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Evaluation of the social and economic burden of road traffic noise-attributed myocardial infarction in Bulgarian urban population

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Road traffic noise is a widely studied environmental risk factor for ischaemic heart disease and myocardial infarction in particular. Given that myocardial infarction is a leading disability and mortality cause in Bulgaria and that a significant proportion of the urban population is exposed to high noise levels, quantification of the burden of disease attributable to traffic noise is essential for environmental health policy making and noise control engineering. This study aimed at estimating the burden of the myocardial infarction cases attributable to road traffic noise in the Bulgarian urban population. We used the methodology for estimating the burden of disease attributable to environmental noise outlined by the World Health Organization. Risk data were extracted from a recently published meta-analysis providing updated exposure-response relationship between traffic noise and the risk for myocardial infarction. Based on these data we calculated the fraction of myocardial infarction cases attributable to traffic noise, loss of quality-adjusted life-years (QALYs), and the economic burden, assuming € 12,000 per QALY. About 2.9 % or 101 of all myocardial infarction cases could be attributed to road traffic noise. Fifty-five of these were fatal. Nine hundred and sixty-eight QALYs were lost to these cases. The monetary value of these QALYs was about € 11.6 million. Although the measures used in this study are crude and give only an approximation of the real burden of disease from road traffic noise, they are indicative of the important social and economic aspect of noise pollution in Bulgaria. Hopefully, these results will direct the attention of epidemiologists, environmental hygienists, and health economists to this pivotal environmental issue.

KEY WORDS: *burden of disease; health economics; ischemic heart disease; noise pollution; quality-adjusted life-years*

Cardiovascular diseases (CVDs) are a major cause of disability and mortality in Bulgaria (1). About 14.4 % of all hospitalisations (2) and 65.6 % of all deaths in 2012 were due to diseases of the circulatory system (ICD-10: I00-I99) (3). Further stratifying the data, we see that 12.7 % of all deaths in 2012 could be attributed to the ischaemic heart disease (IHD) (ICD-10: I20-I25) and 4.6 % to acute myocardial infarction (MI) (ICD-10: I21) (3). This prevalence underscores the social and economic importance of IHD and MI in Bulgaria.

Bulgaria is a country with low quality of life (4), dysfunctional healthcare system (5), and high prevalence of smoking (6) and metabolic syndrome (7). Apart from individual factors such as metabolic disorders and unhealthy lifestyle (8), environmental factors such as noise pollution pose a significant risk for IHD and MI. Babisch (9) has recently published an updated exposure-response relationship meta-analysis between traffic-generated noise and coronary heart diseases, which shows an 8 % risk (95 % CI: 1.04, 1.13) per a 10-dB increase in day-night noise level (L_{dn}) in the exposure range between 52 and 77 dB. There are strong biological grounds for these effects. Noise affects the neuroendocrine system and sleep via direct and indirect pathways, which ultimately leads to increase in cortisol and catecholamines, disturbance of the sleep pattern, and, eventually to metabolic and vascular impairment (10-15).

According to the Noise Observation and Information Service for Europe (16), about 28 % of all Bulgarians in urban areas are exposed to a day-evening-night noise level (L_{den}) of ≥65 dB, while some major Bulgarian agglomerations (Plovdiv and Varna) have half of their residents exposed to L_{den}≥65 dB (16), a threshold regarded by the World Health Organization (WHO) as a risk for cardiovascular diseases (17). This evidence calls for the estimation of the burden of MI cases attributed to road traffic noise in Bulgaria, an issue which, to the best of our knowledge, has not been addressed directly so far. It is essential to provide such information in order to guide future environmental policy and noise control in the country. In 2010, a person exposed to L_{den}≥65 dB cost Bulgaria € 44-97 per year (18). There is no information to suggest additional economic losses due to noise-attributed MI cases. Western Europe loses 61,000

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disability-adjusted life-years (DALYs) annually due to traffic noise-attributed IHD (15). In the United Kingdom 542 new cases of MI each year are expected as a result of noise-related hypertension ($L_{Aeq, 16h} \geq$55 dB), whose burden has been estimated to £ 294 billion per year (19). Although WHO developed a methodological framework for quantifying burden of disease from environmental noise, it has been applied mainly for Western European countries "owing to a lack of exposure data in South-East Europe and the newly independent states" (15). Only recently have eastern European researchers started to take a closer look at this issue; Paunović et al. (20) estimated that the total DALY due to road traffic noise in a sample of residents of central Belgrade, Serbian capital, was 107 years per million inhabitants . Since 2011 when the *Burden of disease from environmental noise* (15) report was published, additional data have been collected for Bulgarian agglomerations, which allows estimating the impact of road traffic noise on a larger scale.

Given the disconcerting prevalence of people suffering from MI and those exposed to high road traffic noise, this study aimed at estimating the social and economic burden of MI cases attributable to road traffic noise in the Bulgarian urban population.

MATERIAL AND METHODS

This study used official data available over the Internet and therefore did not require approval by the university's Ethics Committee. We applied the methodology outlined in the WHO report *Burden of disease from environmental noise* (15), which focused on several endpoints for which there was sufficient evidence to suggest adverse health effects of noise pollution: cardiovascular diseases, cognitive impairment, sleep disturbance, tinnitus, and noise annoyance. Specifically, we followed the procedures described by Wolfgang Babisch and Rokho Kim to estimate IHD burden from road traffic noise in Bulgaria.

The cardiovascular outcome that we were interested in was MI (ICD-10: I21). Burden of disease was expressed in deaths and quality-adjusted life-years (QALYs) lost per case with non-fatal MI. Demographics and the incidence of MI (both fatal and non-fatal) for 2012 were extracted from the report *Healthcare 2013* of the National Statistical Institute of Bulgaria for each of the six studied districts (see below) (3). We assumed that traffic noise had a similar impact on all IHD cases as on MI (15). Noise exposure information (proportion of population exposed to different noise bands) for 2012 was downloaded from the Noise Observation and Information Service for Europe (NOISE) (16). It referred to the agglomerations of Sofia, Plovdiv, Varna, Burgas, Ruse, and Pleven. These data were extrapolated only to the urban population of the six districts in order not to overestimate the effect by extrapolating exposure data to the whole population of the districts, which includes rural population. As the extracted proportions did not add-up to exactly 1.00 (or 100 %), we took two approaches: when the sum of the reported proportions for the L_{den} categories (55-77.5 dB) was<1.00, we assumed that the rest of the residents were exposed to L_{den}<55 dB, which is not reported by NOISE; when the sum of proportions was >1.00 (such as for the agglomerations of Plovdiv and Varna) we subtracted the difference from the biggest proportion for the respective agglomeration (e.g. for Plovdiv the sum of proportions was 1.01, so the difference 1.01-1.00=0.01 was subtracted from the proportion for L_{den}=65-69 dB → 0.34-0.01=0.33).

The next step was to calculate the Population Attributable Fraction (PAF), which is a statistical concept that can be used to quantify the impact of exposure to different risk factors on mortality or morbidity at the population level (21). It is calculated according to the formula:

$$PAF=\{\Sigma(Pi*RRi) - 1\}/\Sigma (Pi*RRi)\},$$

where Pi is the proportion of the population in exposure category i, and RRi is the relative risk at exposure category i compared to the reference level, and ΣPi is 1.00 (15).

The relative risks (RR) for different L_{den} road traffic noise categories were computed based on the most recent meta-analysis by Babisch (9) which updated the exposure-response relationship between noise and risk for MI. Accordingly, we extracted RR for each 5 dB L_{den} category for the mid-category value (e.g. for 60-65 dB → 62.5 dB). As recommended, we used L_{den}<55 dB with RR of 1.00 as reference category. For $L_{den}\geq$75 dB we adopted the 5-dB category width based on the adjacent category and considered the RR corresponding to the 77.5 dB mid-value. In order to compute RRs we meta-analysed the estimates for each L_{den} category based on the individual study estimates reported by Babisch (9). When pooling RR for L_{den}=55-59 dB, we excluded studies using this category as a reference (i.e. with RR=1.00). The meta-analyses were conducted using the random effects model with MetaXL (EpiGear International Pty Ltd., Version 2.0, 2011-2014, Brisbane, Australia) (www.epigear.com) for Microsoft Excel 2010.

In order to calculate the number of MI cases attributable to road traffic noise, the number of all MI cases was multiplied by PAF. The same PAF can be applied to both morbidity and mortality of MI, provided that there is no overlap between fatal and non-fatal cases (15). As we could not distinguish MI incidence data between urban and rural population from *Healthcare 2013* (3), and as about 83 % of the district population is urban, we assumed that the import of MI cases in rural population attributable to road traffic noise was so negligible that it would not seriously affect our estimates.

Additionally, we calculated QALYs lost, which is a measure of disease burden, encompassing both the quality and quantity of the life lived (22). We mostly adhered to Harding et al. (19), as follows:

QALYs lost=quality-of-life lost (QLL) + life expectancy lost,

where QLL corresponds to years lived with disability (YLD) x (quality-of-life weight), YLD is the number of incident cases of non-fatal MI attributed to noise (I) x disability weight (DW) x average duration of disability in years (L), L being 1 year (15), DW equals 0.415 (23), quality-of-life weight equals 1 minus DW (19), and life expectancy lost equals 10 [due to a lack of exact data we conservatively assumed 10-year life expectancy after MI (24, 25)].

Finally, we monetised the QALYs lost (QALYs lost x value of a QALY). One approach to determining the value of a QALY is to set it slightly above the average gross domestic product (26), but we conservatively adhered to a threshold willingness to pay € 12,000 per QALY, which, according to EUROSTAT (27), was the gross domestic product in Purchasing Power Standards (PPS) per capita in Bulgaria for 2012. PPS are "fictive 'currency' units that remove differences in purchasing power" (28); in the EU-28 one PPS equals one euro. The QALYs per case were therefore multiplied by € 12,000 to get the monetary value per case, and then by the number of cases of noise-attributed non-fatal MI in order to obtain a rough estimate of the total economic loss due to those cases.

These findings refer to 2012, chosen as the most recent year for which we had relevant exposure and MI incidence data at our disposal.

All formulae were entered into an Excel 2010 spreadsheet. When possible, we made conservative assumptions in order to avoid unnecessary overestimation of the effects.

RESULTS

Data regarding the number of people exposed to different road traffic noise bands (L_{den}) and associated risks are presented at Table 1. The proportion of those exposed to unacceptable noise levels is high, especially in the agglomerations of Plovdiv and Varna. Based on the proportion of people exposed in each category and the RR estimate for these categories, we calculated PAF for the six agglomerations and then extrapolated it to the urban population of the districts.

PAF values indicated that 2.9 % (or in absolute numbers 101) of all MI cases in urban settlements in 2012 could be attributed to road traffic noise exposure. Fifty-five of these 101 cases were fatal (Table 2).

The burden of MI cases in terms of QALYs lost was 21.13 per each case of non-fatal MI attributable to road traffic noise. Noise exposure accounted for a loss of € 253 529 per case of non-fatal MI. When we multiplied these values by the number of road traffic noise-attributed non-fatal MI cases, we got € 11,620,273 lost annually.

DISCUSSION

Major findings

Overall, our findings suggest that road traffic noise exposure is high in Bulgarian agglomerations, particularly in Plovdiv and Varna. In European countries, 50 % of the city residents (in cities with >250,000 inhabitants) are exposed to L_{den}<55 dB, 17 % to 55-59 dB, 19 % to 60-64 dB, 9 % to 65-69 dB, and 4 % to 70-74 dB (15). In Plovdiv and Varna, on the other hand, half of the residents are exposed to L_{den}≥65 dB and about 16 % (Plovdiv) and 11 % (Varna) to 70-74 dB. These findings are quite alarming and call for decisive measures by Bulgarian authorities.

Fifty-five MI deaths could be attributed to road traffic noise. Moreover, the annual economic loss due to road traffic noise-attributed non-fatal MI cases is about € 11.6 million. If we compare these statistics with those for 2011

Table 1 *Distribution of urban population exposed to different road traffic noise bands across districts*

L_{den} (dB)	Risk[1]	Districts						Total
		Sofia	Plovdiv	Varna	Burgas	Ruse	Pleven	
		N (%)[2]	N (%)[2]	N (%)[2]	N (%)[2]	N (%)[2]	N (%)[2]	N (%)[2]
50-54	1.00	212,872 (17)	0 (0)	0 (0)	88,381 (28)	58,621 (33)	88,819 (50)	447,930 (16)
55-59	1.01	309,527 (25)	100,374 (20)	39,638 (10)	58,540 (19)	52,434 (29)	47,459 (27)	607,972 (22)
60-64	1.01	461,270 (37)	156,187 (31)	156,817 (40)	89,895 (29)	44,167 (25)	20,996 (12)	929,333 (33)
65-69	1.07	217,291 (17)	167,843 (33)	153,596 (39)	61,635 (20)	17,780 (10)	12,797 (7.3)	630,942 (22)
70-74	1.10	34,352 (2.8)	80,832 (16)	45,088 (11)	9,151 (3)	5,436 (3)	6,088 (3.5)	180,947 (6)
≥75	1.45	5,770 (0.5)	888 (0.2)	1,239 (0.3)	2,557 (0.2)	340 (0.2)	124 (0.1)	10,918 (0.4)
PAF		0.023	0.043	0.043	0.025	0.016	0.013	0.029

L_{den}-day-evening-night equivalent sound level; PAF-Population Attributable Fraction
[1]Based on data reported by Babisch (9)
[2]Data from Noise Observation and Information Service for Europe (16)

Table 2 *Morbidity and mortality cases and socio-economic burden of road traffic noise-attributed myocardial infarction across districts*

	Districts						Total
	Sofia	Plovdiv	Varna	Burgas	Ruse	Pleven	
Urban population[1]	1,242,012	506,125	396,378	309,995	178,396	175,135	2,808,041
Proportion from the total district population (%)[1]	95.37	74.56	83.73	74.85	77.03	66.60	83.49
Cases of MI[1]	1151	950	395	444	260	327	3,527
MI deaths[1]	578	449	174	336	72	313	1,922
Cases of non-fatal MI[2]	573	501	221	108	188	14	1,605
Cases of MI attributable to noise	26.22	40.95	16.96	10.99	4.17	4.14	100.72
MI deaths attributable to noise	13.17	19.35	7.47	8.31	1.15	3.96	54.89
Cases of non-fatal MI attributable to noise	13.05	21.59	9.49	2.67	3.01	0.18	45.83
QALYs lost per noise-attributed non-fatal MI case	13.17	15.24	12.30	10.65	10.73	10.04	21.13
QALYs lost due to additional noise-attributed non-fatal MI cases	171.88	329.15	116.75	28.45	32.35	1.78	968.36
Value of each noise-attributed non-fatal MI case (in PPS euro)	158,024.05	182,909.97	147,644.06	127,784.75	128,782.06	120,516.21	253,528.66
Value of the additional noise-attributed non-fatal MI cases (in PPS euro)	2,062,511.51	3,949,768.10	1,400,982.08	341,459.04	388,210.03	21,354.16	11,620,273.02

MI–myocardial infarction; PPS–Purchasing Power Standards

[1]Taken from Healthcare 2013 (3). All data refer to myocardial infarction mortality and morbidity of the total district population in 2012

the total economic loss has increased € 174,864.46 due to urbanisation and increase in MI mortality and morbidity (data not shown). It is essential to address these environmental issues because CVD are not only the leading mortality cause in Bulgaria, but the healthcare system suffers from insufficient funding and resource allocation. We see a large number of costly invasive cardiology procedures performed every month (29), which underscores the importance of minimising or preventing environmental risk factors such as noise pollution.

There are several ways to lower exposure to road traffic noise. One way is to take the so called at-source measures aimed at vehicles (such as quieter types of tyres), road surfaces (such as low-noise tarmac), traffic management, and speed regulation (30). Roadside noise barriers might add another level of control over noise propagation as well as double-skin facades (31). The measures aimed at vehicles are considered the most cost-effective (30). However, there are other solutions derived from the psychoacoustical theory. Using urban greenery as psychological noise buffer has been proposed not only as cost-efficient and accessible to local authorities, but improving the green infrastructure in urban areas endangered by noise pollution can provide other health benefits as well (32). The Plovdiv Municipality has already prioritised its green space system for the years to come and is currently implementing various projects for public park rejuvenation and higher quality inner-neighbourhood green patches and gardens. However, enrolment of public health experts is crucial in order to monitor the epidemics and burden of CVD as a result of improvements in traffic noise control and urban planning.

Strengths and limitations

This was the first study to specifically focus on the social and economic losses of road traffic noise-attributed MI in Bulgarian agglomerations. When *Burden of disease from environmental noise* was published in 2011, noise exposure information for South-East Europe was scarce, and the estimated burden of disease referred mainly to Western European countries (15). This study was also the first to use the Babisch's update on the exposure-response relationship between noise and the risk of IHD (9).

This study is, however, limited in several ways. Data about non-fatal MI cases were based on records from emergency care centres and may thus be underestimating the true morbidity (in this sense it renders our results conservative). On the other hand, morbidity and mortality data refer to whole districts, while noise exposure information was available only for the agglomerations. Linking these exposure and MI incidence data is one of the major limitations of our study, which inevitably comes with a degree of uncertainty. Nevertheless, the fact that the urban population makes about 83 % of the whole district population suggests that most of the MI cases refer to the urban population. Furthermore, road traffic noise exposure in rural population is arguably negligible in comparison to urban population. This lowers possible bias due to differences in the structure of CVD morbidity and mortality across urban and rural settlements. While this mismatch of data on exposure and disease incidence may limit estimation of the actual burden of disease and economic loss, such uncertainty has been justified by the WHO (15). Horton's Precautionary principle states that "we must act on facts, and on the most accurate interpretation of them, using the best scientific information. That does not mean that we must sit back until we have 100 % evidence about everything" (33).

Other issues are generalization of the evidence to both sexes as well as using pooled results from studies carried out in high-income countries when estimating the burden in a country with low socio-economic standard like Bulgaria.

A fair amount of assumptions were made as well. Assuming average life expectancy of 10 years after MI is rough but conservative approximation, as, according to the formulae, with an increase in life expectancy the economic losses are projected to increase as well. The same refers to € 12,000 per QALY. It is still a conservative estimate since thresholds as high as € 30,000 (34) or BGN 30,000-50,000 (35) have been used.

We were unable to calculate DALYs like Paunović et al. (20) did, as the available morbidity and mortality data were not stratified by age groups. Therefore the approach of Harding et al. was adopted (19). Finally, the assumption that quality-of-life weight equals 1 minus DW might need relaxing (36).

Given all of the limitations outlined above, the results of this study are only general approximations and do not fully substantiate the socio-economic effects of road traffic noise. Therefore unsubstantiated speculations with the estimates reported here are not advised. Regardless, it is important to have some evidence we can work with until more accurate statistics have been reported.

CONCLUSION

A significant proportion of the inhabitants of Plovdiv and Varna agglomerations are exposed to unacceptably high noise levels. We have estimated that 968 QALYs are lost every year to road traffic noise-attributed myocardial infarction cases in the six studied districts. The monetary value of these QALYs is about € 11.6 million. Although the measures used in this study are crude and give only an approximation of the real burden of disease from road traffic noise, they are indicative of the important social and economic aspect of noise pollution in Bulgaria.

Conflict of interest statement

The authors have no conflict of interest.

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Procjena socijalnog i ekonomskog tereta infarkta miokarda povezanog s cestovnom bukom u bugarskog urbanog stanovništva

Prometna je buka pomno istražen rizični čimbenik za nastanak ishemijske bolesti srca, napose infarkta miokarda. Budući da je infarkt miokarda vodeći uzrok invalidnosti i smrtnosti u Bugarskoj te da je veliki udio urbanoga stanovništva izložen visokim razinama buke, za donošenje odluka iz područja zdravstvene ekologije i kontrole buke bitno je utvrditi koliki je taj teret bolesti povezane s prometnom bukom. Cilj našeg istraživanja bio je procijeniti teret infarkta miokarda povezanog s cestovnom bukom u bugarskom urbanom stanovništvu oslanjajući se na metodologiju Svjetske zdravstvene organizacije za procjenu tereta bolesti povezanih s okolišnom bukom. Podaci o riziku preuzeti su iz nedavno objavljene meta-analize koja daje pregled odnosa izloženosti i odgovora između cestovne buke i rizika od infarkta miokarda. Na temelju tih podataka izračunali smo udio slučajeva infarkta miokarda koji se mogu povezati s cestovnom bukom, a na temelju njih gubitak u godinama kvalitetnog života (engl. *quality-adjusted life-years*, krat. QALY) te ekonomski teret bolesti, uz pretpostavku da gubitak svake godine kvalitetnog života košta 12.000 eura. Rezultati su pokazali da se oko 3 % odnosno 101 slučaj infarkta miokarda može pripisati cestovnoj buci, od kojeg je njih 55 bilo kobno. Izgubljenih godina kvalitetnog života bilo je 968, a njihova ekonomska cijena iznosila je oko 11,6 milijuna eura. Premda su te procjene grube i daju tek približan uvid u stvarni teret bolesti povezane s cestovnom bukom, one ipak jasno pokazuju koliko je važan socijalni i ekonomski aspekt zagađenja okoliša bukom u Bugarskoj. Nadamo se stoga da će rezultati našeg istraživanja privući pažnju ne samo epidemiologa nego i zdravstvenih ekologa i ekonomista, s obzirom na to da se radi o iznimno važnom ekološkom problemu.

KLJUČNE RIJEČI: *godine kvalitetnog života; ishemijska bolest srca; onečišćenje bukom; teret bolesti; zdravstvena ekonomija*