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OBSERVATIONAL STUDY ON THE INFLUENCE OF NOISE POLLUTION ON THE QUALITY OF SLEEP OF PORTO RESIDENTS COMPARED WITH THAT OF RURAL COMMUNITIES*

ESTUDO OBSERVACIONAL SOBRE A INFLUÊNCIA DA POLUIÇÃO SONORA NA QUALIDADE DO SONO DOS RESIDENTES DO PORTO QUANDO COMPARADO COM POPULAÇÕES RURAIS

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ABSTRACT

Exposure to noise pollution has escalated to alarming levels and is causing a number of health problems. It leads to interrupted sleep, increasing stage 1 and awake and decreasing REM and deep sleep. We sought to find a correlation between exposure to high levels of noise pollution in industrialized districts and sleeping problems reported by their inhabitants compared with rural neighbourhoods, using the Pittsburgh Sleep Quality Index (PSQI). This study was composed of 65 people, 33 living in the district of Porto and 32 in rural villages. Each participant was asked to complete two questionnaires; one where they reported their sociodemographic data and the PSQI which indirectly evaluated their sleep quality in the last month. The results from each of the studied groups were compared and analysed using binomial, T and Chi-Square tests. The present study shows that noise has an implication, although limited, on people's sleeping patterns in the city of Porto, as it affects their daytime life and productivity with a p-value of 0.046. Preventive measures should be taken that focus on reducing nocturnal noise. The responsible departments should enforce the regulations established by the government.

Keywords: Noise pollution, sleep, urban noise.

RESUMO

A exposição à poluição sonora atingiu níveis alarmantes, causando problemas de saúde. Conduz a um sono fragmentado, aumentando o estadio 1 e o de vigília e diminuindo o REM e sono profundo. Pretendemos encontrar uma correlação entre a exposição à poluição sonora existente em distritos industrializados e os problemas de sono relatados pelos seus habitantes através do Pittsburgh Sleep Quality Index (PSQI) quando comparados com populações rurais. Este estudo foi composto por 65 pessoas, 33 residentes no Porto e 32 em espaços rurais. Cada um dos participantes preencheu 2 questionários, um onde relatou os seus dados sociodemográficos, e o PSQI, que avalia de forma subjetiva, a qualidade de sono no último mês. Os resultados de cada uma das populações foram comparados e analisados usando testes binomiais, T e Qui-quadrado. O presente estudo mostra que o ruído tem uma implicação, embora limitada, nos padrões de sono dos portuenses afetando a vida diurna e a produtividade, com um p-value de 0.046. Devem ser tomadas medidas preventivas focadas na diminuição do ruído noturno. Os departamentos responsáveis devem fazer cumprir a regulamentação estabelecida pelo governo.

Palavras-chave: Poluição sonora, sono, barulho urbano.

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Introduction

Noise pollution is defined as a group of annoying sounds to which populations are involuntarily exposed, coming from traffic (aerial, metropolitan or from cars), industrialization or social activities (Jakovljević *et al.*, 2006; Ruparel *et al.*, 2013).

In the past few years, industry and vehicles circulation has increased a great deal in our cities, originating traffic, and therefore, alarming levels of sound and atmospheric pollution that weren't there before (Geravandi *et al.*, 2015). Exposure to these pollutants, especially sound pollution, has a number of damaging effects on the population living in these cities, sleep quality being one of the most affected (Geravandi *et a*l., 2015). Being aware of this problematic, the World Health Organization (WHO, 1995) has set 40 decibels (dB) as the limit at which noise exposure becomes prejudicial (Berglund *et al.*, 1999). Unfortunately, more than 30% of Europeans are exposed to traffic noise above 55dB at nighttime, exposure that may cause sleep problems (Berglund *et al.*, 1999). Nocturnal noise causes arousals at levels as low as 48dB and physiological reactions, like increasing hormonal secretion, cortical arousals and body movements at levels around 33dB (Halperin, 2014). At nighttime, the noise that originates from traffic becomes intermittent, different from daytime when it is more continuous, as more people are driving (Pirrera *et al.*, 2010). This provokes even more sleeping problems than continuous noise does (Pirrera *et al.*, 2010).

The effects of exposure to noise pollution in human organisms are not the same for everyone (De Paiva Vianna *et al.*, 2015). It depends on the specific characteristics of the sound, such as frequency, exposure time, intensity and individual susceptibility (De Paiva Vianna *et al.*, 2015). Because of these differences, in this study, we took in consideration some of these aspects, such as the levels of sound exposure in the studied areas, with help from noise maps given by the councils of each city; and accessed the data from the participants regarding the amount of time they have lived there.

A healthy sleep schedule is fundamental for a good physiologic and mental capacity throughout the day (Griefahn *et al.*, 2004). Sleep disturbances include biological responses that may have numerous adverse effects in health and well-being that range from difficulties in falling asleep (longer latencies to sleep), alterations on sleeping patterns, arousals, increasing blood pressure and even cardiac arrhythmias (Griefahn *et al.*, 2004). The increase in sleep latency and the interference with sleep patterns may occur even when the subject is not consciously awakened by the excessive noise (Ruparel *et al.*, 2013). The fracture of sleep by nocturnal noise typically increases stage 1 sleep and stage awake, decreasing deep and REM sleep, causing a lighter, less restoring sleep (Halperin, 2014). This fact not only disturbs the person during the night, but has repercussions on daily life, as people living with this problem experience fatigue during the day, irritation, mood swings and decrease in cognitive function (Halperin, 2014).

The pathophysiologic basis of the sleep-noise relation is based in the stimulation of the hypothalamus-hypophyses-adrenal axis, the medulla and the sympathetic nervous system with the subsequent secretion of stress hormones, like adrenalin, noradrenalin and cortisone (Maschke *et al.*, 2004). These responses may have long term implications on the health status of exposed subjects (Jakovljević *et al.*, 2006).

To help understand this problem better, WHO (2007) documented 7 categories of adverse effects of noise pollution, it being occupational, social or environmental: hearing loss, verbal communication difficulties, cardiovascular disturbances, mental illness, learning difficulties, negative social behaviors and sleep disturbances (Halperin, 2014). The last one considered the most harmful non-auditory consequence due to its effect in quality of life and daily performance (Halperin, 2014).

An European study carried out in 2015 reveals Portugal as the third country with the highest index of exposure to excessive noise in a group of 11 European countries evaluated. Porto stands out as the loudest city, followed by Lisbon and Coimbra (Albera *et al.*, 2015).

Porto's municipal council, being aware of this problem, created the Municipal Laboratory of Noise in order to measure and control the noise levels in different parts of the city providing a greater guarantee in the control of noise pollution and safeguarding the health of its inhabitants in situations of overexposure to noise pollution. With that in mind, they've created noise maps of the city (FEUP and CMP, 2010).

The additional studied urban areas that are a part of Porto metropolitan area and are not included in the noise map (fig. 1) are the cities of Vila Nova de Gaia, Penafiel, Matosinhos, Lousada, Gondomar and Valongo. According to these cities' noise maps, they also face problems regarding overexposure to noise in levels that variate from 45-65dB, with the nocturnal period being the most problematic in terms of non-regulatory situations (LABORATÓRIO DE METEOROLOGIA E ENSAIOS, 2008; Infraestruturas de Portugal, CERTIPROJECTO, 2020).

The studied rural areas gathered data shows that a good part of the municipality of Cinfães doesn't present significant noise levels, and there are no particularly critical situations from an acoustic point of view (Engineering, 2016). Buildings located in the surroundings of national roads are the most exposed but

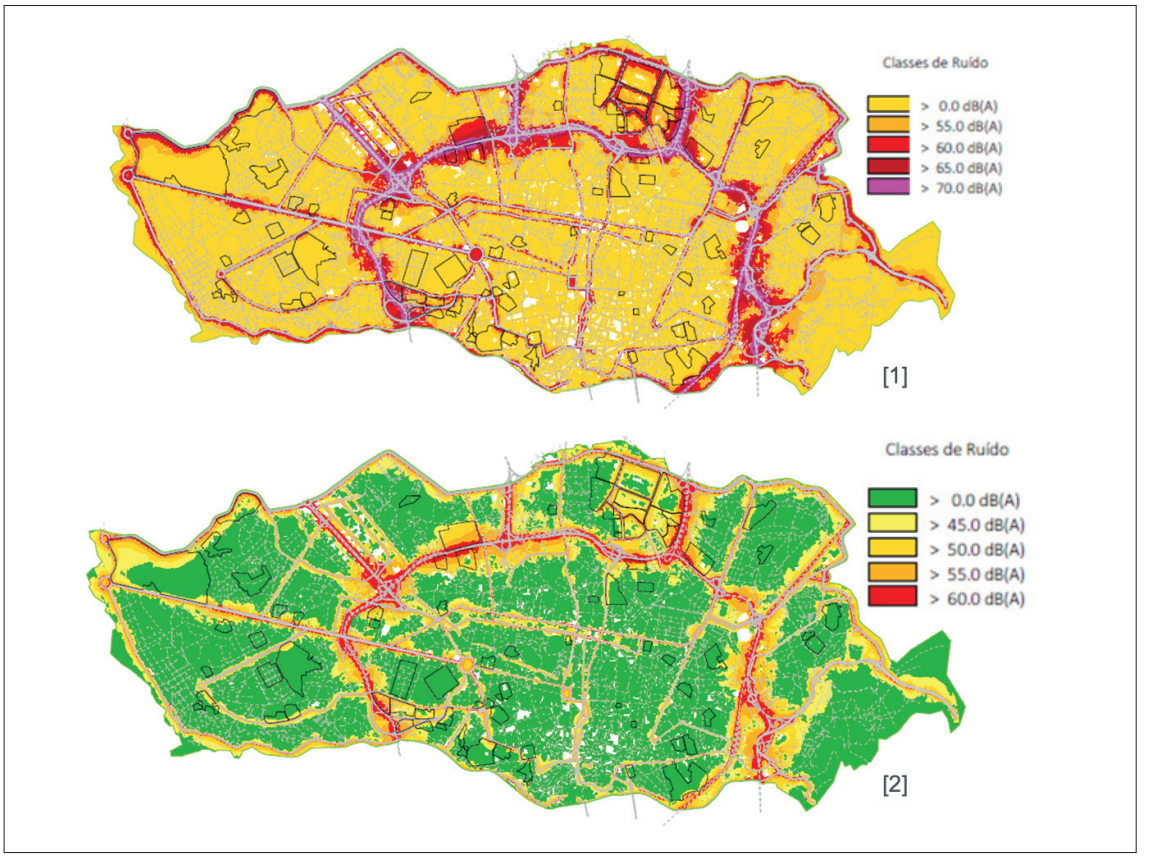

Fig. 1 - Daytime [1] and nocturnal [2] noise in Porto (FEUP and CMP, 2010).

***Fig. 1 -** Ruído diurno [1] e noturno [2] no Porto (Fonte: FEUP e CMP, 2010.*

are still not problematic and the surroundings of the wind parks generate an important level of noise, but it does not influence nearby populations (Engineering, 2016). The analysis of noise maps shows that the municipality of Castelo de Paiva presents, in a part of its territory, low noise levels (RNT, 2019). The highest noise levels are registered in the surroundings next to the main national roads that serve the municipality affecting, at most, the first front of houses (RNT, 2019).

In this paper we aimed to find a correlation between living in the district of Porto, and because of that, being exposed to high levels of sound pollution, and the development of bad sleeping patterns using the Pittsburgh Sleep Quality Index (PSQI). To serve as control group, a sample of people from rural areas of northern Portugal, Cinfães and Castelo de Paiva, was also evaluated. The choice of these two rural areas was due to their greater proximity to the authors, which facilitated data collection. The secondary objective is to study the factor adjustment to sound pollution as a possible influence in the sleep quality, particularly if by adjusting ourselves to this type of pollution over the years, our sensibility to it decreases provoking a less affected sleep or, at least, a loss on the perception of the pollutant.

Methods

Study Characteristics

This is an observational study be as only possible changes in sleep patterns of the sample were documented without exerting any influence on it or on the results found. It is also retrospective since the researched process has already occurred, and descriptive as it describes a reality impartially, without interference from the researchers and lastly, cross-sectional as a single evaluation was performed.

Selection of Participants

Each participant was recruited on social media platforms, such as Facebook, Instagram and Twitter, during February and March 2021, asked to fill 2 questionnaires, one where they report demographic and health-related data, in order to select the eligible participants, which contained 13 questions, and the second questionnaire, the PSQI, wich evaluates indirectly, their sleep quality in the last month. After these answers, the results from each of the studied populations were compared

and analyzed. The selection of the sample used was a sampling by convenience, based on the following inclusion and exclusion criteria (Table I).

Methods to collect the data

The data from the participants was collected "via 2 online questionnaires", and the data from the levels of sound pollution in each studied area was collected from the city's responsible authorities in the subject, most of them, available online to the general public. The Portuguese version of the PSQI was translated by Karina Del Rio, who gave permission to use the questionnaire in the present study. The PSQI includes a scoring key to calculate seven subscores, referring to subjective sleep quality, sleep latency, sleep duration, sleep efficiency, sleeping disorders, use of sleeping pills and drowsiness and daytime dysfunctions, each of which can range from 0 to 3, with 3 being the poorer result and 0 the normal, non-pathological result, using the participant's answers related to each component. The subscores are tallied, yielding a global score that can range from 0 to 21. When the Global score is less than or equal to 5, according to Karina Del Rio, sleep is considered good, and with a score greater than 5, sleep is considered to be poor quality.

Variables

To study the possibility of adjustment, the subjects were inquired about their years of residence in the reported area. The participants were also asked to report if they considered themselves to be stressed people or not on their daily life. The reported stressed and years of residency variables were accessed in the sociodemographic questionnaire along with age, sex, know auditory disease, medication and area of residency (Table II).

Statistical Analyses

The software used for statistical analysis was Statistical Package for the Social Sciences (SPSS) version 27. The data was analyzed using descriptive statistics. To characterize the quantitative variables, we used measures of central tendency (mean and standard deviation) and, for qualitative variables, absolute and relative frequencies. To graphically illustrate the variables, we used frequency tables. For the variables, at inferential level, several statistical tests were performed, such as: a) comparison of categorical variables measured at the same time, in two different groups (city and rural) - chi-square test, b) comparison of continuous variables measured at the same time, also in the two different groups of the sample - T test for independent samples and c) binomial test in the variable area of residence. Exposure time has been taken into account.

Ethics

This study was approved by the Porto Higher School of Health ethics committee on 01/02/2021 with the process number CE0055A (Attachment I) and was carried out according to the ethical presupposes of the Declaration of Helsinki. A signed informed consent was obtained from each participant, where all the interventions were

Table I - Inclusion and exclusion criteria; CNS: central nervous system.

***Tabela I -** Critérios de inclusão e exclusão; SNC: sistema nervoso central.*

Inclusion criteria city group	Inclusion criteria rural group	Exclusion Criteria
Age over 18	Age over 18	Known auditory structural disease
Residents in the metropolitan area of Porto	Residents in Cinfães or Castelo de Paiva	Chronic disease-causing sleep disturbances
		Medication provoking auditory alterations
		Medication with action on the CNS

Table II - Variables; PSQI: Pittsburgh Sleep Quality Index.

***Tabela I -** Variáveis; PSQI: Índice de qualidade do sono de Pittsburgh.*

Variables	Operationalization	Classification	Type
Age	Years	Continuous quantitative	Independent
Sex	Male/Female	Nominal qualitative	Independent
Known auditory disease	Yes/No	Nominal qualitative	Independent
Medication	Yes/No	Nominal qualitative	Independent
Years of residency	Years	Continuous quantitative	Independent
Area of residency	City/Rural	Nominal qualitative	Independent
Reported Stressed	Yes/No	Nominal qualitative	Independent
PSQI Components	Scale from 0-3	Discrete quantitative	Independent
PSQI total Score	Scale from 0-21	Discrete quantitative	Independent

explained, information about the goal of the study as well as the importance of the individual's participation, always guaranteeing the confidentiality of the data.

Results

A hundred and one responses were obtained on the sociodemographic data questionnaire, of which, after analyzing the inclusion and exclusion criteria, 84 eligible individuals for the 2nd questionnaire (PSQI) were selected and 17 volunteers were eliminated, 10 due to their geographic location, which were cities outside the district of Porto, 7 for use of medication with action on the CNS that could have an influence on sleep cycles (one of them also excluded due to their geographic location) and 2 for known structural auditory disease (one of them also excluded due to their geographic location). These 84 people were contacted via email, where they received the link to the Pittsburgh Sleep Quality Index, and responses were obtained from 65 people, in March 2021. Of these 65 people, 32 form the rural group and 33 the city group (fig. 2).

The PSQI and sociodemographic data questionnaire answers were submitted to statistical tests using SPSS version 27 that made the characterization of the sample and the assessment of the sleep quality of the participants possible, and those results are as follows.

Studied Sample description

Adjustment is an important factor that influences the effects of noise on the quality of someone's sleep (Muzet, 2011). Even though some investigators claim exposure to road traffic noise doesn't result in adjustment, some recent studies have provided evidence that it does happen sleep (Muzet, 2011). In these studies, adjustment could be observed when subjective sleep parameters were taken into account and would happen from exposures that may vary from weeks to a few months sleep (Muzet, 2011). The variable years of residency was used to document the possibility of adjustment to noise that can occur in residents and that may vary in individuals based on interindividual variations in the sensitivity to noise sleep (Muzet, 2011). As shown, the mean of this variable is above 10 years in both studied areas (Table III). We could not find a scientific consensus on the time needed to develop adjustment, with it varying from weeks to months or even years in different studies. Thus, even though being statistically significant, the variable years of residency does not present a bias because, if occurring, the adjustment would be present after 10 years of residency. The rest of the variables taken into account do not show statistically significant differences, and so, are not considered biases either.

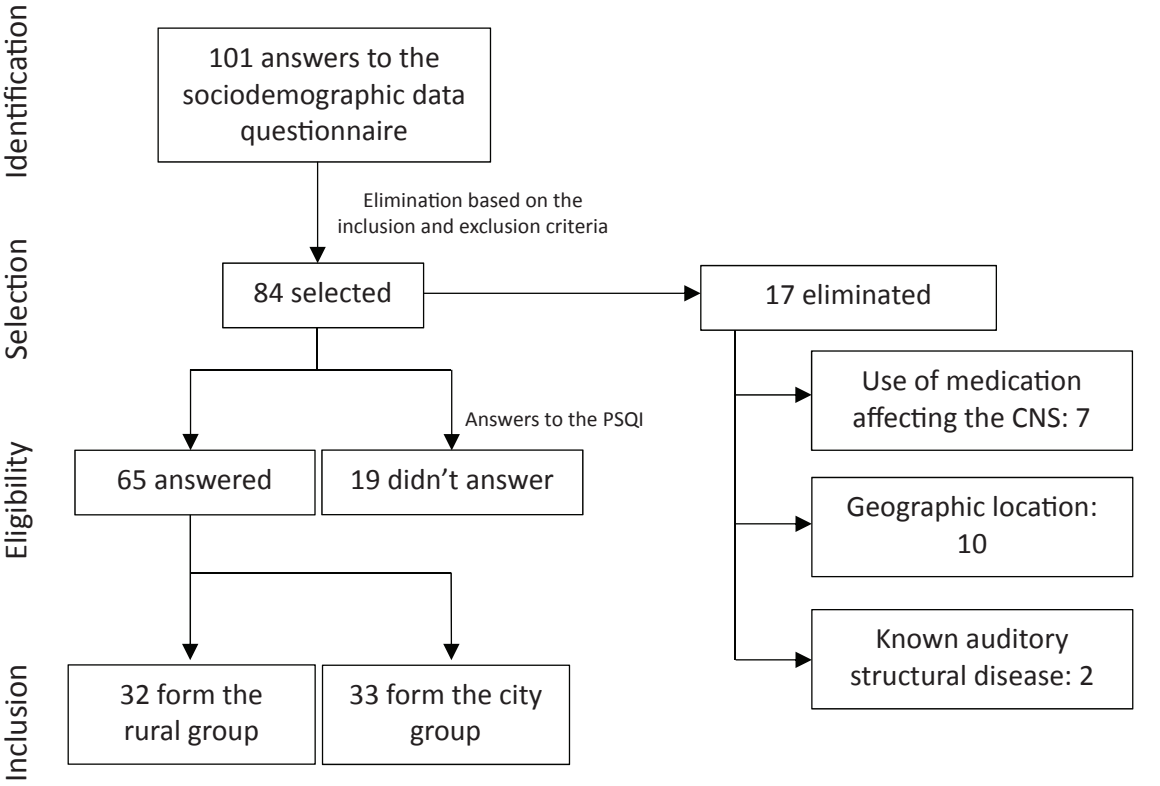

Fig. 2 - Participants FluxogramFlowchart; CNS: central nervous system.

Fig. 2 - *Fluxograma dos participantes; SNC: sistema nervoso central.*

Pittsburgh Sleep Quality Index

The results of the global score found that both groups did not have statistically significant differences. The city sample global score was 6.1 (2.4) (Mean (SD)) and the rural sample was 5.9 (2.6) (Mean (SD)) with a P-Value of 0.73. Even though the city global score was higher than the rural global score, which was expected, it represents a residual difference with no statistical significance. Both groups showed a global score over 5 points, which indicates a poor overall sleep quality, slightly worse in the city group (Table IV).

Even though the 7 components showed a worse result, meaning a generally poorer quality of sleep in the city group, the only statistically significant association found was in the drowsiness and daytime dysfunctions component of the PSQI score (P-value=0.046). As for the 6 other components, no statistical evidence was identified, showing no indications that these parameters are more affected when living in Porto when compared to living in rural areas where the exposure to environmental noise is below 45dB.

Discussion

Our study showed that respondents from city area had significantly more drowsiness and daytime dysfunctions but did not show a bigger predisposition to difficulties falling asleep, a longer time spent in bed, a worse sleeping efficiency, sleeping disorders or use of medication to aid falling asleep (Table IV). They also did not show a significantly poorer sleep quality (PSQI total score). Both samples had a score above 5 points which means a poor sleep quality in the overall population.

In studies on this area, two different approaches and methodologies are commonly chosen, laboratory experiments and field research (Jakovljević *et al.*, 2006), our study falls in the second category. Field research has a powerful advantage over laboratory experiments because noise is an environmental threat that is everywhere in our cities and so it makes the understanding of noise hazards in a daily life setting possible (Jakovljevic *et al.*, 2006). But this method shows disadvantages as well, the most significant being the fact noise is usually only measured outside, making it very hard to access the

Table III - General characteristics of the studied population sample by residential area; SD: standard deviation; †: Student's t test for independent variables; *: p-value statistically significant at 0.05.

Tabela III - *Características gerais da amostra da população estudada por área residencial; DP: desvio padrão; †: Teste t de Student para variáveis independentes; *: Valor P estatisticamente significativo a 0,05.*

	Area		
General characteristics	Rural	City	P-value
No. of residents (n=65)	32	33	≅ 1
Years of Residency (Mean (SD))	21.9 (2.3)	14.5 (9.3)	<0.001†*
Age (Mean (SD))	22 (2.2)	22.5 (3.7)	0.58
Sex			0.32
Male (%; n=28)	50	36.4	
Female (%; n=37)	50	63.6	
Reported stressed			0.61
Yes (%)	37.5	30.3	
No (%)	62.5	69.7	

Table IV - PSQI results of the studied population sample by residential area; p-value was determined using Chi-square and Fisher exact tests; *: P-value statistically significant at 0.05.

***Tabela IV** - PSQI results for the studied population sample by residential area; p-value was determined using Chi-square and Fisher exact tests; *: p-value statistically significant at 0.05.*

	Area								
PSQI Components	Rural				City				P-value
Scores %(n)	0	1	2	3	0	1	2	3	
Subjective sleep quality	6.3(2)	71.9(23)	21.9(7)	0	6.1(2)	69.7(23)	21.2(7)	3(1)	1
Sleep Latency	9.4(3)	43.8(14)	15.6(5)	31.3(10)	15.2(5)	33.3(11)	39.4(13)	12.1(4)	0.072
Sleep Duration	62.5(20)	25(8)	9.4(3)	3.1(1)	51.5(17)	33.3(11)	15.2(5)	0	0.55
Sleep Efficiency	71.9(23)	21.9(7)	3.1(1)	3.1(1)	66.7(22)	30.3(10)	0	3(1)	0.78
Sleeping Disorders	9.4(3)	87.5(28)	3.1(1)	0	9.1(3)	87.9(29)	3(1)	0	1
Use of sleeping pills	87.5(28)	0	9.4(3)	3.1(1)	93.9(31)	0	6.1(2)	0	0.51
Drowsiness and daytime dysfunctions	21.9(7)	62.5(20)	15.6(5)	0	6.1(2)	54.5(18)	39.4(13)	0	0.046*

actual levels inside people's houses, as well as the fact that subjective measures are not as reliable as objective ones (Jakovljević *et al.*, 2006).

Jakovljević and colaborators performed, in 2006, a similar study. On their research there were no significant differences reported between the samples according to the residential area in the duration of sleep, sleep latency or use of sleeping pills (Jakovljević *et al.*, 2006). The rest of the parameters showed a significant difference (Jakovljević *et al.*, 2006). Correlation analysis in their study showed that noise annoyance was significantly related to all sleep quality parameters except for average duration of sleep and the use of medication to fall asleep and also that subjective noise sensitivity was significantly correlated with sleep latency, tiredness after sleep and the use of said medication (Jakovljević *et al.*, 2006). These parameters, annoyance and subjective noise sensitivity, were not evaluated in our study, which could have given important additional information to understand the results better and should be considered in all future studies in the area. The fact that there were no differences in sleep latency between respondents from the city area and the rural area could be due to adjustment to nocturnal noise, considering long-term residence from the subjects in the respective areas (Jakovljević *et al.*, 2006). The poorer sleep quality and daytime dysfunctions such as tiredness after sleep have been previously reported (Öhrström, 2004). The changes that occur in sleep stages, for example, the shortening of time spent in stage 3 and REM sleep and subsequential increase in stages 1 and 2 may explain these late effects of a poor sleep quality (Jakovljević *et al.*, 2006).

The non-existing difference in the use of sleep medication between the two samples may imply that resorting to this means is more of a personality trait, such as neuroticism, and not as much because of the involving environment (Jakovljević *et al.*, 2006). Highly significant correlation coefficient between neuroticism and use of sleeping pills in Jakovljević and colaborators study supports this assumption, showing that the control of such variables as subjects' personality may have a major importance in contextualizing the results (Jakovljević *et al.*, 2006). Not only is the level of noise to which the residents are exposed important, but also, the time of day when this exposure takes place, being a factor influencing the quality of sleep (Jakovljević *et al.*, 2006).

On the other hand, Han and colaborators in 2015, in a study comparing residential, construction, commercial and transportation hub areas of China, found that among the four areas, sleep quality was reported worse in the transportation hub area and there was no statistically significant difference between the other three. All areas had noise levels above the regulation limit and the transportation hub area was the worst (Han *et al.*, 2015). This proves that within the city, different areas have different noise levels that may influence a lot the affection on sleep quality, demonstrating that an important consideration to make in future studies is to account for this fluctuation within areas and describe as good as possible where people actually live, unfortunately, in our study due to ethics and data protection polices, it was not possible to specify the participants exact area of residency.

In another investigation carried by Pirrera and colaborators in 2014 using questionnaires as PSQI and the Epworth Sleepiness Scale showed no significant difference in any of the parameters between groups (quiet and noisy). This study also found that outside noise levels were not reflected inside people's bedroom (Pirrera *et al.*, 2014). These results show that noise measures on the street may not represent noise levels inside the houses and better strategies have to be used to access these levels correctly because a single use of an average sound pressure level as noise indicator in a field study is not sufficient to draw conclusions on noise induced sleep problems (Pirrera *et al.*, 2014). Other questionnaires and sleep logs used in their study showed different results, indicating an overall worse sleep on the noise group volunteers, showing that using more questionnaires, or different ones, may help characterize these populations sleep quality better. Pirrera and colaborators, as Jakovljević and colaborators, also found that individual degree of noise sensitivity is a major determinant for outcomes in noise and sleep research. Overall, Pirreras and colaborators' study shows that the impact of noise on sleep is only modest.

Preventive measure should be taken focusing on the decrease of nocturnal noise to levels between 30 and 45dB maximum (Jakovljević *et al.*, 2006). Socially responsible departments in our cities should enforce the regulation on noise established by the government and improve the available technology to reduce noise pollution as much as possible and assure the well-being of the population (Han *et al.*, 2015). The residents themselves should self-educate on the matter and take all measures available to reduce the hazards of this pollutant (Han *et al.*, 2015). We hope that further research provides more information on policies/interventions as well as health impacts evaluations (Han *et al.*, 2015).

Because this study was performed, in part, during a national lockdown due to the COVID-19 pandemic, people's sleeping patterns may be altered to some degree due to higher levels of stress, different sleeping schedules provoked by working from home, or not being at work at all, a completely different daytime and social life and so many other factors that the pandemic brought on. Also, if our study had a more representative sample of the population, perhaps the results would have been

more significant, given their tendency to be worse on the city group. Not only improving the amount of people in the samples but also only using residents specifically from the city of Porto, which was not possible, could have made a difference. The loss of volunteers on the process of emailing the second questionnaire after the sociodemographic data one could have been avoided if we had presented both questionnaires on the first contact with the individual.

This study, because it was one of the first performed in Porto, opens the path to more investigation on the subject not only in this city but in Portugal, with special attention to the recommendations on this discussion. We showed that noise has an implication on people's sleeping patterns as it affects their daytime life and productivity and has to be better controlled by the authorities to give the residents the best environmental conditions possible to not affect their health negatively.

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