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RETURN TO CONTENTS

RESEARCH & ANALYSIS

Air pollution, mental health, and implications for urban design: a review

Jacob King (1,2)
(1) University of Exeter Medical School, United Kingdom
(2) Centre of Urban Design and Mental Health

SUMMARY

Ameliorating the impact of air pollution has been widely considered within health promotion literature. While the substantial physical health impacts of air pollution have been demonstrated, the effects of air pollution on mental health outcomes are much less clear. Epidemiological evidence shows an emerging association between certain air pollutants and a range of mental health outcomes including depression, anxiety, psychosis, dementia, childhood cognitive development, and suicide. This review of the literature finds that the evidence for associations between air pollution and these mental health outcomes is so far promising but weak, largely due to the positive and negative confounding factors that are challenging to measure and frustrate efforts to identify the true size of the impact. Yet, the availability of green spaces, proximity to major roads and active transport initiatives, zoning of air polluting industries, and high-rise buildings are all features of urban environments identified as targets for improving the population mental health. We argue that on the basis of the evidence to date, it is reasonable to add "reducing exposure to air pollution" to the rationale for implementing these urban design features as an additional facet for addressing urban mental health.

Introduction

For years air pollutants have been implicated in a range of health outcomes, most notably cardiovascular and respiratory diseases. The 2015 Global Burden of Disease survey estimated that just one aspect of air pollution, fine particulate matter, is largely responsible for 7.6% of all deaths worldwide (1).

However, the effects of air pollutants on mental health conditions have been less-well studied, and mostly confined to epidemiological studies, which can demonstrate an association but cannot show causation. Observational evidence has revealed small-to-moderate sized associations between increasing levels of several components of air pollution and a range of mental health outcomes. There is not yet a confident explanation for these observed associations, but a considerable number of biological, psychological and social implications have been hypothesised, and evidenced to varying degrees. This paper first reviews the current evidence for the contribution of outdoor air pollution to the burden of mental disorders, and second, considers key examples of how this relationship might influence the rationale for urban design objectives toward creating a mentally healthy environment.

'Air pollution' describes presence in the air of several key substances each with varying degrees of pathogenicity in humans. The main air pollutants of interest to human health include:

- Gaseous pollutants: nitrogen oxides (NOx), including nitrogen dioxide (NO2), carbon monoxide (CO), ozone (O3), and sulphur dioxide (SO2)
- Particulate pollutants: grouped, by size, into coarse particulate matter (PM10), fine particulate matter (PM2.5) and ultrafine particulate matter (UFPs)
- Heavy metal air pollutants: cadmium, lead and mercury among others.

Smog in Beijing (2014). Credit: Wikimedia Commons

Hypotheses for how air pollution may impact mental health

There is thus far insufficient evidence that air pollution*causes* mental health problems. But increasing neurobiological evidence has begun to point to nervous system pathology from several components of air pollution (2).

Neuroinflammatory hypothesis
In animal studies neuroinflammatory responses have been identified following air pollutants exposure. In particular, exposure to O3 and PM2.5 seem to be implicated in damage to the neurovascular unit, and with production of autoantibodies against neural and tight-junction proteins (3-5). Given evidence which points towards an inflammatory contribution to psychiatric symptoms, (6, 7) neuroinflammation tentatively presents a potential neuropathological pathway for causation (8, 9). Within the epidemiology literature Lim and colleagues have demonstrated an association between certain pollutants and depression. Those pollutants, which have an oxidative stress potential (which can trigger neuroinflammatory responses in the central nervous system), were observed to be associated with depression in the population (10)

Gene-environment interaction hypothesis
The process of genes and the environment interacting to produce an effect that neither would produce alone may also be implicated, and has already been demonstrated in the link between heavy metal air pollutants and the development of psychotic disorders such as schizophrenia (11). Furthermore, given the links between air pollutants and physical disorders (12) it has been suggested that the biological processes that we know mediate the air pollution/physical health association may also be implicated in neuropsychiatric disorders (13).

Context: challenges with air quality and mental health studies

Exposure to air pollutants has been measured variably across papers. While some studies have used land use registries to identify areas of industry, and estimates based on nearest nodal measurement taken from large international datasets, others have used less sophisticated methods to approximate air pollution exposure including distance from major roads to participants' residence. A perennial problem in psychiatric epidemiology, apparent in some of these heterogenous measurements methods, is the complex social, cultural, geographical, meteorological *i.a.* milieu, which invariably confound the air pollution/mental health relationship. These can be difficult to measure accurately, which creates challenges in adjusting for their impact. Case in point, living close to a road has been implicated in many proposed mechanisms affecting mental health, from noise levels to safety concerns. While studies using road proximity as a proxy for air pollution exposure do identify these confounding factors, efforts to adequately adjust for them are lacking, which weakens the studies' ability to accurately measure the association between air pollution and mental health.

Socially, air pollution is unequally experienced, yet exposure can vary by neighbourhood, city, country, income level, ethnicity, age, and whether people live near to the centre, or industrialised areas of cities, or near major roads (14). In the US for example, inner-city poorer neighbourhoods experience higher levels of air pollution and associated health impacts (15). Yet these variations are not predictable: in several European cities, where central areas are associated with higher housing prices, in some cases the more well-off experience greater exposures, but not necessarily greater health impacts (16), and in other cases, poor and less-well educated people are most exposed, despite not living near the centre (17). Globally, the less well-off and least educated in society have poorer mental health outcomes (18). Part of the observed air pollution and mental health association may be reasonably explained by these and other individual and population-level sociocultural confounders, which again, are difficult to measure, control, or adjust for.

With this in mind we turn to reviewing the current evidence for the association between increasing levels of air pollutants and mental health outcomes.

Associations between specific mental disorders and air pollution

It is clear that there is a vital need for systematic reviews and meta-analysis of the associations between air pollutants and mental health outcomes. Yet, as it stands, and despite being notoriously difficult to measure - with the hazard of a wide group of confounding variables that can be difficult to quantify, and additional methodological concerns associated with type I error and publication bias, there still appears to be evidence across many outcomes that there is a positive association between air pollution and various mental health outcomes.

Depression

Vert and colleagues in Barcelona identified significantly increasing rates of depression among those exposed to a range of air pollutants, with doubling odds of depression (2.00, 95% CI; 1.37, 2.93) for each 10 µg/m3 NO2 increase to a population (19). This study also identified associations between higher concentrations of air pollutants and psychiatric medication usage. Similarly, Lim and colleagues demonstrated a significantly increased risk of depressive symptoms, most notably emotional symptoms, in older people in Seoul, Republic of Korea (10). A study in the US found similar, though more conservative increases: 1.06 and 1.08 hazard ratios of depression from 10 µg/m3 increases in 03 and PM2.5 respectively (20). In addition, studies which have assessed emergency department attendances for depressive episodes were significantly associated with poorer 3-day rolling average air quality measures; this was especially true for those with physical co-morbidities and pre-existing depressive disorders (21). Assessing similar outcomes, on a daily basis, emergency department attendance for depressive episodes were significantly higher for particular combinations of air pollutants at certain times, for example, in Edmonton, Canada, a 7.4% (95% CI: 0.5, 14.8) increase in emergency department attendance by female patients was observed when NO2 was particularly high in warm seasons (22).

Wang and colleagues on the other hand found no significant associations between outdoor ambient air pollution and depressive symptoms in their Boston, USA. population (23), and neither did Zijlema *et al*.'s cross-sectional study of four European cities (24). Responses to both studies (25, 26) highlighted key methodological concerns, the latter of these making the pertinent point that systematic review is desperately needed to properly evaluate this association.

Anxiety disorders

The observational cohort study from Power and colleagues using the US nurses' cohort reported on estimations of air pollution exposure, and distance to nearest major road (27). They found significantly higher odds of 'meaningfully high symptoms of anxiety' in nurses exposed to higher levels of particulate matter - PM10 and PM2.5 - in the preceding month and year. Nurses exposed to 10 mcg/m3 increase in PM2.5 on average in the previous year had 1.15 (1.06 to 1.26) higher odds of meaningful anxiety symptoms. Similarly, links have been reported between particulate matter concentration and anxiety symptoms after adjusting for a range of socioeconomic confounders (28). This study also found that the association between anxiety symptoms and air pollution was greater for those in lower socioeconomic groups and those with pre-existing physical health conditions.

Psychosis

Urban-rural differences in the incidence of schizophrenia are well established in the literature, and recently air pollution has been inculpated as having potential to mediate this relationship (29). Thus so far evidence is slim, and a review of the association is only able to highlight a potential for a causal link between environmental heavy metal exposures, especially to cadmium and lead, and neurobiological pathways for developing schizophrenia (11).

Mental health in childhood

A cohort study of four Swedish counties found that children living in an area with higher levels of PM10, PM2.5 and NO2 (as identified by national measures) were more likely to have been dispensed psychiatric medication (HR=1.09, 95% CI 1.06 to 1.12, associated with a 10 microgram/m3 increase in NO2) (30). Furthermore, other authors have identified higher levels of environmental air pollutants in early childhood to be weakly associated with autistic spectrum disorders and psychotic disorders later in life (31, 32). Prenatal exposure to high levels of air pollutants have been implicated in a range of health impacts to children - there has been some work, although incomplete, which suggests there could be evidence for poorer mental development in children born to mothers with high air pollution exposure during pregnancy. (33) These associations remain inconclusive.

Mental health in older people

Literature reviews of environmental determinants of dementia and cognitive decline, covering six studies, have found positive dose-respondent associations with CO, O3, NOx, and fine and coarse particulate matter and dementia and cognitive decline at the population level after adjusting for potential economic and social confounders (34,35). Similarly, another study found that long term exposure to black carbon (a sub-component of particulate matter) which also emanates from traffic, produced 1.3 times greater odds (CI, 95%: 1.1 – 1.6) of decreased cognitive function in older men (36).

Suicide attempts

Yackerson's 2014 study showed a significant but weak positive correlation (rho = 0.3) between Eastern winds in Israel, which carry high concentrations of solid air-suspended particles, and psychotic exacerbations of schizophrenia and suicide attempts in people who have schizophrenia (37). Similar findings were observed for gaseous pollutants and particulate matter and suicide attempts in Vancouver (38), particulate matter and completed suicide in Seoul (39), and PM10 and NO2 on 'suicide risk' in Guangzhou (40). Finally, Bakian and colleagues noted increased short-term rates of suicide completion associated with increased exposures to NO2 and particulate matter during the spring season in Salt Lake City, UT, concluding that there is now convincing global evidence for the positive association between suicidal tendency and air pollutants that persists with geographical, meteorological and cultural variation (41).

Air pollution, mental health and urban design opportunities

Lessons from rapid urbanisation

By far, studies summarised above reflect a general paucity in the literature for studies from low and middle-income countries (LMICs). This may be important. For example, Tian and colleagues, observing Chinese populations, note that rural elderly residents have higher CES-D scores (a screening measure of depression) than urban residents (42). Yet concurrently, that air pollution levels of SO2, which were higher in urban areas, contributed to psychological distress. They conclude therefore, that while SO2 levels are implicated in psychological distress, social factors associated with China's urban environments including improved education and employment opportunities, social connections, and lower rates of chronic illnesses and alcohol use, masked this impact. We may therefore suggest that while the industrialisation of China has invariably increased levels of air pollutants and perhaps therefore psychological distress, the potential air quality impacts may be mitigated by the benefits of city living, including protective factors for mental health such as employment, education, better amenity access. The implications of this are important to urban design. In short, a similar concept has emerged from studies of environmental justice and living environment. While residents are well aware of the negative environmental exposures (including air pollution), other priorities including social connectivity, place attachment and affordable and quality housing in the area were valued more highly (43,44). Broadly, any urban design action which aims to address air pollution's effects on mental health should, arguably, maintain or improve economic, social, cultural, among other determinants of good mental health too.

Using urban design to reduce people's exposure to air pollution

Understanding the sources of air pollution has been key to beginning to develop urban design techniques for reducing overall exposure. Sources of air pollution vary by city, region and by component of air pollution. Fine particulate matter has been most widely studied, and global averages estimate that 25% originates from traffic pollution, 15% from industrial sources, 20% from domestic fuel burning, 22% from other unspecified human origins, and 18% from natural sources: volcanoes, desert dust, sea salt *etc.* (45). There already exist several key urban design ideas evidenced and implemented to varying degrees for reducing the levels of air pollution in polluted cities (46). Pedestrianisation, sensitive zoning of industrial sites, redirection of heavy traffic areas away from residences, extending or introducing low-emission zones, and facilitating public and active transport initiatives for example. But instead of rehashing or adding to this list, this paper seeks to assess how the links between air pollution and mental health as described above have implications for the current themes in urban design initiatives for mental health.

Traffic-related air pollution

As previously highlighted, living near to a major road may have mental health implications for multiple reasons, including: noise, connectedness, air pollution, safety concerns (particularly for children), diminished neighbourhood quality *etc.*. While living near to a major road was the primary exposure variable in many of the epidemiological studies reviewed above, few were able to adjust for these other potential explanations of the relationship. Therefore, even if the positive associations between mental disorders and air pollution may in fact be due in a large part to a confounding factor, intervention to reduce unnecessary exposures to major roads is a key target for urban design's ability to prevent negative mental health impact.

Active travel (including walking and cycling) is considered to promote good mental health through integrating regular physical activity into people's daily routines, and depending on routes available, potentially increasing exposure to natural settings. Active travel may deliver further benefits by reducing stress induced by commuting by car, and by reducing cars on the road, providing the potential to repurpose space for car parking into new public spaces that promote physical activity and positive social interaction. Methods for improving access to useful and affordable travel alternatives is well described in the urban design literature (47,48).

Unfortunately, as pertinently explored by Woodward and Samet, despite the potential mental health benefits of active transport and physical activity, the decision to promote active transport modes as alternative transport choices must include consideration of their potential to increase people's exposure to air pollutants (49). But so far, evidence suggests that this should not necessarily change efforts to encourage active travel: as these authors succinctly surmise in their title, when it comes to health impact, it appears that "exercise trumps air pollution, almost always". Summarising a series of studies looking at the tipping point and break-even points at which the time outside exercising in air pollution becomes negative to (physical) health rather than beneficial, they found that unless one exercises in a city with very high levels of air pollution, or conducts excessive outdoor exercise, the health benefits outweigh the health risks. One study in New Delhi, a city with very high levels of air pollution, attempted to quantify the risk. The authors estimated that in a high-pollution setting, the health benefits of walking for short periods outweigh the health risks, but after walking for 1hr 30 there would be no additional health benefit to be had by walking, and after 4hrs 45 all benefit accrued by walking would be lost to the detrimental effects of air pollution. These studies did not take into account mental health as an outcome (50), but given so far less obvious and weaker associations, it may be reasonable to suggest that this tipping point could be even higher before negative mental health impacts from air pollution trump the mentally beneficial effects of exercise and being outdoors. With that in mind, the other detrimental effects of busy roads, including high cognitive load, excessive noise and safety concerns must not be ignored as a high priority issue for urban design that considers mental health.

Urban vegetation

Green spaces can promote good health for a variety of reasons (51): they provide the settings for people to exercise and socialise, relax and be restored; they improve a sense a place attachment; promote feelings of the quality and safety of neighbourhoods; and facilitate social cohesion (52,53). Even greening roadsides and lining streets with trees have been reasonably well-evidenced for reducing population stress levels (54,55). Studies examining the impact of green space availability on all-cause mortality have identified some of the mechanisms as being the reduction in air pollution exposure and improvements to mental health (56). In 2015 researchers showed positive relations between the amount of greenery surrounding school location and school children's cognitive development. Importantly, air pollution was identified as the key mediating factor, explaining between 20 and 60% of the beneficial observation (57).

Trees, hedges and green walls, and larger urban green spaces have been repeatedly identified as being able to reduce air pollutants by trapping heavy metals and larger particulate matter (58,59), notably, *Platanus* tree species (60) have been used to this effect in London (61). However evidence also indicates that trees which capture pollutants in this manner may reduce air flow and air exchange thus increasing air pollutant concentration around the road, propagating the street-canyon effect in which tall buildings along a roadside act to reduce air particulate dispersion, retaining air pollutants in their area of production (62). There exists a large body of work examining the role of green infrastructure on reducing population and local level air pollution levels. This demonstrates a mixed picture. Some urban vegetation design implementations may increase or decrease air pollution levels based on a wide range of factors: the street design, building architecture, plant types among others. In practise however, in a recent review of the literature, low-level roadside hedges have been shown in a comparably small number of studies to be more effective than trees at 'soaking-up' pollution in street canyons, and notably offer better air pollutant protection for roadside footpath users than high-level trees (58). For urban design it therefore appears that within an urban street canyon environment, low-level vegetation rows may have a joint role in securely separating road from path, greening an area, and reducing air pollutant dispersion to path users. Characteristics of which varieties of vegetation offer these air pollution-abating benefits have been explored much more thoroughly than the analogous vegetation and urban vegetation design characteristics directly beneficial for mental health outcomes have been.

Within the green infrastructure literature, green spaces have further been operationalised through green facades and living walls, collectively called green walls, whereby buildings are covered with vegetation. While their involvement for direct mental health outcomes benefit has been sparely explored, there seems to be good evidence in their a role in abating air pollutants from localised environments, including at roadsides and in street-canyon-esque environments (63).

Promoting more frequent use of large urban green spaces for mental health benefit could also contribute to reducing one's exposure to air pollutants (64), further, providing a space in which exercise can be conducted for a longer time before the negative health impact tipping point is reached. The distribution of vegetation in cities must be carefully considered to optimise their use, fitting common travel patterns, and facilitating of a range of mentally positive activities.

Density and high-rise living

Cities which plan more attentively for the air flow through their urban canopy may provide some benefit in rapidly dispersing air pollutants - including natural air pollutants like desert dust particulate matter in the Israeli context (37) - away from populated areas. There is increasing evidence showing that during times of fleetingly high levels of air pollution and negative mental health outcomes, there is a role for managing air flow. Tall buildings, densely placed, interfere with wind patterns reducing air pollutant dispersion (46).

The complex questions of a population's mental health impact from this sort of dense urban design has not been considered so readily in literature. There is mixed evidence linking population density to both beneficial and detrimental mental health outcomes (65,66), while taller residential complexes have been held aloft in defiant opposition to urban sprawl and its accompanying psychological stressors (67). Findings on the mental health effects of high-rise living are still largely inconclusive; however the role of air pollution should be included in the debate surrounding high-rise density.

Perceptions of risk, and the quality of environments

Air pollution has the nebulous quality of being largely invisible until very significant levels of particulate matter are reached. It seems that public perception is unlikely to be an accurate indicator of true levels of air pollution, rather, a reflection of perceived associated qualities, such as road traffic (68,69). In 1984, a study in Los Angeles assessing depressive symptoms associated with participants' perceived air quality and objective measures of air pollution, found insignificant associations with objective measures but a strong increase in depressive symptomatology among those living in environments which participants self-perceived to have poor air quality, whether it objectively was or not (70). In the same vein, Bullinger later hypothesised that perceived poor-quality air acts as a stressor contributing to poor psychological health. She found that only objective levels of SO_2, which is itself detectable by smell, was linked to psychological distress, those air pollutants undetectable to human faculties were not linked objectively, but were so when SO_2 was also present (71). Perceptions of the level of air pollution in one's neighbourhood are associated with one's belief that there are negative health impacts (72), perhaps explaining the stress associated with this perception. Work exploring the implications of other factors of a 'good' or 'healthy' environment have suggested that individuals who perceive their environment to be bad or of a poor quality were more stressed, with greater psychiatric symptomatology (73). However there are few studies which explore whether there are specific features or measures of a built environment implicated in residents' perceptions of air quality. This thread of research would be interesting to pursue further. It may be reasonable to suggest that improvements in neighbourhood quality may alleviate some of the stressors associated with perceived poor air quality where there objectively are no indications of pathological pollutant concentrations.

Objective and contextual variations in neighbourhood built environment should only be considered alongside the perception of one's environment when looking to understand impact on mental health outcomes (73,74). So while there is a growing effort to highlight correlations between attributes of a built environment and mentally healthy behaviour, with promising results in assessing walkability (and therefore levels of traffic pollution) in urban neighbourhoods (75-77), conflicting priorities and alternative perceptions among residents may render design efforts ineffective.

Industrial air pollution

Zoning, as originally conceived had in part aimed to reduce the environmental and occupational health impacts of heavy industry on urban populations. Where a distance/dose response has been identified for a number of mental health outcomes, the role of isolating polluting industries away from residences as much as reasonably possible makes sense, for reasons of environmental pollutant exposure and perceptions of quality of one's neighbourhood (43). However, there is a fine balance to be had between maintaining mentally beneficial and accessible employment opportunities and banishing all polluting industries from population centres. Similarly the mental and physical health benefits of heating, lightning and electricity provision, currently still generated in the most part by air polluting methods, cannot be understated (78), but this too must be reasoned with the impacts on mental health.

Conclusions

There is reasonable evidence that increasing atmospheric concentrations of a number of air pollutants are associated to varying degrees with a spectrum of mental health disorders, explained in part by biological, psychological and social pathways. Current evidence for the impact of air pollution on mental health is still emerging and inconclusive, and at best, effect sizes have been found to be small but significant. As such, while effort can and should be given to reducing population exposure to air pollutants because of the actual direct and indirect impacts on physical and mental health, and perceived health risk, other factors may, in specific contexts, have greater impact.

Urban design is well-placed to reduce a population's overall exposure to actual air pollution, and also to its perception of health risk, importantly by tackling traffic and industrial causes of air pollution, and leveraging urban features which reduce pollutant dispersion. Given that the current evidence for links between urban design and mental health is promising but still emerging, it may be reasonable to conclude that strategies to reduce air pollution in the mental health context should always be considered alongside other factors that contribute more notably to mental health outcomes. The role of urban design, akin to classical public health interventions, should naturally seek the most effective solutions. It now appears reasonable to add 'reducing population exposure to air pollution' to the rationale of a number of already proposed urban design initiatives beneficial to mental health, especially increasing the provision and use of active travel and distribution of green spaces.

Attempts through urban design to reduce human exposure to air pollution and its health impacts, should not act as a plaster on the wound, undermining attempts to reduce overall production of air pollution. We inhabit one planet: air pollution made in one city has implications for the health of residents in cities often continents away.

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About the Author

Jacob King is an Associate at the Centre for Urban Design and Mental Health, a final year medical student at the University of Exeter, and holds a Masters degree in Global Mental Health from King's College London and the London School of Hygiene and Tropical Medicine. His main interest concerns the association between green space exposure and mental health, and how we can design interventions to promote this relationship.

RETURN TO CONTENTS