Annoyance Caused by Exposure to Road Traffic Noise: An Update

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This paper addresses the negative effects resulting from the exposure to road traffic noise on people's well being with a focus on annoyance. Following the observations that noise exposures engender physiological reactions typical of stress, the non-auditory effects of noise on humans are generally viewed as being stress-related, and annoyance is one of the first and most direct reactions to environmental noise. In general terms, it is found that the continuous exposure of people to road traffic noise leads to suffering from various kinds of discomfort thus reducing appreciably the number of their well being elements. However drawing such a conclusion is hindered by difficulties when non-acoustical factors like sensitivity, socio-economic situation and age are also taken into account along with the usual acoustical factors of road traffic noise. The results of several decades of research on this topic have permitted lately to establish a quantitative relationship between the objective quantities characterising road traffic noise, namely the day to night noise level, and the human subjective reaction to it as expressed by the percentage of highly annoyed people. These findings are important at both the society and the individual level in as much as they may help in regulating in a more efficient way the planning of road traffic activity in order to secure minimum comfort to the affected population.
Keywords: Road Traffic Noise, Annoyance, Non-acoustical Factors

Introduction

In modern times, and with regard to the increasing number of vehicles circulating in urban road networks, road traffic noise is recognised as a serious health problem and raises several aspects of general public awareness. The evidence that noise interferes negatively with people's daily activities is experienced by almost everybody, and methodical research has brought further irrefutable proves to this fact. This problem is exacerbated when one knows that nowadays the number of vehicles circulating in the urban network of roads is steadily increasing whereas at the same time the number of quiet hours during night time has a tendency to diminish, although at a somehow slower rate. Hence, expressed in terms of social cost, the adverse effects of noise on people in general and of traffic noise in particular result in a reduction of their elements of well being. According to the World Health Organisation, "health is a state of complete physical, mental and social well being. Governments have a responsibility for the health of their people which can be fulfilled only by the provision of adequate health and social measures". Noise is in this respect more than just nuisance, and it constitutes a danger that is real to people's health by producing both physical and psychological stress. Between the two decades of the seventies and the nineties, the effectiveness of vehicle noise emission regulations has permitted to reduce progressively and appreciably the maximum permitted noise level of cars. However, the reduction in actual road noise levels does not follow this trend, and consequently smaller achievements are to be expected for the few next coming years. Therefore, noise control programmes must include strategies such as land use planning and traffic restraints (Berge, 1994).

General adverse effects of noise on people

Noise is usually the term attributed to mean any

kind of irritating and obtrusive sound, and noise pollution is one of the environmental concerns to many of us. A consideration of the differences between individuals and the inclusion of acoustical and non-acoustical factors makes it however difficult to assess the effects of noise on people. Noise is in general the term by which it is designated any undesirable sound. A more technical and objective distinction between an acoustical signal in its wider sense and noise stems from the fact that the former has particular characteristics both in time and frequency, and which are usually lacking in the case of noise. However, there still is some ambiguity when reference is made to traffic noise because of the obvious fact that although random, traffic noise has its distinguished spectral and temporal uniformities. In broad terms, these effects can be classified into three main categories: psychological (attitudinal), social (behavioural) and physiological effects. Noise is thought to evoke physiological responses which are characteristic for stress (DeJoy, 1984; Saadu, 1996) and this has led several researchers to consider the hypothesis that long-term noise exposure contributes to the genesis of serious diseases. However, the controversy of the results of epidemiological studies permits to keep this hypothesis only under the assumption of a particular noise sensitivity presented by the affected population (Griefahn and Di Nisi, 1992). However, it is a well established fact that across measurement techniques and cultures, noise-reaction relationships show a remarkable similarity (Job, 1988).

The auditory effects of noise on people have been quite well-known for some decades ago (see for instance Kryter, 1985) but, becoming a relatively accessible personal need, cars are invading the urban landscape increasingly, contributing thereby to a higher level of noise pollution than any other man-powered engine. Therefore, most of today's research on noise control is focused on noise from transportation with special emphasis on that of urban traffic. One should note that until the late seventies or so, active research on the hazardous effects of traffic noise on people focused mostly on auditory-related topics, without however neglecting the non-auditory health dimensions of the problem.

Annoyance resulting from noise exposure: concepts and facts

Used in connection with environmental effects, the term annoyance continues to be the subject of some ambiguities. Annoyance is in general used to mean all those negative feelings like disturbance dissatisfaction, displeasure, irritation and nuisance, but according to Guski the list may even be made longer by including somatic damage, loss of control and orientation, negative assessment of the noise source and high sound levels (Guski, 1999). Noise annoyance may be conceived as an emotional process as this reaction is closely tied to the affective experience of the individual towards the noise source. Evidence of this assertion stems from investigations on aircraft noise where there has been found the existence of some correlation between the judgement of annoyance caused by aircraft noise and the fear of aircraft accidents (Leonard and Borsky, 1973; Miedema and Vos, 1999). In relation to this, noise annoyance may be given an attitudinal dimension as the judgement of annoyance severity often depends on the acquired verbal information about the source of noise (Jonsson and Sörensen, 1970). This relation noise-subject may be extended through considering the dependence of the subject to the source of noise. Hence, subjects who for instance depend economically on the source of noise tend to feel less annoyed by it than those who do not.

Environmental noise is a subject of continuous and increasing concern to people as annoyance and sleep disturbance are the direct and most important of its health effects. Figure 1 presents a simplified model for the main relationships between noise, its effects and the social context of people. The diagram in this figure shows that noise may be represented as the cause of some direct effects and/or more delayed reactions in the form of annoyance.

It can further be seen from the same diagram that a person busy with some activity may react to noise either immediately, or in a more discrete

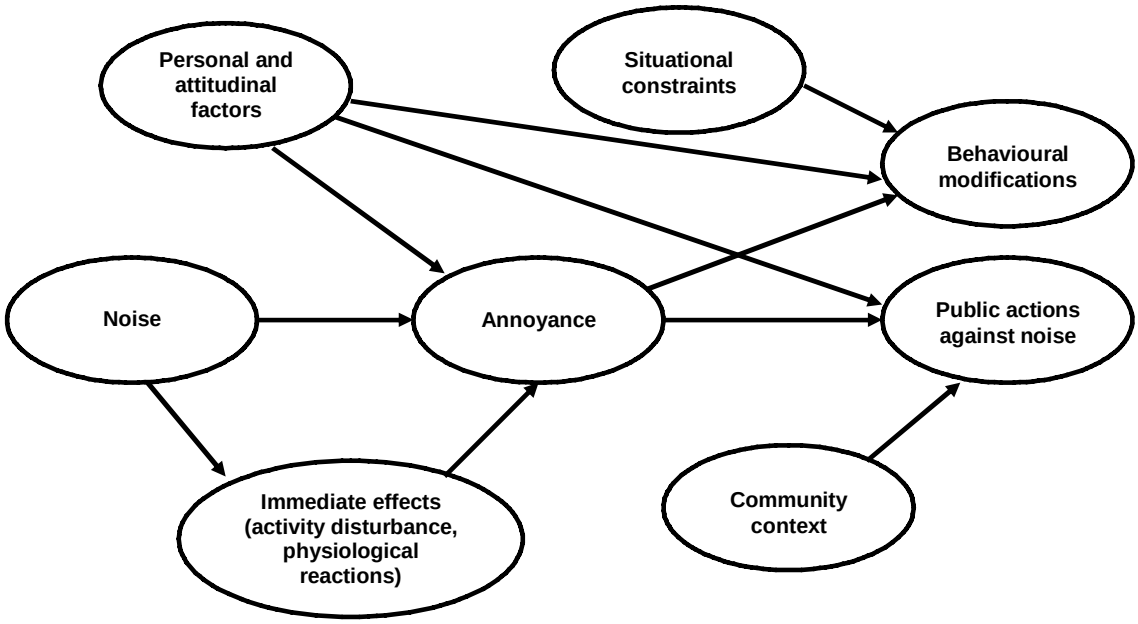

Figure 1. A simplified model for noise and its effects in community. From (Nelson, 1987).

manner in the form of annoyance. Several publications have reported the efforts of researchers for developing similar models helping predicting the degree of annoyance by people as a function of exposure to different noise sources. Hence, Hall et al. were able to synthesise a model that showed a strong relationship between activity interference and the probability of annoyance (Hall et al., 1985). Izumi and Yano used also a "path model" to explain the variations in the annoyance responses and to confirm the strong effect of sleep disturbance to road traffic noise (Izumi and Yano, 1991).

The set of personal characteristics may also cause some annoyance but not necessarily physiological reactions. Consequently, annoyance may lead to some obvious change in one's actions, e.g. shutting the window to isolate the source of noise (or that people with less tolerance to noise tend to move away to quieter areas), or it may engender less evident effects in the form of emotional reactions. Annoyance is in general defined as a feeling of displeasure that is tied to a cause that is believed to affect negatively an individual or a group of individuals. Hence, it follows that judging the degree of noisiness caused by a change in sound level contains two components, the first of which is cognitive and is concerned with the expectations for the sound to meet some characteristics for an ideal environment. The other component is pure emotional, and is related to the change in mood of the affected person as caused by the exposure to the noise event.

The fact that noise is a serious environmental pollutant urged governments, especially in the industrialised world, to set organisations and commissions acting for the regulation of people's exposition to noise (Bryan and Tempest, 1973; Fidell, 1996; Pettersson, 1997; Saadu et al., 1996; SOU, 1974). However, predicting a community's reaction to urban traffic noise is not easily made based only on simple quantitative measures. The major aim of collecting data over the various physical characteristics of urban noise from different parts of the world during the early seventies was to assess the real size of the problem, and to possibly process suitable descriptors for the subjective judgement of noise exposure by means of simple objective measures. This mission, as pointed out earlier, is not easy to fulfil when individual differences come into play. Several attempts have thus been made with the goal of correlating between

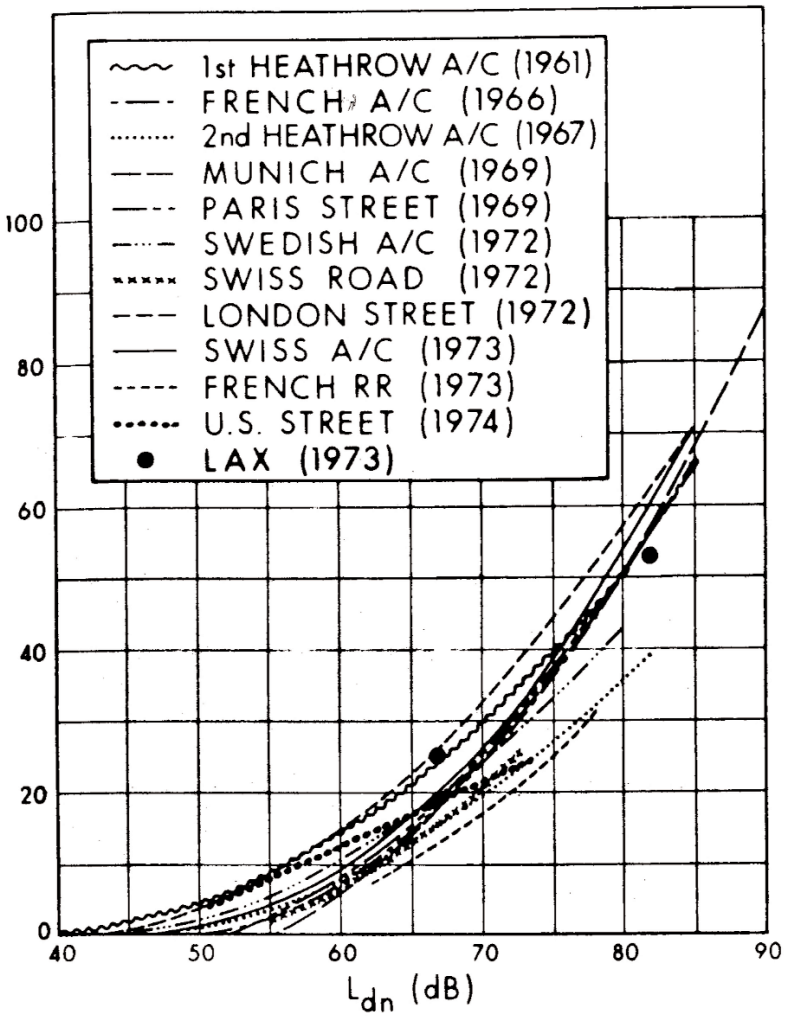

Figure 2. Revised analysis of surveys using highly-annoyed response as the response falling on the 27% of the annoyance scales. From (Schultz, 1978).

subjective annoyance and noise exposure (Langdon and Scholes, 1968; Matschat et al., 1977; Osada, 1991) and after reviewing numerous surveys, Schultz was the first to be able to synthesise a single curve for the relationship between community reaction and noise exposure (Schultz, 1978), see Figure 2.

When attempting to make in a survey of population sample such as the measurement of the degree of annoyance caused by traffic noise, the questionnaires and interviews to be answered by the test volunteers are also important. There are several models of such questionnaires. Fields categorises them under several types (fields, 1984), but among the simplest and most widespread schemes in use is to present a judgement scale of the degree of annoyance. This scale may be set to a range for instance in the order: “Very much”, “Moderately”, “A little”, and “Not at all”, and to ask the person to mark where his/her judgement is the more likely to be. An example of a five-level annoyance scale curve as a function of noise level is shown in Figure 3 for different noise ratings. A more subtle variation of this scheme is to refine the scale “Not at all disturbing” to “Unbearable” by several steps (usually between 7 and 10). If on the other hand the matter of investigation is a noise already causing a collective complaint, the investigator in this case can rely on asking his subjects a single question which example-wise could be formulated as: “Are you much annoyed by this noise ?”. The results are in this latter case presented on a percentage-scale, a method used by Schultz in his review study (Schultz, 1978) as presented in the curve of Figure 3 above, and several others subsequently (Nemecek et al., 1981).

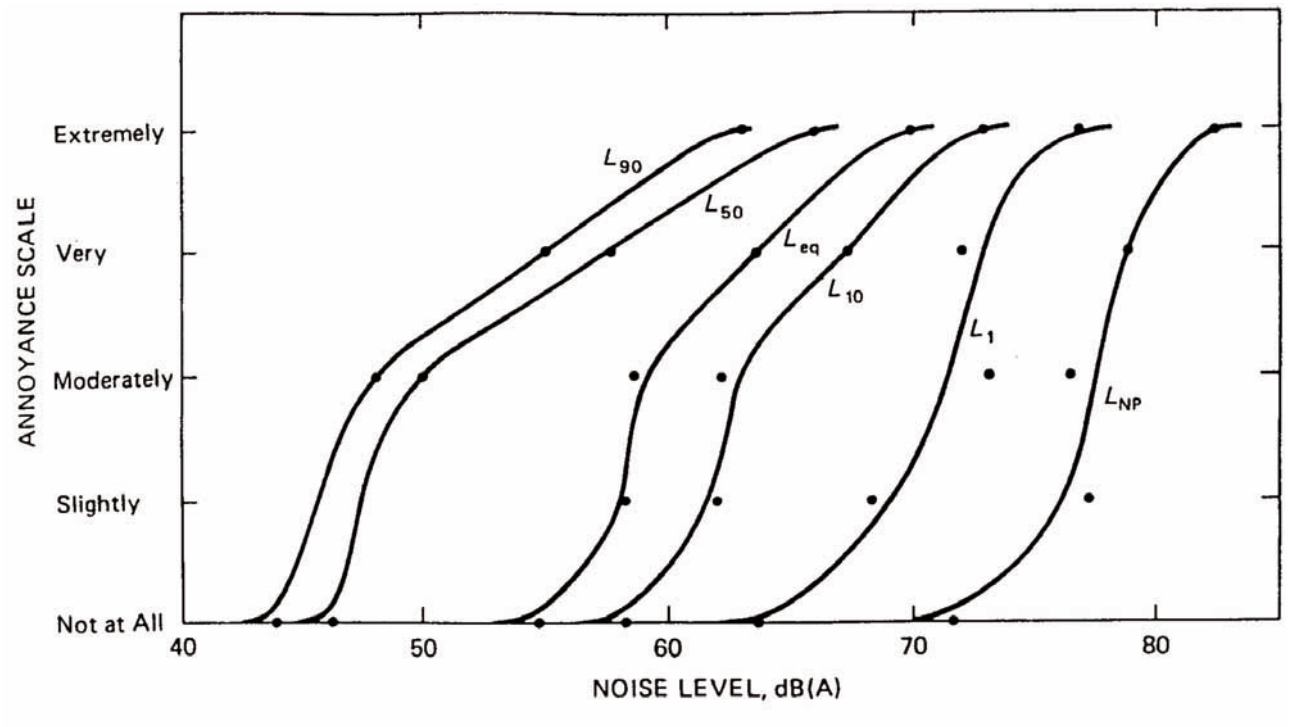

Figure 3. Annoyance as a function of noise level. From (Crocker, 1997).

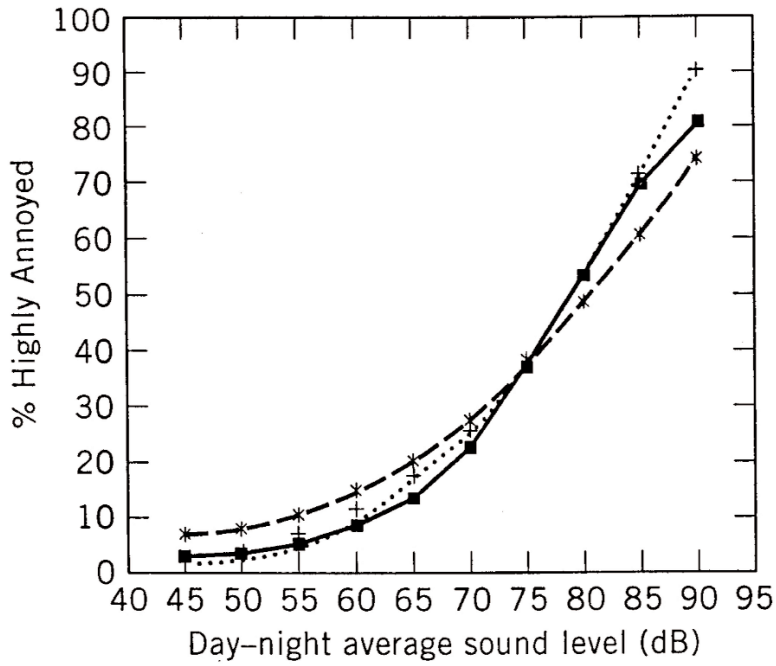

Figure 4. Curves representing the percentage of people that were highly annoyed by noise as function of day-night exposure level. —■—■—: Eq. (8) Finegold et al. 1994, ····+····: Schultz, 1978 and : —*— Fidell et al. 1991. From (Finegold et al., 1994).

Since the publication of Schultz' review analysis, more data have become available, and Fidell et al. processed 453 data curves compared to the 161 available earlier to Schultz. A later study conducted by the US Air Force resulted in an equation for the curve of the percentage of the population that is highly annoyed, *%HA*, as a function of day-night average sound level, *DNL*. This equation is formulated as:

$$\%HA = \frac{100}{1+\exp(11.13-0.14DNL)} \qquad (1)$$

and its curve is plotted in Figure 4 alongside with other curves resulting from other earlier studies.

More recently, Miedema and Vos processed a synthesis of curves for the correlation between day-to-night noise level and percentage of highly annoyed population for the three most common transportation noise sources: road traffic, train and aircraft (Miedema and Vos, 1998). Considering that the degree of annoyance is zero for levels around or below 40dB-45dB, the study permitted to elaborate simpler *DNL*-annoyance relation. Hence assuming that annoyance is zero at a level of 42 dB (this value may be compared to the more cautionary 35 dB value taken by Schultz in his synthesis), the equation for road traffic noise would be:

$$\%HA = 0.24 \cdot (DNL - 42) + 0.0277 \cdot (DNL - 42)^2 \quad (2)$$

A comparison between the exposure implications for the different noise sources permits from this same study to conclude that the rate of increase of annoyance with the noise level is higher for aircraft than road traffic which in its turn is higher than railway.

In his review of the results from studies that lasted over three decades, Job concludes that the studies, although carried in different nationalities and with different measurement techniques have led to almost similar results (Job, 1988). The studies may be subdivided into two main categories: in the field, where the subjects are answering the questionnaires in their homes, and in the laboratory where the subjects are subjected to artificial experimental conditions. In his analysis of several different surveys on the effect of the number of noise events on people's reactions, Fields identified a major difference between rating the results under field or laboratory conditions. In the field, residents attempt to concentrate on ongoing activities, whereas in the laboratory subjects tend to notice each noise event. In the field, people use adaptive mechanisms helping in ignoring many noise events for long times because the noise becomes routine (Fields, 1984). In interpreting the results of these different kinds of studies on the relationship between noise and reaction, Job stresses on the fact that authors, with a few exceptions, often consider many other issues of the problem like, for instance, culture or socio-economic status, only as secondary topics and instead take considerable attention to only the classical factors like noise indices, or scales of community reaction. Hence, in the light of the latest findings, and in order to achieve a better understanding of the human reactive mechanism to noise exposure, more factors than just the noise level index must be taken into consideration. Variables such as previous experience and attitudes towards the noise source account for more variation in reaction than does just noise exposure for example.

Stansfeld et al. support the observation that noise sensitive individuals are likely to be more annoyed by traffic noise than people who are less sensitive to it (Stansfeld et al., 1993), and this replicates the outcomes of several other studies (Griffiths and Langdon, 1968; Langdon, 1976b; Matsumara and Rylander, 1991; Öhrström et al., 1988). There are also difficulties associated with the measurement of noise sensitivity, but it is worth mentioning in this respect the scale developed by Weinstein, which has been used in road traffic noise assessments, and where the respondants are asked to state their agreement or disagreement on a scale for different items related to sensitivity to noise in daily life (Weinstein, 1980). In an investigation made with the purpose to examine the effect of changed traffic noise conditions on subjective response to noise, Raw and Griffiths found that self-related sensitivity to noise is apparently the most important individual characteristic for predicting dissatisfaction with road traffic noise. From this same study, the authors confirm furthermore that sensitivity to traffic noise is independent of noise level, and that based on several measures of response to noise, no advantage can be gained by combining several scales (dissatisfaction, loudness and interference in the investigation) to produce a annoyance index (Raw and Griffiths, 1988). To give stronger evidence on the importance of sensitivity, data from a random sample population taken from a survey on a medium-sized city show that the proportion of

sensitive people to noise may be estimated to be about 25%, which is a quite significant figure (Matsumara and Rylander, 1991; the city-case was actually Gothenburg, Sweden's second largest city). These findings are to a large degree ascertained by more recent reviews where particular weight is given to the factor of sensitivity in even wider investigations on noise induced annoyance (Miedema and Vos, 1999).

The control variable in assessing the traffic noise reaction of people is of course primarily the sound pressure with its level, frequency and time characteristics. Annoyance is not only dependent on the noise level (Lambert et al., 1984; Osada, 1991) so that reducing exposure levels through erecting noise barriers has positive effects (Yano et al., 1997), but also the length of the time period of exposure is also a factor to be accounted for (Fields, 1993). There has been found a correlation between noise and annoyance, and this correlation becomes even stronger for high levels of road traffic noise reaching inside dwellings. More specifically, people can get annoyed by noise for *DNL* below 55 dB (Fields, 1993) and that levels above 65 dB(A) may induce forced behavioural responses like moving to quieter rooms or blocking sound transmission paths (Lambert et al., 1984; Langdon, 1976a). Jonah et al. found also that the correlation between noise level and individual response is improved a little by incorporating individual differences measures in the analysis (Jonah et al., 1981). However, it has also been concluded from independent studies that the best correlation between traffic noise at moderate levels and community reactions was found for the A-weighted sound levels, and for L_{eq} and L_{10} evaluations (respectively the time averaged over a long period of time and the level which is exceeded over 10% of the total measurement time). Therefore, and due to their relative simplicity, the A-weighted level, L_{eq} and L_{10} have sometimes been recommended as useful predictors of community response to traffic noise annoyance (Rylander et al., 1976, Watts and Nelson, 1993; Yaniv et al., 1982), the observations which were also proven for the case of free flowing traffic (Yeowart et al., 1977). Gjestland proposes instead a combination of L_{eq} and L_{max} (Gjestland, 1987), whereas Eldred proposes the L_{eq} as a principal component of what he introduced as the normalised *DNL* (Eldred, 1975).

The generalisation of the L_{eq} -annoyance relationship is made more evident by the high correlation between L_{eq} and annoyance which was also found in experiments under artificial laboratory settings where simulated road traffic noise was presented to test subjects (Labiale, 1983; Rasmussen, 1979), and more specifically that the L_{eq} index may be used as an adequate measure of nuisance for traffic noise distributions whose L_{10}-L_{50} values range from 0.4 to 24.6 dB(A) (Pearsons, 1978). It has also been conjectured that the use of L_{eq} is limited by a possible disadvantage which is its inability to account for the background noise situations. In conjunction with this, it may further be added that the relative importance of individually noisy vehicles in the mainstream road traffic noise is determinant for community annoyance. Hence, noisy vehicles cause annoyance in excess relatively to their contribution to the overall traffic noise level, while the background traffic noise causes annoyance even when none of the constituent vehicles is especially noisy (Hede, 1984). Sato et al.'s more recent analysis agrees partly with these conclusions, namely that annoyance may be reduced through controlling the number of noisy vehicles, whereas the effect of volume flow is lesser (Sato et al., 1999). Similar conclusions have been known from studies where judgements of nuisance caused by aircraft noise has been found to be influenced by varying road traffic noise backgrounds (Rice, 1975). Related to this issue, Fields re-examined lately the publications of many field- and laboratory surveys on several different environmental noises. He found that the residents' annoyance reactions to an audible (target) environmental noise is scarcely reduced by the presence of another (ambient) noise in residential areas. Laboratory studies show also from this analysis that the perceived loudness of tones and the annoyance with individually presented noise events are reduced in the presence of background noise (Fields, 1998).

The universal use of the L_{eq} measure as a unifying index for noise annoyance appears also not to be strongly substantiated for all types of traffic noise, at least when considering the results of laboratory experimentation (Rice, 1977). A further aspect of the problem is that a study on residential areas heavily exposed to road traffic noise found that measures such as L_{eq} and *DNL* were unsatisfactory indices in explaining the variation in annoyance responses (Izumi and Yano, 1991). A socio-economic consideration of this aspect gives evidence to the fact that people living in detached houses tend to be more annoyed by road traffic noise than apartment house residents who instead are more affected by neighbourhood noise (Carvalho and Rocha, 1997). Moreover, in studying seasonal effects on annoyance, noise is in general considered as a problem in any season (Saadu et al., 1996) and no evidence has been found for the effect of different seasons of the year or of open or shut windows (Griffiths et al., 1980). Depression, a psychological effect of the noisy environment on residents which is more lasting than annoyance, was on the contrary found to affect less severely people having their windows away from traffic activity than those having their windows facing it (Öhrström, 1991).

Conclusions

This paper reviewed the various effects of road traffic noise on people's well being with a special emphasis on annoyance. Though people seem to adjust to noise by ignoring it, the ear, in fact, is always operative by transmitting signals to our nervous system stimulating therefore reactions to noise from our bodies. The fact that irritability is a very apparent reaction to noise has made of legislators to often consider public annoyance as the basis of noise control programs. The annoyance that humans feel when faced with noise is the most common outward symptom of stress building up inside them. Therefore these symptoms may be considered as indications for possible more serious health problems.

Among the direct and most obvious effects of noise on awake subjects, annoyance is in general the one which interferes negatively with the individual's speech communication, on concentration ability and consequently on the performance of tasks. Variables influencing the subjective judgement of a situation where prevails noise from traffic, like the weight of running vehicles, traffic fluidity and time of the day, may also contribute to the degree of annoyance and to causing sleep disturbances during the night with resulting after effects the following day. However, some recent reviews suggest that despite different measurement techniques, and which are used within different cultures, the relationships noise-reactions show in general some similarities. Factors like noise sensitivity and attitude towards the noisy situation, have presumably some potential effect on modifying noise reactions and account for more variation within data surveys than do noise exposure parameters.

The processing of a large number of quantitative noise scores allows for a versatile number of tools to make objective evaluations under specific noise situations. In the case of traffic noise measures of daily averaged sound levels have most of the time been of much concern. Although the proliferation of these noise-rating indices has the common goal to predict the general adverse human response, it has, at least during its early development, contributed to further complicate the development of noise abatement and control programs. Nevertheless, the noise index that comes most often in the literature on noise/annoyance relationships is still L_{eq}, though several late reports suggest it be used with some cautions when matters come to drawing conclusions for serving general purposes. The relative simplicity of evaluating L_{eq} from the time history of the noise signal is perhaps a major reason for its selection among many related noise-rating indices. These indices belong to a group based on the assumption that averaged sound levels over equal time periods produce equivalent adverse effects. However, it is known that, especially in the case of road traffic, noise may stand for a wide range of variability in the sound level during the period of observation. Hence in the absence of better

predictors, researchers in environmental noise believe thus to have some convincing grounds for a continuing reference to the L_{eq} index.

Despite the different natures of the studies on induced traffic noise annoyance, and conducted across different social, cultural and urban environments, and also for noise emanating from different means of transportation, it has lately been possible to develop models that predict the acuity of annoyance following diurnal noise exposure. In the studies conducted by Finegold et al. (1994), and more recently by Miedema and Vos (1998), the Day to Night Level, *DNL*, was the parameter which gave the best correlation for the percentage of highly annoyed individuals, and again this descriptor is a refined version of the L_{eq} index. The *DNL* accounts also for the nocturnal noise exposition and gives it in fact a higher score than that of daytime.

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