Annoyance response to helicopter noise

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ABSTRACT

Exposure-response relationships for aircraft noise may not be directly valid for specific sources such as helicopters. In addition to several non-acoustic attitudinal factors, acoustic characteristics of helicopter noise may influence its perception and the annoyance response. The present study investigates the role of helicopter noise-induced rattle (i.e. sounds of rattling objects or windows within the dwelling induced by low frequency components impacting the building) in heightening the annoyance response. This was done by asking 120 subjects to compare the annoyance due to recorded helicopter noise (either with or without rattle) with that due to fixed-wing aircraft noise in a paired comparison test. Subjects were seated in one of three dwelling types which differed substantially in their susceptibility to produce rattle or vibration. The present findings confirm earlier evidence that rattle noise and vibration increase the annoyance induced by helicopter noise above a certain $L_{A,max}$ level.

INTRODUCTION

In comparison to the evidence on annoyance induced by other transportation noise sources, relatively little is known on the community response to helicopter noise. While exposure-response relationships were presented for annoyance by aircraft noise, it was explicitly stated that the curves were not necessarily valid for specific sources such as helicopters, low-flying military aircraft or aircraft ground noise [1]. Firstly, there are indications that several non-acoustic, attitudinal factors may increase the annoyance response to helicopter noise, such as fear of a crash or low perceived necessity of the helicopter flights or the noise that is produced by them [2, 3, 4].Secondly, specific acoustic characteristics of helicopter noise may be hypothesized to increase the annoyance response. In the past, several studies have explored whether the degree of impulsiveness of helicopter noise influences the annoyance [5, 6, 7, 8, 9], but the overall consensus is that there is no evidence to justify the application of an impulse correction to the noise level of helicopters with impulsive characteristics [10, 11]. There is evidence, however, for a role of helicopter noise-induced rattle (i.e. sounds of rattling objects or windows within the dwelling) or vibration (the perception of vibrating building elements or furniture) which may be induced by the low frequency components of helicopter noise impacting the building [12]. In a large field study in the United States [13] with subjects seated in a house of wood-frame construction, noise from helicopters flying over was rated as more annoying than a white noise control stimulus with equal indoor A-weighted SEL (L_{AE}), but only when the helicopter induced rattle noise or vibration within the building. The results suggest a decibel offset of at least 10 dB to account for the extra annoyance when rattle or vibration were induced by the helicopter noise (i.e. the white noise control stimulus had to be at least 10 dB higher to induce equal annoyance). An extension of this study suggested similar offset values of 10 and 8 dB for two helicopter types inducing rattle and vibration [14]. In the present study, the role of rattle and vibration in the annoyance response to helicopter noise is revisited with subjects comparing the annoyance due to helicopter noise with that due to fixed-wing aircraft noise in a paired comparison test, while they were seated in one of three dwelling types which differed substantially in their susceptibility to produce rattle or vibration. The aim was to investigate whether helicopter noise, at certain levels or distances where there is a high probability of rattle and vibration in the dwelling, can be adequately described by A-weighted noise levels, or whether it should be rated more strictly than regular aircraft noise.

METHODS

Subjects

Through employment agencies 60 male and 60 female healthy volunteers were recruited, receiving a small remuneration for their participation in the study. Ages ranged between 18 and 65 years, with the distribution of age and gender across the three selected study sites being very similar, as shown by the breakdown of subjects in age and gender in Table 1. Furthermore, while 40% of the subjects were unemployed (n=48), also many working people (n=42) and students (n=14) were recruited. Although subjects were screened for hearing acuity, a priori some hearing loss was allowed to preserve representativeness of the sample and to prevent excluding elderly subjects (a hearing loss between 20-35 dB is considered normal for subjects over 50 years). Still, 12 subjects had higher hearing thresholds than expected for their age, 7 of which were younger than 50 years (with local hearing loss between 25-45 dB) and 5 were older than 50 years (with local hearing loss between 45-56 dB). Hearing loss was primarily found at the higher frequencies (4000-6000 Hz). Rather than excluding these subjects, the influence of hearing loss was tested in a sensitivity analysis.

Table 1: Breakdown per study site of subjects' age and gender (Male/Female), and working status

	The Hague		Den Helder 1		Den Helder 2			Working/	
Age [yr]	**M**	**F**	**M**	**F**	**M**	**F**	**Unemployed**	**Student**	**Other**
18-25	11	9	9	3	11	6	13	31	5
26-35	3	5	6	6	6	6	14	14	4
36-45	2	2	1	7	2	1	10	4	1
46-55	2	3	2	6	0	4	8	6	3
56-65	2	1	0	0	3	1	3	1	3
Total	20	20	18	22	22	18	48	56	16

Study sites

Study sites were selected to reflect a variety in constructive characteristics (e.g. wooden versus concrete foundation; single versus double glazing) that are likely to be associated with different susceptibility to rattle or vibration. Furthermore, some practical demands had to be met, such as availability, being at some distance from residential areas that could potentially experience disturbance by the test sounds, and little chance of disturbance by other noise-inducing activities. The following three study sites were chosen, of which the first and second were considered beforehand to be highly susceptible to rattle and vibration, whereas the last one was viewed as unlikely to produce rattle or vibration:

The Hague: bungalow (±1975) at the grounds of one of TNO's offices, with wooden foundation and ceiling, and a mostly (rather thin) double glazed façade with two single glazed doors.

Den Helder 1: villa (±1930) at the grounds of the Netherlands Ministry of Defense, with steel foundation and a wooden roof covered with tiles, and single glazed (rather loose) windows.

Den Helder 2: apartment flat (±1960) at the grounds of the Netherlands Ministry of Defense, with concrete foundation, ceiling and walls, and relatively new double glazed windows.

Helicopter and aircraft noise stimuli

The helicopter noise stimuli consisted of two recorded Boeing CH-47 Chinook helicopter flights, one flying over the microphone and the house (Chinook Flyover, hereafter referred to as ChFO), the other approaching, then turning and flying by the house (Chinook Flyby, hereafter referred to as ChFB). The aircraft noise stimuli consisted of a recording of a jet fighter flying over (F-16), and a recording of a civil airbus approaching (A-319). The recorded sound clips of helicopter and aircraft noise were played from speakers placed outdoors at 10 meters distance from the main window façade of the dwelling at each study site (except for the first study site where they were placed at 6.6 meters distance due to spatial restrictions). Three 2-canal Crown I-Tech 4000 amplifiers were used, two of which were connected to four JBL SRX 728S speakers for low frequencies (subwoofers). The third amplifier was connected to two JBL SRX 715F 2-way speakers. By using digital crossover filters the signal was split at 80 Hz into a low-frequency signal for the subwoofers and a higher frequency signal for the 2-way speakers. For frequencies above 20 Hz, the sound system was capable of presenting the sound clips at the required levels, which was verified by an outdoor microphone placed at 1 meter from the façade. Subjects rated the presented stimuli afterwards to be well (up to highly) recognizable as helicopter and aircraft noise.

Experimental design

The chosen study design is paired comparison, which means that subjects were repeatedly asked to make a (forced) choice which of two stimuli (one helicopter and one aircraft sound clip) they judged to be more annoying. In addition, they were asked to indicate on a scale from 1 to 5 ('not at all' to 'extremely') how difficult it was to choose between the two. This method allows to determine the (relative) sound levels at which the annoyance response to both stimuli is equivalent, which is reached when 50% of the subjects judge the helicopter noise as more annoying and 50% judge the aircraft noise as more annoying. Four façade levels of helicopter noise were each compared with four ascending levels of aircraft noise. Each of these paired comparisons were presented two times, varying the order of noise type (helicopter noise first versus aircraft noise first), yielding a total of 32 comparisons. The order of presentation of the 32 comparisons was balanced systematically according to two 4 x 4 Latin squares.

Procedure

At each study site there were three days of testing, with one session in the morning and one in the afternoon. Per session 5 to 7 subjects were invited, in total yielding 40 subjects per study site. Prior to the paired comparison test, subjects were asked to read the information with test instructions and sign the informed consent form. Subjects were informed that during the test they were supposed to compare the annoyance induced by helicopter and aircraft sound clips, but in order to avoid an influence on the results they were not told that the primary aim of the study was to investigate the potential influence on annoyance of any induced rattle noise and vibration. In addition, subjects filled in a questionnaire on their demographic characteristics, their general sensitivity to noise (using an abbreviated Weinstein Scale) and the degree to which they are exposed to annoying transportation noise in their home situation. Subsequently, subjects were individually submitted to a hearing test in a separate room to establish their hearing thresholds in both ears for frequencies from 125 to 6000 Hz (using the autoscreening option of a Madsen Xeta audiometer).

Then the paired comparison test started, with the subjects being seated around a table with a low partition in between them to keep them from distracting or influencing each other. After a training block with two comparisons (2 x 2 sound clips) the four blocks of 8 comparisons each were presented. The duration of each sound clip was indicated by a small flickering blue LED. Each comparison took around two minutes: the sound clips themselves lasted 40-45 seconds each, with 10 seconds in between them and 30 seconds afterwards during which they were asked by the experimenter to score on paper which of the two was more annoying. Thus, each block lasted 16 (8 x 2) minutes and the whole test session of 32 comparisons (including the training block and a 10 minutes break between block 2 and 3) lasted 78 minutes. At every test session, at least one experimenter was present in the same room to rate for every sound clip the degree of rattle noise heard or vibration perceived (tactually or visually) on a 5-point scale with labels 1 ('not at all'), 2 ('hardly'), 3 ('somewhat'), 4 ('clearly') and 5 ('strongly'). If applicable, separate ratings were given for rattle noise and vibration. The subjects themselves were only asked at the very end of the study to evaluate (on the same scale) the overall degree of rattle and vibration they had perceived during the test, because mentioning rattle and vibration at an earlier stage might have influenced the results. In addition, they were asked to what degree they regarded the helicopter and aircraft noise as realistic, whether they were annoyed or frightened by it, and whether they had perceived, were annoyed or frightened by rattle or vibration from several sources (windows, glass objects, floors/ceiling).

Data analysis

The results were analysed separately per study site, combining data of 40 subjects from 6 sessions. For each of the 32 comparisons, the mean difficulty (score between 1 and 5) to choose the most annoying of the two stimuli was calculated, as well as the percentage of the 40 subjects indicating that the helicopter noise was more annoying than the aircraft noise. In addition, for each of the 32 helicopter noise stimuli and each of the 32 aircraft noise stimuli, the mean score of the rattle ratings by the experimenter (score between 1 and 5) was calculated across the 6 sessions per study site.

Furthermore, several noise variables were calculated based on the indoor and outdoor noise measurements of the 32 sets of stimuli, again averaged across the 6 sessions per study site: outdoor L_{AE}, L_{Amax} and L_{CE} at the façade; indoor L_{AE} and L_{CE} at the table; ΔL_{AE}, $\Delta L_{A,max}$ and ΔL_{CE}, i.e. the difference between the two stimuli per comparison (aircraft minus helicopter noise level,) both outdoor and indoor (see Table 2).

Table 2: Mean and range (in dB) of façade and indoor noise levels for the 32 sets per site.

		The Hague		Den Helder 1		Den Helder 2	
Façade levels	**Sets**	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**
L_{AE} Helicopter	32	88	80-95	88	80-96	87	80-95
L_{AE} Aircraft	32	90	76-105	90	76-103	90	75-105
ΔL_{AE}	32	2	-6-10	2	-6-9	3	-5-10
L_{CE} Helicopter	32	103	94-111	106	98-115	103	95-111
L_{CE} Aircraft	32	95	84-108	96	88-107	95	82-108
ΔL_{CE}	32	-8	-16-0	-10	-18 - -3	-9	-16-0
$L_{A,max}$ Helicopter	32	79	71-86	79	71-87	78	71-86
$L_{A,max}$ Aircraft	32	82	67-97	82	67-96	82	68-97
$\Delta L_{A,max}$	32	3	-5-11	3	-5-11	3	-5-12
Indoor levels	**Sets**	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**
L_{AE} Helicopter	32	70	62-78	71	64-79	64	56-71
L_{AE} Aircraft	32	69	56-83	65	56-76	67	54-81
ΔL_{AE}	32	-1	-8-7	-7	-15-0	2	-6-10
L_{CE} Helicopter	32	88	80-96	93	86-100	84	76-92
L_{CE} Aircraft	32	79	70-92	81	75-90	73	64-87
ΔL_{CE}	32	-10	-17- -3	-12	-20 - -5	-10	-18--3
$L_{A,max}$ Helicopter	32	63	54-70	63	54-72	56	47-62
$L_{A,max}$ Aircraft	32	61	48-76	56	45-69	59	47-75
$\Delta L_{A,max}$	32	-1	-10-7	-8	-18-1	3	-6-13

Stepwise regression analyses were run using the 32 comparisons per study site as cases, with as dependent variable the percentage of subjects indicating that the helicopter noise was more annoying than the aircraft noise. In line with the experimental design of the study, the following predictors were entered into the model in step 1 to 4 if their contribution was significant ($p < 0.05$): 1) ΔL (aircraft minus helicopter level); 2) Heli_first (order of presentation: 1 ‘helicopter first’ versus 0 ‘aircraft first’ ; 3) Type_heli (1 ‘Chinook Flyover’ versus 0 ‘Chinook Flyby’) and Type_air (1 ‘A319’ versus 0 ‘F16’); 4) Rattle (rattle noise or vibration, dichotomized based on a cut-off applied to the experimenter’s scores, 1 ‘yes’ versus 0 ‘no’). This regression model was first run with outdoor ΔL_{AE} and ΔL_{Amax} (being the main variables of interest for legislation), but subsequently also with indoor ΔL_{AE} and ΔL_{Amax} (since indoor levels are expected to show higher association with annoyance reported indoors) and successively with outdoor and indoor ΔL_{CE} as ΔL (to explore whether C-weighted levels better account for any differences in annoyance, including those caused by rattle or vibration). The parameters of the regression analyses were then used to determine the ΔL at which 50% of subjects judge helicopter noise as more annoying than aircraft noise, as well as the effect of rattle on this ΔL. To verify results, reported difficulty to choose was curve-fitted to ΔL, hypothesizing that the ΔL at which subjects find it most difficult to choose coincides with the equivalent annoyance level.

RESULTS

Rattle evaluation

The degree of rattle or vibration was evaluated by the experimenter for each helicopter and aircraft noise stimulus presented. This was done for two reasons: 1) to investigate per study site from which L_{Amax} level helicopter or aircraft noise induces rattle or vibration within the building; 2) to investigate to what extent the perception of rattle or vibration increases the likelihood that helicopter noise is rated as more annoying than aircraft noise. When no rattle noise but only vibration was perceived, the experimenter scored the degree of vibration. When rattle noise could be heard during some of the stimuli (which was exclusively the case at the site Den Helder 1), the experimenter scored the degree of rattle and vibration separately, but only the scores for rattle noise were used in further analyses.

As expected, aircraft noise hardly induced any rattle or vibration, regardless of study site or level. The degree of helicopter noise-induced rattle or vibration as rated by the experimenter, however, depended on both study site and level: 1) The Hague: vibration (but no rattle) was slightly to clearly perceived (score > 2) when façade levels were above $L_{A,max}$ 80 dB; 2) Den Helder 1: rattle noise (next to vibration) was clearly to strongly perceived (score > 3) starting at an $L_{A,max}$ of 75 dB; 3) Den Helder 2: vibration (no rattle) was only perceived (score > 2) at the highest $L_{A,max}$ (85 dB). To be able to distinguish in subsequent analyses between helicopter noise stimuli with and without rattle (or vibration), a different cut-off was used at each study site, following the distribution of the scores. At sites The Hague and Den Helder 2, where only vibration was perceived (mean score across 32 stimuli 2.2 and 1.8 respectively), 'rattle' was defined as at least slight vibration (score > 2), while at Den Helder 1, where rattle noise was clearly heard (mean score 3.5), rattle was defined as at least clear rattle noise (score > 3). The overall rattle scores as given afterwards by the subjects (averaged across 40 subjects per site) were in agreement with those of the experimenter, with a mean score of 2.1 at site The Hague, a mean score of 3.8 at Den Helder 1 and a mean score of 1.8 at Den Helder 2.

Annoyance

Helicopter noise, as played by speakers outside the façade, was judged by subjects seated indoors to be more annoying than aircraft noise of the same A-weighted façade noise level. This was particularly true for the site where the helicopter was found to induce rattle noise (Den Helder 1), although a small increase was also found at a site with only vibration (The Hague) and at a site without rattle noise or vibration (Den Helder 2). Apparently, the increase was partly caused by a reduced façade insulation of the helicopter noise compared to the aircraft noise: helicopter and aircraft noise of the same noise level as measured indoors, reflecting the noise level actually heard by the subjects, were on average not rated differently. Within sites, concurrent rattle noise or vibration by the helicopter noise increased the chance that it was rated as more annoying than aircraft noise at the same façade level. At the site where rattle noise was reported, it was found to increase annoyance by helicopter noise equivalent to an increase in the noise level of 5.5 dB (ΔL_{AE}) to 6 dB ($\Delta L_{A,max}$). At the site where only vibration was reported, it was found to increase annoyance equivalent to an increase of 2.5 dB (ΔL_{AE} and $\Delta L_{A,max}$). When differences in C-weighted façade levels were used to predict relative annoyance by helicopter and aircraft noise, no difference was found between helicopter noise with and without rattle noise or vibration, but differences in annoyance between helicopter noise and aircraft noise could not be adequately explained by ΔL_{CE}.

DISCUSSION

The decibel offsets found for rattle noise are lower than the offset values of at least 10 dB observed in previous research in the United States for helicopter noise accompanied by rattle [9,13]. This discrepancy may be due to differences in design, in particular the use of a real and different type of helicopter and the choice of white noise as a reference stimulus in the earlier study, or to differences in susceptibility to rattle between typical housing types in the United States and the Netherlands. Nevertheless, the present findings confirm that rattle noise and vibration increase the annoyance induced by helicopter noise above a certain $L_{A,max}$ level.

The results raise the question whether A-weighted façade levels alone can adequately describe the expected annoyance induced by helicopters. The present findings indicate that the risk of rattle noise should be taken into account, and perhaps also the lower attenuation of helicopter noise by the façade. It could be argued that C-weighted noise levels are more suitable to take both of these aspects into account, because they better reflect the low frequency components. However, C-weighted levels proved less able than A-weighted levels to predict annoyance differences between helicopter and aircraft noise, as shown by the mostly larger decibel offsets. Therefore, a better way of taking the extra annoyance due to rattle noise and vibration into account would be through adding a correction factor to the A-weighted noise levels at the façade.

A subsequent question is how and when to apply such a correction factor. Rattle noise or vibration will only occur under specific conditions, requiring high façade levels as well as housing types with weak construction or insulation characteristics. Based on the present findings, even in the most susceptible dwelling rattle noise is not expected below an $L_{A,max}$ of 75 dB, and in other buildings only some vibration may occur when $L_{A,max}$ is higher than 80 dB. This means that a rattle correction factor is applicable in areas where helicopters fly particularly close to the dwellings producing high façade levels, and where one or more dwellings are of a housing type that can be labelled as potentially susceptible to rattle.

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