Systematic review of evidence of the effect of transport noise interventions on human health: Implications for future studies and noise management policy

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Published

2016

Conference Title

Proceedings of the INTER-NOISE 2016 - 45th International Congress and Exposition on Noise Control Engineering: Towards a Quieter Future

Version

Version of Record (VoR)

Systematic review of evidence of the effect of transport noise interventions on human health: Implications for future studies and noise management policy.

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ABSTRACT

Van Kamp and Brown (2016) systematically reviewed transport noise interventions, providing an evidence base of studies that examined association between interventions and changes in health outcomes. The findings: that most interventions result in changes in health outcomes, and that changes in annoyance for road and aircraft noise are at least of the magnitude predicted from relevant exposure-response functions (ERFs) - support policies of noise management interventions. Outcome differences between different types of interventions could not be examined. Annoyance ERFs for road and aircraft noise provide at least a starting point for the health impact assessment of future interventions., but interventions also generally resulted in excess responses - changes in annoyance that were greater than predicted by the relevant ERF. Possible explanations for this excess response phenomenon have different implications for policy. Various system-wide issues may also be associated with interventions though these had not been considered in the studies reviewed. The review showed that diverse intervention study designs, methods of analyses, exposure levels, and changes in exposure, restricted the analysis of findings. Further studies of transport interventions should be based on a protocol of measuring change in exposures, outcomes and confounders, not just change in noise levels.

Keywords: Transport noise, interventions, noise effects I-INCE Classification of Subjects: 62.5, 13.1, 13.2

1. INTRODUCTION

Van Kamp and Brown (2016) report a systematic literature review of the effects of transport noise interventions (or noise management, or noise control) on human health outcomes. Interventions included exposure-related actions that aimed to change the level of noise exposure as well as actions that were non-exposure-related. Five broad categories of intervention (Brown and van Kamp, 2015) apply at various points along the system pathway between sources and outcomes: source interventions, path interventions, infrastructure change interventions, indirect interventions and change in behavior interventions. Categorization of intervention type is necessary as synthesis of evidence of effects may only be appropriate when conducted across studies that belong to the same intervention category. The noise sources for which the evidence of interventions were systematically reviewed and reported here were roadways, railways, and air traffic, and the relevant exposures were the levels at the external façades of dwellings of the general population.

Van Kamp and Brown (2016) assessed the nature and quality of the evidence in the individual studies on the impacts of transport noise interventions on human health. The adverse health outcomes included changes in sleep disturbance, in annoyance, in cognitive impairment of children and in cardiovascular diseases. They summarized the available evidence in each study by examining if the study demonstrated that the intervention lead to a change in health outcome and if, for source, path and infrastructure change interventions, the observed change in outcome was of a magnitude at least equivalent to that which would be predicted from a relevant exposure-response function (ERF) and the given change in exposure. A summary of these findings across the 43 studies included in their review is shown in Table 1, grouped by noise source, by outcome measure, and by intervention type.

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Table 1 – Summary of evidence from the individual studies (numbers of studies in parentheses)

	Number of Papers	Evidence that health outcome changed?			Observed magnitude of change in health outcome		
		YES	**NO**	**n.a.**	**Magnitude *at least* as predicted by ERF[1]**	**Excess Response**	**n.a**
ROAD TRAFFIC NOISE SOURCES (33)							
Outcome: Annoyance (23)							
A Source Intervention	9	####***		**	## *****	## *****	**
B Path Intervention	6	### ***			# ***	# * ?	**
C New/Closed Infrastructure	2	##			**	**	
D Other physical	6	##### *					
Outcome: Sleep Disturbance (6)							
A Source Intervention	1			*			*
B Path Intervention	2	# *					**
C New/Closed Infrastructure	2	##					**
D Other physical	1	*					
Outcome: Cardiovascular Effects (4)							
D Other physical	4	## *	*				
AIRCRAFT NOISE SOURCES (7)							
Outcome: Annoyance (4)							
B Path Intervention	1	*					*
C New/Closed Infrastructure	3	###			## *	## *	
Outcome: Sleep Disturbance (2)							
C New/Closed Infrastructure	2	# *			#		*
Outcome: Cognitive Development in Children (1)							
C New/Closed Infrastructure	1	#					*
RAIL NOISE SOURCES (3)							
Outcome: Annoyance (3)							
A Source Intervention	1	#					*
C New/Closed Infrastructure	1			*			*
E Education/Communication	1	*					

Statistical significance of finding reported in the original study
*Finding interpreted by original or current authors based on data/tables/plots in original study
n.a.= not applicable/not available: no change in exposure; or not reported. ? = unclear finding

This current paper considers the implications of these findings for noise policy and management for transport noise sources. It also provides guidance for future studies of the association between transport noise interventions and changes in human health.

The exposure-related interventions in most of the studies were associated with a decrease in transport noise exposure. However, in five studies (four road traffic noise studies and one aircraft noise study) some or all of the participants experienced noise exposure increases. Observations below with respect to change in responses apply equally to the increases as they do to the decreases.

2. GUIDANCE FOR FUTURE INTERVENTION STUDIES

2.1 Future Studies

There are many examples in the noise management/control literature of interventions which report a change in noise emissions from sources, or a change in noise levels in various locations, but these do not help elucidate the relationship between interventions and health unless they also reported changes in exposures of affected populations and changes in health outcomes or the beneficiaries. The systematic review of the literature reported by van Kamp and Brown (2016) had found 43 published intervention studies that reported observed changes in health outcomes together with observed changes in peoples' exposures. Of the 43 transport noise studies, 77% were for road traffic noise, with fewer for aircraft noise (16%) and rail traffic noise (7%) – with the majority of them (70%) reporting annoyance outcomes. Further studies directly linking transport noise interventions to health outcomes are required, particularly for aircraft and rail noise sources, and for human health outcomes other than annoyance.

We suggest that authorities proposing interventions, whether those are at local, national or international level, and whether or not the primary purpose of the intervention concerns noise, should be encouraged to include significant funding for the design and implementation of studies to evaluate outcomes from the interventions. At present many of the evaluations appear to be afterthoughts. The effect of the intervention on the exposure of defined populations need to be assessed, and its effect on the health outcomes of the same populations - not just the changes in noise levels that result from the intervention. We note a potential impediment is that some government and private instrumentalities who initiate noise intervention programs may have little interest in undertaking an evaluation of that intervention once a decision to implement it has been taken – avoiding any possible reputational risk that could be associated with a costly intervention later being shown to have little effect on human health. We also note the potential for an associated bias (though we have no evidence of it): publication bias may have influenced the findings of the systematic review in that intervention studies that failed to find a change in human health outcomes may tend to go unreported compared with those that did find a change.

2.2 Designs and Analysis

We recognize the difficulty in doing so in many intervention studies, but precise specification of the change in exposure for individuals, or subgroups, is required. In part to encourage this, we suggest that there are advantages in following the approach, used in two of the individual aircraft noise studies (Breugelmans et al., 2007; Brink et al., 2008), of reporting both the noise exposure before the intervention, and change in noise exposure as a result of the intervention, of the study participants, and using both in the analysis.

Other observations arising from the systematic review included that future intervention studies should use validated, and where possible, harmonized, measures of exposures and outcomes as well as of moderators and confounders. Most interventions result in step changes in exposure with expected step changes in human response to this change. While many intervention studies used a before and after design, there has generally been insufficient consideration that the change in human response to a step change in exposure may have a different time course to that of the change in exposure. A protocol is required for the conduct of future intervention studies that provides longitudinal assessment of both exposure and human response, and Brown (2015) reported a design that is suitable (included here as Table 2). With a change in noise exposure over the interval between t_0 and t_1, sequential measurements of effect should be made before and after the change, preferably with multiple after measurements (A_{-1}, A_0, A_1, A_2 , ... A_x). Repeated measurements should also be made of activity interference (Act_x), potential confounders such as noise sensitivity ($Sens_x$), coping strategies (Cop_x), and a range of other attitudinal, retrospective, and prospective, assessments. In addition, that model incorporates steady-state controls into the study design. The protocol in Table 2 is specific to studies of the effect of interventions on annoyance, but the principles of longitudinal measurements of exposure, of responses, and of potential confounders, can be adapted readily to studies of other human outcomes. It should be noted that the factors considered in Section 3.6 below ('other physical interventions' such as the provision of a quiet side to the dwelling, or the provision of green space in the neighborhood) need to be incorporated in this model

Table 2 -Model protocol for intervention studies. After Brown and van Kamp (2005)

Sequential Measurements	**before$_{-1}$**	**before$_0$**	**after$_1$**	**after$_2$ ...**
Time	t_{-1}	t_0	t_1	t_2 ...
noise exposure	L_{-1}	L_0	L_1	L_2 ...
Effect Measures (or Respondent Attribute Measures)				
annoyance	A_{-1}	A_0	A_1	A_2
activity interference	Act_1	Act_0	Act_1	Act_2
retrospective annoyance			RA_{01}[1]	RA_{02}
noise sensitivity	$Sens_{-1}$	$Sens_0$	$Sens_1$	$Sens_2$
attitudes to authorities etc.	Ats_{-1}	Ats_0	Ats_1	Ats_2
opinion of neighbourhood	$Neigh_{-1}$	$Neigh_0$	$Neigh_1$	$Neigh_2$
coping strategies	Cop_{-1}	Cop_0	Cop_1	Cop_2
prior knowledge	…	X_{10}[2]	…	…
expectations	…	Y_{10}[2]	…	…
Steady-state Controls	Before Control		After Control	

[1] RA_{01} is a respondent's retrospective assessment of annoyance at t_1 of conditions that existed at t_0
[2] X_{10} and Y_{10} are respondent's prior knowledge, and expectations, at t_0, of conditions that will exist at t_1.
Other non-acoustic factors may have to be added.

3. IMPLICATIONS FOR NOISE MANAGEMENT AND POLICY

3.1 Interventions Lead to a Change in Health Outcome

Table 1 shows that nearly all interventions led to a change in the aggregate health outcome of those who experienced the intervention, irrespective of the source type and irrespective of the type of intervention. Excluding those studies for which no observation was appropriate (because there was no change in exposure, or the study was a follow-up survey at some interval after the original) there was only one study that reported no change in health outcomes. The authors of the individual studies had provided statistically significant tests of this change in the majority (58%) of studies; in others (29% of all studies) change was observed, either by the original authors or in the process of this review, from the data, tables or plots presented in the individual papers. While this provides only a minimal test of the efficacy of noise control interventions, the consistency of the finding across nearly all of the transport noise interventions is a general assurance that the noise management strategies that are currently utilized have, at least, the potential of a beneficial effect on human health. The caveat to this positive finding is that the evidence is not extensive or well distributed over all transport noise sources, intervention types, or health outcomes, and of course this minimal test says nothing about the magnitude of the improvement in health outcomes arising from the interventions.

3.2 Magnitude of the Change in Health Outcomes

Seventeen studies (these included source, path and new/closed infrastructure interventions) for road and aircraft noise sources, reported that the ***minimum magnitude*** of the change in annoyance outcomes matched that estimated from a relevant exposure-response function (ERF) and the given change in exposure. In addition, one aircraft noise intervention study reported that the magnitude of the change in sleep disturbance outcomes could have been predicted from an ERF for sleep-disturbance.

The implication is that, at least for road traffic sources, relevant exposure-response functions for annoyance can provide an estimate of the minimum change in human outcomes that can be expected from a given change in exposure as a result of any source, path and new/closed infrastructure

intervention. Again this is a useful confirmation of current noise management approaches. It supports policy and planning as relevant annoyance ERFs for road (and possibly aircraft) noise can provide at least a starting point for the health impact assessment of future interventions. Examples of 'relevant ERFs' were provided in van Kamp and Brown (2016). The available evidence is, however, too poorly conditioned across different group of studies to be able to test for any differences in change in annoyance arising from different types of interventions. The evidence for being able to predict the minimum change on sleep disturbance is restricted to one aircraft noise study only.

3.3 Implications of Excess Response

However, beyond observations in Section 3.2 with respect to the minimum magnitude of change in annoyance outcomes that can be expected from an intervention, the review evidence is that, for road and aircraft noise, changes in annoyance responses are frequently greater than predicted by ERFs. In 17 (81%) of the studies (14 of road traffic noise and three of aircraft noise) the change in annoyance also exhibited an *excess response*, that is a *change effect* in addition to the *exposure effect* predicted by an ERF (Brown and van Kamp (2009a) provides definitions of these terms). Excess response occurs where the total difference between the before-outcome and the after-outcomes is greater than the magnitude of the change in response estimated from an ERF for the given change in exposure. A similar result was found for sleep disturbance for one aircraft noise study.

The notion of *excess response* to interventions has been considered in depth by Brown and van Kamp (2009b) where they examined, and rejected some of, the multiple explanations that have been proposed for this phenomenon and the policy implications. They concluded that: "*The evidence of the magnitude, and the persistence over time, of the change effect ... and the existence of plausible explanations for it, suggest that it is a real effect and needs to be taken into account in assessing the response of communities in situations where noise levels change. Within the limitations of existing evidence on change, communities that experience an increase in noise exposure are likely to experience greater annoyance than is predicted from existing exposure-response relationships, and communities that experience a decrease in exposure experience greater benefit than predicted. Policy makers need to be informed of these potential change effects, particularly as situations in which noise levels increase as a result of infrastructure changes are always likely to be contentious. To do otherwise would be to deny them important information regarding potential community response in these contexts*.".

The current systematic review of the effects of interventions supports this conclusion by demonstrating the existence of a change effect for annoyance in a high proportion of the studies of source, path and infrastructure change interventions for road and aircraft noise. It does not, however, help resolve which of the different explanations Brown and van Kamp (2009b) suggest remain plausible are the cause of the phenomenon.

3.4 Thresholds for Effects of Change

There is no clear evidence with respect to thresholds regarding changes in health outcomes as a result of interventions. Interventions thresholds could have two dimensions: 1) the smallest change in exposure levels that result in a change in outcome, and 2) the minimum before-level. The only observation we can make is that several interventions that reduced noise exposures by 1 to 2 dB (energy-based scales) did not result in any observed change in health outcomes.

3.5 Sustainability of the Change in Health Outcomes

While there is little evidence available with respect to the longitudinal path of health outcome changes following the initial change as a result of an intervention, there is no evidence to suggest the initial change in response is not sustained over at least several years.

Nearly all of the studies were before-and-after studies, with the magnitude of the change in outcome obtained at the time of the after-survey following the intervention. This was normally some one to twelve months after the intervention, but varied considerably. For some of the interventions such as barriers or housing reconfiguration involving construction, the gap between before and after studies was long: five years, six years, and eight to ten years, in some studies.

However, a handful of studies continued to assess participant health outcomes longitudinally beyond the initial after-survey. Four road traffic studies, two aircraft studies and two railway studies resurveyed participants after various intervals: five surveys out to 20 months; six surveys out to three years; twelve months; two years, seven to nine years, etc. While the evidence is meagre and scattered across different sources and intervention types, the consistent finding is that the latter after-surveys

showed no difference in outcomes to those surveys immediately following the intervention – with generally no diminution in the magnitude of the effect, including excess response if present. The exception was that the survey seven to nine years after the intervention did show some attenuation in the excess response observed at the first after-survey.

In summary, while there is little evidence available with respect to the longitudinal path of health outcomes changes following the initial change resulting from an intervention, none of it suggests the initial change in response is not sustained over, at least, several years. In other words, there is no evidence of adaptation in the outcome arising from the intervention. Here adaptation refers to attenuation in the after-change outcome subsequent to the intervention – not its regression to levels of the outcome that existed before the change. In any examination of adaptation/habituation it is important that terms are adequately defined as there is ambiguity in the way different authors use these terms. Brown and van Kamp (2009b) provide discussion on this topic.

3.6 Studies of "Other Physical Interventions"

The studies of 'other physical interventions' (such as the provision of a quiet side to the dwelling, or the provision of green space in the neighborhood) were not intervention studies per se as they did not provide direct evidence of an intervention. Instead they provide comparisons of health outcomes from groups with and without the particular physical dimension of interest. These 'other physical interventions' did, in the majority of studies, demonstrate the efficacy of potential interventions of this sort, but it must be noted that this is indirect evidence consisting of comparison of outcomes of different groups under different conditions, rather than before-after comparisons on the same group.

3.7 Systems-wide Considerations

There is a range of systems-wide matters that additionally should be considered in future evaluations of the health outcomes of transport noise interventions. We note them here, largely without comment, except to indicate that few of these matters were raised within any of the papers examined in the systematic review. However, they are important as they provide, in contrast to most of the evidence which is based on a specific intervention within specific space and time bounds, a more systems-wide understanding of transport noise interventions that is likely to be important in any comprehensive evaluation of the human health effects of transport noise interventions:

- Spatial scales of interventions and effects will vary from highly local (e.g. noise barrier on a particular roadway) to regional, national (emission limits for motor vehicles) or international (e.g. emission limits for aircraft).
- There may be lag times between interventions (e.g. regulations specifying vehicle limits which might take years to implement, or which rely on natural turnover in the vehicle fleet) and measurable effect. There may also be lag times between noise reduction and health consequences e.g. decreased risk of cardiovascular disease.
- Some interventions are applied for short periods (e.g. temporary flight path changes) vs permanent interventions.(Studies of temporary interventions were excluded from the current review).
- Interventions may result in unintended displacement outcomes. For example, a traffic restriction intervention that forces traffic into surrounding areas, introduces higher exposures in other areas, even though at the point of application the exposure is reduced. Examples include: a traffic circulation plan in Den Haag (Hoek et al. 2011), congestion charging in London (Tonne et al, 2008) and the removal of diesel cars in Rome (Cesaroni et al, 2011). In all of these examples the gained reduction in noise levels at one location was accompanied by an increase elsewhere and often in a more deprived area.
- A related consideration is that there may be subgroup differences in health outcomes from an area-wide intervention (e.g. effects on different socio-economic subgroups) and interventions that redistribute exposures across different areas need to be cognizant of differential socio-economic status of populations in these different areas.
- There may be effects on human health responses to noise generated by interventions in other fields (e.g. intervention with respect to traffic congestion, or planning interventions that alter urban density).

4. SUMMARY

With the caveat that the available studies are unequally distributed across noise sources and health

outcomes, the finding overall is that transport noise interventions change the health outcomes reported by those who experience the intervention, irrespective of the source, the outcome or whether the intervention type is source, path or new/closed infrastructure. For the annoyance outcome and road and aircraft sources, the *minimum* magnitude of the change in annoyance outcomes can be predicted from a relevant exposure-response function and the given change in exposures. However, the observation in a majority of road and aircraft studies was that the magnitude of the change in annoyance to an intervention exhibited a *change effect* - an *excess response* in addition to the level effect predicted using an exposure-response function. Policy makers need to be informed of the existence of the *change effect* associated with interventions.

While there is little evidence available with respect to the longitudinal path of health outcomes changes following the initial change as a result of an intervention, there is no evidence to suggest the initial change in response is not sustained over at least several years.

The available evidence was too poorly conditioned across different group of studies to be able to test for any differences in change in health outcomes arising from different types of interventions.

The results of the studies regarding other physical interventions were obtained primarily through indirect evidence (comparison of outcomes under different conditions, rather than before-after designs). These have proved useful as a means of estimating the efficacy of such potential interventions, however they need to be supplemented in the future by direct evidence.

The environmental noise intervention studies included in this review were focused on the site of the intervention. There are also systems-wide factors that need to be considered in any comprehensive evaluation of the human health effects of environmental noise interventions.

Further studies directly linking transport noise interventions to health outcomes are required, particularly for aircraft and rail noise sources, and for human health outcomes other than annoyance. A protocol has been recommended for the design of future studies.

ACKNOWLEDGEMENTS

This work was conducted as part of a project for the World Health Organization. Views expressed are those of the authors.

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