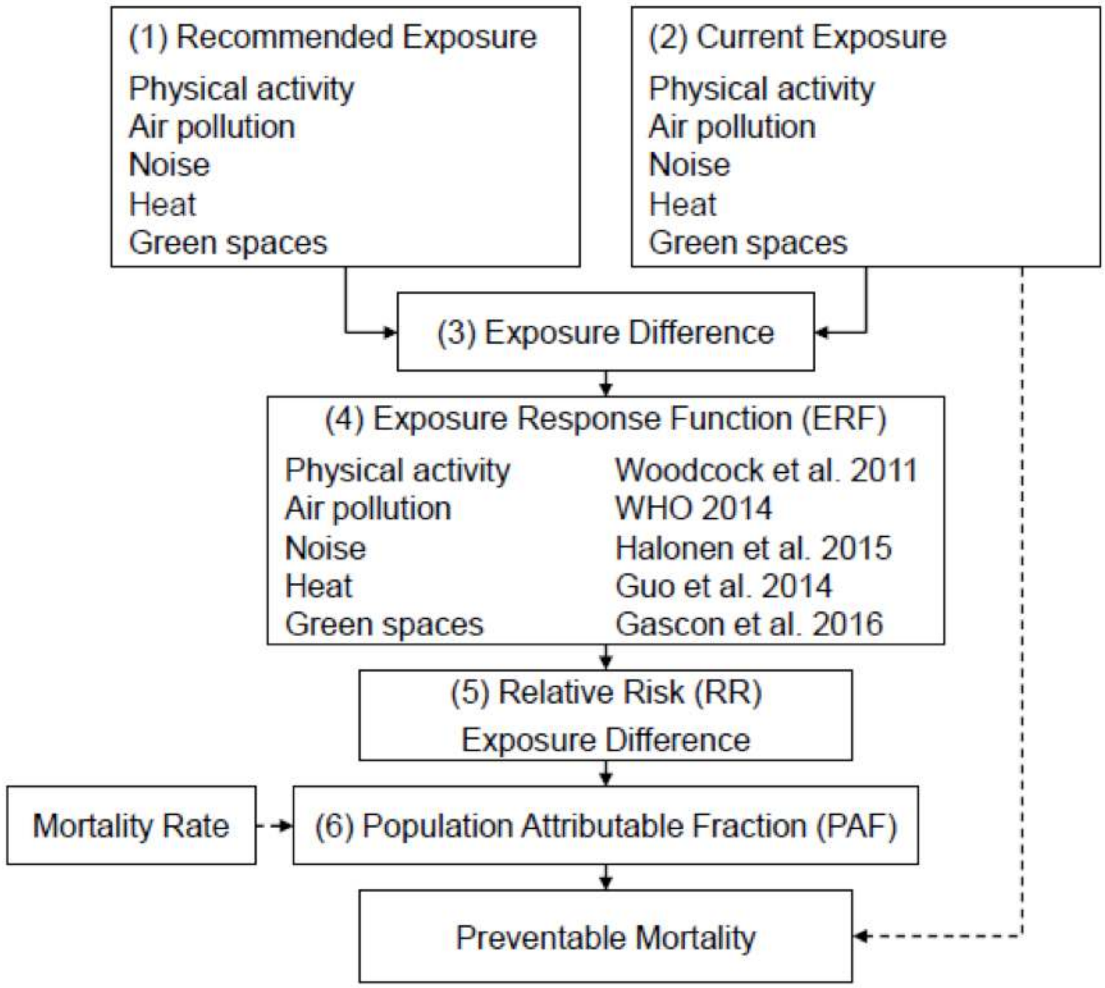
(1) Recommended Exposure
Physical activity
Air pollution
Noise
Heat
Green spaces
(2) Current Exposure
Physical activity
Air pollution
Noise
Heat
Green spaces
(3) Exposure Difference
(4) Exposure Response Function (ERF)
Physical activity
Air pollution
Noise
Heat
Green spaces
Woodcock et al. 2011
WHO 2014
Halonen et al. 2015
Guo et al. 2014
Gascon et al. 2016
(5) Relative Risk (RR)
Exposure Difference
Mortality Rate
(6) Population Attributable Fraction (PAF)
Preventable Mortality

Figure 2.

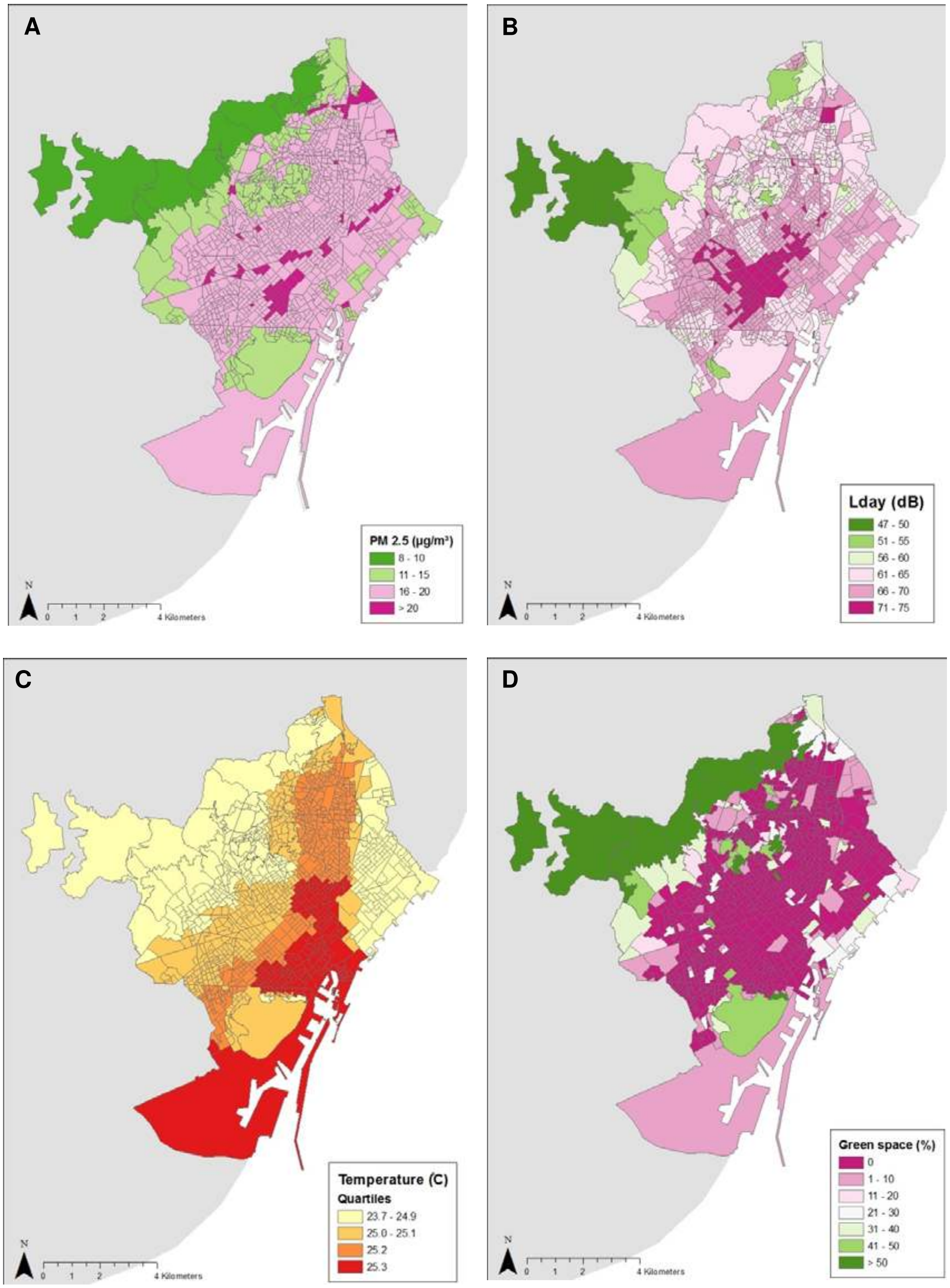
A
PM 2.5 (µg/m³)
8 - 10
11 - 15
16 - 20
> 20
B
Lday (dB)
47 - 50
51 - 55
56 - 60
61 - 65
66 - 70
71 - 75
C
Temperature (C)
Quartiles
23.7 - 24.9
25.0 - 25.1
25.2
25.3
D
Green space (%)
0
1 - 10
11 - 20
21 - 30
31 - 40
41 - 50
> 50
N
0 1 2 4 Kilometers

Figure 3.

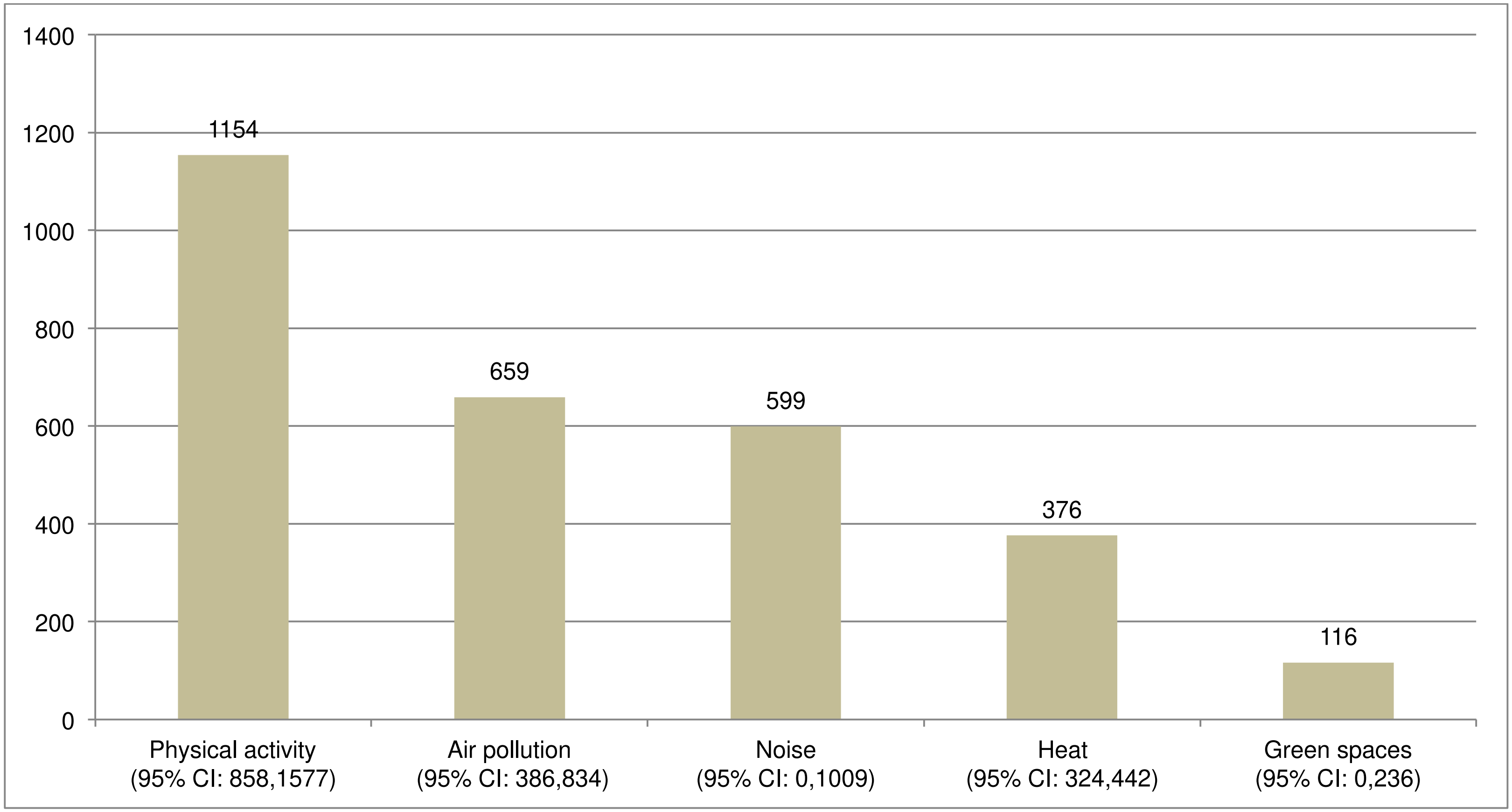
1400
1200
1000
800
600
400
200
0
1154
659
599
376
116
Physical activity
(95% CI: 858,1577)
Air pollution
(95% CI: 386,834)
Noise
(95% CI: 0,1009)
Heat
(95% CI: 324,442)
Green spaces
(95% CI: 0,236)

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Figure 4.