Environmental Science & Policy 56 (2016) 49–55

Contents lists available at ScienceDirect

Environmental Science & Policy

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

Minimizing air pollution exposure: A practical policy to protect vulnerable older adults from death and disability

Nick Woodward [a,*], Morgan Levine [b,c]

[a] University of Southern California, Davis School of Gerontology, McClintock Avenue 3715, Los Angeles, CA 90089, United States
[b] University of California Los Angeles, Department of Human Genetics, 695 Charles E. Young Dr., Los Angeles, CA 90095, United States
[c] University of California Los Angeles, Center for Neurobehavioral Genetics, 695 Charles E. Young Dr., Los Angeles, CA 90095, United States

ARTICLE INFO

Article history:
Received 14 May 2015
Received in revised form 30 October 2015
Accepted 31 October 2015
Available online 17 November 2015

Keywords:
Particulate matter
Older adult
Air pollution
Ultrafine
Cardiovascular disease
Policy

ABSTRACT

Air pollution causes an estimated 200,000 deaths per year in the United States alone. Older adults are at greater risk of mortality caused by air pollution. Here we quantify the number of older adult facilities in Los Angeles County who are exposed to high levels of traffic derived air pollution, and propose policy solutions to reduce pollution exposure to this vulnerable subgroup. Distances between 20,362 intersections and 858 elder care facilities were estimated, and roads or highways within 500 of facilities were used to estimate traffic volume exposure. Of the 858 facilities, 54 were located near at least one major roadway, defined as a traffic volume over 100,000 cars per day. These 54 facilities house approximately 6000 older adults. Following standards established for schools, we recommend legislation mandating the placement of new elder care facilities a minimum of 500 ft from major roadways in order to reduce unnecessary mortality risk from pollution exposure.

1. Introduction

Today it is estimated that 200,000 people die per year in the United States alone due to inhalation of air pollution (Caiazzo et al., 2013). The relative risk for mortality due to living in a heavily polluted area is roughly equivalent to the relative risk of being overweight (a BMI between 25 and 39.9 kg/m^2) (Pope et al., 2002). Study of the ACS Cancer Prevention II population showed that for every 10 μg/m^3 increase in fine particulate matter ($PM_{2.5}$) concentration, an important component of air pollution, there was a concurrent increase of 6% in mortality due to cardiopulmonary conditions, an 8% increase in mortality from lung cancer, and a 4% increase in total all-cause mortality (Pope et al., 2002). National guidelines are 35 μg/m^3 daily maximum and 12.0 μg/m^3 annual maximum for $PM_{2.5}$.

While air pollution negatively affects everyone, children and older adults are especially vulnerable to adverse health effects. Air pollution exposure at a young age can cause cognitive impairments and asthma (Perera et al., 2006; Morgenstern et al., 2008), while pollution exposure at older ages causes a disproportionate increase in mortality, when compared to middle aged individuals (Hoek et al., 2002; Katsouyanni et al., 2001). Mortality from air pollution exposure is mainly due to cardiovascular and cardiopulmonary effects (Brook et al., 2004; Chen et al., 2013; Pope et al., 2002).

Typical age related declines in the cardiovascular system, such as decreased reserve capacity, decreased elasticity of the arterial wall, and decreased ability to respond to norepinephrine signals to adjust blood pressure, make the older adult population extremely vulnerable to cardiovascular and cardiopulmonary disease, and exposure to air pollution amplifies these risks. Although individuals aged 65 and over only represent 13.3% of the population, they account for 42.8% of all cases of heart disease, and 52.1% of coronary disease (Center for Disease Control, 2010). Exposure to high levels of $PM_{2.5}$ is associated with an increased intima-medial thickness, a common measure of the progression of atherosclerosis (Adar et al., 2013). Individuals exposed to $PM_{2.5}$ also showed a decrease in heart rate variability resulting in less adaptability to changes in cardiovascular demands, increasing susceptibility to myocardial infarction (Adar et al., 2007). Particulate matter also causes inflammation of the alveolar cells in the lung, which then releases signaling molecules that increase blood coaguability, raising the chances of clot formation (Ruckerl et al., 2006).

Older adults, especially those in poor health with diminished cardiovascular function, are not as adept at handling these added stressors, therefore they have a higher risk of mortality as a result of the exposure. Individuals with preexisting conditions, especially

* Corresponding author.
E-mail address: Nwoodwar@usc.edu (N. Woodward).

http://dx.doi.org/10.1016/j.envsci.2015.10.018
1462-9011/

cardiovascular or cardiopulmonary conditions, are more vulnerable to air pollution (Goldberg et al., 2001). Also, individuals who sustained a myocardial infarction during heavy pollutant exposure show an increased 10-year future mortality risk, and survivors of a previous myocardial infarction show greater all around mortality later in life if exposed to air pollution (Rosenbloom et al., 2012; Berglind et al., 2009). Exposure to $PM_{2.5}$ has also been associated with increased mortality to individuals with type-2 diabetes (Peters, 2012; Katsouyanni et al., 2001), where older adults are again overrepresented, comprising 39.4% of the diabetic population.

Increasing awareness of the harmful effects of air pollution has led to the development of guidelines to prevent excess exposure to these toxicants. The EPA has been successful in monitoring and reducing air pollution across cities in the United States, however, its measurement methods are coarse and very poorly measure the variability within the city. Two locations within the same city often have greater differences in pollution concentration than the difference between two cities, and the difference in risk can also be larger within a city than between two cities (Jerrett et al., 2005; Miller et al., 2007). In one study, the range of exposure to particulate matter within Los Angeles was 20 $\mu g/m^3$, versus a range of 16 $\mu g/m^3$ between 116 other cities studied (Jerrett et al., 2005). Colloquially know as hot spots, these are areas within a city with much higher pollution concentration than background, often due to higher traffic volume. Identifying these areas of greater pollution concentration, and minimizing exposure to sensitive populations in these areas is a critical step to minimize adverse health effects from pollution exposure.

In this study we quantify the number of older adult facilities, specifically nursing homes, assisted living facilities, and adult day healthcare centers, in Los Angeles County that are currently being exposed to unnecessarily high levels of traffic derived air pollution. Methods for the reduction in pollution exposure through the strategic placement of facilities are proposed.

2. Materials and methods

2.1. Data acquisition

Data were compiled from publicly available databases, which provided information for line coordinates of roads and highways in Los Angeles, traffic counts at one mile intersections or freeway exits, and addresses and occupancies for facilities throughout Los Angeles which cater to the older adult population. These sources were the 2010 TIGER road file for road and highway coordinates, while the Los Angeles Department of Transit traffic survey 10-year summary and the State of California 2012 Annual Average Daily Traffic Report provided traffic data. The nursing home data was provided by the CA.gov site, with the Department of Social Services providing data on adult day health care and assisted living facilities, and skilled nursing facilities data provided by the health facilities section.

Data on road and highway coordinates came from a 2010 TIGER road file (Topologically Integrate Geographic Encoding and Referencing) of the county of Los Angeles. The TIGER file contained geographical coordinates in GCS_NORTH_AMERICAN_1983 for 2,366,677 nodes on the centerline networks of roads used by the US Census Bureau. Additionally, the TIGER road file also contained MAF/TIGER feature classification codes (MTCC), depicting the type of road on which each node was located. Node coordinates were converted to latitude and longitudes using Global Mapper 15 software so that they could be more easily incorporated with traffic and facility location data. Traffic data is a combination of the Los Angeles Department of Transit traffic survey section 10 year 2001–2010 summary, and the State of California 2012 Annual Average Daily Traffic Report. The first file had eastbound, westbound, southbound, and northbound traffic counts for 20,362 intersections in Los Angeles. The second file contained traffic count data for one mile increments on major highways throughout the Los Angeles area. Information on freeway name, exit names, and average monthly and daily traffic counts were available for 763 points.

Data on assisted-living facilities (ALF), adult day health care (ADHC), and skilled nursing facilities (SNF) were available for download from the CA.gov website. Information on ADHC and ALF was provided through the department of social services link (https://secure.dss.cahwnet.gov/ccld/securenet/ccld_search/ccld_search.aspx), while information for SNF was provided through the health facilities section (https://hfcis.cdph.ca.gov/search.aspx). These files contained facility addresses and capacity. Very small facilities—those with less than 6 beds—and those without current licenses were excluded from our analysis. Overall, our analytical sample consisted of 858 facilities (192 ADHC, 400 SNF, and 266 ALF), see Fig. 2.

2.2. Analysis

The high performance computing cluster from the University of Southern California was used for analyses. From available information on city addresses, latitude and longitude were estimated for the facilities and intersections using the STATA module, Geocode3 (Bernhard, 2013). Next, the Haversine distances—a measure of the distance between two points on a sphere—was estimated between the 858 facilities and 2,366,677 geographical points in the TIGER road file using the STATA module Vincentry (Nichols, 2003). Given that node coordinates for roads were calculated for the midpoint of the road, distances to facilities were adjusted based on road type to reflect a more accurate measure of the distance between the facility and the nearest side of a road. We subtracted 66 ft from distances between facilities and major freeways, based on the assumption that most major freeways in Los Angeles have eight lanes and two shoulders, leading to an overall diameter of 132 ft. Similarly, 52 ft was subtracted from distances between facilities and major freeways, given that the average diameter for a Secondary Highway Class II is 104 ft. Finally, for residential roads, whose diameters are estimated to be approximately 60 ft, we subtracted 30 ft from their distances to nearby facilities.

Once the distance was estimated for every facility by road point combination, only road points that were less than or equal to 500 ft away from any given facility were kept (n = 33,064). The 500 ft cut-off was chosen in light of the proposed policy of restricting construction of new building to a minimum of 500 ft from a major roadway, a distance based on established school regulations, and founded on numerous studies modeling spatial dispersion characteristics of $PM_{0.1}$, including studies done in Los Angeles (CARB, 2005; CA SB 352; Hagler et al., 2009; SCAQMD, 2005; Zhu et al., 2002, 2009). The goal in the current analysis is to quantify the number of facilities within this 500-ft radius and exposed to high $PM_{0.1}$ concentrations. We choose to calculate distance between facilities and road points rather than between facilities and intersections or highway exits given that the later may not actually represent the closest road point to a facility. However, given that traffic counts are only provided for intersections and freeway exits, traffic counts for road points within 500 ft of a facility were estimated by matching them with the nearest intersection or freeway exit on the same street and then assigning that traffic count to them. This was done by calculating the Haversine distance between each road point and each intersection or freeway exit which shared either a primary or cross street. Based on these distances, the closest location with measured traffic count was selected and that traffic count was assigned to the road point, assuming they were no more than one mile apart. From this we were able to match 18,048 pairs (measured traffic points and TIGER file road points). Those that were not matched mainly consisted of local neighborhood roads or city streets, which had relatively low levels of use; therefore traffic counts were not measured.

Roads were defined into three categories of traffic density: high (≥100,000 cars per day), moderate (50,000–99,999 cars per day), and low (<50,000 cars per day). The proposed legislation focuses on roads in the high-risk category. High-risk cutoff was determined from previous legislation, which uses 100,000 as definition for a major roadway in urban environments (CARB, 2005; CA SB 352; SCAQMD, 2005). It is important to note that epidemiological evidence points to detrimental physiological effects at lower levels of traffic, however the purpose of the present study is to propose a feasible policy solution, therefore the already utilized standard of 100,000 cars per day was chosen (Garshick et al., 2003; Rosenbloom et al., 2012).

3. Results

Of the 858 elder care facilities we identified in the Los Angeles County area (Fig. 1), nearly half (n = 392) were located within 500 ft of at least one road or freeway for which we had measured traffic counts (Table 1). The 392 facilities included 187 skilled nursing facilities (SNF), 131 assisted living facilities (ALF), and 74 adult day health care centers (ADHC). The majority of the SNF were relatively large facilities, having on average 187 (s.d. = 98.6) beds each—with 65 of the 187 facilities housing over 100 beds apiece. The ALF had approximately 108 beds on average—and over half (n = 70) of the 131 facilities had 100 or more beds. Finally, capacities for the ADHC averaged about 60, with only 10 of the 74 facilities reaching capacities of 100 residents or more. Just over 150 of the facilities were located in the city of Los Angeles, with the next most represented cities being Long Beach and Van Nuys, which both housed around 4% (n = 16 and n = 15, respectively) of the 392 facilities.

Overall, there were 1013 roads or freeways within very close proximity (500 ft or less) of one of the 392 elder care facility. On average the traffic counts for these roads were approximately 43,000 cars per day, with some roads reaching average traffic counts of over 500,000 cars per day. Approximately 5% of the roads in our analytic sample were major freeways, 16% were Secondary Highway Class II, and 79% were residential roads. On average, these roads were 332 ft from at least one facility. Overall, highways had the closest proximity to facilities (μ = 318 ft, s.d. = 126), followed by residential roads (μ = 330 ft, s.d. = 120), and finally freeways (μ = 398 ft, s.d. = 86). When definitions of high risk (traffic ≥100,000 cars per day) and moderate risk (traffic 50,000–99,999 cars per day) were considered, we found that 54 of the 392 facilities were located within high pollution concentration areas—less than 500 ft from a high risk roadway (Fig. 2), whereas 51 facilities were located in close proximity to roads with moderate risk traffic counts. The facilities located in these dangerous areas also tended to be significantly larger (p = .008) than those not located in high pollution areas. On average the facilities in close proximity to busy roadways had 115 beds, whereas those in lower pollution locations only had 92 beds, on average.

Table 1
Descriptive statistics of all the facilities mapped in the study. Descriptive characteristics for facilities (n = 392) within 500 ft of a major road or freeway with measured traffic.

Characteristic	Statistic
Facility type (*N*)	
ADHC	74
ALF	131
SNF	187
Capacity, mean (SD)	94.82 (58.95)
Distance from major road/freeway, mean feet (SD)	332.32 (120.69)
Traffic count for major road/freeway, mean (SD)	43,459.2 (102, 127.5)
Road type for major road/freeway (N)	
Primary road (interstate)	5.0%
Secondary road (major/US highway)	16.1%
Local road (residential road)	78.87%

ADHC, adult day health care; ALF, assisted living facility; SNF, skilled nursing facility.

Breakdown of facility type and size of the 54 facilities with 500 ft of a high traffic roadway are given in Table 2. Of the 54 facilities, 24 were SNF's, 26 ALF's, and 4 ADHC's, with an average capacity of 106, 133, and 49, respectively. There were 51 facilities located within 500 ft of a moderate risk roadway. Of these 51 facilities, 18 were SNF's, 19 ALF's, and 14 ADHC's, with an average capacity of 97, 125, and 65, respectively. In total the facilities next to high risk roadways had a maximum capacity of 6198, while the facilities located next to a moderate risk roadway could house up to 5031 individuals.

A few facilities were located next to multiple major roads, exacerbating pollution exposure (Table 3). Nine of the facilities were within 500 ft of two high risk roads (traffic ≥100,000 cars per day), while three facilities were within 500 ft of one moderate and

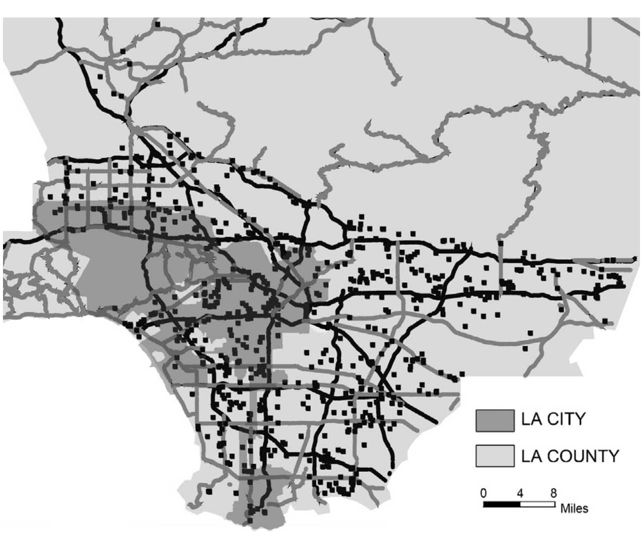

Fig. 1. Older adult care facilities in Los Angeles county. A descriptive map of major roadways in Los Angeles combined with older adult care facilities. Gray lines denote primary roads/highways, black lines are interstate freeways, and black squares are older adult facilities.

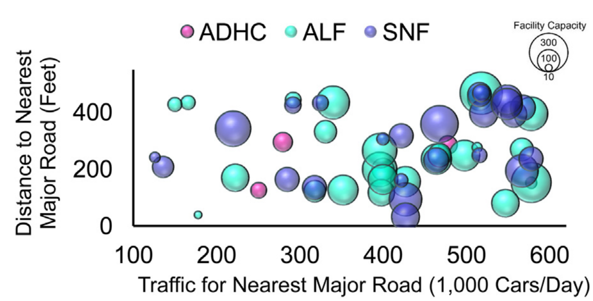

Fig. 2. High risk facilities in Los Angeles county. A plot of older adult facilities, measuring distance to a major roadway on the y-axis and average traffic count per day on the x-axis. The size of the circle indicates size of the facility, and color indicates type.

Table 2
Number and capacity of facilities next to major roadways.

Facility type	Number next to high risk road (capacity)	Number next to moderate risk road (capacity)
Skilled nursing facility	24 (106)	18 (97)
Assisted living facility	26 (133)	19 (125)
Adult day health care center	4 (49)	14 (65)
Total individuals	6198	5031

Depicts the number and average capacity (given in parenthesis) of facilities located next to high risk and moderate risk roadways. Total given is the maximum number of people housed at one time in these 54 high risk, and 51 moderate risk facilities.

two high risk traffic count roads. Additionally, one facility sat between two moderate and one high risk road; three facilities sat between one moderate and one high risk road, and 38 were located next to a single high risk road.

4. Discussion

The large body of evidence illustrating the harm of particulate matter inhalation makes a clear argument for reducing exposure, but what exactly is a safe distance away from sources of air pollution? In order to understand what is a safe distance away from emission sources it is necessary to look at both epidemiological evidence of near roadway exposure, and the spatial dispersion characteristics of the components of air pollution.

There is a clear increase of mortality for older adults when residing near a major roadway. A Dutch study on individuals, aged 55–69, recorded a relative risk of 1.41 for all-cause mortality when living within 100 m (330 ft) of a freeway, or 50 m (165 ft) of a major urban roadway (Hoek et al., 2002). Older adults have higher levels of mortality from pollution exposure, versus middle-aged individuals (Katsouyanni et al., 2001). Another study, monitoring individuals in Ontario, Canada, with a median age of 63 observed a relative risk of 1.18 for mortality when living near a major roadway (Finkelstein et al., 2004). These findings have been corroborated in the Nurses' Health Study, which found women residing near a major roadway to have a relative risk of 1.11 for myocardial infarction, and 1.05 for all-cause mortality (Hart et al., 2013). Aside from the immediate risks of myocardial infarction, being in a high pollution environment at the time of a myocardial infarction increases 10-year mortality rates as well (Rosenbloom et al., 2012). Though the evidence for mortality from air pollution exposure is strong, there is need in the field for more studies focusing specifically on older adults. In the current study, the 54 facilities located close to major roadways housed approximately 6000 individuals. Considering the minimal distance needed to drastically reduce pollution concentration and lower mortality risk, this level of exposure is truly unnecessary.

Table 3
The number of facilities with combinations of high and moderate risk roads.

	Number of high risk roads			Total
	0	1	2	
Number of moderate risk roads				
0	294	38	9	341
1	42	3	3	48
2	2	1	0	3
Total	338	42	12	392

Understanding the spatial dispersion characteristics of the relevant components of air pollution is also critical in determining appropriate safe distances, and in creating informed policy solutions. There are three classes of particulate matter: PM_{10}, $PM_{2.5}$, and $PM_{0.1}$, known as coarse, fine and ultrafine particulate matter, respectively. Coarse particulate matter (PM_{10}) is any particle between 2.5 and 10 μm, whereas fine particulate matter ($PM_{2.5}$) are particles with a diameter between 2.5 and 0.1 μm, and $PM_{0.1}$ is any particle with a diameter less than 0.1 μm (1×10^{-6} m). For comparison human hair is around 70 μm in diameter—seven hundred times larger than the largest $PM_{0.1}$. $PM_{2.5}$ has been the most widely measured and recorded, however $PM_{0.1}$, with particles ranging from a couple nanometers to 100 nm, is increasingly recognized as being especially harmful (Schulz et al., 2005; Utell and Frampton, 2000; Weichenthal, 2012). Due to their small size, this component of particulate pollution has gone relatively unnoticed, however their small size also makes this component of air pollution especially dangerous, as it is able to bypass physiological barriers (Schulz et al., 2005; Utell and Frampton, 2000; Weichenthal, 2012). Polystyrene beads, a model nanoparticle, can rapidly cross the human placenta *ex* vivo, and titanium dioxide nanoparticles (25–70 nm diameter) subcutaneously delivered to pregnant mice was observed in male offspring brains, crossing both the placenta of the mother and blood brain barrier of offspring (Takeda et al., 2009; Wick et al., 2010). The small size of nanoparticles is especially relevant to inhalation, as particles <34 nm in diameter can rapidly translocate from the lung to the mediastinal lymph node (Choi et al., 2010). It is this small size class, $PM_{0.1}$, which is of special importance when considering near roadway pollution. The dispersion of $PM_{0.1}$ into background concentrations has been well studied, providing valuable information on areas of high exposure, and necessary distances for safe levels of exposure (Hagler et al., 2009; Roorda-Knape et al., 1998; Zhou and Levy, 2007; Zhu et al., 2002, 2009).

Although adverse health effects of air pollution exposure diminish the farther an individual is from a major roadway (Hoek et al., 2002; Gauderman et al., 2007; Peters et al., 2004), distribution patterns show that neither $PM_{2.5}$ nor PM_{10} decreases substantially in that distance (Roorda-Knape et al., 1998; Zhou and Levy, 2007). Meanwhile, $PM_{0.1}$ quickly returns to background levels, with pollution concentration closely resembling observed health risks (Hoek et al., 2002; Zhou and Levy, 2007; Zhu et al., 2002). Concentrations of $PM_{0.1}$ show a 25-fold increase at 100 ft (30 m) from a freeway compared to ambient levels within the city (Zhu et al., 2002). The dilution of $PM_{0.1}$ from the source into background ambient levels occurs in an exponential decline with levels returning to background at 1000 ft away from the source (Hagler et al., 2009; Zhu et al., 2002, 2009). A distance of 500 ft would reduce concentration by approximately 80%, with diminishing returns after 500 ft (Hagler et al., 2009; Zhu et al., 2002, 2009). Zhu et al. (2002) is of importance for the current study, as it measured $PM_{0.1}$ drop-off from Los Angeles freeways. These results are consistent with sampling from three locations in Austin, Texas, and with sampling in Raleigh, North Carolina, demonstrating that the concentration drop-off rates can be confidently generalized to different locations (Hagler et al., 2009; Zhu et al., 2009). Therefore 500 ft, which is the end of the exponential decline for $PM_{0.1}$ concentration, is recommended for proposed guidelines, as it balances functionality and safety by minimizing $PM_{0.1}$ exposure as much as possible and reducing adverse physiological outcomes, without creating overly restrictive regulations (Finkelstein et al., 2004; Rosenbloom et al., 2012). The spatial dispersion characteristics of different classes of PM highlight the importance of a more precise analysis of pollution exposure within a city.

4.1. Policy responses to protect older adults from air pollution

The National Ambient Air Qualities Standards (NAAQS) has developed special rules for air pollution exposure of certain vulnerable segments of the population. This special attention is based upon observations that sensitivity to particulate matter can be much higher in vulnerable populations compared to healthy individuals. The NAAQS has developed non-binding recommendations for reducing exposure to pollution among these groups. For example the EPA drafted national guidelines dictating steps that should be undertaken in the "school sitting process" (EPA, 2007). The guide offers recommendations for accurately measuring air quality in a new location, deciphering the sources of the pollution, and choosing an appropriate site, all in an effort to reduce pollution exposure to children. Although currently there are no national requirements, several states have taken steps to reduce pollution exposure for children. California, Indiana, and New Mexico all have minimum safe distance requirements, and many other states have recommendations for placing schools away from busy roadways. One example, California Senate Bill 352 (Chapter 668, statutes of 2003, effective January 2004) outlines regulations against school sitting within 500 ft (150 m) of a heavily traffic roadway, as defined by 50,000 cars per day in rural areas, and 100,000 cars per day in urban environments. This policy is based on studies showing a 70% drop-off of particulate matter with a distance of 500 ft from a freeway (SCAQMD, 2005). The California Air Resource Board's (CARB) *Air quality and land use handbook* also recommends 500 ft as a minimum distance from busy roadways, and California's Office of Environmental Health Hazard Assessment (OEHHA) defines close proximity as within 500 ft of a major roadway (SCAQMD, 2005). School sitting laws offer a valuable template to reduce pollution exposure by enacting regulations that ensure the safe placement of facilities for older adults. Based on available epidemiological data, we recommend that these regulations (California State Senate Bill 352, minimum school distance 500 ft from roadway) be extended to include older adult facilities (Hoek et al., 2002; Finkelstein et al., 2004; Hart et al., 2013). Specifically, a distance of 500 ft from the roadway is recommended as the mandatory minimum, as it reduces ultrafine particulate matter ($PM_{0.1}$) concentration by 70–80% (Hagler et al., 2009; SCAQMD, 2005; Zhu et al., 2002, 2009). Currently in Los Angeles County alone there are approximately 6000 individuals unnecessarily being exposed to these dangerous levels of pollution, and the proposed policy offers a simple and affordable method to attenuate this significant risk.

While enforced regulation offers one remedy, intermediate steps should also be considered. Currently, public awareness of the effects of pollution exposure, and especially its variance within a city, is minimal. Through educating the public, consumer demand for safer, less polluted sites, could drive supply. Rating elder care facilities based on air quality, either relative to city average or on an absolute scale, would provide the public with an opportunity to make an educated decision. The rating system could be modeled after the Department of Health's ratings of A, B, and C for restaurant sanitation standards. Facilities could be given a score based on the traffic count of the largest roadway within 500 ft of the facility. The score could be in increments of 25,000, with three categories. These categories would be: 50,000 cars per day and below being low risk, 50,000–100,000 being moderate risk, and over 100,000 cars per day being high risk. This alternative to a mandatory requirement would be an extremely low cost and readily available solution. Indeed the data generated here is sufficient to rank all the facilities within Los Angeles County. This method could rely upon consumer demand to drive lower pollution exposure to future facilities. Combining the two proposed policy solutions would create a mix of enforced legislation at the higher end, and consumer demand at the lower end to drive reductions in pollution exposure.

5. Limitations

The patterns of spatial distribution of air pollution are not as clear-cut in very dense urban areas. In a study modeling spatial distribution of air pollution in Brooklyn, New York, $PM_{0.1}$ showed only a 15–20% decrease in concentration after the first 330 ft (100 m) from the roadway (Zwack et al., 2011). This study illustrates a primary problem for dense urban areas, where there is such a plethora of pollution coming from multiple sources that there may be no "safe" distance. Thus, while locating facilities a "safe" distance away from a major pollution source (approximately 500 ft) may reduce negative health outcomes, the effects will not be as beneficial in very densely packed urban areas compared to smaller or more diffuse cities.

Also, the proposed policy does not take into account the possibility of multiple heavily trafficked roadways being located within close proximity of the facility, such as being located on a busy street corner. This would create especially high pollution conditions. The decision for the single roadway perspective was made in light of ease of implementation of the proposed policy. It is believed that the relative advantage gained by multiple roadway analysis would be relatively few, however the cost of added complexity for such a policy to be implemented would be much greater. Analysis of the current dataset showed only a small subset fell within this category of being located within 500 ft of two moderately high traffic roads.

The present analysis provides only an estimate of individuals that are exposed to high levels of air pollution. The estimate of risk is based on documentation of spatial dispersion patterns of components of air pollution, and we believe is sufficient evidence toward establishing guidelines for the placement of older adult care facilities (Hoek et al., 2002; Zhu et al., 2002). While it is clear that such pollution exposure increases mortality risk, the limitation of this paper is that it cannot adequately estimate excess mortality, and more epidemiological studies focusing specifically on older adult populations are needed for the field to confidently generate predictions of excess mortality. We calculate this estimate based on the maximum occupancy of SNF, ALF, and ADHC. These facilities, while often quite full, are not always at maximum capacity. For example, SNF's have an average occupancy rate of 87% in California (OSHPD, 2013). However, these facilities also experience significant turnover, increasing the number of individuals that will be housed in a high-risk facility over the course of a year.

One additional factor related to placement is the assumption that being indoors will reduce exposure. However, residing indoors does not confer protection from $PM_{0.1}$ generated outdoors, because of its small size. The concentration of $PM_{0.1}$ indoors is similar to outdoor measurements; meaning that older individuals indoors are still at risk for pollution exposure (Arhami et al., 2010). In fact, outdoor derived particulate matter has been shown to be one of the most harmful components of indoor air pollution (Delfino et al., 2008). The best ways to reduce pollution exposure are still at the source, or by creating distance away from the source. This highlights the importance of continuing to develop reduced emission vehicles.

6. Conclusion

Air pollution is a ubiquitous environmental toxin that has been documented to have numerous adverse health effects on all members of the population. However, this burden of risk is shared unequally across the population, with children and older individuals more prone to adverse health effects than young and middle aged adults. In some areas, this problem has begun to be addressed in children, with state legislatures enforcing a mandatory 500 ft away from a major roadway. In light of the available scientific evidence, we propose that the same regulations be considered for facilities and community services for older adults, including services such as skilled nursing facilities, assisted living facilities, and adult day health care centers. Regulations ensuring that these facilities are required to be a safe distance from the highest levels of air pollution offer a low cost preventative approach to reduce morbidity and mortality associated with pollution exposure in older individuals.

Funding

National Institute on Aging (Number: T32AG0037).

Acknowledgements

We would like to thank the generous guidance and support of Dr. Kate Wilber and Dr. Marti DeLiema.

References

Adar, S., Gold, D., Coull, B., Schwartz, J., Stone, P., Suh, H., 2007. Focused exposures to airborne traffic particles and heart rate variability in the elderly. Epidemiology 18, 95–103.
Adar, S.D., Sheppard, L., Vedal, S., Polak, J.F., Sampson, P.D., 2013. Fine particulate air pollution and the progression of carotid intima-medial thickness: a prospective cohort study from the multi-ethnic study of atherosclerosis and air pollution. PLOS Med. 10, e1001430.
Arhami, M., Minguillón, M.C., Polidori, A., Schauer, J.J., Delfino, R.J., Sioutas, C., 2010. Organic compound characterization and source apportionment of indoor and outdoor quasi-ultrafine particulate matter in retirement homes of the Los Angeles Basin. Indoor Air 20, 17–30.
Berglind, N., Bellander, T., Forastiere, F., von Klot, S., Aalto, P., Elosua, R., . . .Study HEAPSS Group, 2009. Ambient air pollution and daily mortality among survivors of myocardial infarction. Epidemiology 20 (1), 110–118.
Bernhard, S., 2013. GEOCODE3: Stata Module to Retrieve Coordinates or Addresses from Google Geocoding API Version 3, Statistical Software Components S457650. Boston College Department of Economics.
Brook, R.D., Franklin, B., Cascio, W., Hong, Y., Howard, G., Lipsett, M., Smith, S.C., 2004. Air pollution and cardiovascular disease: a statement for healthcare professionals from the expert panel on population and prevention science of the American Heart Association. Circulation 109, 2655–2671.
Caiazzo, F., Ashok, A., Waitz, I., Yim, S., Barrett, S., 2013. Air pollution and early deaths in the United States. Part I: Quantifying the impact of major sectors in 2005. Atmos. Environ. 79, 198–208.
California Air Resource Board, 2005. Air Quality and Land Use Handbook: A Community Health Perspective. CA EPA.
California Senate Bill No. 352, 2003, October 3. Retrieved November 9, 2015, from: http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=200320040SB352.
Center for Disease Control, 2010. Summary Health Statistics for U.S. Adults: National Health Interview Survey, Series 10, Number 252.
Chen, H., Goldberg, M.S., Burnett, R.T., Jerrett, M., Wheeler, A.J., Villeneuve, P.J., 2013. Long-term exposure to traffic-related air pollution and cardiovascular mortality. Epidemiology 24, 35–43.
Choi, H.S., Ashitate, Y., Lee, J.H., Kim, S.H., Matsui, A., Insin, N., . . .Tsuda, A., 2010. Rapid translocation of nanoparticles from the lung airspaces to the body. Nat. Biotechnol. 28 (12), 1300–1303.
Delfino, R., Staimer, N., Tjoa, T., Polidori, A., Arhami, M., Gillen, D., . . .Sioutas, C., 2008. Circulating biomarkers of inflammation, antioxidant activity, and platelet activation are associated with primary combustion aerosols in subjects with coronary artery disease. Environ. Health Perspect. 116, 898–906.
Environmental Protection Agency, 2007. Clean air fine particle implementation. Federal Register 72–79.
Finkelstein, M., Jerrett, M., Sears, M., 2004. Traffic air pollution and mortality rate advancement periods. Am. J. Epidemiol. 160, 173–177.
Garshick, E., Laden, F., Hart, J.E., Caron, A., 2003. Residence near a major road and respiratory symptoms in U.S. veterans. Epidemiology (Cambridge, MA) 14 (6), 728–736, http://dx.doi.org/10.1097/01.ede.0000082045.50073.66.
Gauderman, W.J., Vora, H., McConnell, R., Berhane, K., Gilliland, F., Thomas, D., Lurmann, F., Avol, E., Kunzil, N., Jerrett, M., Peters, J., 2007. Effect of exposure to traffic on lung development from 10 to 18 years of age: a cohort study. Lancet 369, 571–617.
Goldberg, M.S., Burnett, R.T., Bailar 3rd, J.C., Tamblyn, R., Ernst, P., Flegel, K., . . .Vincent, R., 2001. Identification of persons with cardiorespiratory conditions who are at risk of dying from the acute effects of ambient air particles. Environ. Health Perspect. 109 (Suppl. 4), 487.
Hagler, G.S.W., Baldauf, R.W., Thoma, E.D., Long, T.R., Snow, R.F., Kinsey, J.S., . . .Gullett, B.K., 2009. Ultrafine particles near a major roadway in Raleigh, North Carolina: downwind attenuation and correlation with traffic-related pollutants. Atmos. Environ. 43 (6), 1229–1234.
Hart, J., Rimm, E., Rexrode, K., Laden, F., 2013. Changes in traffic exposure and the risk of incident myocardial infarction and all-cause mortality. Epidemiology 24, 734–742.
Hoek, G., Brunekreef, B., Goldbohm, S., Fischer, P., van den Brandt, P.A., 2002. Association between mortality and indicators of traffic-related air pollution in the Netherlands: a cohort study. Lancet 360, 1203–1209.
Jerrett, M., Burnett, R., Ma, R., Pope, C., Krewski, D., Newbold, K., Thun, M., 2005. Spatial analysis of air pollution and mortality in Los Angeles. Epidemiology 16, 727–736.
Katsouyanni, K., Touloumi, G., Samoli, E., Gryparis, A., Tertre, A., Monopolis, Y., Schwartz, J., 2001. Confounding and effect modification in the short-term effects of ambient particles on total mortality: results from 29 European cities within the APHEA2 project. Epidemiology 12, 521–531.
Miller, K., Siscovick, D., Sheppard, L., Shepherd, K., Sullivan, J., Anderson, G., Kaufman, J., 2007. Long-term exposure to air pollution and incidence of cardiovascular events in women. N. Engl. J. Med. 356, 447–458.
Morgenstern, V., Zutavern, A., Cyrys, J., Brockow, I., Koletzko, S., Krämer, U., Group, L., 2008. Atopic diseases, allergic sensitization, and exposure to traffic-related air pollution in children. Am. J. Respir. Crit. Care Med. 177, 1331–1337.
Nichols, A., 2003. VINCENTY: Stata module to calculate distances on the Earth's surface, Statistical Software Components. S456815. Boston College Department of Economics (revised 16 Feb 2007).
Office of Statewide Health Planning and Development, 2013. Long-term Care Facility Annual Utilization Data, In: www.oshpd.ca.gov.
Perera, F., Rauh, V., Whyatt, R., Tsai, W.-Y., Tang, D., Diaz, D., Kinney, P., 2006. Effect of prenatal exposure to airborne polycyclic aromatic hydrocarbons on neurodevelopment in the first 3 years of life among inner-city children. Environ. Health Perspect. 114, 1287–1292.
Peters, A., von Klot, S., Heier, M., Trentinaglia, I., Hörmann, A., Wichmann, H.E., Löwel, H., 2004. Exposure to traffic and the onset of myocardial infarction. N. Engl. J. Med. 351, 1721–1730.
Peters, A., 2012. Epidemiology: air pollution and mortality from diabetes mellitus. Nat. Rev. Endocrinol. 8, 706–707.
Pope, C., Burnett, R., Thun, M., Calle, E., Krewski, D., Ito, K., Thurston, G., 2002. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. JAMA 287, 1132–1141.
Roorda-Knape, M.C., Janssen, N.A., De Hartog, J.J., Van Vliet, P.H., Harssema, H., Brunekreef, B., 1998. Air pollution from traffic in city districts near major motorways. Atmos. Environ. 32 (11), 1921–1930.
Rosenbloom, J., Wilker, E., Mukamal, K., Schwartz, J., Mittleman, M., 2012. Residential proximity to major roadway and 10-year all-cause mortality after myocardial infarction. Circulation 125, 2197–2203.
Ruckerl, R., Ibald-Mulli, A., Koenig, W., 2006. Air pollution and markers of inflammation and coagulation in patients with coronary heart disease. Am. J. Respir. Crit. Care Med. 173, 432–441.
Schulz, H., Harder, V., Ibald-Mulli, A., Khandoga, A., Koenig, W., Krombach, F., Radykewicz, R., Stampfl, A., Thorand, B., Peters, A., 2005. Cardiovascular effects of fine and ultrafine particles. J. Aerosol Med. 18, 1–22.
South Coast Air Quality Management District, 2005. Air Quality Issues in School Site Selection. Guidance Document.
Takeda, K., Suzuki, K.I., Ishihara, A., Kubo-Irie, M., Fujimoto, R., Tabata, M., . . .Sugamata, M., 2009. Nanoparticles transferred from pregnant mice to their offspring can damage the genital and cranial nerve systems. J. Health Sci. 55 (1), 95–102.
Utell, M.J., Frampton, M.W., 2000. Acute health effects of ambient air pollution: the ultrafine particle hypothesis. J. Aerosol Med. 13, 355–359.
Weichenthal, S., 2012. Selected physiological effects of ultrafine particles in acute cardiovascular morbidity. Environ. Res. 115, 26–36.
Wick, P., Malek, A., Manser, P., Meili, D., Maeder-Althaus, X., Diener, L., . . .von Mandach, U., 2010. Barrier capacity of human placenta for nanosized materials. Environ. Health Perspect. 118 (3), 432.
Zhou, Y., Levy, J.I., 2007. Factors influencing the spatial extent of mobile source air pollution impacts: a meta-analysis. BMC Public Health 7, 89.
Zhu, Y., Hinds, W., Kim, S., Sioutas, C., 2002. Concentration and size distribution of ultrafine particles near a major highway. J. Air Waste Manag. Assoc. 52, 1032–1042.
Zhu, Y., Pudota, J., Collins, D., Allen, D., Clements, A., DenBleyker, A., Fraser, M., Jia, Y., McDonald-Buller, E., Michel, E., 2009. Air pollutant concentrations near three Texas roadways. Part I: Ultrafine particles. Atmos. Environ. 43, 4513–4522.
Zwack, L., Paciorek, C., Spengler, J., Levy, J., 2011. Modeling spatial patterns of traffic-related air pollutants in complex urban terrain. Environ. Health Perspect. 119, 852–859.

Nick Woodward is a doctoral student in the Davis School of Gerontology, at the University of Southern California. He works in the laboratory of Caleb Finch, with research focuses on the effect of air pollution on aging, and the cognitive conse-

quences of air pollution exposure during development. He obtained his bachelors of science in biopsychology from the University of California, Santa Barbara, where he studied the effects of drug addiction on memory consolidation in mouse and rat models.

Morgan Levine has a PhD in Gerontology from the University of Southern California, and is currently a Postdoctoral fellow in Neurobehavioral Genetics at the UCLA David Geffen School of Medicine. Her work relies on interdisciplinary approaches that integrate theories and methods from statistical genetics, bioinformatics, demography, and epidemiology, to examine how genes and environments contribute to variations in the pace of aging and longevity. She is particularly focused on exploring the molecular pathways through which social/behavioral and environmental stressors influence morbidity and mortality risk, as well as identifying genes associated with stress resilience.