Assessing the role of mediators in the noise-health relationship via Structural Equation analysis

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INTRODUCTION

Over the past four decades the global aviation sector has developed rapidly and is, with an average annual growth rate of 5 % (De Haan 2007), expected to continue to do so over the coming years. With respect to aircraft noise, one of the negative consequences of this transportation mode, it is estimated that in 2007 roughly 2.7 million European inhabitants will be exposed to noise levels of 55 dB(A) or more (ANOTEC Consulting 2004), the upper limit in residential areas as set by the World Health Organization (WHO 1999). In addition, this number is expected to increase to 3.4 million in 2015 (ANOTEC Consulting 2004).

In previous research it has been established that noise can have several negative effects on human health. These range from “soft” effects, like annoyance (Schultz 1978), mental health (Stansfeld et al. 2000) and psychological well-being (Ohrstrom 1993), to “hard” effects, like hypertension and ischemic heart disease (Babisch 2000; 2006). However, the interrelationships between noise, subjective reaction (e.g. annoyance), reaction modifiers (e.g. attitude to the noise source), health effects (e.g. blood pressure) and health modifiers (e.g. smoking) are, as indicated by Job (1996), poorly understood.

One way to provide a deeper understanding in these interrelationships is to study them within an individual or situational difference model (Lercher 1996), in which relationships between variables are modeled at an individual level. Next to physical stimuli and human responses, this perspective acknowledges the role of cognitive mediators.

In line with the individual difference model, the first aim of the present study is to empirically estimate, via a (tentative) theoretical model, the total effect (i.e. direct and indirect) of noise exposure on (self-reported) perceived health. The main hypothesis is that inclusion of mediator variables will significantly decrease the direct effect between noise exposure and perceived health. Hence, next to an estimation of the direct effect between noise exposure and perceived health, several possible indirect mediation paths are identified and estimated. The following variables are considered to be important mediator variables and are therefore included in the model: noise annoyance from aircrafts, noise annoyance from neighbors and residential satisfaction. The second aim of this study is to provide an estimate of the relative importance of the model variables on perceived health.

Since Structural Equation Modeling (SEM) is especially suitable to model complex paths (in this case the indirect mediation effects) this method will be used to estimate the developed model. An additional benefit of this method is that it can take measurement errors into account. This leads to less bias in the parameter estimates and generally larger proportions of explained variance in the endogenous variables. Data to estimate the constructed model is obtained via a previously conducted survey among residents living within in a 25 kilometer radius around Schiphol Airport in the Netherlands.[1]

This paper is structured as follows. In the next section a theoretical model will be developed based on previously found associations between variables. The two sections that follow will discuss the research method and results respectively. The last section will present the conclusion and end with some reflective remarks.

Development of a theoretical model

In the following evidence related to the associations between aircraft noise exposure, noise annoyance from aircrafts, noise annoyance from neighbors, residential satisfaction and perceived health will be discussed and used to develop a theoretical model.

In previous research noise exposure has been shown to correlate with "soft" health outcomes, like mental health, psychological well-being, psychiatric hospital admission rate, use of prescriptive drugs and sedatives and self-reported health symptoms (e.g. headaches, tiredness) (for reviews see Job (1996) and Stansfeld et al. (2000)). As mentioned in the introduction, the main hypothesis (H1 in Figure 1) is that this direct effect (i.e. the effect between aircraft noise exposure and perceived health) will become smaller or even insignificant after effects *via* indirect paths from noise exposure to perceived health are accounted for.

The first considered mediator variable is noise annoyance (i.e. negative reaction to noise). This variable has, next to noise exposure, also been shown to be associated with psychosocial well-being, nervous stomach and health ratings (Job 1996), as well as with self-reported general health and health symptoms like headaches (Franssen et al. 2004). Based on such results Job (1996) has suggested that negative reaction to noise might predict health outcomes over and above the direct effect of noise exposure. This constitutes the second hypothesis of the developed model: noise annoyance from aircrafts influences perceived health (H2 in Figure 1). The well-established relationship between noise exposure and negative subjective reaction (see e.g. Schultz 1978; and Miedema & Vos 1998) leads to the specification of the third relationship: aircraft noise exposure influences noise annoyance from aircrafts (H3 in Figure 1).

For the following two hypotheses, a second indirect mediation path between noise exposure and perceived health is considered. The existence of this path is prompted by research of Yokoshima et al. (2007) who, via Structural Equation Modeling, showed there is a significant negative relation between road traffic noise exposure and railway noise annoyance. We believe an explanation for this effect is that the existence of the road traffic noise source captures the attention of the affected resident and therefore has a diminishing effect on the railway noise annoyance. This principle is applied to our model in the formulation of the following hypothesis (H4 in Figure 1): aircraft noise exposure has a negative effect on noise annoyance from

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neighbors.[2] In addition, since there is empirical evidence for an effect between noise annoyance from aircrafts and perceived health, this relation is also assumed to be present between noise annoyance from neighbors and perceived health (H5 in Figure 1). Note, however, that no empirical evidence pertaining to this relationship could be found in the literature.

Three additional mediation paths arise from the inclusion of residential satisfaction. Theories related to residential satisfaction generally conceptualize this construct as a measure for the difference between residents' actual and desired residential conditions (Galster & Hesser 1981). According to Rossi (1955) in**c**ongruence between the current and desired conditions creates dissatisfaction and more importantly stress. As such, residential satisfaction can be classified in the group of ambient stressors which is defined by Campbell (1983) as 'chronic, global conditions of the environment – pollution, noise residential crowding, traffic congestion – which, in a general sense, represent noxious stimulation, and which, as stressors, place demands upon us to adapt or cope.' Additional support for this classification is provided by a study of Phillips et al. (2005) who showed that residential satisfaction plays a mediating role between residential living conditions and psychological well-being. In line with this conclusion residential satisfaction is, in the theoretical framework developed here, posited in between the different components of the residential environment, being noise annoyance from aircrafts, noise annoyance from neighbors and aircraft noise exposure, and, on the other side, perceived health (H6 through H9 in Figure 1).

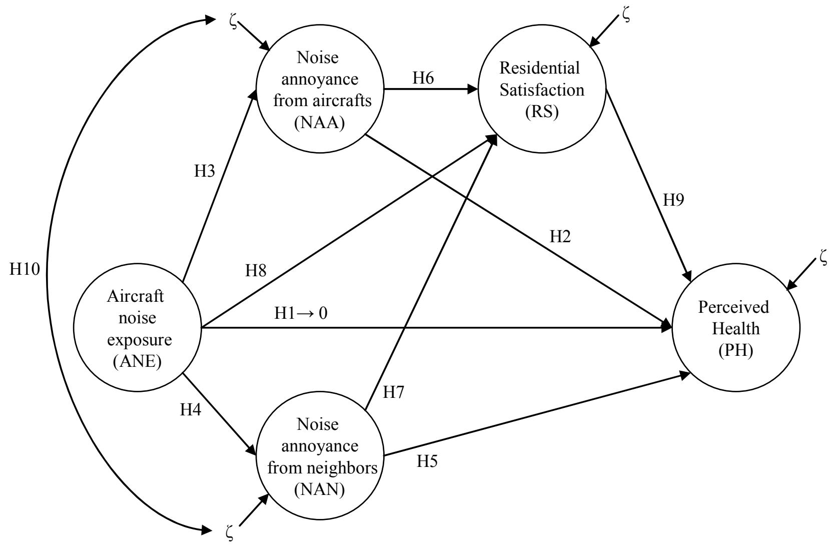

Figure 1: Theoretical model for studying the direct and indirect effects of aircraft noise exposure

Lastly, since noise annoyance from neighbors and noise annoyance from aircrafts are expected to have additional co-determinants next to aircraft noise exposure, like noise sensitivity (Miedema & Vos 2003), the errors terms of these variables are hypothesized to correlate (H10 in Figure 1). Reverse relationships between perceived health and its determinants have also been suggested. Job (1996), for example, notes that 'if a respondent believes he/she is suffering ill-health because of the noise, it would seem likely that this would increase dissatisfaction and annoyance with the noise.' However, inclusion of these reciprocal effects in the present framework would render the model unidentified. The choice is therefore made to include only those

[2] It needs to be noted that this principle can also be used the other way around, in that the physical noise caused by the neighbors has a diminishing effect on noise annoyance experienced from aircrafts. However, since this physical index is not measured this effect is excluded from the present model.

paths towards perceived health, since the theory underlying these paths is more compelling than the notions related the existence of the reverse effects. In Figure 1 the full theoretical model is presented.

METHOD

To estimate the model in Figure 1 data is used from a survey among residents around Schiphol Airport conducted in 1996 (N=11,812; response rate 39 %). For a description of this dataset and the data gathering procedure we refer to TNO/RIVM (1998), Miedema et al. (2000) and Franssen et al. (2004). Cases with more than 10 % missing values are deleted (N=954).

In Table 1 the used constructs and their indicators are presented. Via the use of multiple indicators for the constructs the structural estimates of the paths between the constructs are corrected for random measurement errors. Table 2 presents the intercorrelations and the reliability estimates (Cronbach alpha's) of the constructs. The signs of the correlations are all consistent with the a priori expectations. In addition, the correlation between aircraft noise annoyance and perceived health (r=-0.10) clearly shows that an estimated direct effect between the two, without controlling for additional variables, would become significant.

Table 1: Constructs and indicators

Construct	Label	Observed indicator
Aircraft noise exposure	ANE	Yearly mean aircraft noise exposure during day-time (7:00h-22:00h) (L_{0722} in dB(A))
		Yearly mean aircraft noise exposure during night-time (22:00h-7:00h) (L_{2207} in dB(A))
Noise annoyance from aircrafts	NAA	Noise annoyance from aircrafts
		Noise annoyance from aircrafts during weekdays
		Dissatisfaction with aircraft noise
Noise annoyance from neighbours	NAN	Noise annoyance from neighbours
Residential satisfaction	RS	Satisfaction with residential environment
		Unpleasant aspects of residential environment (summated scale)
Perceived health	PH	Perceived health status
		Recent health complaints (summated scale)

Table 2: Intercorrelations (all p<.001) and reliability estimates (on the diagonal in italic)

Construct	# indicators	ANE	NAA	NAN	RS	PH
ANE	2	*0.81*				
NAA	3	0.38	*0.92*			
NAN	1*	-0.09	0.14	*0.92*		
RS	2	-0.21	-0.45	-0.36	*0.71*	
PH	2	-0.10	-0.24	-0.10	0.32	*0.64*

* For noise annoyance from neighbors (NAN) only one indicator was present in the dataset. The reliability of this construct was therefore fixed by constraining the error variance of the observed indicator underlying this construct. For this purpose the assumption is made that NAN is measured with the same reliability as NAA (α=0.92).

The Asymptotic Distribution Free estimation procedure, as employed by software program AMOS 7.0, is used to estimate the structural equation model. As a result of the large sample size (N=10,858), the chi-square statistic is expected to be significant (which would unjustly suggest a lack of model fit). The following fit indices are therefore used to evaluate the fit of the estimated models: the Root Mean Square Error of Approximation (RMSEA) (Browne & Cudeck 1993), the Standardized Root

Mean Residual (SRMR) and the Comparative Fit Index (CFI) (Bentler 1990). A well-fitting model is defined as having values below .06 and .08 for RSMEA and SRMR respectively and a CFI value greater than .95 (Hu & Bentler 1999).

RESULTS

The estimated model provides a good fit to the data ($\chi^2_{d.f.=26}$=272.16, RSMEA=.03, SRMR=.0131, CFI=.99). The results indicate that two estimates are insignificant. These are related to the paths from aircraft noise exposure to perceived health (H1) and from noise annoyance from neighbors on perceived health (H5). Insignificant parameters can be considered irrelevant to the model (Byrne 1998) and should, based on the parsimony criterion, be deleted. After deletion of these paths and re-estimation of the model, the obtained model fit ($\chi^2_{d.f.=28}$=273.00, RSMEA=.03, SRMR=.0131, CFI=.99) indicates that this more parsimonious model did not fit the data significantly worse ($\Delta\chi^2_{\Delta d.f.=2}$=0.84, p=0.657). Hence, it can be concluded that the direct effects of aircraft noise exposure on perceived health and of noise annoyance from neighbors on perceived health (-.10 and -.24 respectively, see Table 4), are fully mediated through the other model variables. In other words, the main hypothesis (H1 in Figure 1) is confirmed: inclusion of the mediator variables renders the direct effect between noise exposure and perceived health insignificant.

Figure 2 presents the standardized direct effects of the re-estimation structural model. All estimates are significant at the .001 level and the signs of the estimates are as expected.

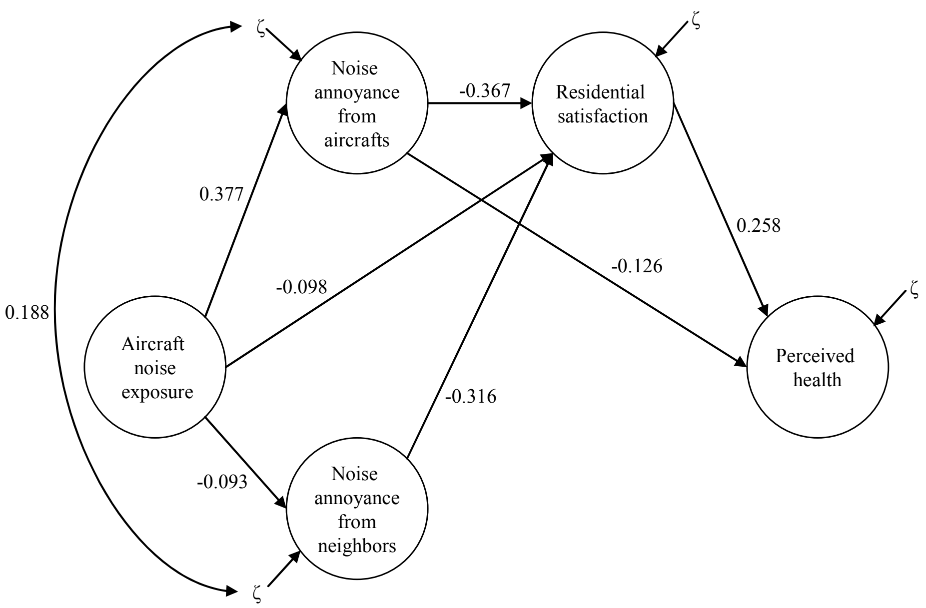

Figure 2: Standardized direct effects of the final structural model

Table 2: Standardized total effects and proportions of explained variance

	NAN	NAA	RS	PH
ANE	-0.093	0.377	-0.206	-0.101
NAA	0	0	-0.367	-0.220
NAN	0	0	-0.316	-0.082
RS	0	0	0	0.258
Explained variance (%)	0.9	14.2	29.7	11.1

Summation of the indirect and direct effects yields the total effects of the model variables on the endogenous variables in the model. These effects (in their standardized form) as well as the proportions of explained variance are presented in Table 2.

DISCUSSION AND CONCLUSION

With respect to the present study the following conclusions can be summarized. Firstly, the main hypothesis is confirmed: inclusion of the mediation paths between aircraft noise exposure and perceived health renders the direct effect between these two variables insignificant. Secondly, aircraft noise exposure is not the largest environmental determinant of perceived health. The standardized effects of noise annoyance from aircrafts and residential satisfaction (-.220 and .258 respectively) are more than twice as large as the effect of aircraft noise exposure (-.101). Since the effect of aircraft noise exposure is fully mediated, it holds that *only* if people become annoyed by the noise will it have negative health consequences. However, it should be noted that if there is no noise present there will be no annoyance. The significance of noise exposure, that is, of noise reduction measures, should therefore not be underestimated.

In relation to this study several reflective remarks can be made and related research directions be formulated. Firstly, the used health indicators, i.e. a general health rating and a summated scale of recent health complaints, can be qualified as "soft". It therefore remains unknown whether for "hard" medical outcomes, like hypertension and cardiovascular diseases, the effects of aircraft noise exposure are also mediated via cognitive variables, like noise annoyance. However, the three basic requirements for a mediator relationship (see Baron & Kenny 1986) are also present for these effects: 1) there is an effect between the independent variable (i.e. noise) and the outcome variable (i.e. hypertension), as recently evidenced by Jarup et al. (2008), there is an effect between the mediator (i.e. annoyance) and the outcome variable, as evidenced by Babisch et al. (2007), and there is an effect between the independent variable and the mediator, as evidenced by Schultz (1978) and Miedema & Vos (1998). In addition, a study of Black et al. (2007) has provided evidence that the effect of noise on (self-reported) hypertension becomes insignificant if chronic noise stress is included as a mediator. To study the extent of the mediation effect we recommend inclusion of these objective "hard" outcomes in future models. In addition, models can be developed that include both the "soft" and the "hard" health indicators to investigate their underlying relational pattern.

Secondly, the estimated model in this study is based on cross-sectional data. This means that the assumption of time-precedence required to make causal inferences is solely based on theoretical grounds and cannot be empirically investigated. Due to theoretical uncertainty it remains unknown whether the specified model structure is indeed correct. For example, as mentioned earlier, there is reason to believe that reciprocal effects between health and its determinants are present. These might be direct, as indicated by Job (1996), in that an awareness of ill-health can lead to more dissatisfaction with the noise, as well as indirect, as indicated by Babisch et al. (2007), in that ill-health can lead to an increased sensitivity to the noise which, in turn, causes more dissatisfaction with the noise. Useful ways to assess the tenability of the time-precedence criterion as well as to study reciprocal effects are to develop models based on panel data or to conduct experiments in the controlled environment of the laboratory.

Lastly, with respect to the present model it could be objected that the estimated relationships are confounded by several personal characteristics such as sex, age, etc. Therefore, a second model was estimated which included the variables: sex, age, education level, country of origin, smoking behavior and degree of urbanization (cf. Franssen et al. 2004). Because the estimates of this extended model did not differ substantially from those of the model of interest in this study (see Figure 1), the choice was made to present the results of this latter more parsimonious model.

The conclusion that the direct effect of noise exposure is mediated has important implications for researchers as well as policy makers. For researchers it means that the effect of noise exposure on health can be better estimated when also taking into account factors influencing noise annoyance and residential satisfaction. For policy makers it means that noise policies should not solely be concerned with controlling the physical level of exposure, but also with subjective factors that function as cognitive mediators and the causes behind these factors. For example, next to the role of noise exposure, which in this study can only explain 14.2 % of the variation in noise annoyance, research has consistently shown the important role of so-called non-acoustical factors in the appraisal of aircraft noise (Fields 1993; Miedema & Vos 1999; Maris et al. 2007). These factors constitute variables like fear of the source, trust in the noise source authorities or the capacity of people to control or cope with noise. Hence, effective noise management should take such factors into account (Stallen 1999; Guski 1999). The second conclusion, that noise exposure is not the most important determinant of perceived health, further supports the use of a broad range of regulatory actions aimed at these subjective evaluations instead of a narrow focus on noise exposure. The Thomas theorem, a fundamental law in sociology, applies to this situation: ‘if men define situations as real, they are real in their consequences’ (Thomas 1966).

To conclude, we refer to Passchier-Vermeer & Passchier (2000), who mention that most effects of noise on health were already identified in the 1960s. In addition, they emphasize that ‘a subject for further research is the elucidation of the mechanisms underlying noise-induced cardiovascular disorders and the relationship of noise with annoyance and non-acoustical factors modifying health outcomes’ (Passchier-Vermeer & Passchier 2000). We concur with this assessment and believe that the present study constitutes a step in this direction.

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