Evaluating Health Effects of Noise from High Speed Railways

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ABSTRACT

The UK Government is proposing to build a new high-speed (360 km/h) railway to provide an increase in the capacity of the rail network and better connectivity to cities in the north and south of England. The construction and operation of any major infrastructure project may have consequences for the people who live and work within its vicinity. Phase One of the scheme is most advanced and an Environmental Impact Assessment (EIA) and a Health Impact Assessment (HIA) have been published [http://www.hs2.org.uk/hs2-phase-one-hybrid-bill/hybrid-bill]. These identify and evaluate likely environmental and health effects and identify appropriate and reasonably practicable measures either to prevent adverse effects occurring or to reduce them. Mitigation is focused at source in terms of train and track low noise specification and noise barriers. This paper reviews the evidence on the possible effects of noise from high speed trains on physical health and social well-being and, in particular: annoyance, sleep disturbance, cardiovascular disease, mental illness, and cognitive impairment in schoolchildren. It also reviews the scientific literature on exposure response relationships which could be used to assess the scale of such effects and explains how the evidence base has been applied.

INTRODUCTION

According to the World Health Organisation (WHO 1995), 'In some situations, but not always, noise may adversely affect the health and well-being of individuals or populations'. In the everyday environment, the response of an individual to noise is more likely to be behavioural or psychological (i.e. non-auditory) than physiological. There are a wide range of non-auditory health effects that may be associated with exposure to environmental noise, although the pathways, strength of association, and possible causal mechanisms for these are not fully understood. Examples of non-auditory health effects linked to environmental noise include annoyance, sleep disturbance, cardiovascular and physiological effects, mental health effects, reduced performance, communication and learning effects.

Previous reviews of the links between everyday noise exposure and longer term health outcomes have proposed various conceptual “models” to try to simplify and describe the complexities of the subject and to help to design and improve future research. One such model that encompasses many of the known and suggested health outcomes is that proposed by Babisch 2002 and updated in Babisch 2013.

The Babisch model seeks to simplify the cause-effect chain (i.e. noise- annoyance- physiological arousal- biological risk factors- disease). This model initially differentiates between the direct (non-conscious) and indirect (conscious and

subjective) effect pathways, acting through an intermediate stress reaction stage which then, depending on individual risk factors, may lead to disease outcomes.

The UK Government's Noise Policy Statement for England (Defra, 2010) acknowledges that noise can affect people's quality of life and that there is emerging evidence linking noise with direct health effects.

ANNOYANCE

Annoyance is the most frequently reported problem caused by exposure to transport noise and is often the primary outcome used to evaluate the effect of noise on communities. The research on noise annoyance from high speed trains is relatively recent and a review paper by Fenech et al. 2013 reports significant variability between studies. No evidence was found that the different spectral content of high speed train sound might affect annoyance. Studies report no difference in noise annoyance between traditional and high speed rail for the same timetable frequency (Botteldooren et al. 2005). In contrast, earlier studies from Japan report higher levels of annoyance than the Miedema synthesis curves predict, particularly amongst respondents living very close to high speed railways, although a higher level of annoyance response was also seen in other studies from China and Korea for people living very close to conventional railways. Recent studies have shown that annoyance from Shinkansen schemes with appropriate noise and vibration mitigation measures is comparable to that represented by the Miedema curve (Oka et al. 2013).

The on-going research into noise annoyance from high speed rail suggests a number of modifying factors may be influencing response. These factors include distance from railway, onset rate, combined effects of noise and vibration, and number of train passbys (especially for people living very close to the railway). For new railway schemes there is also evidence that uncertainty about the future may increase annoyance whilst subsequent habituation with the changed situation may reduce annoyance. In one study in France 75% of the sample living close to TGV-Atlantique became accustomed to the noise within one year (Lambert et al. 1996). Although the number of studies which cover high speed rail is relatively small, there is nothing to suggest that response to noise will fall outside the applicability of the Miedema and Oudshoorn synthesis curves, provided that any modifying factors are accounted for.

SLEEP DISTURBANCE

The WHO Night Noise Guidelines for Europe (2009) cites numerous studies that detail the effects of transport noise on sleep. Studies have shown that noise can effect sleep in terms of immediate effects (e.g. arousal responses, sleep state changes, awakenings, body movements, total wake time, autonomic responses), after-effects (e.g. sleepiness, daytime performance, cognitive function) and long-term effects (e.g. self-reported chronic sleep disturbance). Sleep disturbances can be quantified either by subjective means or by monitoring physiological or behavioural awakenings. However, it is important to recognise that people are not conscious of their own bodies when asleep and studies have reported inconsistencies between the physiological effects of noise exposure (objective measures) and the subjects' perceived disturbance (Moehler & Greven, 2005 and Basner et al. 2011). At least one study found no statistically significant relation between the subjective assessment of perceived sleep quality and noise data (Griefahn et al. 2000). In fact, self-reported sleep disturbance is often considered to be a poor indicator of actual sleep disturbance and associated health effects. Nonetheless, self-reported sleep disturbance is an important indicator of community perception of night noise effects.

Miedema & Vos 2007 have undertaken an updated meta-analysis of twenty eight datasets from twenty four field studies of self-reported sleep disturbance from transport noise using the outdoor L_{night} noise indicator. The results confirm earlier findings that at the same equivalent night time noise exposure levels, aircraft noise is associated with more self-reported sleep disturbance than road traffic noise, and road traffic noise is associated with more sleep disturbance than railway noise. Of the twenty eight datasets, five were for conventional railway noise and none were for high speed rail. This updated dataset is the best currently available for assessing self-reported sleep disturbance effects from land based transport noise.

As with the research on noise annoyance, studies from the Far East seem to show large deviations from the Miedema and Vos dose-response relationships. For example, one study found that in Korea railway noise is associated with more sleep disturbance than road traffic noise (Hong et al. 2010). The authors suggest that this difference could be due to several factors including shorter distances between homes and the railway and consequent increased vibration, high proportion of freight and heavy diesel locomotives and cultural and situational differences between Korea and the countries covered by the Miedema dataset.

Over the last five decades a lot of research has been carried out into noise-induced sleep disturbance using objective techniques such as polysomnography. Rice & Morgan 1982 performed a synthesis of studies on noise-induced sleep disturbance. It concluded that: “Source specific noise disturbance of sleep may be expected to become significant once the outdoor night-time (22:00-07:00 hour) L_{pAeq} exceeds 55 dB providing the peak levels do not exceed about 75-80 dB. Higher L_{pAeq} values up to 60 dB may be allowed providing the peak levels do not exceed 85 dB(A), and the number of such events is less than about 20 per night. In this latter context, special account also needs to be taken of the 22:00-24:00 hour going-to-sleep period, when particularly noisy events should be avoided.” This conclusion was based on the best available studies at that time, and included data from social surveys, and laboratory and field studies using objective measures of awakenings.

In 1992, findings from a study into aircraft noise and sleep disturbance commissioned by the Department of Transport were published (Ollerhead et al. 1992). The results suggested that below outdoor event levels of 90 dBA SEL (about 80 dB L_{pAmax}), aircraft noise events are most unlikely to cause any increase in measured sleep disturbance from that which occurs naturally during normal sleep. For events above this level, the average arousal rate was about 1 in 30, corresponding to a wakening rate of about 1 in 75. This study used social survey methods together with actigraphy and electroencephalogram (EEG) measurements on sub-groups of participants.

A number of more detailed laboratory and field studies on sleep disturbance have been carried out by the German Aerospace Centre in recent years (Basner et al. 2004, 2006, 2011, Brink et al. 2009 and Elmenhorst et al. 2012). In these studies sleep disturbance is defined as the transition to the wake stage or S1 from any deeper stage of sleep, measured by means of polysomnography. Sleep stage S1 representing a lighter state of sleep which contributes little to the recuperative value of sleep.

As already noted, many studies have shown that sleep state changes are not specific to noise events; they also regularly occur as part of normal every day sleep patterns. Basner et al. 2006 report an 8.6% probability of spontaneous awakenings, equivalent to approximately 24 awakenings per night. They used this figure as a baseline

against which to derive the probability of noise-induced sleep state changes as a function of the maximum indoor noise level.

A study by Elmenhorst et al. 2012, drawing on the methodologies of Basner et al, focused on sleep disturbance from passenger and freight railway traffic.

Elmenhorst et al. developed a random intercept multivariate logistic regression model for the probability of observed awakenings from freight and passenger railway noise, as a function of L_{pASmax} and rise time. The probability of noise induced sleep state changes for railway noise has been derived assuming that the probability of spontaneous awakenings is similar to that determined by Basner et al. 2006. This is a reasonable assumption given that similar methods were used to measuring sleep state changes. Figure 1 shows the observed and noise-induced awakening probability curves for noise from passenger and freight rail traffic so obtained.

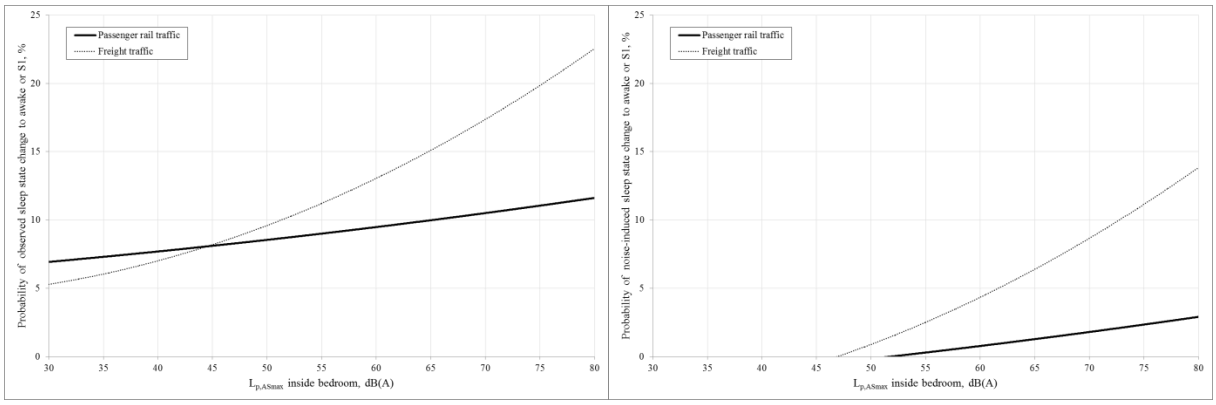

Figure 1: Probability of observed (left) and noise-induced (right) sleep state changes from freight and passenger rail traffic as a function of maximum SPL (L_{pASmax}) inside the bedroom. Relationships based on a random effects multivariate logistic regression model developed by Elmenhorst et al. 2012. Probability of spontaneous awakenings = 8.6% from Basner et al. 2006.

Elmenhorst et al. found that railway noise did not lead to prolonged sleep latencies or to impaired sleep efficiency compared to normal population values. Important reported modifying factors include the number and duration of train passbys; passby sound rise time (onset rate); distance to railway; and incidence of perceptible vibration.

The probability of noise-induced EEG-awakenings according to Elmenhorst's model is a function of both L_{pASmax} and rise time. Rise time is proportional to train speed and inversely proportional to distance from railway. The US Federal Railroad Association (FRA 2012) provides some information on measured rise times (onset rates) for a steel wheel train. The data suggests that the rise time experienced by receptors situated 70m or more from the railway for a train travelling at 360km/h is less than 10dB/s and therefore falls within the data range of passenger rail traffic which the Elmenhorst model was based on.

The long term health consequences of noise induced EEG awakenings are not fully understood. There are some suggestions that humans may be able to adapt to a certain level of noise induced awakening without negative health consequences. On a precautionary basis, it is necessary to consider the level of impact on sleep resulting from noise induced EEG awakenings in comparison to those that would naturally occur in the absence of noise.

In order to avoid adverse effects on nonrestorative sleep, resulting from changes in sleep structure, Basner et al. 2006 recommended: (1) On average there should be less than one additional EEG awakening induced by aircraft per night; (2) Awakenings recalled the following morning (reported sleep disturbance) should be prevented as much as possible; and (3) There should be no impairment to the process of falling asleep again.

Assuming, for the busiest section of HS2, 36 night-time train movements (23:00-07:00) and 56 movements (22:00-07:00) additional noise induced EEG-awakenings have been predicted (Table 1). To relate internal and external levels, three scenarios have been considered: a partially open window with a sound level difference of 15 dB(A); a closed well sealed single glazed window with a sound level difference of ~30 dB(A); and secondary glazing with a sound level difference of ~40 dB(A).

Table 1: Average number of additional noise-induced EEG-awakenings per year as a factor of passenger railway noise events L_{pASmax}

L_{pASmax} inside bedroom, dB(A)	L_{pASmax} outside property, dB(A)			Number of additional noise-induced EEG-awakenings per year	
	Partially open window	Single-glazed window	Secondary glazing	23:00 – 07:00 (36 events)	22:00 – 07:00 (56 events)
80	95	110	120	402	584
75	90	105	115	329	511
70	85	100	110	219	365
65	80	95	105	183	292
60	75	90	100	110	146
55	70	85	95	37	73
50	65	80	90	0	0
45	60	75	85	0	0

It can be seen in Table 1 that using the probability curve for passenger rail traffic, less than 365 additional noise-induced EEG-awakenings per year (on average less than one additional EEG-awakening per day) are predicted, assuming 36 night-time train movements (23:00 to 07:00) and partially open windows, for events with an average maximum sound level of 90dB L_{pASmax} outside. Assuming 56 night-time train movements (22:00 to 07:00) and partially open windows, less than 365 additional noise-induced EEG-awakenings per year are predicted for events with average maximum sound levels of 80dB L_{pASmax} outside.

To prevent recalled awakenings Basner et al. 2006 proposed that the maximum noise level inside the bedroom should not exceed 65dB. The impairment to the process of falling asleep again is suggested to be dependent upon the number of events and the time interval between events. The findings of Basner and Elmenhorst are generally consistent with the findings of Rice & Morgan and Ollerhead.

CARDIOVASCULAR DISEASE

According to the literature review by Fenech et al. 2013, there have been three relevant studies of conventional railway noise to date, one of which found a statistical (non-significant) association between railway noise and hypertension, and two of which found no such association. There are no reported studies that specifically investigate possible associations between cardiovascular disease and noise from high speed rail. Hypertension is one of many risk factors for cardiovascular disease; other risk factors include genetic predisposition, age, sex, socio-economic status, lifestyle and risk taking behaviour. Exposure to air pollution may also be a relevant

factor. Studies to date have not clarified whether noise exposure during the day or night (or total noise dose) are contributing to any possible health outcome.

Considering the results of these studies it is not possible to draw definitive conclusions about the presence or absence of an association between hypertension /cardiovascular disease and exposure to noise from conventional or high speed railways. Laszlo et al. 2012 have highlighted the uncertainties at lower levels of exposure and the problems associated with establishing the Lowest Observable Adverse Effect Levels for both hypertension and heart disease. Notwithstanding the uncertainties, it is clear that individuals exposed to higher levels of noise are exposed to the greater risk, especially at daytime noise levels above 60 dB L_{pAeq}. Moreover, to some extent the level of uncertainty is less important when considering relative risks, such as risk introduced by a proposed scheme in comparison to the risk caused by existing levels of exposure. It is reasonable therefore to perform a high level risk assessment considering daytime noise levels above 60 dB, with and without a scheme, as an approximation of relative risk.

There are still uncertainties on the relative importance of exposure during the day and night periods, and the importance of sleep disturbance as a mechanism that leads to cardiovascular diseases. Given the uncertainties it is considered that a risk assessment of railway noise and sleep disturbance is more meaningful.

MENTAL ILLNESS

Recent reviews on noise effects and mental health have concluded that there is no direct association between environmental noise and mental health, in both adults and children. Noise annoyance is consistently found to be an important mediator. Evidence for an effect of noise on psychological health suggests that, for both adults and children, noise is probably not associated with serious psychological ill-health, but may affect quality of life and well-being (van Kamp et al. 2013).

COGNITIVE IMPAIRMENT IN SCHOOLCHILDREN

Fenech et al. 2013 identifies three relevant studies on cognitive impairment in schoolchildren from transport noise. Of these, only one included railway noise within its scope, and this was in a specific Alpine valley setting where it was difficult to separate road and rail noise. There is evidence from the other two studies (Munich and RANCH) of an association between aircraft noise exposure and cognitive performance in schoolchildren (reading comprehension and recognition memory), but the same association was not seen for road traffic noise. Neither aircraft noise nor road traffic noise affected sustained attention, self-reported health, or mental health.

Data from the Munich and RANCH studies was reanalysed by Stansfeld et al. 2010, who concluded that night aircraft noise exposure did not appear to add any cognitive performance impairment to that induced by daytime aircraft noise alone. Based on the two studies, the authors suggested that the school should therefore be the main focus of assessment and protection.

The lack of studies on cognitive impairment and railway noise means that it is not been possible to quantify this effect for HS2. However, the absence of evidence does not mean that there is an absence of effect or that there is not a potential risk. Consequently, a high level risk assessment based upon noise exposure levels above 50 dB day (07:00-23:00) outside schools, where noise levels from the railway would be equal to or higher than existing noise levels, is appropriate.

VIBRATION

A recent study in the UK was undertaken for Defra and carried out by a team from Salford University, reporting in 2011 (Waddington et al. 2014). This was a study involving almost one thousand face to face interviews and over 500 measurements of vibration inside buildings (Sica et al. 2013). The study was carried out in the North-West of England and the Midlands area during 2009 and 2010. Exposure-response relationships were developed for human response to railway vibration.

The percentage of respondents expressing a given level of annoyance is higher for night than it is for evening and higher for evening than it is for day. For a vibration dose value of $0.1ms^{-1.75}$ the proportion of respondents expressing high annoyance is around 2% during the day, 4% in the evening, and 12% during the night.

There is very little evidence in the existing literature to suggest direct long term physical health effects on people inside buildings are relevant in relation to vibration at the typical levels encountered in the everyday environment (ANC 2012).

COMBINED EFFECTS OF NOISE AND VIBRATION

Numerous laboratory and field studies have consistently found an interaction between vibration and noise with respect to annoyance to both stimuli (Öhrström 1997, Gidlöf-Gunnarrsson et al. 2012 and Lee & Griffin 2013). Vibrations may facilitate the perception of noise and make it difficult to ignore and habituate to, which may lead to an increased risk of perceiving the railway noise as more annoying than in situations with no simultaneous vibrations. This synergistic effect is believed to be one of the main factors why studies in the Far East report higher level of annoyance than that predicted using the Miedema curve (Oka et al. 2013 and Yokoshima et al. 2013). In the Far East properties tend to be close to the railway, and ground-borne vibration can be exacerbated by the lightweight residential constructions.

The Defra-commissioned study on human response to vibration in residential environments gives exposure-response relationships for annoyance caused by noise for a given noise exposure and different levels of vibration exposure (Woodcock et al. 2011). A comparison of these curves with the Miedema curve suggests that the latter takes into account the synergistic effect of low to moderate levels of vibration at high levels of noise exposure. This is not surprising, given that approximately one-third of the data points used in Miedema and Oudshoorn's meta-analysis is from Swedish studies at sites with weak or strong railway-induced vibrations.

CONSTRUCTION NOISE AND VIBRATION

Most evidence underpinning the discussion of noise and vibration related health effects relates to long term exposure to sources of transport noise. The current models which suggest an association between noise exposure and adverse health effects such as hypertension and heart disease operate through longer term stress reaction mechanisms and are therefore not generally applicable to construction.

Construction activities represent a non-steady source of noise and vibration and are highly variable over time. These characteristics make it difficult to design socio acoustical studies (Sica et al. 2013).

One study investigating community response to noise and vibration from light rail construction presented exposure response curves for a sample population of 350 residents (Waddington et al. 2014 and Woodcock et al. 2011) suggesting that annoyance from construction noise and vibration is greater for the same exposure level in comparison with a steady state sources.

Although response may be greater at equivalent levels of exposure, annoyance is considered less important in the context of an HIA because the duration of the exposure is limited.

CONCLUSION

The evidence used to undertake the HIA for the Phase One of HS2 has been presented.

REFERENCES

Association of Noise Consultants (2012). Measurement & Assessment of Groundborne Noise & Vibration, 2nd edition.

Babisch W (2002). The noise/stress concept, risk assessment and research needs. Noise Health 4(16):1-11.

Babisch W (2013). Exposure-response curves of the association between transportation noise and cardiovascular diseases - an overview. First International Congress on Hygiene and Preventative Medicine, Belgrade, Serbia.

Babisch, W (2006). Transportation Noise and Cardiovascular Risk - Review and Synthesis of Epidemiological Studies. Federal Environmental Agency, Germany.

Basner M et al (2004). Effects of nocturnal aircraft noise - Volume 1- Executive Summary, German Aerospace Centre (DLR).

Basner M, Samel A, Isermann U (2006). Aircraft noise effects on sleep: Application of the results of a large polysomnographic field study. J Acoust. Soc. Am. 119(5) pp2772-84.

Basner M, Müller U, Elmenhorst E (2011). Single and Combined Effects of Air, Road, and Rail Traffic Noise on Sleep and Recuperation. SLEEP 34(1).

Brink M, Basner M, Schierz C, Spreng M, Scheuch K, Bauer G. Stahel W (2009). Determining physiological reaction probabilities to noise events during sleep. Somnologie 13:236-243.

Botteldooren D, De Coensel B, De Muer T (2005). Experimental investigation of noise annoyance caused by high speed trains. Proc. 12th International Congress on Sound & Vibration.

Department for Environment, Food and Rural Affairs (Defra) (2010). Noise Policy Statement for England.

Department of Transport (1991). Railway Noise and Insulation of Dwellings, Report of the Mitchell Committee, HMSO.

Department for Transport (1992). Report of a field study of aircraft noise and sleep disturbance – Summary. December.

Department for Transport (2011). <http://www.dft.gov.uk/webtag/>.

Elmenhorst E, Pennig S, Rolny V, Quehl J, Mueller U, Maaß H, Basner M (2012). Examining nocturnal railway noise and aircraft noise in the field: sleep, psychomotor performance and annoyance. Science of the Total Environment, 424.

European Communities (2002). Position paper on dose response relationships between transportation noise and annoyance. Luxembourg: Office for Official Publications of the European Communities. 2002. ISBN 92-894-3894-0.

European Environment Agency (EEA) (2010). Good practice guide on noise exposure and potential health effects, EEA Technical Report 11/2010.

Federal Railroad Association (FRA) (2012). High-Speed Ground Transportation Noise and Vibration Impact Assessment. DOT/FRA/ORD-12/15.

Fenech B, Cobbing C, Greer R, Marshall T (2013). Health effects from high-speed railway noise - a literature review, Proc Internoise.

Gidlöf-Gunnarrsson A, Ögren M, Jerson T, Öhrströml E (2012). Railway noise annoyance and the importance of number of trains, ground vibration, and building situational factors. Noise Health 14:190-201.

Griefahn B, Schuemer-Kohrs A, Schuemer R, Moehler U, Mehnert P (2000). Physiological, subjective, and behavioural responses to noise from rail and road traffic. Noise & Health 3, 59-71.

Grimwood C, Skinner C, Raw G (2002). The UK national noise attitude survey 1999/2000. Noise Forum Conference.

Notley H, Grimwood C, Raw G, Clark C, Van de Kerckhove R, Zepidou G (2013). The UK national noise attitude survey 2012 - the sample, analysis and some results. Proc. Internoise.

Hong J, Kim J, Lim C, Kim K, Lee S (2010). The effects of long-term exposure to railway and road traffic noise on subjective sleep disturbance. J. Acoust. Soc. Am. 128(5):2829-2835.

Janssen S, Vos H, van Kempen E, Breugelmans O, Miedema H (2011). Trends in aircraft noise annoyance: the role of study and sample characteristics. J. Acoust. Soc. Am. 129 (4), pp 3746-3753.

Koziel Z, Peris E, Woodcock J, Sica G, Moorhouse A, Waddington D (2011). Calculation of noise in residential environments, proc ICBEN 2011.

Laszlo H, Berry B, Abbott P, Hansell A (2012). Environmental noise and cardiovascular disease - observations on a well known dose response relationship. Proc. Internoise.

Lee P and Griffin M (2013). Combined effect of noise and vibration produced by high-speed trains on annoyance in buildings. J. Acous. Soc. Am. 133(4):2126-2135.

Miedema H and Vos H (1998). Exposure-response relationships for transportation noise, J. Acoust. Soc. Am. 104 (6)

Miedema H and Oudshoorn C (2000), Elements for a position paper on relationships between transportation noise and annoyance, TNO Report PG/VGZ/00.052.

Miedema H and Vos H (2007). Associations between self-reported sleep disturbance and environmental noise based on reanalyses of pooled data from 24 studies. Behavioural Sleep Medicine, 5(1), 1-20.

Moehler U and Greven L (2005). Community response to railway and road traffic noise - a review on German field studies. Internoise 2005.

Öhrström E (1997). Effects of exposure to railway noise - a comparison between areas with and without vibration. J. Sound & Vibration 205(4):555-560.

Oka S, Murakami Y, Tetsuya H, Yano T (2013). Community response to a step change in railway noise and vibration exposures by the opening of a new Shinkansen Line. Internoise 2013.

Ollerhead J, Jones C, Cadoux R, Woodley A, Atkinson B, Horne J, Pankhurst F, Reyner L, Hume K, Van F, Watson A, Diamond I, Egger P, Holmes D, McKean J (1992). Report of a field study of aircraft noise and sleep disturbance, Department of Transport.

Peris E, Woodcock J, Sica G, Sharp C, Moorhouse A, Waddington D (2014). “Effects of situational, attitudinal and demographic factors on railway annoyance in residential areas,” Journal of the Acoustical Society of America, vol 135, p 194.

Rice C, Morgan P (1982). A synthesis of studies on noise-induced sleep disturbance, ISVR Memorandum No. 623.

Sica G, Peris E, Woodcock J, Moorhouse A, Waddington D (2013). “Design of measurement methodology for the evaluation of human exposure to vibration in residential environments,” Science of the Total Environment, In Press, Corrected Proof, Available online 26 July 2013; <http://dx.doi.org/10.1016/j.scitotenv.2013.07.006>.

Skinner C, Grimwood C (2005). The UK Noise Climate 1990-2001: Population Exposure and Attitudes to Environmental Noise, Applied Acoustics Vol 66 (2) pp231-243.

Stansfeld S, Hygge S, Clark C, Alfred T (2010). Night time aircraft noise exposure and children's cognitive performance. Noise Health 24 (49).

van Kamp I, van Kempen E, Baliastas C, Houthuijs D (2013), Mental health as a context rather than health outcome of noise: competing hypotheses regarding the role of sensitivity, perceived soundscapes and restoration. Proc. Internoise 2013.

Waddington D, Woodcock J, Peris E, Condie J, Sica G, Moorhouse A, Steele A (2014). “Human response to vibration in residential environments,” Journal of the Acoustical Society of America, vol. 135, pp. 182.

Woodcock, J (2013). “Field and laboratory studies into the human response to groundborne vibration:exposure-response relationships, perceptual dimensions, and models of annoyance,” Univesity of Salford.

Woodcock J, Peris E, Condie J, Sica G, Moorhouse A, Waddington, D (2011). “Human Response to Vibration in Residential Environments (NANR209), Technical Report 6: Determination of Exposure-Response Relantionships.,” Defra, London.

Woodroof H, Griffin M (1987). A survey of the effect of railway-induced building vibration on the community. ISVR Technical Report 160, University of Southampton.

World Health Organisation (1995). Community Noise. Edited by B. Berglund & T. Lindvall.

World Health Organisation (1999). Guidelines for Community Noise.

World Health Organisation (2009). Night Noise guidelines for Europe.

World Health Organization (2000). Transport, environment and health. WHO Regional Publications, European Series. No.89.

Yokoshima S, Morihara T, Ota A, Tamura A (2008). “Reanalysis of dose-response curves of Shinkansen railway noise,” Proc. 9th International Congress on Noise as a Public Health problem.