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A prediction of annoyance due to high speed train noise in the netherlands

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SUMMARY

The question to be answered in this desk study is formulated as follows:

how does annoyance due to the noise caused by high speed trains (HST's) and conventional trains compare, exposure expressed in L_{etm} being equal?

The issue was approached from two perspectives: the perspective of exposure and the perspective of effects.

The following aspects of exposure have been considered: the average noise level during a train pass-by, the peak level, the numbers of passages and pass-by time, the frequency spectrum, the onset velocity, and vibrations. A close examination of these aspects does not indicate that the nuisance value of HST's might be either higher or lower than that of conventional trains.

Only one social survey on the effects of noise caused by the HSL (= line for high speed trains) exists, which was conducted in situations which bear some resemblance to the Dutch situation. This survey was carried out in France and has been thoroughly set up. Twenty five sites included in the survey guarantee a minimization of locational effects. Though the noise measurements were conducted unattended, the number and organization of the measurements warrant a satisfactory quality of the noise data. The questionnaire has a logical format; questions were formulated and organized well. Adequate statistical analyses were conducted. A limitation of the survey is the small number of respondents exposed to high noise levels.

Actually approximately one-third of the respondents are not only exposed to noise which was absent before the HSL was opened, but also experienced rather radical changes in land use and in the visual aspects of the area. Many residents anticipated these changes reluctantly: 35% actively participated in anti-HSL activities. Three to four years after the opening of the line negative attitudes towards these changes still appear to be rather strong. They co-vary with the evaluation of the noise situation. The annoyance due to HSL noise is considerably higher than the annoyance reported in earlier studies on conventional trains. More behavioral adaptations are observed as well. The "suddenness" of the noise appears to be not important and thus will not enhance annoyance.

Both approaches - from the perspective of exposure and from the perspective of effects - lead to clearly different results. From the perspective of exposure there seems to be no reason to expect

FOREWORD

The TNO-report *'Geluideffecten Hogesnelheidstrein'* (Noise effects of the high speed train) was published in 1993. The report reviewed the state-of-knowledge at that time. The main conclusion read: no more annoyance is to be expected from lines with high speed trains than from lines with conventional trains, noise exposure (in L_{etm}) being equal.

After publication of this report, in the spur of research on high speed trains, new data became available, both on the acoustical characteristics of high speed train noise, and on residents' reactions to the noise. Therefore the Netherlands Ministry of Housing, Spatial Planning and Environment requested TNO to update the report.

The present report provides the update. The conclusion of the earlier report cannot be maintained unequivocally. There is still a fair probability that no more annoyance is to be expected from lines with high speed trains than from lines with conventional trains, noise exposure (in L_{etm}) being equal. But the results of a single social noise survey, though too isolated to be granted a generalizable validity, cast some doubts upon this conclusion.

The report reflects the combined efforts of two TNO-institutes. The authors thank Jacques Lambert and Paul de Vos for their valuable contributions to the project. They provided the data, essential for making the update, and optimized the final report by commenting a draft version.

We thank Isabelle Vernet (INRETS) for re-analyzing the original data of the French TGV-study in order to provide us with a data set suited to calculate dose-response relations according to our requirements.

that HST's and conventional trains differ in their potential to cause noise annoyance. From the perspective of the effects, however, substantial differences become apparent: at a given noise level, HST's seem to cause much more annoyance than conventional trains, differences being larger as lesser degrees of annoyance are considered. When the percentages "highly annoyed" are compared, differences are nog big. In fact the rating of "highly annoyed in wintertime" coincides with the response curve for conventional trains. Especially the percentages "moderately annoyed" are, however, very high over the whole range of noise levels, and are hardly related to this level. Thus, it seems plausible that other variables, such as attitudinal ones, are driving this effect, and are doing so more than we have ever found in other studies. Due to several uncertainties, for instance about the role of the time difference (about 15 years lie between the surveys on conventional trains and the one about the TGV), about the role of the climate and about the role of the decision making and communication process, no definite conclusions can be based on this latter approach.

SAMENVATTING

De vraagstelling voor deze bureaustudie is als volgt geformuleerd:

hoe verhoudt zich de geluidhinder door hogesnelheidstreinen (HST's) met de geluidhinder door conventionele treinen, bij een gelijke geluidbelasting in L_{etm}*?*

De vraagstelling werd vanuit twee gezichtspunten benaderd: vanuit het gezichtspunt van de expositie en vanuit dat van de effecten.

De volgende aspecten van de expositie zijn in beschouwing genomen: het equivalente geluidniveau tijdens een treinpassage, het bijbehorende piekniveau, het aantal passages en de tijd dat een passage hoorbaar is, het frequentiespectrum, de stijgtijd en (het vermoedelijke belang van) trillingen. Een nauwkeurige analyse van deze aspecten geeft geen aanleiding te vermoeden dat HST's meer of juist minder hinder zullen veroorzaken dan conventionele treinen.

Er is slechts één enquête over effecten van geluid van de HSL (= lijn voor hogesnelheidstreinen) gehouden in min of meer met de Nederlandse situatie overeenkomende omstandigheden. Dit - goed opgezette - onderzoek vond in Frankrijk plaats. Het optreden van eventuele locatie-effecten is minimaal doordat het onderzoek op 25 verschillende plaatsen is uitgevoerd. Hoewel de geluidmetingen onbemand zijn uitgevoerd, is een voldoende kwaliteit van de geluidgegevens gewaarborgd door het grote aantal metingen en de wijze waarop deze zijn georganiseerd. De vragenlijst heeft een logische opbouw; de vragen zijn goed gesteld en geordend. Er zijn adequate statistische analyses uitgevoerd. Het geringe aantal ondervraagden met een hoge geluidbelasting vormt een minder sterk punt van het onderzoek.
Ongeveer eenderde van de ondervraagden is blootgesteld aan geluid dat er niet was voordat de HSL in gebruik werd genomen, en heeft bovendien ingrijpende veranderingen op ander gebied, zoals ruilverkaveling en de andere aanblik van het landschap meegemaakt. Veel bewoners hebben deze veranderingen met tegenzin zien komen: 35% van de ondervraagden heeft actief deelgenomen aan activiteiten tegen de komst van de HSL. Drie tot vier jaar nadat de lijn in gebruik is genomen blijken de negatieve gevoelens over deze veranderingen nog altijd tamelijk sterk aanwezig. Ze hangen samen met de waardering voor de geluidsituatie. De geluidhinder door de HSL is aanzienlijk meer dan de hinder die in eerdere onderzoeken over conventionele treinen is gevonden. Er zijn ook meer gedragsveranderingen waargenomen. Het vermeende plotselinge karakter van het HST-geluid blijkt niet van belang en zal niet of nauwelijks tot meer hinder aanleiding geven.

Beide benaderingen - vanuit het gezichtspunt van expositie en vanuit dat van de effecten - leiden tot sterk verschillende uitkomsten. Vanuit het gezichtspunt van expositie schijnt er geen reden om van HST's meer hinder te verwachten dan van conventionele treinen. Gezien vanuit het gezichtspunt van de effecten komen er echter grote verschillen naar voren: bij gelijke geluidniveaus schijnen HST's aanzienlijk meer hinder te veroorzaken dan conventionele treinen. De verschillen zijn groter naarmate een geringere mate van hinder in ogenschouw wordt genomen. Als de percentages "erg gehinderd" worden vergeleken zijn de verschillen niet zo groot. De scores voor "erg gehinderd in de winter" laten zich zelfs beschrijven met de respons curve die geldt voor conventionele treinen. In het bijzonder de percentages 'een beetje gehinderd' liggen echter over de hele range van geluidbelastingen op een zeer hoog niveau en houden daar nauwelijks verband mee. Het lijkt dan ook aannemelijk dat andere variabelen, zoals de attitudes, dit effect veroorzaken en wel sterker dan wij tot nu toe in andere studies hebben gevonden. Vanwege diverse onzekerheden, zoals bijvoorbeeld de rol van het tijdsverschil (de HSL enquête vond ongeveer 15 jaar later plaats dan de enquêtes over de conventionele treinen), of de rol van het klimaat, of de rol van het beslis- en communicatieproces, kunnen op basis van de benadering vanuit het gezichtspunt van de effecten geen definitieve conclusies worden getrokken.

1. INTRODUCTION

1.1 Background of the study

In the near future high speed trains (HST's) will be introduced in the Netherlands. A train is defined to be a high speed train if its maximum speed is 250 km/h or more on new tracks, and 200 km/h or more on (adjusted) existing lines [1].

Two lines (HSL's) are in preparation:

A: from Amsterdam, via Schiphol and Rotterdam to Brussels (and further to London and Paris), the so-called HSL-S(outh). This line will be opened in the year 2005;

B: from Amsterdam via Breukelen and Utrecht to Arnhem and Cologne, the so-called HSL-E(ast). This line will be opened in the year 2015.

Ad A:

The decision procedure concerning the HSL-S is nearly completed. Soon the Government will decide on the preferred track. Two alternatives are being considered for the track north of Rotterdam, while south of Rotterdam the track will probably run parallel to highway E19 towards the Belgian border and Antwerp. Once the Government has made its decision, the decision will be discussed in Parliament. Once the Parliament has ratified the decision, the definite corroboration is due in autumn 1997.

In view of the connection with the French TGV-network TGV-like rolling stock will run on this new line with a speed up to 300 km/h. From May 1996 on, the Thalys (or TGV-PBA = TGV Paris - Brussels - Amsterdam) will already run on the existing track Amsterdam - Schiphol - Leiden - The Hague - Rotterdam - Dordrecht - Roosendaal - Brussels - Paris, with a speed up to 140 km/h. The Thalys is also suited for the new track.

Ad B:

The decision procedure concerning the HSL-E is just started. The plan is to extend and upgrade the existing route via Arnhem and Utrecht to Amsterdam, where the German ICE 2.2 will run with a speed up to 200 km/h.

On the noise characteristics of HST's some knowledge is available [2,3]. For this investigation knowledge on specific aspects of the noise, such as *noise level*, *frequency spectrum* and *onset* *velocity*, and on *vibrations* as well, is essential to decide whether HST noise may be evaluated with the same legal norms as set for conventional trains.

In January 1993 TNO-PG published a report on this issue [4]. After that time new information became available, both on the traffic intensities, the acoustical properties of the HST's, and on the annoyance caused by the trains on the TGV-Atlantique line in France. Therefore the Netherlands Ministry of Housing, Spatial Planning and Environment requested TNO to update the report mentioned.

1.2 Aim of the study

The question to be answered in this study is formulated as follows:

> *how does annoyance due to the noise caused by HST's and conventional trains compare, exposure expressed in L_{etm} being equal?*

1.3 Organization of the study

The earlier TNO report [4] serves as a basis for this update. Relevant new knowledge is gained from [5, 6 and 7], and from personal communications with P.H. de Vos of the Netherlands Railways (NS), and J. Lambert of the Institut National de Recherche sur les Transports et leur Sécurité (INRETS). P.H. de Vos procured the data on the numbers and types of trains planned to ride on the HSL-S and HSL-E lines. J. Lambert provided TNO with the noise and annoyance data from his recent TGV survey [5], in order to enable us to calculate dose-response relations. Together with M. van den Berg of the Netherlands Ministry of Housing, Spatial Planning and Environment they were the experts who helped optimize the report by their comments.

The report is structured as follows. In chapter 2 the relevant specific noise characteristics are analyzed. For each characteristic the theoretical impact on perception and annoyance is indicated.
In chapter 3 the results of a recent survey on the impact of the HSL in France are presented, as far as relevant in the scope of this study. In chapter 4 the conclusions and a discussion are presented.

2. THE NOISE GENERATED BY HIGH SPEED TRAINS: A PREDICTION OF THE FUTURE SITUATION IN THE NETHERLANDS

2.1 High speed lines in the Netherlands

In the Netherlands two lines are planned for high speed trains: the HSL-South between Amsterdam and Brussels, via Schiphol, Rotterdam and (probably) Breda, and the HSL-East between Amsterdam and Cologne via Utrecht and Arnhem. The predicted traffic frequency is shown schematically in Table 1.

Table 1 Frequency of High Speed Trains in the Netherlands (prediction for the year 2015).

	number of trains per hour			total number of trains
	7 a.m. - 7 p.m.	7 p.m. - 11 p.m.	11 p.m. - 7 a.m.	in 24 hours
HSL-South (total in both directions)	11	11	2	192
HSL-East (total in both directions)	11,5	7,5	0	168

Two types of trains will be used on the HSL-S(outh), the 'Thalys', running at speeds up to 300 km/h, and Intercity trains ('shuttles') with a maximum speed of 200 km/h. The Thalys is modelled on the French TGV-Atlantique (TGV-A). It will consist of one power car at either end with eight passenger coaches between them, resulting in a total length of about 200 metres (or 400 metres in the case of two trains coupled together). This is about 40 metres (the length of two passenger coaches) less than the length of a single TGV-A. With respect to noise production this is the main difference between the Thalys and the TGV-A. For the shuttles no information relevant to noise production is yet available.

For the HSL-E a new train (ICE 2.2) is being developed, consisting of motor driven carriages only. The maximum speed on the HSL-E in the Netherlands will be 200 km/h.

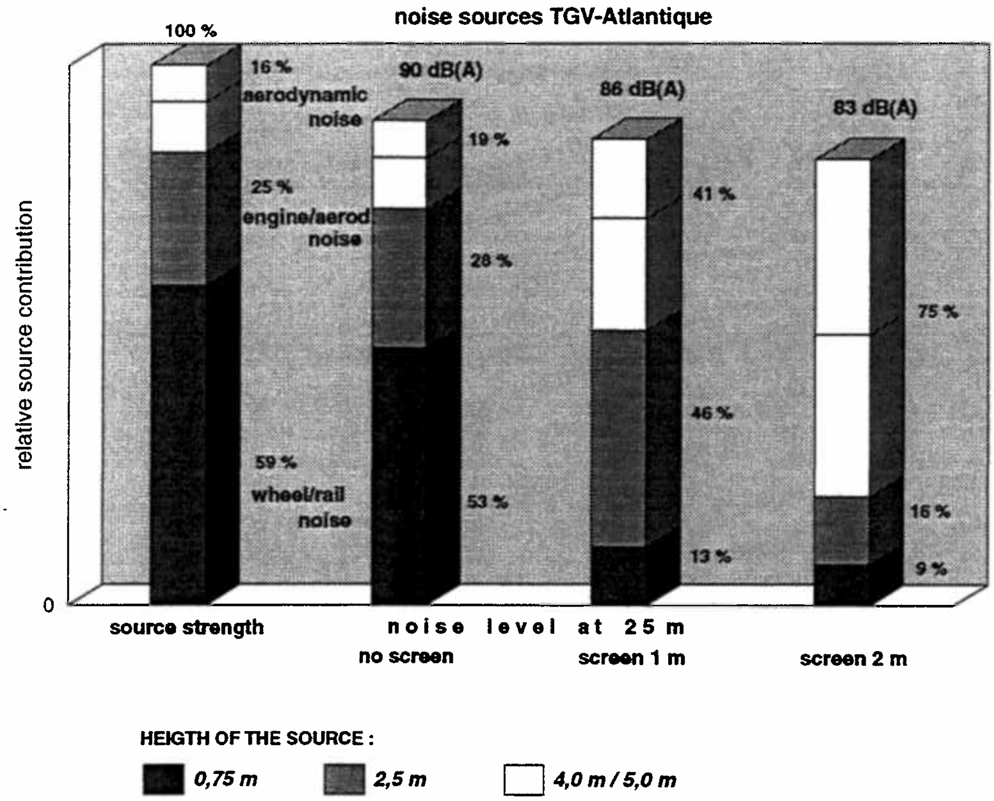
2.2 Sound characteristics of the HSL

2.2.1 Average noise levels and peak levels during a train pass-by

In the second half of this year (1996) the Thalys will be running in the Netherlands on existing track, until a new high speed line is constructed. Without radical modifications to the track, the Thalys will not exceed 140 km/h on the existing track. After analysis of available data Thompson and Ten Wolde [3] arrived at the conclusion that the acoustic aspects of high speed trains in those cases are more favourable than those of Intercity trains of the Dutch Railways (NS). From research on the noise production of current and new rolling stock in the Netherlands [6], it appears that the noise levels during a pass-by of the French TGV-Atlantique at 300 km/h are about the same as those of the older NS rolling stock ("Mat64") travelling at 140 km/h, but will be higher than those of new NS Intercity trains without block brakes (e.g. "IRM") at 140 km/h.

In the case of high speed trains we can distinguish noise generated by the rail-wheel contact (rolling noise), by the electric power cars ("engine noise") and by turbulent air flow along the train surface and at discontinuities (aerodynamic noise). At 300 km/h rolling noise (or in fact the combined noise caused by the sources close to the track, dominated by rolling noise) contributes about 60% to the total noise production. However, the importance of the noise sources in terms of the contribution to the sound pressure level along the track will depend on the situation. Figure 1 shows that the contribution of aerodynamic noise generated along the upper part of the train is less than 20% in a normal situation without a barrier and may increase to 75% when a barrier 2 metres high is placed next to the railway line [7]. This can be explained by the fact that rolling noise is generated at a height close to the track and will be effectively reduced by the barrier, whereas the barrier has no influence on the transmission of noise generated at a height of 4 or 5 m above the rail.

Figure 1 Contribution of the noise sources of the TGV-Atlantique at 300 km/h to the total source strength and to the total sound pressure level at 25 m from the track for situations with and without a barrier. Source: [7].

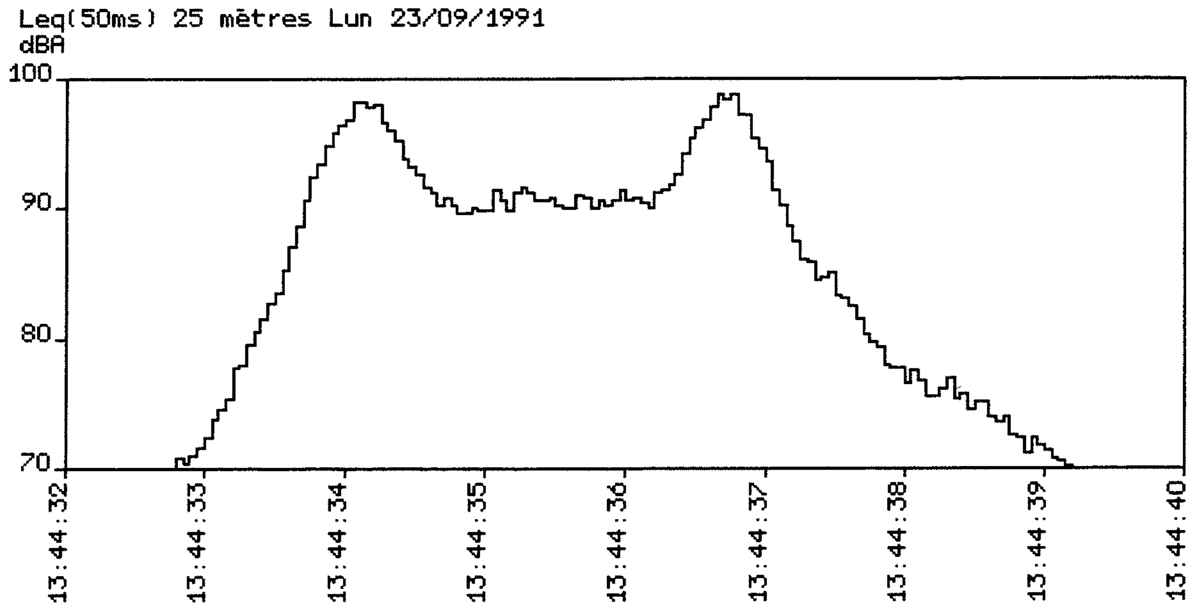


The pass-by of a TGV-A is characterized by what the French call 'les oreilles du chat' (cat's ears): the motor cars at the front and rear produce an extra peak, as shown in Figure 2. Probably these "cat's ears" are mainly caused by the additional block brakes of the motor cars, which have a negative effect on the perfect round shape of the wheels - and therefore on the rolling noise. Engine noise may also contribute to the cat's ears. As the motor cars of modern generations of TGV's will be equipped with disc brakes (and with block brakes for emergency situations), it is likely that the cat's ears will be reduced in the near future.

The ICE 2.2 on the HSL-E (disc-braked only) will consist of motor driven carriages only and therefore will cause less variation in the noise level during a pass-by.

In conclusion, the noise levels during a pass-by of the current French TGV-Atlantique at 300 km/h are about the same as those of the older NS rolling stock travelling at 140 km/h, but will be higher than those of new NS Intercity trains without block brakes at 140 km/h. Due to foreseeable technical developments the noise levels generated by future HST's will be comparable with those of the modern NS Intercity trains. Hence from the analysis of the pass-by noise levels as such, no more annoyance is to be expected of the modern HST's which will be running in the Netherlands.

Figure 2 Noise level versus time as a TGV-Atlantique passes. Speed 300 km/h, distance 25 m. Source: INRETS.



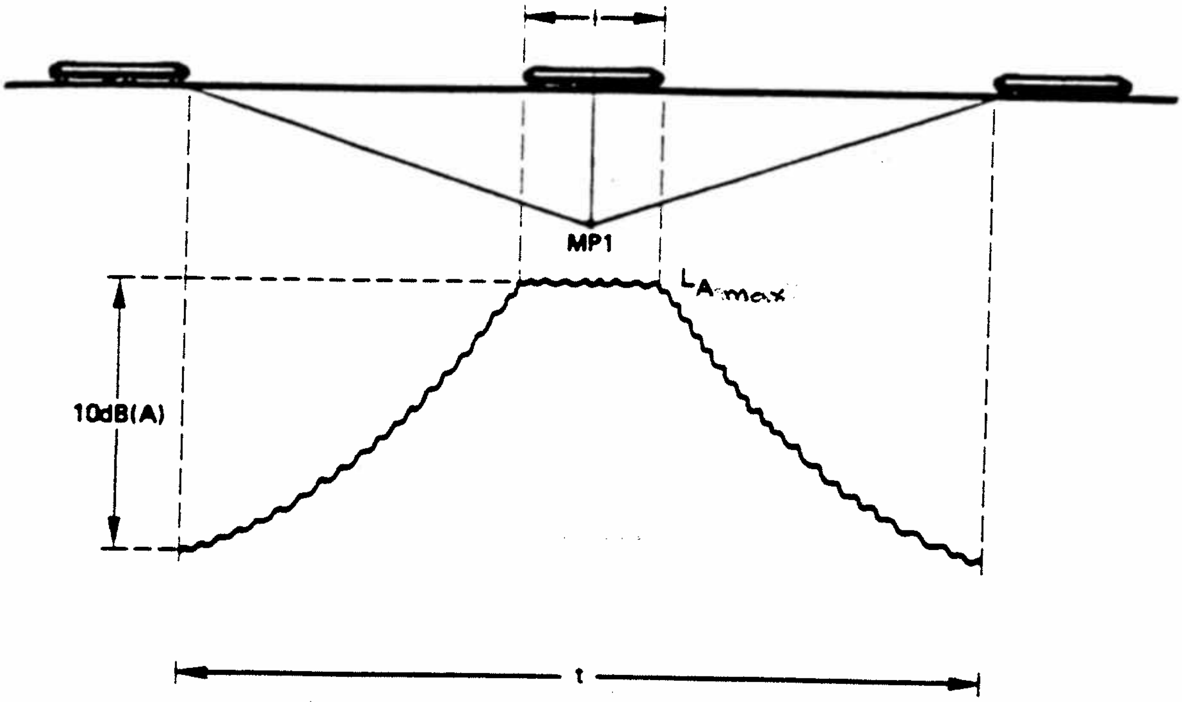
Apparitions (L-10)				
Horaire	Durée	Leq	SEL	Max
13:44:33:700	3.450	94.1	99.4	98.9

2.2.2 Numbers of passages and pass-by times

According to table 1 there will be 192 train passages on the HSL-S and 168 on the HSL-E every 24 hours. To place this in a reference frame: in an earlier study on annoyance due to noise from conventional trains in the Netherlands [10], carried out in nine locations, passage frequencies varied from 90 to 332 trains/24h, with an average of 191.

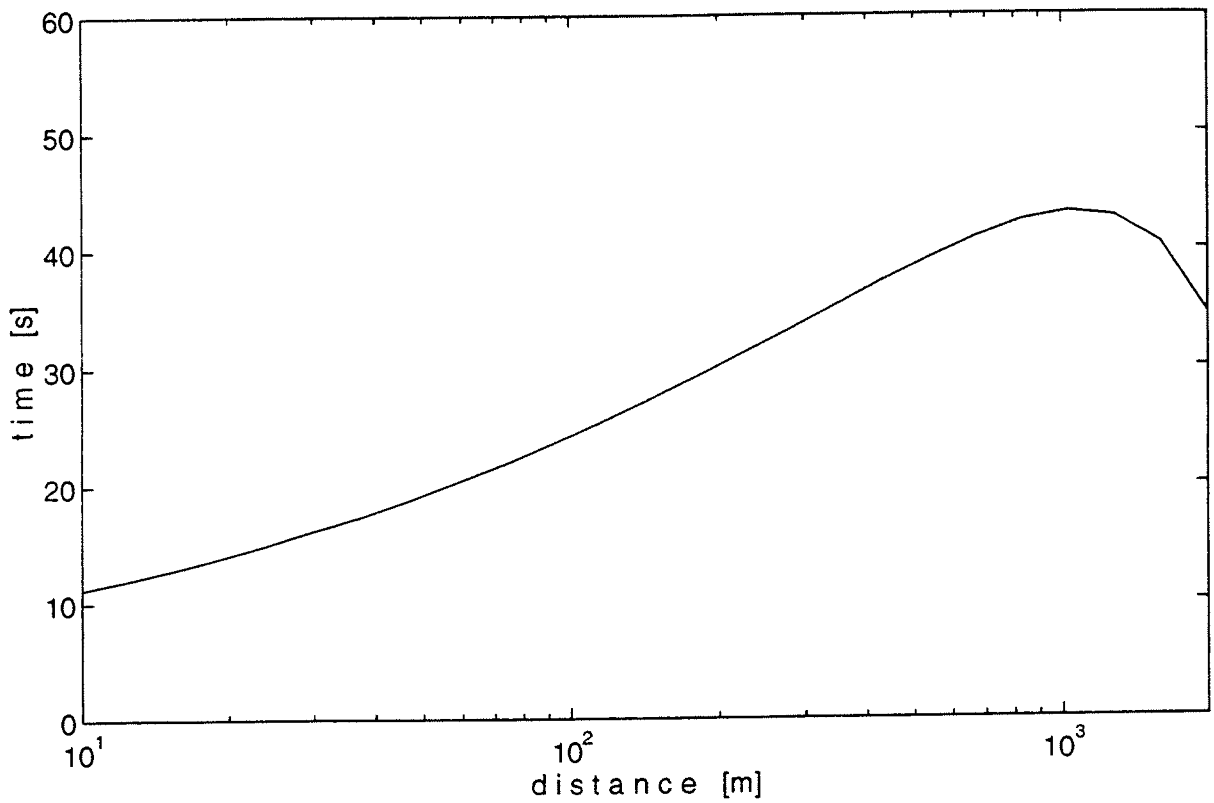
At a speed of 300 km/h, the pass-by of a train 200 metres long will take about 3,5 seconds at a distance of 50 metres from the track. In the case of two trains coupled together, the pass-by time is about 6 seconds. The pass-by time is defined here as the time between L_{max}-10 dB(A) points (see figure 3). The noise level during this time is approximately 86 dB(A) at a distance of 50 m.

Figure 3 Pass-by time, defined as the time between the L_{max}-10 dB(A) points.



The pass-by time can also be defined differently, i.e. as the time that elapses between the moment the sound of a train becomes audible and when it is no longer audible. According to information provided by the French researcher Lambert [8] the pass-by time of a TGV-A travelling at a speed of 300 km/h defined in this way amounts to an average of 21 and 32 seconds, respectively, for single and double trains. (A double TGV-A has a length of 474 m.) Lambert's measurements were made outside at a location with low background noise (< 40 dB(A)) at a distance of 25 m from the track. This distance is not representative for all situations in practice. According to a simple model [9] in which the sound source of 400 m length is represented by an array of uncorrelated dipoles, the relationship between distance and pass-by time is as shown in figure 4. As the distance increases, a lower noise level will be associated with a longer pass-by time, until the pass-by level reaches the background level.

Figure 4 Pass-by time as a function of the distance to the track, calculated [9] for a TGV-Atlantique (length 400 m, speed 300 km/h) and a background noise level of 40 dB(A).



Assuming 192 passages of double trains every 24 hours, of which 117 at a speed of 300 km/h (Thalys) and 75 at 200 km/h ("Shuttle"), and assuming a background level of 40 dB(A), the sound of the HSL at a distance of 50 m from the track will be audible for about 75 minutes (≈ 5 % of the time). The sound of the HSL will be considerable (> 60 dB(A)) for 35 minutes (≈ 2.5 % of the time). At a distance of 100 m these percentages are about 6.5 % and 3 %, respectively. For the rest of the time, the HSL will be silent. In comparison: Dutch field research into railway noise levels [10] has shown that at 50 m from the nearest track, train noise was considerable (> 60 dB(A)) between approximately 3 and 9 % of the time.

Exposure to noise with predictable noise occurrences (set timetable) and considerable quiet periods is less of a nuisance than exposure to continuous noise [11]. This principle was also established in the field research into train noise [10,12,13], which resulted in the more favourable position of rail traffic in comparison to road traffic. In the case of the HSL, the total time of quiet periods lies within the range offered by conventional trains in the Netherlands.

In conclusion, neither the numbers of passages, nor the total time period during which HST's will exceed a noise level of 60 dB(A), makes it plausible that either more or less nuisance might be expected by the planned HSL's in the Netherlands.

2.2.3 Frequency spectrum

The frequency spectrum of the passage of the TGV-A is characterized by relatively high levels of both low frequency sound and sound in the higher medium range (with concentrations below 125 Hz and around 2500 Hz). This is shown in Figure 5. However, sound in the lower medium range is also abundant, so in terms of perception, the noise comprises wide-band sound with a relatively high level of low and medium-high frequencies. As far as this aspect is concerned, there seems to be no significant difference between High Speed Trains and traditional intercity trains. Figure 6 shows the average frequency spectrum of a number of German Intercity trains travelling at speeds of 158 km/h [14]. There are definite concentrations apparent below 100 Hz and around 1000 to 2000 Hz. If the rails are properly maintained, the concentration between 1000 and 2000 Hz is minimal.

The findings above lead to the following conclusions: at the moment, these differences from the traditional train spectrum are not expected to have a negative effect on annoyance. If the band width is the main criterion in the evaluation of the sound, the nuisance value will not change. Even if the low frequencies play a major role in the perception, no difference is expected. If the high frequency components play a major role in the perception, however, the nuisance value may increase. We believe the chance of this occurring to be minimal, because the range from 1000 to 2500 Hz is within the scope of the speech spectrum. On the other hand, it is unlikely that the different spectrum of the TGV-A will cause less nuisance than traditional Intercities.

Figure 5 Frequency spectrum of the TGV-Atlantique, at a distance of 25 metres. Source: [15]

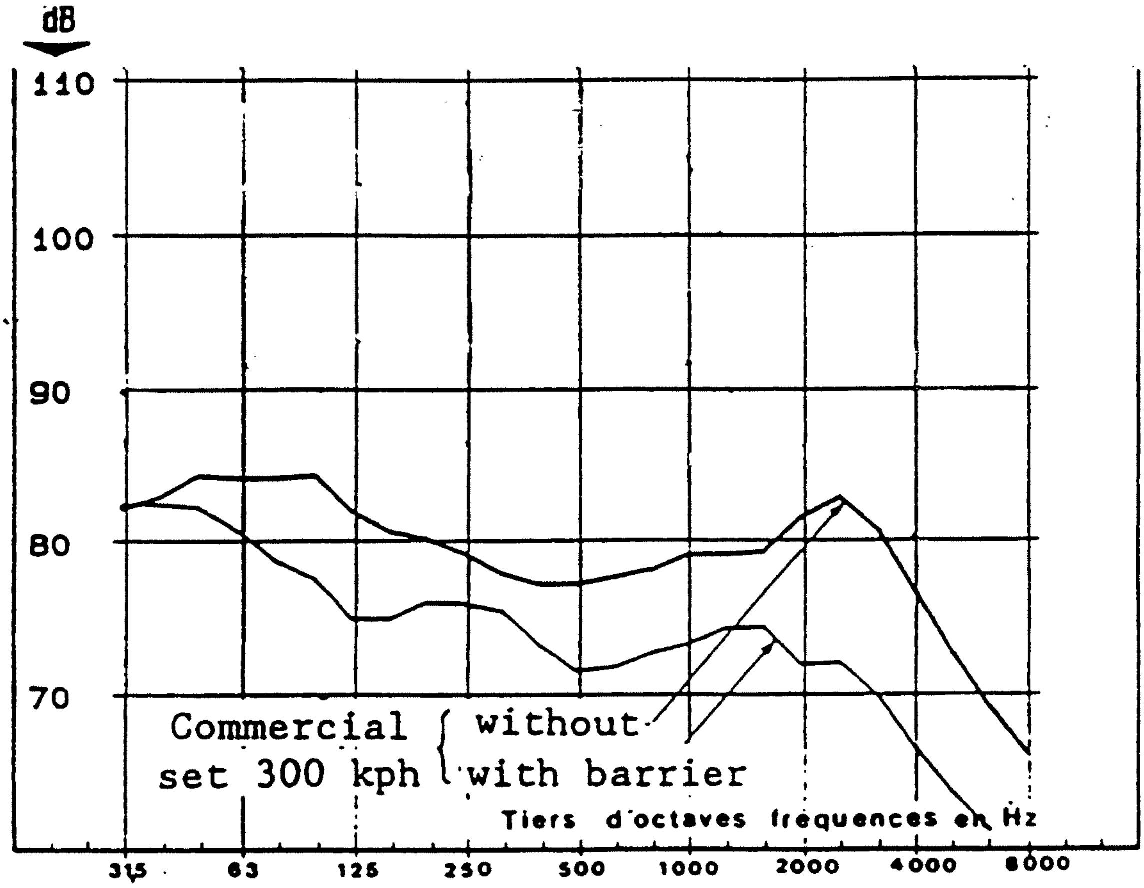
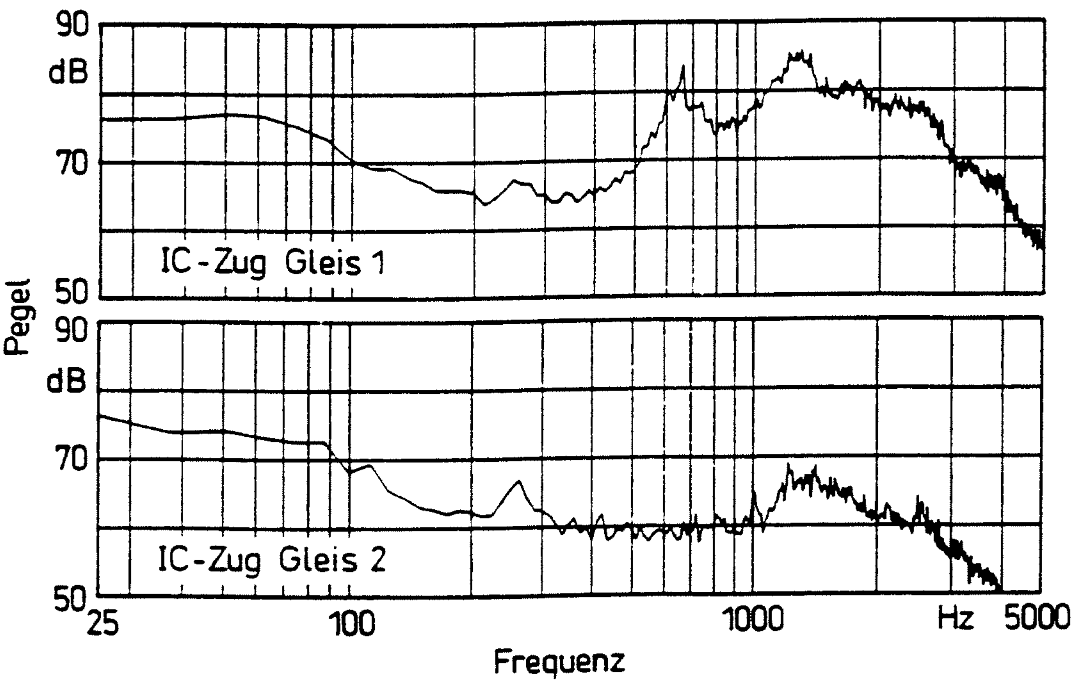


Figure 6 Average frequency spectrum of a number of Intercity trains, on well and poorly maintained rails. Source: [14]



2.2.4 Onset velocity

Studies of pulse-like sounds have shown that the onset velocity is generally related to nuisance. Onset velocities can be categorized in three classes [23]:

a. onset velocity >> 1000 dB/s;

b. onset velocity approx. 50 dB/s;

c. onset velocity < 10 dB/s.

Impulse sounds have onset velocities above 1000 dB/s, which is far more disturbing than continuous sound. Examples are the sound of hammering, shooting and pile-driving, all measured from close by.

Low-flying military aircraft produce onset velocities that are often in the order of magnitude of 50 dB/s. This causes considerable nuisance, both as a result of the noise level itself and the sudden build-up of the noise.

Passages of all kinds of vehicles fall into the third category. They hardly ever startle people, with the exception of incidental situations such as honking horns or screeching tires.

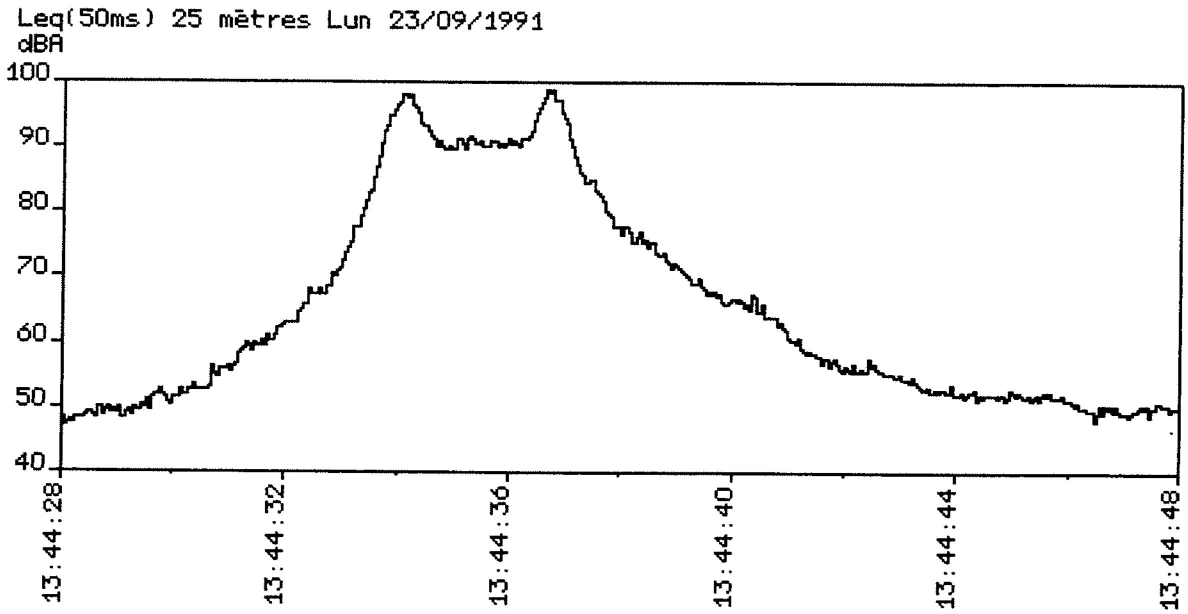
Where would the TGV fit in this categorization? Inspection of the noise level versus time of the TGV-A at various speeds (as shown in [2]) have produced the following indicative (at face-value, so not exact) onset velocities:

Table 2 Indicative onset velocities (in dB/s) on the steepest section of the curve, at various speeds. Measured 25 metres from the rails.

120 km/h	8 - 10
160 km/h	11 - 12
220 km/h	10 - 13
300 km/h	15 - 16

Although these figures, which have been determined roughly, may not be very accurate, the approach does show that the onset velocities for the HSL are more akin to the class of < 10 dB/s than to that of approximately 50 dB/s, even at higher speeds. These indicative onset velocities apply at a distance of 25 metres from the rails. As that distance increases (and, generally speaking, people exposed to HSL noise will live further than 25 metres from the rails), the onset velocities will decrease. In addition, noise emanating from the rails will ensure that a train's approach is announced in plenty of time, as can be seen in Figure 7.

Figure 7 Noise level versus time as a TGV-Atlantique train passes. Speed 300 km/h, distance 25 m. Source: INRETS.



On the basis of the arguments stated above, there are no grounds for worrying about added nuisance caused by a sudden build-up of noise.

2.2.5 Vibrations

At high speeds, the track alignment will have to be perfect to ensure safety, passenger comfort and avoid damage to the rolling stock. A heavier superstructure will provide more resistance to the forces that cause lateral displacement. On the other hand, the rolling stock will have to be lighter, in order to reduce these same forces. A heavier superstructure can be achieved by using heavier rails (60 kg/m instead of 54 kg/m), heavier (concrete) sleepers and a thicker ballast bed of stone chippings.

These factors will help to reduce the possibility of vibrations. On the basis of these data, however, the possibility of nuisance caused by vibrations of the HSL in the Dutch situation cannot be compared with that of vibration nuisance caused by the rolling stock currently in service. In the literature on exposure aspects of the TGV, vibrations are not presented as a problem factor. The different soil conditions render a forecast of the Dutch situation based on the French situation impossible.

2.3 Expectation of nuisance, based on the examination of aspects of exposure

In this chapter, the question whether a high speed railway line will cause more or less nuisance than a conventional railway line, under the condition that the equivalent noise levels (average noise level within a period of several hours) in this comparison are equal, was approached from the 'exposure' point of view. The following aspects have been considered:

* the average noise level during a train pass-by and peak level;
* the numbers of passages and pass-by time;
* the frequency spectrum;
* the onset velocity;
* vibrations.

For a High Speed Train, the average noise level during a train pass-by will be about the same as those for the older Intercity rolling stock of the Dutch Railways, which is still in use. The peak level during the pass-by may be slightly higher for a current High Speed Train than for a modern conventional train. Peak levels of future High Speed Trains will be lower than of the current ones.
The relative frequency of passages in combination with the short pass-by times makes the HSL audible during a total time which lies in the range of the times during which conventional trains are audible. Nor this, nor the data on onset velocities do lead to the conclusion that the nuisance will be either higher or lower.
As for the vibration aspect, it is impossible to make a projection, which is why it has not been taken into consideration.

3. AVAILABLE DATA ON ANNOYANCE DUE TO HIGH SPEED TRAIN NOISE

3.1 Review of a report on the TGV-Atlantique

The available data on annoyance due to HSL noise stem exclusively from the survey by Lambert *et al.* [5]. The three Japanese surveys on the Shinkansen line mentioned in an article of Igarashi [17] were not taken into account because it is assumed that the differences in noise attenuation of the dwellings between Japan and Europe will lead to incomparable results.

3.1.1 Appraisal of the survey

The report of Lambert *et al.* contains many interesting data. For our purpose only a selection of these data is presented. In particular the data are used which are relevant for assessing the quality of the study, and for comparing the annoyance due to noise of the HSL with the annoyance due to noise of conventional railway lines. Key data from the report are:

Aim of the survey
The aim of the survey (freely summarized) was to assess the noise impact on the residents living in the vicinity of the new TGV-Atlantique line, alongside which noise abatement measures (shields, earth walls and incisions in the terrain) were applied in order to comply with the guideline adopted to protect these residents. This guideline reads: L_{Aeq}(08-20h) < 65 dB(A).

Organization of the survey and sampling
The survey was conducted in September 1993, at least three years after the line was opened. The sample consisted of 259 respondents from 25 sites in rural areas alongside the TGV-only track. The speed of the TGV was fairly stable in all sites: the average speed is approximately 300 km/h, the speed of approximately 95% of all passages is between 280 and 310 km/h. In some sites virtually all residents had to be interviewed to find enough respondents exposed to high noise levels. About one-third benefitted from noise abatement measures such as shields, earth dikes and incisions in the landscape. Eighty-five percent of the respondents already lived in their present home before the construction of the line started. The sample differed slightly from the rural population on the variables age and sex [5, page 10].

Noise measurements

Forty long term measurements (24 hours each) were conducted, one per part of a site which is homogeneous with respect to noise exposure. Additionally 40 complementary short term (1 h) measurements were conducted at several spots in the sites. The measurements comply to the norm NFS-31110 [18]. All measurements were recorded. Several acoustical indexes are derived from the recordings:

* L_{Aeq} of the environmental noise, *without the noise caused by the HST's*. This is supposed to be identical to the L_{Aeq} *before the opening of the line*;
* the *total* L_{Aeq} *after the opening of the line*;
* L_{Aeq} *HSL*;
* ΔL_{Aeq} (total L_{Aeq} after the opening of the line minus L_{Aeq} before the opening of the line);
* *number of HSL events* exceeding a level of 70 respectively 80 dB(A);
* the *accumulated time* in 24 hours the events exceed 70 and 80 dB(A), respectively;
* average SEL.

Each index was determined for every single respondent.

Assessment of annoyance

General annoyance is assessed, separately for summer and winter, with Q26:
D'une manière générale, sur 24 heures, quelle note de gêne due au bruit du T.G.V. donneriez-vous? (Generally speaking for a 24 hour period, how would you rate the annoyance due to the HST noise?) A four point scale is used for the annoyance rating, with the categories "pas gênés" (not annoyed), "peu gênés" (a little annoyed), "assez gênés" (quite annoyed), "très gênés" (highly annoyed).

Conclusion

The survey has been thoroughly set up. Twenty five sites included in the survey guarantee a minimization of locational effects. Though the noise measurements were conducted unattended, the number and organization of the measurements warrant a satisfactory quality of the noise data. The questionnaire has a logical format; questions were formulated and organized well. Adequate statistical analyses were conducted. A limitation of the survey is the small number of respondents exposed to high noise levels. In conclusion: the survey is of good quality and can be used for our purpose as formulated in 1.2 (Aim of the study).

3.1.2 Results of the survey

The noise guideline appears to have been applied satisfactorily. Only a few houses are exposed to daytime (08-20h) HST noise with an L_{Aeq} > 65 dB(A), under prevailing weather conditions. However, noise exposure early in the morning (06-08h) and in the evening (20-22h) are very similar to daytime noise exposure level, and these periods commonly are regarded as more sensitive periods. Night time noise levels are much lower. Wind velocity and direction considerably affect the noise levels. Variations in noise level (= differences between HST noise level and ambient noise level) exceeded 10, and often 15 dB(A), especially in early morning and in the evening. 88 Respondents are exposed to 140 trains/24h, 59 respondents to 75 trains/24h and 112 respondents to 65 trains/24h.

HST noise is most often described by respondents as a whistling (33%) or a thundering (28%) and sometimes compared to aircraft noise (15%). Only few respondents indicate to be ever surprised by HST noise (3%). Furthermore, HST noise with L_{Aeq}(20-22h) < 40 dB(A) is described as *brief, expected* and *low*, while HST noise with L_{Aeq}(20-22h) > 55 dB(A) is mainly described as *impulsive, metallic, high-pitched* and *clear*. These findings reflect the relatively high levels of both low frequency sound and sound in the higher medium range, described in 2.2.3. It is not known from previous studies how the noise caused by other types of trains is characterized verbally.

The number of trains (= number of noise events, 39%), vibration (34%) and the loudness of the noise (27%) are reported as the most annoying aspects of the HST. Noise is a daily annoyance particularly in the evening (9% highly annoyed) and early morning (8% highly annoyed); during the weekends (no single percentage mentioned in the report) and in the summer (17% highly annoyed). It must be kept in mind that the number of noise events envisaged for the HSL-S (192) and for the HSL-E (168) exceed the numbers of noise events in the French survey (maximum 140).

Residents whose bedrooms or living rooms are directly exposed to HST noise are more annoyed than those with such rooms situated at the less exposed side of the house.

The following behavioral adaptations due to the changed noise situation have been identified: closing windows (35%), insulating the most exposed facades (11%) and changing the use of rooms (4%) (insulating the facades was done after the opening of the line; no recompensation for the costs was received). Furthermore 7 percent of the respondents expressed the intention to move because of the noise.

After the opening of the line (3 to 4 years ago, depending on the part of the line) 83% of the respondents got used to the line (75% within one year). Those reporting no habituation are mainly exposed to L_{Aeq}(20-22h) ≥ 55 dB(A).

Forty percent of the people who are annoyed, report being bothered by the modification of the landscape, and also approximately forty percent regret the devaluation of the dwellings.

Linear relationships between noise exposure and effect variables (perception, annoyance, activity disturbance, behavioral changes) show modest correlation coefficients ($r = 0.36$ at best). The statistical analyses highlights some interesting issues [19]:

* the correlations between annoyance indicators and noise indexes for separate periods (early morning - day - evening - night) are higher than for the 24 hour period;
* though L_{Aeq} is the most effective descriptor in minimizing the likelihood of underestimating noise annoyance, it rarely provides the highest correlations with annoyance indicators, except for the day period;
* during early morning and in the evening, the number of noise events (or their total duration) exceeding 70 dB(A) seems to be a more relevant noise index than L_{Aeq}, in particular when related to activity disturbances;
* the relationship between annoyance and noise level co-varies with attitudinal variables such as the opinion about the HST as a new transport mode (30% very positive, 16% very negative), the attitude towards the new railway line itself (66% disfavourable), and the satisfaction of the residents with the noise abatement measures (two-third satisfied). However, no causality can be inferred.
* 35% of the respondents were actively involved in movements against the new line.

3.2 Comparison with conventional trains

3.2.1 Some remarks in advance on the comparability of data

The results of French TGV-study will be compared with data from the TNO-archive for noise annoyance surveys, on annoyance caused by conventional trains. The data in the archive mainly originate from three large scale surveys on train noise conducted in England, Germany and the Netherlands around 1980, and from an inventory of annoyance caused by different sources in the Netherlands. Before making the comparison a number of situational variables have to be considered, which could possibly lead to differences in annoyance between TGV and conventional trains.

The following variables were examined briefly:

* time of the surveys.
  About 15 years lie between the surveys on conventional trains and the TGV-survey. In the mean time societal changes might have caused changes in response patters to noise in general and to train noise in particular. This hypothesis has never been tested systematically. Thus, the influence of the time difference remains uncertain for the time being.
* urban versus rural situations.
  The railway data in the data archive stem from both urban and rural areas. A comparison of data in the archive on annoyance in rural and in urban areas makes it clear that in general, noise levels being equal, annoyance caused by conventional trains will be <u>lower</u> in rural than in urban areas. See table 3. This leads to the hypothesis that annoyance reported in the TGV survey (conducted in rural areas) would be less than annoyance due to noise from conventional trains (studied in boths types of areas).

Table 3 Average expected and observed annoyance due to noise caused by conventional trains, in urban and in rural areas. (minimum = 5; maximum = 95)

	L_{dn}	expected annoyance	observed annoyance
urban areas	65	33	36
rural areas	62	31	30

* climate and related aspects such as living outside or with open windows. The regions in which the TGV survey was conducted, are situated slightly more southern than the

regions in which the English, Dutch and German surveys were carried out. With the same exposure at the facade the personal exposure to train noise of people in more southern regions might, generally speaking, be higher because the milder climate more often allows them to have windows or doors open or to sit outside. The TGV survey does not include data about these aspects, which precludes any firm comparison on this issue. A higher personal exposure could lead to more annoyance.

* new versus existing (=steady state) situations.
  In general habituation in a substantial portion of a population is likely after an exposure time of 3 to 4 years. For aircraft noise a habituation time of 2 to 3 years at most has been found [25]. Therefore a steady state situation is expected in the situations of the TGV survey, which was held 3 or 4 years after the opening of the line. This aspect does not feed an expectation of a difference in annoyance levels between the TGV and conventional trains.
* passenger only lines versus lines with mix (passengers and freight) traffic.
  Recently a secondary analysis of data from the TNO-archive indicated that passenger and freight trains cause the same amount of annoyance, noise levels being equal [28]. Thus, there is no reason to expect differences between the results of the TGV survey and of the data relating to conventional trains due to this aspect.
* advantages and disadvantages for residents.
  In general, conventional trains will have more advantages (public transport facilities) for residents living along their tracks than the TGV has for the residents in mid-France, far from any station. Disadvantages of railways such as acting like barriers between parts of a society, or between home and work, etc., also leading to changes in land use, are generally speaking more severe for the residents living alongside TGV tracks than for the residents of conventional trains because distances between openings in the barriers are longer. In rural areas the view of the landscape will deteriorate very much by the building of a new railway line. These aspects will probably lead to a more negative attitude towards the TGV line and, consequently, to more noise annoyance.
* ways of decision making.
  Too little information is available about the way decisions are reached in France, to be able to make a comparison with the situation in the Netherlands.

Taking these aspects into account it must be concluded that two aspects lead to expecting more annoyance due to TGV noise, one to the opposite expectation, while the influence of other aspects is uncertain. Thus making a comparison between TGV and conventional trains has its restrictions. The results must be interpreted prudently.

3.2.2 Comparison of annoyance and related concepts

Dose response relations

For HST's two measures of annoyance were assessed: one for the summer and one for the winter. Both measures are compared with the dose response relations for conventional trains. Dose response curves for conventional trains stem from the surveys [10, 11, 13, 20, 21, 22] in the TNO-archive for noise annoyance surveys. In these surveys annoyance was measured without reference to a specific season. Theoretically, the more precise formulation of the questions in the French survey will lead to a slight overestimation of the reported annoyance compared with the annoyance due to the noise caused by conventional trains.

The comparisons are made for L_{Aeq}(24h), L_{etm} and L_{dn}, against the annoyance measures A72 (percentage highly annoyed), A50 (percentage annoyed) and A28 (percentage at least a little bit annoyed). Definitions of the measures are presented in [23] and [24].

In figure 8 the French TGV-results are presented as data points (not as curves because of the limitations described in 3.2.1); for conventional trains dose response curves, based on a large database (n = 4097) are drawn. As the figure shows, at a given noise level HST's cause more noise annoyance than conventional trains do. The percentages "highly annoyed" do not differ that much. In fact the data points representing the winter situation near the TGV do not differ from the response function valid for conventional trains. In contrast, especially the percentages "moderately annoyed" are extremely high for the TGV data, compared with the response functions for conventional trains. In fact, this reaction appears to be on a very high and constant level, and is hardly related to the noise level. As far as we know, annoyance scores that high, at relatively low noise levels, are unique. Other variables, such as attitudinal ones, will probably cause this effect.
As expected, the judgments based on the summer situation show a larger number of people who are annoyed than the judgments based on the winter situation.
In 3.2.1 we concluded that there were some specific reasons to interpreted the results prudently. The uniqueness of these results makes it even more necessary to do so.

Behavioral adaptations
More behavioral adaptations due to train noise were observed in the French TGV-survey than in the Dutch survey on conventional trains: closing windows (35% against 17%), insulating the most exposed facades (11% against 1%), having the intention to move (7% against 1%).

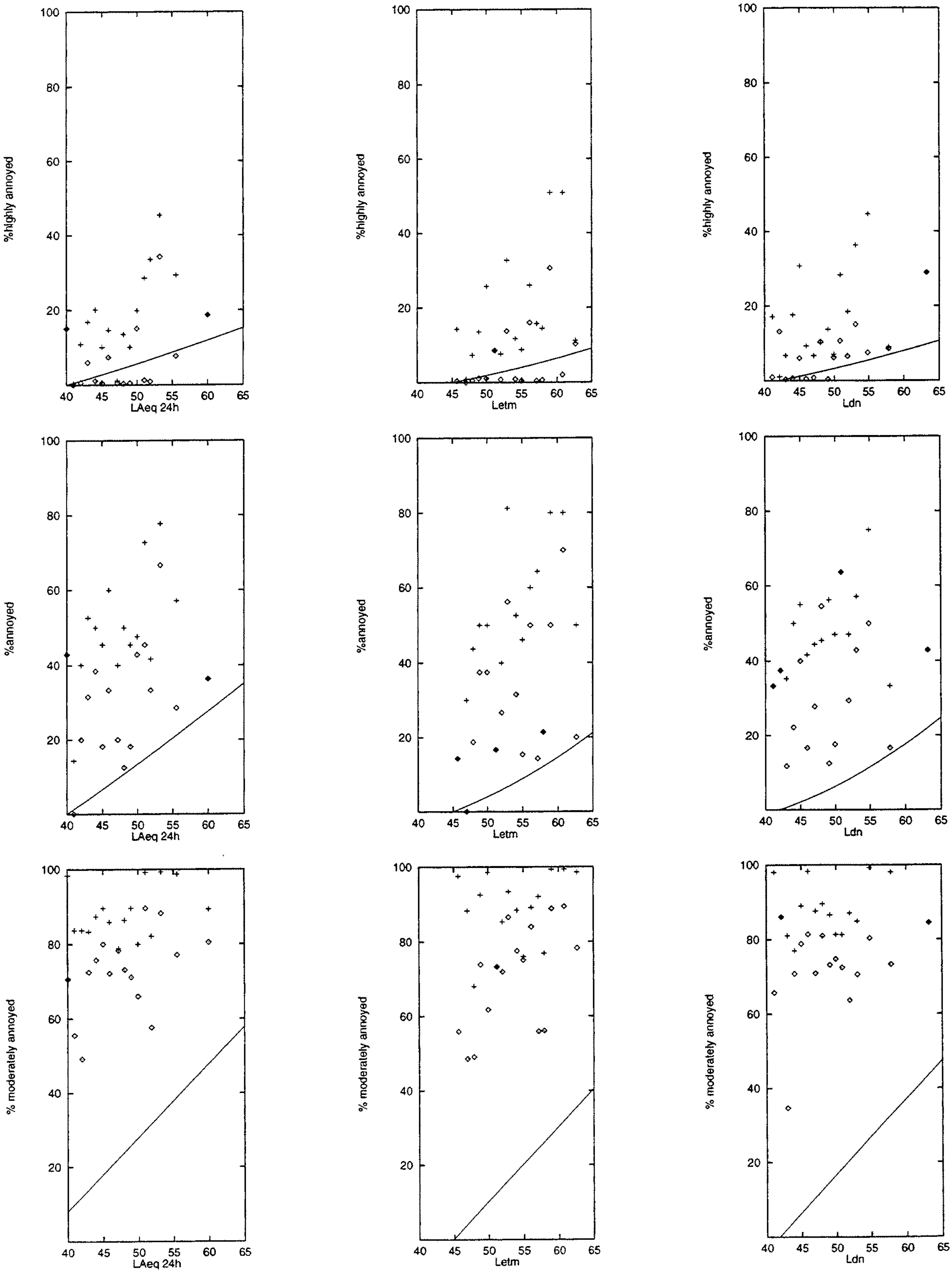
Vibrations
In the scope of subjective experience vibrations, caused mainly by heavy goods trains, are the most significant specific source of nuisance in a Dutch survey on conventional trains [10]. Sixty percent report vibrations as a drawback of living near a (conventional) railway line. In the recent French TGV-study [5] 34 percent report to be annoyed due to vibrations.

Habituation
As stated before, in general habituation in a substantial portion of a population is likely after an exposure time of 3 to 4 years. For aircraft noise a habituation time of 2 to 3 years at most has been found [25]. In the TGV-survey still 17% reports to be not habituated even after this time. Being not yet habituated co-varies with being annoyed, and also with noise level. A causal relation between (a lack of) habituation and annoyance cannot be inferred.
In Dutch surveys on railway noise [26] the concept of habituation has been made operational in a different way than in the French study. Therefore comparison with habituation in the French survey is not a straight forward task and cannot be executed in the limited scope of this study.

Attitudes
The relationship between annoyance and noise level is moderated by attitudinal variables such as the opinion about the HST as a new transport mode (30% very positive, 16% very negative),
the attitude towards the new railway line itself (66% disfavourable), and the satisfaction of the residents with noise reduction due to the noise abatement measures (two-third satisfied).
The high percentages of unfavourable attitudes seem quite remarkable in relation to train noise.
In a Dutch survey on nuisance due by the noise caused by conventional trains [10] no attitudinal variables were used which are comparable to the ones used in the French survey.

Efficacy of noise abatement measures
Large proportions of the respondents express unfavourable feelings towards the noise abatement measures: unaesthetic (89,5%), unpleasant (60,5%), ineffective (29,2%), dirty (27%), and oppressive (19%).

Figure 8 Percentage highly annoyed (first row), annoyed (second row) and at least moderately annoyed (third row) as a function of the overall exposure level. The solid lines (________) represent the dose response relations for conventional trains, the + + represent the TGV-data for the summer; the ◇ ◇ represent the TGV-data for the winter.



3.3 Preliminary conclusions with respect to nuisance

In this chapter, the question whether a high speed railway line will cause more or less nuisance than a conventional railway line, under the condition that the equivalent noise levels (average noise level within a period of several hours) in this comparison are equal, was approached from the "effects" point of view. The following aspects have been considered:

* some highlights from the results of the French survey;
* general annoyance;
* behavioral adaptations;
* vibrations;
* habituation;
* attitudes;
* efficacy of noise abatement measures.

In advance some aspects were considered which could be important for interpreting the results of the comparison. Due to the observed uncertainties the results of the comparisons have to be interpreted prudently.
The factor of "surprise" appears to be not important and thus will not enhance annoyance. The description of the HST noise with L_{Aeq}(20-22h) > 55 dB(A) contains some unfavourable semantic characterizations which reveal associations with more annoying types of noises such as impulsive ones: *impulsive, metallic, high pitched.*
The TGV-Atlantique causes more annoyance than conventional trains do, differences being larger as lesser degrees of annoyance are considered. When the percentages "highly annoyed" are compared, differences are not big. In fact, the rating of "highly annoyed in wintertime" coincides with the response curve for conventional trains. Especially the percentages "moderately annoyed" are, however, on a very high and constant level, and are hardly related to the noise level. Thus, it seems plausible that other variables are driving this effect, and are doing so more than we have ever found in other studies. Due to TGV noise more behavioral adaptations (closing windows, insulating the most exposed facades, having the intention to move) were observed than in a Dutch survey on conventional trains. With respect to vibrations there is no reason to suppose that HST's will cause more annoyance than conventional trains.
Non-habituation, negative attitudes towards the source, and dissatisfaction with the efficacy of noise abatement measures co-vary with the annoyance. In a cross sectional survey it is not allowed to infer causal relationships.

4. CONCLUSIONS AND DISCUSSION

4.1 Conclusions

The question to be answered in this study is formulated as follows:

how does annoyance due to the noise caused by HST's and conventional trains compare, exposure expressed in L_{etm} being equal?

The answer to this question was approached from two perspectives: the perspective of exposure and the perspective of effects.

The following aspects of exposure have been considered: the average noise level during a train pass-by and peak level, the numbers of passages and pass-by time, the frequency spectrum, the onset velocity, vibrations. A close consideration of these aspects does not indicate that the nuisance value of HST's might be either higher or lower than that of conventional trains.

Only one social survey on the effects of noise caused by the HSL exists, which was conducted in situations which bear some resemblance to the Dutch situation. This survey was carried out in France and has been thoroughly set up. Twenty five sites included in the survey guarantee a minimization of locational effects. Though the noise measurements were conducted unattended, the number and organization of the measurements warrant a satisfactory quality of the noise data. The questionnaire has a logical format; questions were formulated and organized well. Adequate statistical analyses were conducted. A limitation of the survey is the small number of respondents exposed to high noise levels. In conclusion: the survey is of good quality and can be used for our purpose as formulated in 1.2 (Aim of the study).

Actually approximately one-third of the respondents are not only exposed to noise which was absent before the HSL was opened, but also experienced rather radical changes in land use and in the visual aspects of the area. Many residents anticipated these changes reluctantly: 35% actively participated in anti-HSL activities. Three to four years later negative attitudes towards these aspects still appear to be rather strong. They co-vary with the evaluation of the noise situation. The reported noise annoyance is considerably higher than the annoyance reported in earlier studies on conventional trains. More behavioral adaptations are observed as well. The factor of "surprise" appears to be not important and thus will not enhance annoyance.

Both approaches - from the perspective of exposure and from the perspective of effects - lead to clearly different results. From the perspective of exposure there seems to be no reason to expect that HST's and conventional trains differ in their potential to cause noise annoyance. From the perspective of the effects, however, large differences become apparent: at a given noise level, HST's seem to cause much more annoyance than conventional trains, differences being larger as lesser degrees of annoyance are considered. When the percentages "highly annoyed" are compared, differences are not big. In fact, the rating of "highly annoyed in wintertime" coincides with the response curve for conventional trains. Especially the percentages "moderately annoyed" are, however, on a very high and constant level, and are hardly related to the noise level. Thus, it seems plausible that other variables, such as attitudinal ones, are driving this effect, and are doing so more than we have ever found in other studies. For several reasons, such as uncertainty about the role of the time difference (About 15 years lie between the surveys on conventional trains and the one about the TGV), uncertainty about the role of the climate and about the role of the decision making and communication process, this latter approach should be weighted less than the approach from the perspective of exposure.

4.2 Discussion

The results of the French TGV-survey offer surprising results. Some intriguing questions force themselves on us:

* Does the French TGV survey really investigate a 'steady state' situation? In most cases, 3 to 4 years after opening of a line a steady state situation can be assumed, as described in 3.2.2. In this particular case the building of the line was accompanied by vehement community reaction. How long will it take for these emotions to subside? Many negative feelings still exist. On the other hand, the attitude might be driven by noise annoyance. Personal communication with Lambert learned that a closer consideration of the steady state principle in relation with the TGV is being formulated and will be published soon.
* Is railway noise evaluated identically in different countries? In the data archive no data are included about French surveys on conventional trains. Therefore theoretically the

possibility cannot be excluded that reactions towards (conventional) train noise in France differ from reactions in other countries. This does not seem a very plausible explanation because such differences were, to our knowledge, not demonstrated for other noise sources. Personal communication with Lambert learned that a more thorough comparison between available French data on nuisance due to TGV-noise versus noise from conventional trains is envisaged in autumn.

* Have reactions to noise changed over time? The TGV survey was conducted approximately 15 years after the surveys on conventional trains. To our knowledge a systematic and strong change in reactions over time has never been demonstrated.
* Does climate have such a big influence? This aspect remains uncertain, though in the opinion of the authors the relative small differences in climate can hardly be held responsible for the substantial differences.
* The TGV survey was conducted in very quiet areas with a low background noise level. The building of the HSL meant a significant change in the noise exposition of the respondents. Might this have contributed to the high annoyance, imperfect habituation, and negative attitudes? It might be so, but on the other hand a significant moderating role of ambient noise has seldom been demonstrated [27].
* Are the strong negative attitudes caused by the way of decision making? We cannot tell.

With regard to the Japanese Shinkansen it is known that this HSL causes more noise nuisance than road traffic and even more than aircraft [17]. Could high speed trains (also the European ones) have such specific characteristics that a relative high degree of nuisance has to be expected? It might be valuable to ask Japanese colleagues whether they have data on conventional trains and on HST's, which can be compared.

Apart from these considerations it should be noted that the planned traffic on the Dutch HSL's (HSL-S: 192 trains/24h; HSL-E: 168 trains/24h) will be more intensive than the traffic on the TGV-Atlantique in the French survey (65, 75 or 140 trains/24h).

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