TORONTO Public Health

HOW LOUD IS TOO LOUD?

Health Impacts of Environmental Noise in Toronto

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Executive Summary

There is increasing concern about the impacts of environmental noise on health, especially in urban areas. The growing body of evidence indicates that exposure to excessive environmental noise does not only impact quality of life and cause hearing loss but also has other health impacts, such as cardiovascular effects, cognitive impacts, sleep disturbance and mental health effects.

Health studies usually report on average noise exposure for a specific period (daytime, nighttime or 24 hrs) and measured as A-weighted decibel levels (dBA). Toronto Public Health (TPH) conducted a noise monitoring study in the early fall of 2016. The average 24-hour equivalent noise levels in Toronto were 62.9 dBA. Average daily levels at individual locations ranged from a low of 50.4 to a high of 78.3 dBA, with mean levels of 64.1 dBA daytime (7:00 a.m. to 11:00 p.m.) and 57.5 dBA nighttime (11:00 p.m. to 7:00 a.m.). Nearly 60 percent of noise in Toronto can be attributed to traffic noise and it is estimated that dissemination areas in the lowest income quintile are almost 11 times more likely to have 50 percent of their residents exposed to night noise levels over 55 dBA, than residents in the highest income quintile. The results of the study show that levels of noise in Toronto are similar to levels found in other large cities such as Montreal and Toronto; as well, similar to other cities there is a disparity between income and exposure to noise.

Non-auditory health impacts of environmental noise were reviewed by the World Health Organization (WHO) in 2009 and 2011. The reports show that cognitive impacts, sleep disturbance mental health and cardiovascular effects could occur at noise levels commonly experienced in urban environments. Toronto Public Health has reviewed the evidence that has accumulated since the WHO evaluation. Newer evidence confirms that health impacts can occur at levels between 42 and 60 dBA outdoors, which is below the 70 dBA benchmark that TPH had previously been considered protective of health. The available evidence suggests that environmental noise in Toronto occurs at levels that could be detrimental to health.

The World Health Organization (2009) established health-protective guidelines of 55 dBA outdoors (Leq 16 hours) for daytime and evening exposures and night-noise exposure guidelines of 40 dBA (outdoors Leq night 8 hours, to keep an indoor average of 30 dBA). Given that 40 dBA is often difficult to achieve in urban centres, the WHO indicated an interim nighttime limit of 55 dBA. The Ontario Ministry of Environment and Climate Change has recommendations for road-related noise thresholds: for sensitive land uses, such as residential uses, mitigation measures are required if outdoor levels at the centre of a window or door opening exceed 55 dBA daytime or 50 dBA nighttime.

Reducing the exposure of environmental noise to residents is multi-pronged and includes periodic assessment of the noise environment through monitoring and modelling, policy interventions (for example, traffic management, building code standards, equipment performance standards, and noise bylaws), and education and engagement of the public. Maintaining a quality outdoor noise environment will contribute to better health and wellbeing. Not only will such an environment promote a more active lifestyle (walking, cycling and active recreation), which can reduce noise levels from transportation, it will also contribute to a reduction in the risk of chronic disease, making Toronto a healthier city for all.

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Glossary

Sound levels are reported in decibels (dB) or A-weighted decibels (dBA) which take into account the human perceptions of loudness atto different frequencies. The loudness of sound (L) may be expressed in different ways:

Leq: The equivalent continuous level, which is the average level of sound over a period of time (for example hour, day, or year)

Leq 24: The equivalent continuous level, which is the average level of sound over a period of 24 Hours

Ldn: the average equivalent sound level over a 24 hour period with a penalty added for noise during the nighttime hours

Lden: the average equivalent sound level over a 24 hour period with a penalty added for noise during the evening and nighttime hours

Lmax: the maximum level of sound that occurs in a period of time

Lnight: average level during the night (usually 8-hours, for example 11pm to 7 am)

Plane of door or of window: the centre of an exterior window or door opening in a building

SEL: the sound exposure level measured over one second

Environmental Noise and Health

Environmental noise is considered to be any unwanted sounds created by human activity (Murphy, King, & Rice, 2009). Environmental noise includes noise from roads, rail and air, as well as construction noise, music systems (amplified sound), neighbours, small machinery and air conditioners. This makes it an important issue for densely populated urban environments. This definition allows for environmental noise to be considered a type of pollution, an element that can be regulated, controlled and mitigated. As is common practice, environmental noise for the purpose of this study refers to noise outdoors. It does not include noise generated indoors such as noise that travels between units in multi-residential buildings.

Noise is a complex issue to measure as it has several important properties including: loudness (intensity, measured in decibels on a logrithmic scale [dB or dBA]), duration (continuous, intermittent, or impulsive), and frequency (pitch). Measurements of loudness are often reported on the A-weighted scale, and can include additional penalties for evening and night levels (see glossary for additional information on noise measurements). In environmental noise and health research the focus tends to be on average noise levels for a specific period (day, night or 24 hrs) and measured in dBA. Since the decibel is a logarithmic unit, a sound received by the ear at 60 dBA is perceived as twice as loud as sound at 50 dBA.

Until recently the impacts of environmental noise were generally deemed a quality of life issue and the main concern was impact on hearing and annoyance. As Figure 1 shows, within an exposed population, the most severe health impacts from noise exposure will be experienced by a relatively small proportion of the population, but a larger number of people will experience feelings of discomfort or stress.

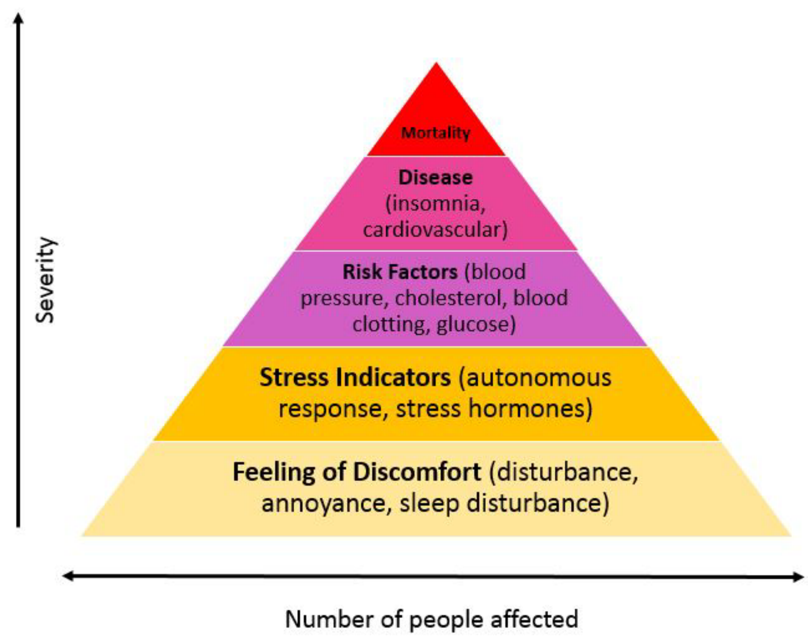


Figure 1: Source: adapted from (Wolfgang Babisch, 2002) as cited in (W Babisch et al., 2010)

Noise is considered a biological stressor and a component of one's physical environment, and this therefore one of the determinants of health (Mikkonen & Raphael, 2010). The experience of noise is based on both noise as heard by the observer and individual sensitivities to noise, with physical and psychological mediators influencing the non-auditory impacts of noise exposure (Murphy & King, 2014). The majority of the available health evidence comes from studies that modelled outdoor noise levels using proximity to roadways, railway tracks or airports to estimate exposure.

Noise-induced Hearing Loss

For a long time, the main health concern related to noise was related to occupational exposure and hearing loss. The World Health Organization (World Health Organization, 2009, 2011) has determined that noise-induced hearing loss is unlikely when average daily exposure to noise is below 70 dBA and impulse sound levels do not exceed 110 dBA. The equivalent 8-hour exposure threshold for hearing loss that includes impulse sounds is 75 dBA(World Health Organization, 1999, 2009, 2011). In Ontario, the Occupational Health and Safety Act protects workers so that no employee is exposed to levels exceeding 85 dBA (8-hour average) (Government of Ontario, 2014). Noise at this level could still result in some hearing loss.

It is important to note that hearing loss or damage is a cumulative impact, as people are exposed to noise throughout their lifetime and hearing damage can build over time. In some cases personal noise exposure is based on choices made, such as ear buds and personal listening devices, operating small equipment without protection or attending concerts and events. While these personal choice exposures were not considered in this review, they can have an impact on health. The WHO considers hearing loss or damage from acute or chronic exposure a health concern as this can affect a person's ability to function in society and result in social isolation. There is now evidence that noise can have other health impacts not related to hearing.

Non-Auditory Health Impacts of Environmental Noise

There has been growing interest in the non-auditory impacts of environmental noise on health. In 2009, the World Health Organization Regional Office for Europe released its Night Noise Guidelines for Europe and in 2011 the Burden of Disease from Environmental Noise. From these comprehensive reviews, the WHO recommended that outdoor noise levels do not exceed an average of 55 dBA during the day and an average of 40 dBA at night.

Toronto Public Health searched the literature published between 2010 and January 2017 to identify any new evidence that had emerged since the WHO review. The health effects that were included were impacts identified in the previous WHO reviews as well as emerging health impacts supported by strong evidence. Diabetes and adverse behavior in children are emerging end-points of concern. Health impacts considered in this review are:

- **Cardiovascular Effects:** myocardial infarction, hypertensive heart disease, ischemic heart disease, high blood pressure, cerebrovascular disease (stroke), coronary heart disease
- **Cognitive Impacts:** impairment (attention, memory adults, errors upon testing in children)

- **Sleep Disturbance:** increased arousals, changes to sleep structure
- **Mental Health:** annoyance, depression, quality of life
- **Pulmonary Effects:** chronic obstructive pulmonary disease, pneumonia
- **Other Effects:** diabetes, behaviour in children

Cardiovascular Effects

Noise exposure has been linked to cardiovascular diseases as vascular tension is impacted by stress responses (Babisch, 2005 in Bodin et al., 2016). These effects have been reported to occur at levels ranging from 55 to 73.6 dBA oudoors.

Myocardial infarction occurs when stress hormones like noradrenaline and cortisol interfere with beta-adrenergic receptors of the circulatory system (Gan, Davies, Koehoorn, & Brauer, 2012). Noise has been associated with an increased risk of mortality from myocardial infarction. Outdoor noise has been linked to increased odds of hypertensive health outcomes as a result of stress which affects individual hormone and blood pressure levels (Sørensen et al., 2011a). A higher arousal of the autonomous nervous and endocrine systems, which is adversely influenced by road traffic noise exposure, is associated with an increased risk of mortality from ischaemic heart disease (World Health Organization, 2011).

Adverse increases in blood pressure from environmental noise are associated with cardiovascular mortality (Chobanian et al., 2003; Ezzati et al., 2002 as cited in Fuks et al., 2011). By influencing factors like atherosclerosis and elevated blood pressure, road traffic noise exposure has been linked to an increased risk of mortality from cerebrovascular disease (stroke) (Sørensen et al., 2014). Exposure to certain noise levels indicate an increase risk in mortality due to impacts on blood pressure, which is a risk factor for the advancement of coronary heart disease, a condition that indicates the blood vessels of the heart are compromised (World Health Organization, 2016).

Recio and colleagues (2016) found a 3.5 percent increase in the risk of death from myocardial infarction and 2.9 percent increase in the risk of death from ischaemic heart disease, and 2.4 percent increase in the mortality rate of cerebrovascular disease for every 1 dBA increase in nighttime noise levels between 58.7 – 76.3 dBA (Lmax night) for people 65 and older. For people younger than 65, there was an 11 percent increased risk of death from myocardial infarction and ischaemic heart disease for every 1 dBA increase in average nighttime noise levels between 56.2 – 69.9 dBA. Similar results were found in other studies with increased risk of mortality from myocardial infarction and ischaemic heart disease (approximately 55-60 dBA during the day, >50dBA at night)(Seidler et al., 2016a; Sørensen et al., 2012).

Seidler and colleages (2016b) reported a statistically significant increase in odds of hypertensive heart disease for every 10dBA increase in noise over 55dBA (Leq 24). Banerjee and colleagues (2014) found similar results of increased odds of hypertension at 60dBA (Lden) for women and 65dBA (Lden) for men. The WHO (2011)found that road traffic noise and air pollution independently impact the prevalence of hypertension. Indoor environmental nighttime noise levels above 30dBA have been associated with increased odds of hypertension and high systolic blood pressure per increase of 5 dBA (Foraster et al., 2014). Sørensen and colleagues (2011a) reported that in people over 64.5 years of age, exposure to every 10 dBA (Lden) increase in residential road traffic noise was associated with a 27 percent higher risk for stroke.

In analysis of road traffic noise, Gan and colleagues (2011) reports an increased relative risk of mortality from coronary heart disease of 13% for every 10 dBA over 58dBA and 29% for every 10dBA increase over 70 dBA when the effect of PM2.5 was taken in to account. Significant correlations for noise were still found when the effect of black carbon was taken in to account with an increased relative risk of mortality from coronary heart disease of 9% for every 10 dBA over 58 dBA and 22% for every 10 dBA increase over 70 dBA when compared to those with noise exposures less than 58 dBA.

Cognitive Impairment

Van Kempen and colleagues (2012) found an association between students exposed to road and air noise pollution at school and the number of errors made during SAT testing. In contrast, another study reported that children had increased information and conceptual recall when exposed to road or aircraft noise at school (Matheson et al., 2010). It was suggested this was due to context-dependent memory, where people recall information better when exposed to a similar environment where it was originally introduced (Matheson et al., 2010).

Cognitive impairment in adults as a result of exposure to noise has only recently been studied. Initial evidence suggests environmental noise, acts as a sensory stimulant and may hinder cognitive abilities including "attention, memory and executive function" (Wright, Peters, Ettinger, Kuipers, & Kumari, 2016b).

Sleep Disturbance

Sleep disturbance due to noise exposure is a common complaint among noise exposed populations (World Health Organization, 2011). Sleep is important to physical and mental health and well-being. Sleep is involved with the healing and repair of the body, and disturbed or deficient sleep has been linked to an increased risk of many chronic diseases. Sleep disturbance has an impact on metabolic and endocrine function and contributes to the risk of cardiovascular disease. Sleep loss is associated with weight gain, risk of diabetes, and susceptibility to viral illness (World Health Organization, 2009). Chum and colleagues (2015), indicated an increased odds of self-reported sleep disturbance in areas with elevated noise and traffic levels. Increased odds of worse quality sleep was found with outdoor daytime aircraft noise between 50-60 dBA and nighttime noise levels between 50-55 dBA (Schreckenberg, Meis, Kahl, Peschel, & Eikmann, 2010).

Mental Health

Annoyance and its link to mental health is an emerging area of research on the impacts associated with exposure to environmental noise. Annoyance to noise results in a multitude of emotional responses including "disturbance, dissatisfaction, displeasure, irritation, nuisance, or anger" ((Van Kempen & Van Kamp, 2005)as cited in Babisch, Schulz, Seiwert, & Conrad, 2012). The condition of annoyance can be conceptualized in one of two ways - as a mediating factor in, or indicator for, biological responses to noise (Evans & Cohen, 1982 as cited in Oiamo, Luginaah, & Baxter, 2015). In general, the extent and impact of annoyance varies among individuals exposed to environmental noise (Murphy & King, 2014).

A recent study looking at self-reported noise exposures found higher odds of high annoyance in populations exposed to moderate truck traffic when compared to those exposed to light truck traffic and similarly when comparing people exposed to constant truck noise to those exposed to no truck noise (Dratva et al., 2012). When looking at residents living in buildings with one quiet façade, De Kluizenaar and colleagues (2011) found that individuals benefited from both decreased noise exposure at the most exposed façade as well as lower levels of annoyance from road traffic noise. In buildings without a quiet façade the odds of annoyance increased as traffic noise increased(De Kluizenaar et al., 2011). In a study by Schlittmeier and colleagues (2015) that individuals reported average outdoor noise levels of 50 dBA Leq (10 sec) were “significantly less annoying” than when average levels were 70 dBA Leq (10 sec). In 2011, the WHO estimated 42 dBA outdoors as the point at which individuals exhibit high levels of annoyance when exposed to road traffic noise.

Increased stress and sleep disturbance have been suggested as the biological pathways by which environmental noise influences depression. Orban and colleagues (2016) found an association between high noise exposure, defined as 55 dBA Lden outdoors and greater than 50 dBA Lnight and an increased risk of self-reported high depressive symptoms.

Quality of life is defined as "an individual's perception of their position in life in the context of culture and value systems in which they live and in relation to their goals, expectations, standards and concerns" (WHO as cited in Shepherd et al., 2010). The World Health Organization Quality of Life (short-form) scale consists of 26 factors divided into four domains: physical health (7 items), psychological wellbeing (6 items), social relationships (3 items), and environmental factors (8 items). Shepherd and colleagues (2013) found higher scores across all dimensions of the Health-Related Quality of Life (HRQL) scale (except for the social dimension) for individuals residing in areas of median 55 dBA Ldn noise levels, compared to those living in “noisy” regions of median 76 dBA Ldn. In 2016, Shepherd and colleagues found noise annoyance more predictive of "pyschological, social and environmental" domain variability on the HRQOL when compared to annoyance from air pollution.

Pulmonary Effects

Chronic obstructive pulmonary disease (COPD) is a term that describes multiple chronic conditions that limit airflow to the lungs (World Health Organization, 2017). Recio and colleagues (2016) found a 4% increase in the risk of death from for every 1 dBA increase with nighttime noise levels ranging from 58.7 to 76.3 dBA (Lmax night) for people 65 and older.

Recio and colleagues (2016) found a 3% increase in the risk of death from pneumonia for every 1 dBA increase with nighttime noise levels from 58.7 – 76.3 dbA (Lmax night) in people 65 and older. The authors suggest that this association is the result of chronic stress from exposure to noise which leads to reduced immunity.

Emerging Health Evidence

There is new but limited evidence for an association between exposure to environmental noise exposure and diabetes and metabolic processes. (Basner et al., 2014; Muenzel et al., 2014 as cited in Tonne et al., 2016). In individuals 65 years and older, exposure to noise at levels ranging from 56.2 to 69.9 dBA Leq night has been associated with a 11 percent increase in relative risk of mortality from diabetes for every one dBA (Recio et al., 2016).

There is some evidence of an association between road traffic noise and increased risk of a higher abnormal total difficulties score, hyperactivity, conduct problems and difficulties with peer relationship in children as based on a standardised Strengths and Difficulties Questionnaire (Hjortebjerg et al., 2016). Another study found an association between increased road traffic noise exposure at school sites and attention deficit hyperactivity disorder symptoms(Forns et al., 2016).

There has been limited focus on low-frequency noise exposure and health impacts in traditional literature (Murphy & King, 2014). Low-frequency noise is generally referring to noise levels from 20-200 Hz, and buildings tend to have difficulty with attenuating these levels (Wise & Leventhall, 2011). There is some evidence that low-frequency noise may contribute to annoyance and sleep disturbance.

Annoyance while known as an impact of environmental noise, it had not been studied much in regard to its relationship with health. Environmental noise is starting to be recognized as an important factor in the health of individuals, particularly as we undergo rapid development and urbanization.

Discussion

Based on the best available health evidence at that time, Toronto Public Health (2000) had concluded that exposure to noise at levels of up to 70 dBA (Leq 24) would not result in any adverse impacts. This review along the WHO 2009 and 2011 reviews indicate that health effects occur at much lower exposure levels (see for example Table 1). Previous evidence found ischaemic heart disease at threshold around 70 dBA, current evidence finds this threshold to start around 58 dBA. Currently, the thresholds for self-reported sleep disturbance is 42 dBA nighttime, where as previously there were around 60 dBA. The more recent evidence reviewed for this report (refer to the Appendix) supports these lower thresholds.

Table 1: Effects of noise on health and wellbeing with sufficient evidence (source: European Environment Agency, 2010)

Effect	Exposure Measure *	Threshold ** (dBA)	Effect type
Annoyance disturbance	L_{den}	42	Chronic
Self-reported sleep disturbance	L_{night}	42	Chronic
Learning, memory	L_{eq}	50	Acute, chronic
Stress hormones	L_{max} L_{eq}	NA	Acute, chronic
Sleep	$L_{max, indoors}$	32	Acute, chronic

Reported awakening	$SEL_{indoors}$	53	Acute
Reported health	L_{den}	50	Chronic
Hypertension	L_{den}	50	Chronic
Ischaemic heart diseases	L_{den}	60	Chronic

Note: * Lden and Lnight are defined as outside exposure levels. Lmax may be either internal or external as indicated.
** Level above which health effects start to occur or start to rise above background. NA – not available.

Policy makers benefit from noise thresholds as they provide standards on which to base limitations on. Some health impacts have been suggested to occur using a no threshold model but evidence for this is limited at the current time. Due to the difference in measurement of the time periods where health effects are seen (day, evening, night), the thresholds are not directly comparable to each other and to guideline levels without conversion.

Noise Levels Recommended for Health

To protect health, the World Health Organization (2009) established night-noise guidelines of 40 dBA (outdoors Leq night 8 hours) to keep an indoor average of 30 dBA. Understanding that 40 dBA is often difficult to achieve in urban centres, they added an interim value of 55 dBA night. Additionally, the WHO recommended daytime levels of 55 dBA (Leq 16 hours). The Ministry of Environment and Climate Change (MOECC) (Government of Ontario, 2013) has recommendations for road related noise thresholds before mitigation measures are required of 55 dBA daytime and 50 dBA nighttime (See Table 2). These levels are applicable to road and stationary sources of noise at the centre of window or door openings for sensitive land uses such as residential properties, hotels, schools, hospitals, and community centres. More information on the MOECC guidelines can be found in the Noise Regulation in Ontario section of this report. The evidence identified in this review supports using the WHO guidelines as maximum noise exposure to protect health.

Table 2 – Outdoor Residential Noise level guidelines from the WHO and MOECC

Measure Detail	**Noise Level (dBA)**		
	Day	**Evening**	**Night**
Noise Duration	12 Hr	4 Hr	8 Hr
Timeframe	7:00-19:00	19:00-23:00	23:00-7:00
Authority			
WHO Target noise guideline	**55**		**40**
	Calculated Maximum Equivalent Ldn: 55.6 Calculated Maximum Equivalent Lden: 56.5 Calculated Maximum Equivalent Leq (24h): 53.3		
MOECC Target noise guideline (1 hr Average)	**55**		**50**
	Calculated Maximum Equivalent Ldn: 58.2 Calculated Maximum Equivalent Lden: 58.7		

	Calculated Maximum Equivalent Leq (24h): 53.9

Noise Levels in Toronto

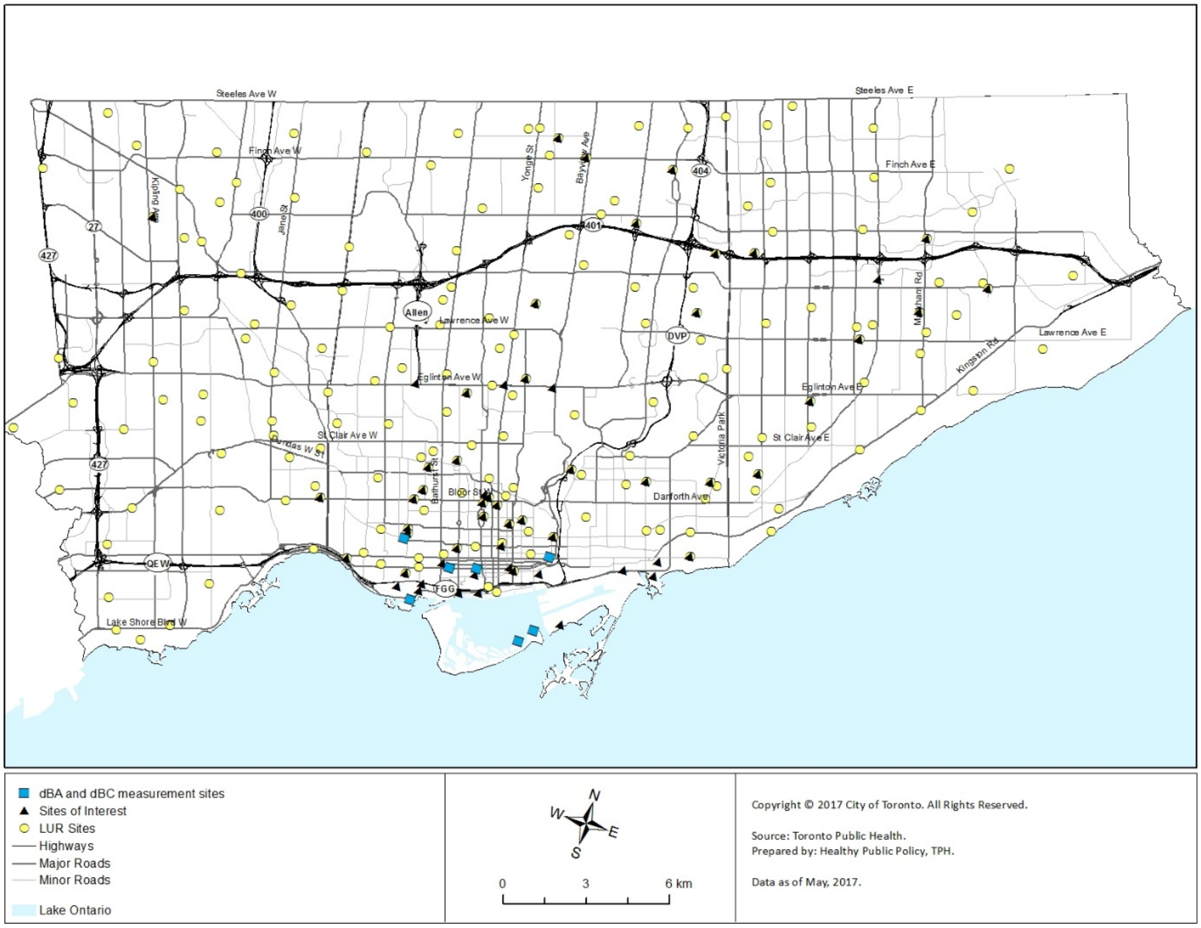
The City of Toronto is currently undergoing a noise bylaw review. To determine if current exposures to noise in Toronto could have a negative impact on health, and inform the revisions to the bylaw Toronto Public Health commissioned a noise monitoring and modelling study, the results of which can be found in Environmental Noise Study in the City of Toronto report (Oiamo, et al., 2017).

Noise Monitoring

Over the period of August to October 2016 a total of 227 noise measurements were made. Noise was monitored using the A-weighted decibel scale at 220 different locations across the City (see Figure 2) for approximately a one week period at each site. Additional measurements were done using the C-weighted scale at seven locations where the noise environment was influenced by sources of amplified sound to provide information on the distribution of lower frequency sounds. The sites were chosen based on a combination of population densities, land uses and sites of interest as determined by the project advisory committee. The project advisory committee suggested locations where events are held, or where residents have expressed concerns about noise or noise levels are expected to be high. The sites were categorised by land use (residential, open space, employment, industrial/commercial, residential), road type (local, collector, major arterial) and sites of interest (schools, long-term care/hospitals, community housing, concert venues, EMS, CNE, BMO field, TTC yards, historic or cultural sites and Toronto island).

The monitoring data was analysed in a number of traditional noise metrics for each site as well as for different categories of sites. Measurements for the full week, weekend and weekdays as well as average measurements for 24 hours (Lden, Leq 24h), day (Leq 16h), night (Leq 8h) and maximum measured 1 second (Lmax). Exceedance levels, values that describe the sound level exceeded in a specified period of time (L1 is 1% of the time, L5 is 5% of the time) were determined for the listed time periods as well. In addition, values were calculated that described the percent of time a noise level was exceeded (for example 95% of the time noise levels at night are above 40dBA).

Figure 2: Noise Monitoring Locations in Toronto (recreated from Oiamo et al., 2017)



Noise Modelling

To better understand the distribution of noise levels and exposure in Toronto, two modelling methods were used; a propagation model, which estimated the percentage of noise from road traffic specifically and a receptor-based land-use regression model that extrapolates the effect of environmental features on observed noise levels. These models were combined to create maps of predicted noise levels for daytime and nighttime across the city.

The modelling results compared the traffic based model to the receptor based land use regression model to determine the areas where the traffic model was over or under predicting noise levels based on the built environment and monitoring results. The study found that the traffic model was over predicting noise levels in areas with high levels of vegetation coverage and was under predicting noise levels in areas where population density was high. The lack of data for rail and air traffic noise means noise emissions from these sources were not modelled in this study. However, the monitoring and modelling process would still take these noise sources in to account but their precise impact on the soundscape could not be inferred. Due to data limitations sound barriers and noise walls could not be included in the modelling process. This led to some of the major roadways noise levels being over estimated in the initial traffic model. These over and under estimations were corrected for in the final modelling process.

It should be noted that land use regression is a math based approach to predicting exposures, and in this case a modelled approach to predicting where the noise from the traffic model was over or under estimated. The predictors for vegetation coverage, population density, distance to airports and railways all logically relate to noise level estimates. The interpretation of how other predictor's effect noise levels is less straight forward. Detailed methods for the modelling methods uses can be found in the report of Oiamo and colleagues (2017).

To estimate population noise exposures, the noise estimates from the final daytime and nighttime surface models were linked to Statistics Canada population estimates. Noise was estimated for the exposed façade of all residential buildings in Toronto and dissemination block level population data were used to estimate the number of residents in each building based on building size. From this, the proportion of residents exposed to daytime and nighttime levels at certain thresholds was estimated. To estimate the impact on vulnerable populations a logistic regression model was used to look at the relationship between income and noise. Household incomes were linked to dissemination areas where nighttime noise levels exceeded 55dBA for at least 50% of the residents.

Results

The monitoring study found the average 24-hour equivalent noise levels across the city to be 62.9 dBA. Average daily levels at each site ranged from a low of 50.4 to a high of 78.3 dBA. Daytime and night time averages can be seen in Table 3. Weekdays were found to be louder than weekends across the city.

The dBC measurements were primarily taken in areas where there was a known source of amplified sound. It was observed that the dBC values did not decrease with the dBA values during the latenight hours but the cause of this is unknown, but could be due to vibration of low frequency amplified sound.

Table 3 – Average dBA levels from noise monitoring. (Source: Oiamo et al., 2017)

	Full Week				Weekday				Weekend			
dBA (n=220)	Lden	Leq24h	LeqD	LeqN	Lden	Leq24h	LeqD	LeqN	Lden	Leq24h	LeqD	LeqN
Mean	66.4	62.9	64.1	57.5	66.7	63.2	64.5	57.6	65.3	61.2	62.4	56.8
Median	65.3	61.9	63.2	56.4	65.4	62.1	63.4	56.1	64.5	60.6	61.9	55.9
Std. Devi	6.9	6.4	6.3	7.8	6.9	6.3	6.2	7.9	7.3	7	7	7.9
Minimum	54	50.4	51.6	42.6	53.9	50.7	52.2	42.2	51.3	47.5	48.4	43.5
Maximum	82.3	78.3	79.5	74.4	82.9	78.9	80.1	74.8	80.8	76.5	77.8	74.1

Note: Lden is the average equivalent sound level over a 24 hour period with a penalty added for noise during the evening and nighttime hours; Leq is The equivalent continuous level, which is the average level of sound over 24 hours; LeqD is The equivalent continuous level, which is the average level of sound over 16 daytime hours; LeqN is The equivalent continuous level, which is the average level of sound over 8 nightime hours;

Observed average noise levels among the sites of interest varied depending on the type of site or land-use. The lowest noise levels were observed in residential areas and along local roads. As expected, the highest levels were observed in mixed-use areas and along major arteries. Sites identified as close to construction activities also exhibited higher average noise compared to the overall average noise levels. Monitoring was completed in late summer early fall, which corresponds to peak construction season. High average noise levels were noted near busy TTC facilities and an EMS station and monitors in proximity to large gatherings of people also indicated high noise exposures at specific periods in time (BMO Field and CNE). The noise bylaw identifies quiet zones, which are defined as hospital, retirement home, nursing home, senior citizens residence, or other similar uses. Monitoring locations in or near ‘quiet zones’ showed similar patterns to overall levels. This might be due to the fact these facilities are generally found along major roads, and may have a larger number of emergency vehicles passing close by.

Overall the study found that 62% of the time the mean noise level was above 55dBA during the day (Leq_{day}) and 54% of the time above 50dBA (Leq_{night}) at night. The modelling indicated that 59% of the noise in Toronto can be attributed to traffic (Leq24). This result is similar to the results of comparable studies in Montreal and Vancouver. Sound levels at the majority of locations that were specifically selected because of concerns about noise did show higher noise levels overall than other sites.

Figure 3, is a map of the final predicted daytime noise levels based on traffic and land use regression modelling combined. The traffic noise dominates the map, there are higher levels in the downtown core and some areas near the highways. Areas of parkland and ravines have the lowest estimated noise levels. Figure 4 is the average predicted night time noise levels, and demonstrates a similar pattern as the daytime results. At night, the roads still dominate and the downtown core is still relatively loud, but the overall noise levels are lower.

Figure 3 - Predicted daytime (Leq16) noise levels in Toronto

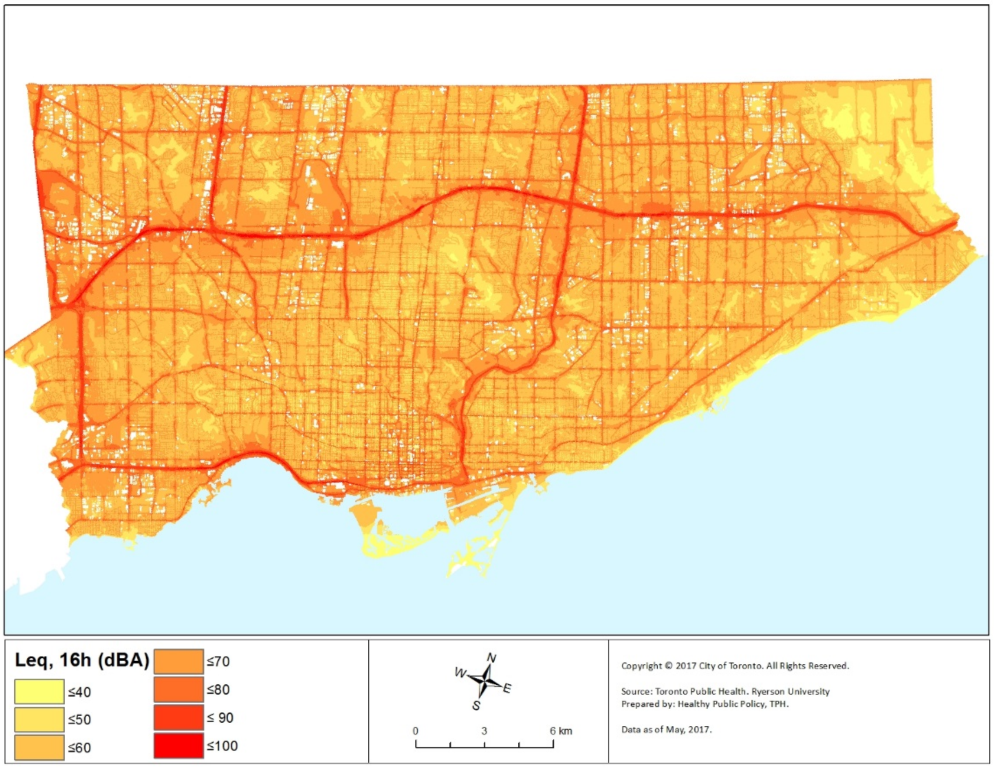
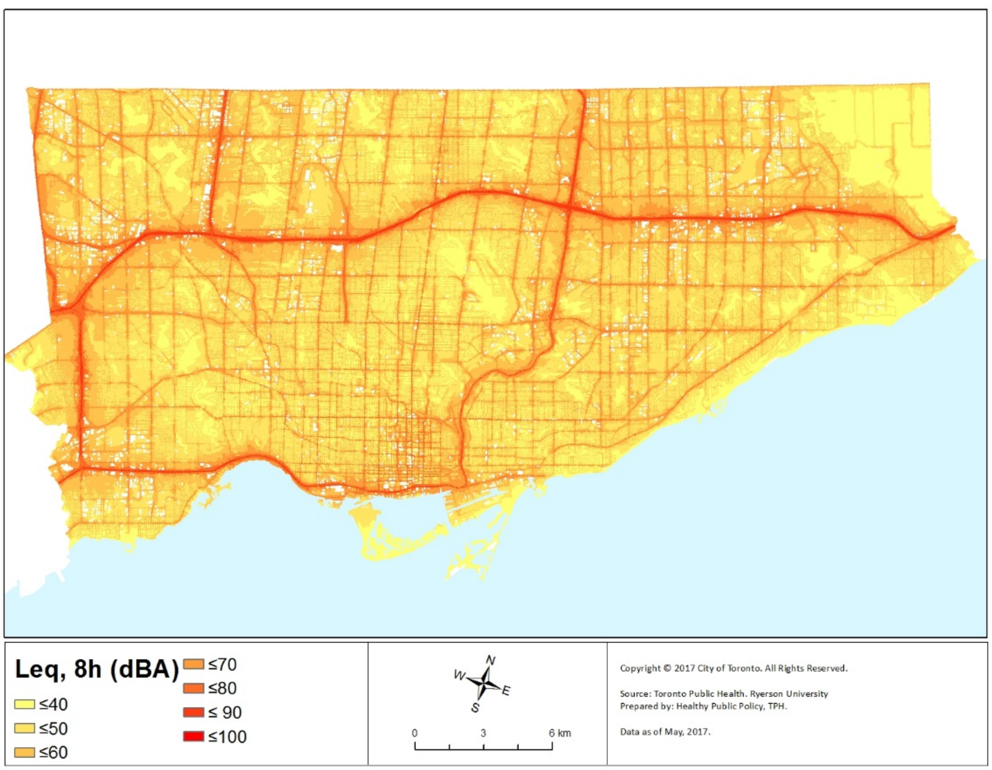


Figure 4 - Predicted nightime (Leq8) noise levels in Toronto



Populations Affected

Table 4, has the percent of the estimated population exposed to certain noise levels at various time periods. For example, 88.7% of the population is estimated to be exposed to levels above 55 dBA during the day, and 43.4% is estimated to be exposed to above this level at night.

Table 4 – Estimated Population Exposed to Noise above selected noise exposure levels

Noise Threshold	**Number of people exposed above the threshold (millions)**	**Percentage of people exposed above the threshold**
LAeq, 24h, 65 dBA	0.85	30.1%
LAeq, 24h, 55 dBA	2.03	72.2%
LAeq16, day, 65 dBA	1.09	38.8%
LAeq16, day, 55 dBA	2.49	88.7%
LAeq8 ,night, 55 dBA	1.22	43.4%
LAeq8, night, 45 dBA	2.60	92.3%

Dissemination areas in the lowest income quintile are nearly 11 times more likely have 50% of their residents exposed to a nighttime noise above 55 dBA than do residents in dissemination areas in the highest income quintile (Table 5). Overall, a large percentage of residents in Toronto are exposed to noise that exceed objectives for outdoor noise, especially nighttime exposure at home. People living near major arterial roads or in areas with mixed commercial and residential uses are also more exposed.

Table 5 – Logistic regression predicting dissemination areas with 50% of residents exposed to nighttime noise levels exceeding 55 dBA. (Source: Oiamo et al., 2017).

	Odds Ratio**	**95% Confidence Interval**
Highest Income Quintile (Reference Category)		
4	1.84	1.38-2.44
3	2.18	1.64-2.89
2	3.76	2.87-4.92
Lowest income Quintile	10.99	8.42-14.36

** significant at $p<0.0001$

Mitigation and Regulation

Noise Regulation in Ontario

Health Canada does not have any exposure guidelines for environmental noise. The 8-hour workplace permissible exposure limit in Ontario is 85 dBA. Some hearing loss can still be expected at this level of exposure.

The Ontario Environmental Noise Guideline, from the Ministry of Environment and Climate Change is applicable to stationary and transportation sources of noise (NPC-300) identifies various limits depending on area, source of noise, time of day, and type of noise. Noise sensitive land uses include residential properties, hotels, schools, hospitals, and community centres.

For example, the MOECC guidelines indicate that for road-related noise, control measures (such as sound proofing and ensuring adequate ventilation so that windows or doors can be kept closed) is not be required if the sound level in the plane of a bedroom or living/dining room window is less than or equal to 55 dBA (daytime) and 50 dBA (night-time). If the sound level in the plane of a bedroom or living/dining room window is greater than 65 dBA (daytime) or 60 dBA (night-time), noise mitigation is required, which may include installation of central air conditioning to maintain adequate ventilation, so that noise levels are kept below an average of 45 dBA in living areas, with a provision of night-time average levels of 40 dBA in sleeping quarters due to road-related noise; the corresponding values for rail-related noise are 40 and 35 dBA.

NPC-300 also includes a graduated scale for impulse noise (short burst of loud noise) depending on number of impulses per hour ranging from 80-50 dBA (impulse, outdoor), with a provision for higher allowable noise levels in Class 4 areas (areas where new sensitive land uses are built next to existing stationary source of noise).

The current City of Toronto noise bylaw sets out specific rules for noise depending on the location and time of day. The bylaw covers a variety of noise sources including amplified sound, construction noise and general noise. The bylaw regulates types of noise not covered in other regulations, and includes provisions for quiet zones and times. Other common sources of noise such as transportation, rail, industrial and workplace noise are regulated through provincial or federal instruments.

Mitigation Best Practice

There are a number of strategies available to help mitigate impacts from environmental noise. Land-use planning is a preferred choice, which includes separating loud land uses from sensitive ones and site design and building layouts that site sleeping areas away from noise sources. In developed urban environments this option is not always available to planners.

Controlling the noise at the source would be the next best choice in mitigation practice. This can include enclosing it, use of silencers or mufflers, and limiting the times of operation. Amplified sound for events such as large scale concerts or outdoor events, noise leakage can be mitigated through specific time limitation, speaker layout and design and other noise insulation strategies, such as soundproofing or using tents.

Creating barriers to reduce the amount of sound that reaches the receiver is also a common approach. This includes noise barriers, setback requirements, and mounds and trenches. Controls on the receiver of the noise generally are related to building design, such as sound insulation, window glazing, and enclosed balcony to buffer noise. Codes may require stronger attenuation requirements for buildings near major noise sources to reduce the intrusion on occupants.

Many jurisdictions have noise level limits for road noise which may vary according to the adjacent land use. Most commonly limits are between 55-70 dBA, for daytime road traffic noise levels near residential land uses. In addition to physical noise barriers, walls and buffers for traffic noise, dynamic traffic management has been suggested as an effective mitigation strategy. This could include traffic restrictions around vulnerable populations (schools, hospitals), reduced nighttime vehicle operations, coordinated traffic signals, and street design that favours non-automobile uses. Higher vehicle speeds results in higher road noise; for example, there is an effective doubling of noise levels from 30km/h to 50km/h (Department of Transportation, 1998). Updates in paving materials can create smoother surfaces and thus result in less road noise.

The way things are built and the materials used can have a large impact on the noise levels being produced from all sources of environmental noise. For example, wheel and tire design and materials can lower noise levels by 2-15 dBA; new paving materials can reduce road noise; and, the electrification of cars, buses, trains and trucks are expected to reduce traffic noise.

Some construction noise levels can be reduced through method and equipment choices, noise barriers and scheduling both time of day and limiting the number of concurrent noise sources. Generally electric versions of small equipment are quieter than their gas powered counterparts. The requirement for noise ratings and labelling can encourage and facilitate the purchase of and use of more quiet equipment.

The European Union noise directive (European Comission, 2002) requires urban areas with population of over 100,000 to assess their noise environment on a regular basis, including the impact road, rail, and airport noise. Municipalities are also required to develop noise management action plans in consultation with the public. These plans cover the exposure to environmental noise, prevention and reduction strategies and preserving environmental noise quality where levels are good[1]. A review of this requirement has found this practice effective as it has brought attention to the importance of noise as a public health risk (European Commission, 2016).

[1] For a Step by step approach for developing noise Action Plans, see Kloth, M and colleagues (2008) http://www.noiseineu.eu/fr/3527-a/homeindex/file?objectid=3161&objecttypeid=0

Conclusions

The health impacts associated with environmental noise are both acute and chronic in nature. In addition to noise-induced hearing loss, there is growing body of evidence that shows an association between environmental noise and health impacts including cardiovascular disease cognitive impairment in adults and children, sleep disturbance and mental health impacts. Emerging evidence suggests that exposure to environmental noise could lead to adverse pulmonary effects increased mortality from diabetes, and negative impact on behaviour in children.

The health evidence suggests that older adults and young children may be more at risk. Furthermore, in Toronto lower income populations who are already experience poorer health are also more likely exposed to more noise than people with higher income.

Results of the noise monitoring and modelling study indicate that noise levels in Toronto are above the World Health Organization's limits for both daytime and nighttime exposure, and thus likely to contribute to the burden of illness in the city. Given the ubiquitous nature of this exposure a comprehensive approach to noise management in the city will be required to effectively limit unnecessary exposure to noise and ensure that noise exposures do not increase over time.

Approaches that can be used to reduce exposure to noise include choosing technologies that are quieter, setting planning requirements, adopting improved building codes, implementing traffic management measures, and prescribing limits and noise mitigation measures in the noise bylaw.

Given that almost 60% of the noise in Toronto can be attributed to traffic noise, implementing measures to reduce exposure to noise from transportation sources should be a priority. Maintaining a quality outdoor noise environment will contribute to better health and wellbeing. Not only will such an environment promote it a more active lifestyle (walking, cycling and active recreation), which can reduce noise levels from transportation, it will also contribute to a reduction in the risk of chronic disease, making Toronto a healthier city for all.

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Appendix: Health Impacts of Environmental Noise Exposure: Literature Review Evidence Summary Table

Reference	Noise Source	Adjustment for Air Pollution	Noise Detail	Threshold, or Mean and Range measured, or Lowest effect level (as available)	Findings
Cardiovascular mortality (overall)					
Recio et al., 2016	All	Yes	Leq night (0-8h)	Mean (SD) = 60.2 (1.0) Range = 56.2 – 69.9 dB(A)	RR = 1.033 (95% CI: 1.017, 1.049) per 1 dB(A) increase in Leqn at lag 0, ≥ 65 age
					RR = 1.050 (95% CI: 1.004, 1.098) per 1 dB(A) increase in Leqn at lag 0, < 65 years of age
Myocardial infarction morbidity or mortality					
Recio et al., 2016	All	Yes	Lmax night (0-8h)	Mean (SD) = 63.9 (1.7) Range = 58.7 - 76.3 dB(A)	RR = 1.035 (95% CI: 1.011,1.061) (mortality rate of myocardial infarction) per 1 dB(A) increase in Lnmax at lag 0, ≥ 65 age
			Leq night (0-8h)	Mean (SD) = 60.2 (1.0) Range = 56.2 – 69.9 dB(A)	RR = 1.11 (95% CI: 1.042,1.192) (mortality rate of myocardial infarction) per 1 dB(A) increase in Leqn at lag 0, < 65 years of age
Sorensen et al., 2012	Road	Yes	Lden	Range = 42–84 dB	IRR = 1.12 (myocardial infarction) per 10 dB(A) increase for both yearly exposure at the time of diagnosis (95% CI: 1.02, 1.22) and 5 years, time-weighted mean (95% CI: 1.02, 1.23) preceding the diagnosis
Seidler et al., 2016a	Road	No	Leq (24h) The evaluation was performed on the basis of the	Increased risk estimates can be seen starting from a road traffic noise level of 55 dB. The	OR = 1.028 (95% CI: 1.25, 4.5) per 10 dB(A) increase in Leq (24h) (myocardial infarction)

			continuous 24-hour noise level and the categorized noise level (in 5 decibel classes).	OR reaches statistical significance at a noise level between 60 dB and <65 dB (OR = 1.09 (95% CI: 1.02, 1.16)); the highest OR of 1.13 (95% CI: 1.00, 1.27) is found with a 24-hour continuous noise level ≥ 70 dB. For night-time hours between 10 p.m. and 6 a.m., the risk increases when road traffic noise increases above 50 dB (statistically significant in some cases).	
	Rail			For rail traffic, in the 50 to <55 dB category there is a statistically borderline significantly raised OR of 1.05 (95% CI: 1.00, 1.10); in the 55 to <60 dB category the OR is 1.04 (95% CI: 0.97, 1.12); while in the highest sound level category, 70 dB and upwards, the OR is 1.16 (95% CI: 0.93, 1.46). For night-time hours from 10 p.m. to 6 a.m, the ORs begin to rise notably at noise levels of ≥ 60 dB (OR = 1.10 (95% CI: 1.01, 1.20)).	OR = 1.023 (95% CI: 0.5, 4.2) per 10 dB(A) increase in Leq (24h) (myocardial infarction)
Hypertensive heart disease					

Babisch et al., 2014a	Road	Yes	Lden Unit scale was 10 dB(A). For graphical presentation of the results the noise levels were categorized in 5-dB(A) categories using ≤45 dB(A) as a reference category [noise level categories: ≤ 45, 46–50, 51–55, 56–60, 61–65, ≥ 66 dB(A)].	Range = 31–80 dB(A)	OR = 1.43 (95% CI: 1.10, 1.86) per 10 dB(A) increase in Lden (isolated systolic hypertension)
Seidler et al., 2016b	Road	No	Leq (24h) For all continuous analyses, a starting point of 35 dB was chosen for noise in the range virtually indiscernible from background noise, below 40 dB. The continuous sound levels for each traffic noise source were grouped in 5 dB categories. For the analysis of road and railway traffic noise, cases and control subjects with noise exposure of less than 40 dB were grouped into the reference category. For the analysis of aircraft noise, individuals exposed to a continuous sound pressure level below 40 dB with the nightly maximum level exceeding 50 dB six or more times(NAT 6) were grouped into a	The categorical analysis showed a nearly monotonous risk increase, reaching statistical significance from 55 dB upwards.	OR = 1.024 (95% CI: 1.016, 1.032) per 10 dB(A) increase in Leq (24h) (hypertensive heart failure)
	Rail				OR = 1.031 (95% CI: 1.022, 1.041) per 10 dB(A) increase in Leq (24h) (hypertensive heart disease)
	Aircraft			In the categorical analysis, the OR was significantly elevated to 1.07 (95%CI 1.04–1.09) at 45 to <50 dB sound levels. For individuals with 24-h continuous aircraft noise levels <40 dB and nightly maximum aircraft noise levels exceeding 50 dB six or more times, a significantly increased risk was observed.	OR = 1.016 (95% CI: 1.003, 1.030) per 10 dB(A) increase in Leq (24h) (hypertensive heart disease)

			separate exposure category.		
Banerjee et al., 2014	Road	No	Lden Noise exposure was grouped into two categories (<60 dB(A)) according to the facade Lden levels. The choice of 60 dB(A) as cutoff point was due the fact that, firstly, it was close to the median Lden value (62.5 dB(A)) and, secondly, most studies have reported 60 dB(A) for similar investigations.	>65 dB(A) Lden (for men) >60 dB(A) Lden (for women)	OR = 1.99 (95% CI: 1.66, 2.39) per 5 dB(A) increase in Lden (hypertension)
Foraster et al., 2014	Road	Yes	Lnight	Median indoor sound modelled = 27.1 dB(A)	OR = 1.06 (95% CI: 0.99, 1.13) per 5 dB(A) increase in Lnight (hypertension)
				Median sound modeled at bedroom façade = 53.5 dB(A)	OR = 1.07 (95% CI: 1.01, 1.14) per 5 dB(A) increase in Lnight (hypertension)
				Median sound modeled outdoors = 56.7 dB(A)	OR = 1.19 (95% CI: 1.02, 1.40) per 5 dB(A) increase in Lnight (hypertension)
Ischemic heart disease morbidity and mortality					
Recio et al., 2016	All	Yes	Lmax night (0-8h)	Mean (SD) = 63.9 (1.7) Range = 58.7 - 76.3 dB(A)	RR = 1.029 (95% CI: 1.010, 1.048) (mortality rate of ischemic heart disease) per 1 dB(A) increase in Lnmax at lag 0, ≥ 65 age
			Leq night (0-8h)	Mean (SD) = 60.2 (1.0) Range = 56.2 – 69.9 dB(A)	RR = 1.108 (95% CI: 1.042, 1.177) (mortality rate of ischemic heart disease) per 1 dB(A) increase in Leqn at lag 0, < 65 years of age

Sorensen et al., 2011a	Road	Yes	Lden Linear and categorical analyses performed with seven noise exposure categories (55–58, 58–61, 61–64, 64–67, 67–70, 70–73, and >73 dB) and a reference category (≤55 dB). 55 dB used as the reference because this is often the limit value for noise in outdoor residential areas, and used exposure categories of 3 dB because this difference is a doubling in acoustical energy. IRRs were calculated for above and below 64.5 years of age, corresponding to the median age at stroke diagnosis among the cases.		IRR = 1.14 (95% CI: 1.03, 1.25) (ischaemic stroke) per 10 dB increase in Lden
				Mean exposure < 64.5 years = 57.8 dB Mean exposure ≥ 64.5 years = 58.2 dB	IRR = 1.27 (95% CI: 1.13, 1.43), (ischaemic stroke) per 10 dB increase in Lden, ≥ 64.5 years of age
Systolic blood pressure					
Foraster et al., 2014	Road	Yes	Lnight	Median indoor sound modelled = 27.1 dB(A)	β = 0.72 (95% CI: 0.29, 1.15) per 5 dB(A) increase in Lnight (systolic blood pressure)
Cerebrovascular disease morbidity or mortality					
Recio et al., 2016	All	Yes	Lmax night (0-8h)	Mean (SD) = 63.9 (1.7) Range = 58.7 - 76.3 dB(A)	RR = 1.024 (95% CI 1.001,1.048) (mortality rate of cerebrovascular disease) per 1 dB(A) increase in Lnmax at lag 0, ≥ 65 age
Sorensen et al., 2011a	Road	Yes	Lden Linear and categorical analyses performed with seven noise exposure categories (55–58, 58–61, 61–64, 64–67, 67–70, 70–73, and >73 dB) and a		IRR = 1.14 (95% CI: 1.03, 1.25) (ischaemic stroke) per 10 dB increase in Lden

			reference category (≤55 dB). 55 dB used as the reference because this is often the limit value for noise in outdoor residential areas, and used exposure categories of 3 dB because this difference is a doubling in acoustical energy.		
			IRRs were calculated for above and below 64.5 years of age, corresponding to the median age at stroke diagnosis among the cases.	Mean exposure < 64.5 years = 57.8 dB(A Mean exposure ≥ 64.5 years = 58.2 dB(A)	IRR = 1.27 (95% CI: 1.13, 1.43), (ischaemic stroke) per 10 dB increase in Lden, ≥ 64.5 years of age
Coronary heart disease mortality					
Gan et al., 2011	Road	Yes	Lden Continuous variable to calculate the relative risks of CHD mortality associated with a 10-dB(A) elevation in noise levels and categorical variable to examine exposure-response relations by dividing study subjects into deciles based on noise levels	Mean (SD) = 63.4 (5.0) Range = 33.0 – 90.0 Median (Interquartile Range) = 62.4 (59.8–66.4)	RR = 1.13 (95% CI: 1.06, 1.21) per 10 dB(A) increase in Lden (Coronary Heart Disease mortality when adjusting for $PM_{2.5}$)
					RR = 1.29 (95% CI: 1.11, 1.50) per 10 dB(A) increase in Lden, noise > 70 dB(A) (Coronary Heart Disease mortality when adjusting for $PM_{2.5}$)
					RR = 1.09 (95% CI: 1.01, 1.18) per 10 dB(A) increase in Lden (Coronary Heart Disease mortality when adjusting for $PM_{2.5}$ and black carbon)
					RR = 1.22 (95% CI: 1.04, 1.43) per 10 dB(A) increase in Lden, noise > 70 dB(A) (Coronary Heart Disease mortality when adjusting for

					$PM_{2.5}$ and black carbon)
Cognitive impairment (children)					
Pujol et al., 2013	All	No	The school average outdoor $L_{Aeq, day}$ was selected for analysis.	Mean (SD) = 51.5 (4.5) Range = 38 – 58 dB	β = - 0.44 (95% CI: -0.85, -0.02) (Math test scores) per 10 dB increase in $L_{Aeq, day}$, ages 8-9
					β = - 0.44 (95% CI: -0.85, -0.02) (French test scores) per 10 dB increase in $L_{Aeq, day}$, ages 8-9
van Kempen et al., 2012	Road	Yes	Leq (7-23h)	Mean (SD) = 48.7 (8.6) Range = 34.0 – 62.0	β = 0.30 (95% CI: 0.10, 0.50) (Attention scores: SAT, arrow)
	Aircraft			Mean (SD) = 48.6 (7.1) Range = 36.3 – 62.8	β = 0.92 (95% CI: -0.02, -1.850) (Attention scores: SAT, switch)
Matheson et al., 2010	Road	No	Leq16h	Range = 32 to 71 dB	β = 0.065 (95% CI: 0.02, 0.11) (conceptual recall) per 5 dB(A) Leq16h increase, 8-10 years of age
Sleep disturbance					
Chum et al, 2015	Road	Used local traffic data (together with noise as a control variable) as a proxy for air pollution (common in other studies)	Self-reported level of noise disturbance	Neither agree or disagree - disturbed by noise at home	OR = 1.13 (95% CI: 1.01,1.28) (≤ 6 vs.7 hrs sleep)
				Agree - disturbed by noise at home)	OR = 1.66 (95% CI: 1.39,1.98) (≤ 6 vs.7 hrs sleep)
				Strongly agree - disturbed by noise at home	OR = 2.24 (95% CI: 1.77,2.84) (≤ 6 vs.7 hrs sleep)
				Disagree -disturbed by noise at home	OR = 1.15 (95% CI: 1.00, 1.31) (any vs. none: sleep problems)
				Neither agree or disagree - disturbed by noise at home	OR = 1.84 (95% CI: 1.65, 2.04) (any vs. none: sleep problems)
				Agree - disturbed by noise at home	OR = 2.74 (95% CI: 2.25, 3.34) (any vs. none: sleep problems)

				Strongly agree - disturbed by noise at home	OR = 3.03 (95% CI: 2.26, 4.07) (any vs. none: sleep problems)
Schreckenberg et al., 2010	Aircraft	No	$L_{Aeq, 16h}$	Sleep quality is worst for residents exposed to 50 to 60 dB(A) at daytime and 50 to 55 dB(A) at night-time than for residents with less or higher noise exposure.	OR = 0.95 (95% CI: 0.93, 0.97) (bad sleep quality)
Annoyance among adults					
Dratva, et al., 2010	Road		Self-Reported Noise Exposures	The degree of noise annoyance was measured by a thermometer scale ranging from 0 (not at all) to 10 (strong and unbearable, Fig. 2) [10, 37–39]. We created a dichotomous noise annoyance variable, defining high noise annoyance as a value of >6 on the original 11-point scale, similar to the dichotomization presented by Li et al. and Conzelmann-Auer et al. [10, 37].	OR = 0.42 (95% CI: 0.24, 0.74) (high annoyance), countryside vs. heavy traffic location
					OR = 1.82 (95% CI: 1.38, 2.39) (high annoyance), moderate vs. light traffic
					OR = 1.46 (95% CI: 1.09, 1.95) (high annoyance), infrequent truck noise vs. no truck noise
					OR = 3.20 (95% CI: 2.17, 4.82) (high annoyance), constant truck noise vs. no truck noise
de Kluizenaar et al., 2011	Road	No	Lden (without quiet side dwelling) <45 defined as reference category	45 – 50 dB(A)	OR = 1.19 (95% CI: 1.03, 1.39)
				45 – 52.5 dB(A)	OR = 1.26 (95% CI: 1.09, 1.44)
				50 – 55 dB(A)	OR = 1.74 (95% CI: 1.47, 2.05)
				52.5 – 57.5 dB(A)	OR = 2.23 (95% CI: 1.87, 2.66)
				55 – 60 dB(A)	OR = 2.75 (95% CI: 2.27, 3.34)
				57.5 – 62.5 dB(A)	OR = 3.83 (95% CI: 3.09, 4.74)
				>60 dB(A)	OR = 6.93 (95% CI: 5.65, 8.50)
				>62.5 dB(A)	OR = 8.00 (95% CI: 6.30, 10.16)
			Lden (with quiet side dwelling)	50 – 55 dB(A)	OR = 1.63 (95% CI: 1.25, 2.13)

			<45 defined as reference category	52.5 – 57.5 dB(A)	OR = 2.05 (95% CI: 1.67, 2.52)
				55 – 60 dB(A)	OR = 2.38 (95% CI: 1.99, 2.84)
				57.5 – 62.5 dB(A)	OR = 2.96 (95% CI: 2.52, 3.48)
				>60 dB(A)	OR = 5.30 (95% CI: 4.63, 6.07)
				>62.5 dB(A)	OR = 6.54 (95% CI: 5.64, 7.58)
Chronic obstructive pulmonary disease mortality					
Recio et al., 2016	All	Yes	Lmax night (0-8h)	Mean (SD) = 63.9 (1.7) Range = 58.7 - 76.3 dB(A)	RR = 1.04 (95% CI: 1.010, 1.070) (mortality rate of Chronic Obstructive Pulmonary Disease) per 1 dB(A) increase in Lnmax at lag 1 , ≥ 65 age
Pneumonia mortality					
Recio et al., 2016	All	Yes	Lmax night (0-8h)	Mean (SD) = 63.9 (1.7) Range = 58.7 - 76.3 dB(A)	RR = 1.03 (95% CI: 1.002, 1.058) (mortality rate of pneumonia) per 1 dB(A) increase in Lnmax at lag 1 when NO2 > 30µg/m^3, ≥ 65 age
Diabetes mortality					
Recio et al., 2016	All	Yes	Leq night (0-8h)	Mean (SD) = 60.2 (1.0) Range = 56.2 – 69.9 dB(A)	RR = 1.11 (95% CI: 1.040, 1.192) (mortality rate of diabetes) per 1 dB(A) increase in Leqn at lag1, ≥ 65 age
Depression					
Orban, et al., 2016	Road	No	L_{den} High noise exposure was defined as annual mean 24-hr noise levels > 55 dB(A) (High noise at night was also defined as >50 dB(A) L_{night} and in general had similar associations)		RR = 1.29 (95% CI: 1.03, 1.62) (high depressive symptoms), middle-age
Quality of Life scores					

Schreckenberg et al., 2010	Aircraft	No	$L_{Aeq, 16h}$	HQoL with regard to vitality and mental health decreases with increasing aircraft sound level at daytime from <45 dB(A) up to the sound level class 50–55 dB(A), but then increases again for residents exposed to higher sound level classes at daytime.	OR = 0.95 (95% CI: 0.93, 0.97) (vitality) OR = 0.96 (95% CI: 0.94, 0.98) (mental health)
Adverse behaviour among children					
Hjortebjerg et al., 2016	Road	Yes	Time-weighted mean exposure from birth to 7 years of age	For time-weighted mean exposure from birth to 7 years of age, estimated that a 10-dB higher exposure to road traffic noise was associated with a 7% increase in abnormal total difficulties scores (95% CI: 1.00, 1.14) (Table 2), which seemed to follow a monotonic exposure–response relationship until 60–65 dB, after which the curve leveled off (Figure 1A).	RR per 10 dB(A) increase (age 7, exposure from birth) = • 1.07 (95% CI: 1.00, 1.14) (abnormal vs. normal total difficulties) • 1.05 (95% CI:1.00, 1.10) ("borderline and abnormal hyperactivity") • 1.09 (95% CI: 1.03, 1.18) ("borderline and abnormal inattention") • 1.05 (95% CI: 0.98, 1.14) ("abnormal conduct problems") • 1.06 (95% CI: 0.99, 1.12) ("peer relationship problems")
	Rail			≤ 60 dB In the cohort as a whole, exposure to railway noise ≤ 60 dB at the time of birth was positively associated with abnormal emotional	OR = 1.11 (95% CI: 1.00, 1.23) (abnormal emotional symptom scores), exposure at time of birth

				symptom scores (OR = 1.11; 95% CI: 1.00, 1.23 compared with unexposed children) but this outcome was not associated with railway noise > 60 dB (OR = 1.01; 95% CI: 0.83, 1.22).	