



V CONVEGNO NAZIONALE
IL CONTROLLO DEGLI AGENTI FISICI:
AMBIENTE, SALUTE E QUALITÀ DELLA VITA

Novara 6 - 7 - 8 giugno 2012



Noise And Health

The State Of The Art

Wolfgang Babisch

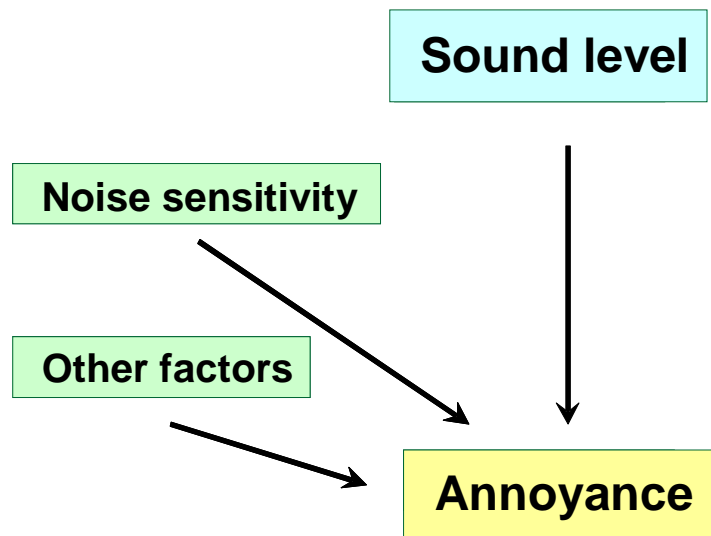
Department of Environmental Hygiene
Federal Environment Agency
Berlin, Germany

Overview

- Specifics of noise
- Health endpoints
- Shortterm and longterm effects
- Exposure response curves
- Quantitative risk assessment

Noise Annoys

Social sciences



We Can Hear

The human organism is primed to pick up sound

Communication

Orientation

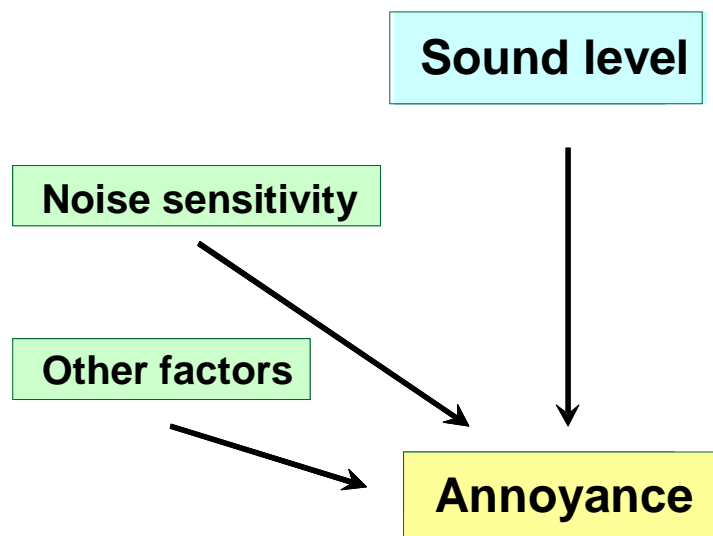
Warning signal

Continuous processing and analysing of acoustical information, including unwanted sound (= noise)

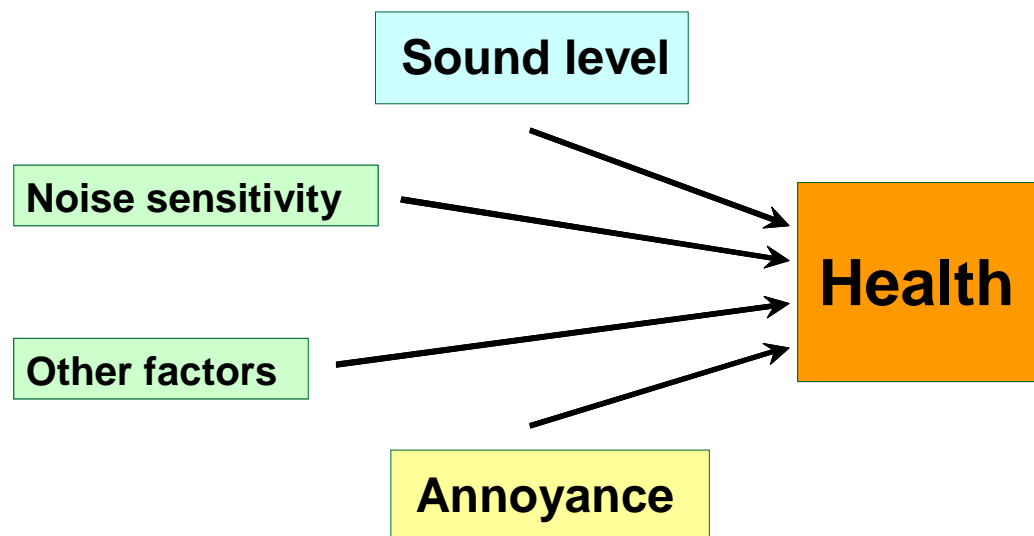
Adverse
health effects

Subjective Wellbeing And Ill-Health

Social sciences



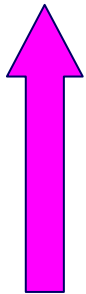
Environmental medicine



Interference With Activities

- Adverse effects of noise occur, in particular, when the acoustic stimulus disturbs intended activities of people.
- E. g.: communication, concentration, relaxation, sleep.

Magnitude of effect



50 dB(A) at home during night-time (outdoors)

65 dB(A) at home during daytime (outdoors)

80 dB(A) at work

Noise Characteristics

- (Maximum) sound levels
 - Noise level rise time
 - Time course
 - Frequency spectrum
 - Tonality
 - Informational content
- ➔➔➔ Source-specific dose-response curves

Noise Annoyance By Noise Source

Highly annoyed by noise

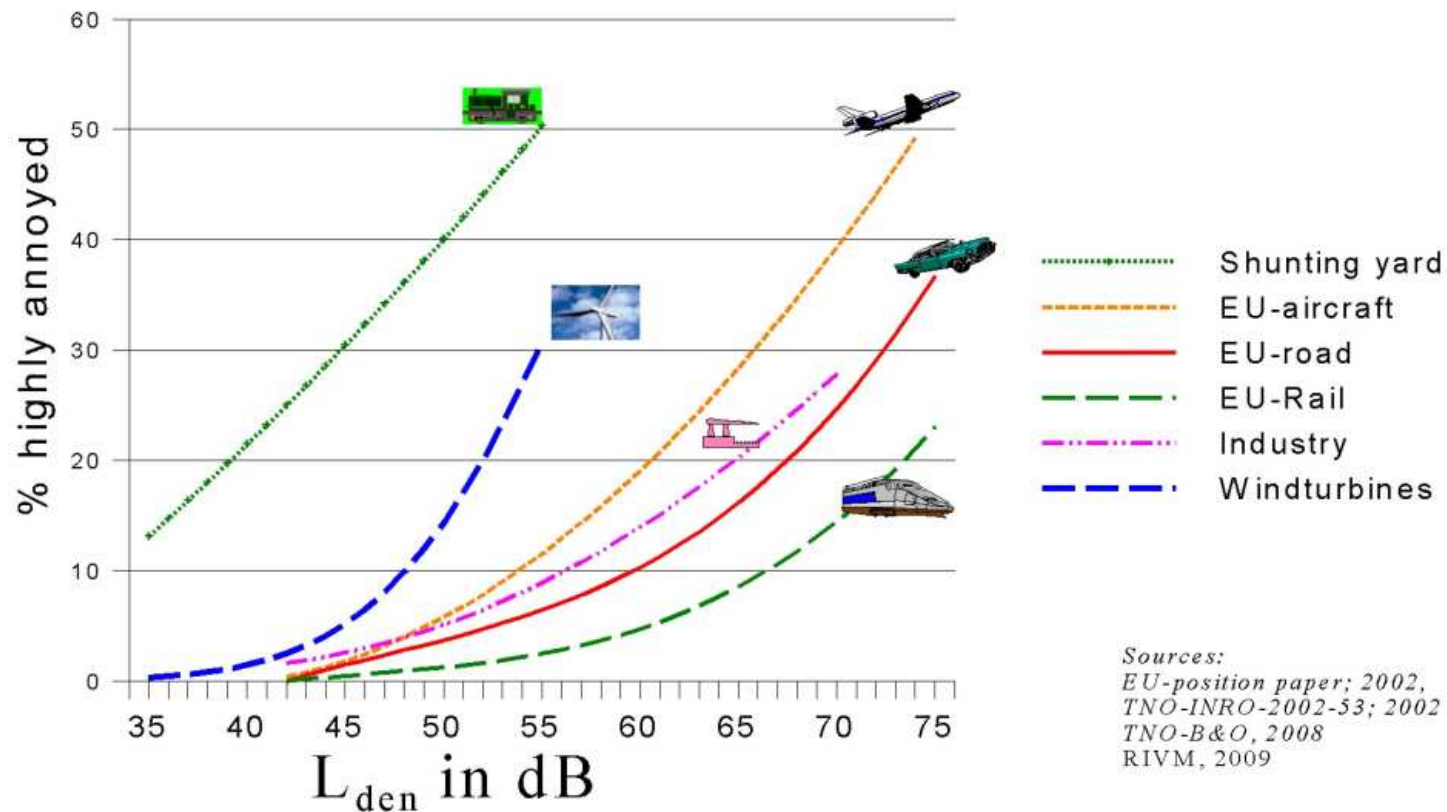


Image: M. van den Berg, VROM (2012)

Toxicological Concept Does Not Apply


- Different noise sources cause different effects at the same noise level.
- Noise effects are different dependent on the interference /disturbance of certain activities.
- 24 hour noise dosimetry is inappropriate.
"We do not accumulate decibels like micrograms in the body".
- The daily amount of time spent at home does not necessarily determine the magnitude of adverse health effects due to environmental noise exposure at home. Adverse health effects occur when noise is present at times when we do not want it.

Laboratory Studies

Acute (Shortterm) Effects

- Finger pulse amplitude
- + Vasoconstriction of peripheral blood vessels
- +/- Heart beat frequency
- + Stress hormones
- + Blood pressure
- + Stroke volume
- + Cardiac output


Experiments 1



Effect variable	Car-Racing Noise	
	$L_{AFm} = 85 \text{ dB}$ 57 Males 18-34 years	
Adrenaline (urine)	+ 27 % (*)	
Noradrenaline (urine)	+ 8 %	
Cortisol (blood)	Not assessed	
Systolic blood pressure	+ 3.4 mmHg (*)	
Diastolic blood pressure	+ 1.8 mmHg (*)	

Source: Ising and Günther (1983), Ising, et al. (1991)


Experiments 2



	Car-Racing Noise	Work Noise	
	$L_{AFm} = 85 \text{ dB}$	$L_{AFm} = 95 \text{ dB}$	
	57 Males	30 Males	
Effect variable	18-34 years	25-51 years	
Adrenaline (urine)	+ 27 % (*)	- 5 %	
Noradrenaline (urine)	+ 8 %	+ 16 % (*)	
Cortisol (blood)	Not assessed	Not assessed	
Systolic blood pressure	+ 3.4 mmHg (*)	+ 6.6 mmHg (*)	
Diastolic blood pressure	+ 1.8 mmHg (*)	+ 2.3 mmHg	

Source: Ising and Günther (1983), Ising, et al. (1991)


Experiments 3



	Car-Racing Noise	Work Noise	Jet-Fighter Noise	
	$L_{AFm} = 85$ dB	$L_{AFm} = 95$ dB	$L_{AFm} = 125$ dB	
	57 Males	30 Males	12 Males	
Effect variable	18-34 years	25-51 years	30-50 years	
Adrenaline (urine)	+ 27 % (*)	- 5 %	No change	
Noradrenaline (urine)	+ 8 %	+ 16 % (*)	No change	
Cortisol (blood)	Not assessed	Not assessed	+ 30 % (*)	
Systolic blood pressure	+ 3.4 mmHg (*)	+ 6.6 mmHg (*)	+ 3.9 mmHg (*)	
Diastolic blood pressure	+ 1.8 mmHg (*)	+ 2.3 mmHg	+ 4.8 mmHg (*)	

Source: Ising and Günther (1983), Ising, et al. (1991)

Experiments 4



	Car-Racing Noise	Work Noise	Jet-Fighter Noise	Road Traffic Noise
	$L_{AFm} = 85$ dB	$L_{AFm} = 95$ dB	$L_{AFm} = 125$ dB	$L_{AFm} = 60$ dB
	57 Males	30 Males	12 Males	42 Males
Effect variable	18-34 years	25-51 years	30-50 years	24-54 years
Adrenaline (urine)	+ 27 % (*)	- 5 %	No change	- 4 %
Noradrenaline (urine)	+ 8 %	+ 16 % (*)	No change	+ 11 % (*)
Cortisol (blood)	Not assessed	Not assessed	+ 30 % (*)	Not assessed
Systolic blood pressure	+ 3.4 mmHg (*)	+ 6.6 mmHg (*)	+ 3.9 mmHg (*)	+ 1.7 mm Hg (*)
Diastolic blood pressure	+ 1.8 mmHg (*)	+ 2.3 mmHg	+ 4.8 mmHg (*)	+ 1.2 mmHg (*)

Source: Ising and Günther (1983), Ising, et al. (1991)

General Stress Model

Chronic (Longterm) Effects

**Dysregulation, disturbed biorhythm,
physiologic and metabolic imbalance!**

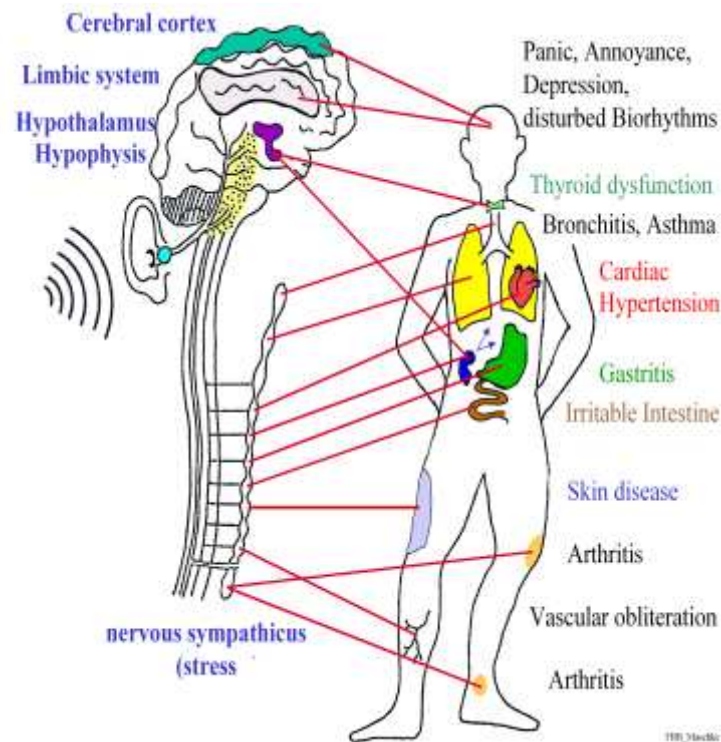


Image: Maschke (2004)

Habituation / Adaption

- Even subjects that have been working or living for many years in noise-exposed environments show physiological stress reaction in response to acute noise events.
- Even subjects who are subjectively not disturbed by the noise show acute electrophysiological (EEG, EMG, ECG) and vegetative (blood pressure, heart rate) responses to single noise events during sleep.

Autonomous Responses

- The physiological reactions cannot be (fully) controlled by cognitive processes.
- The stress mechanism is evolutionary determined to enable survival.

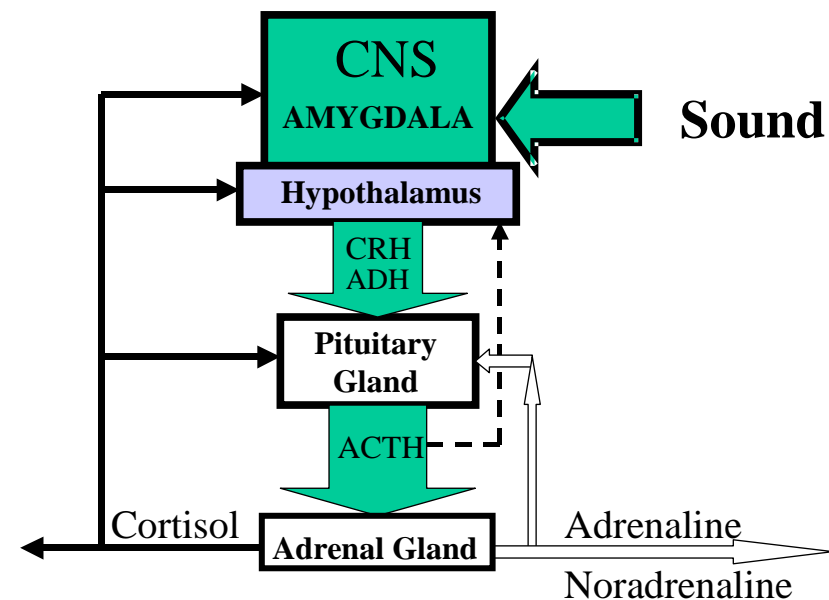
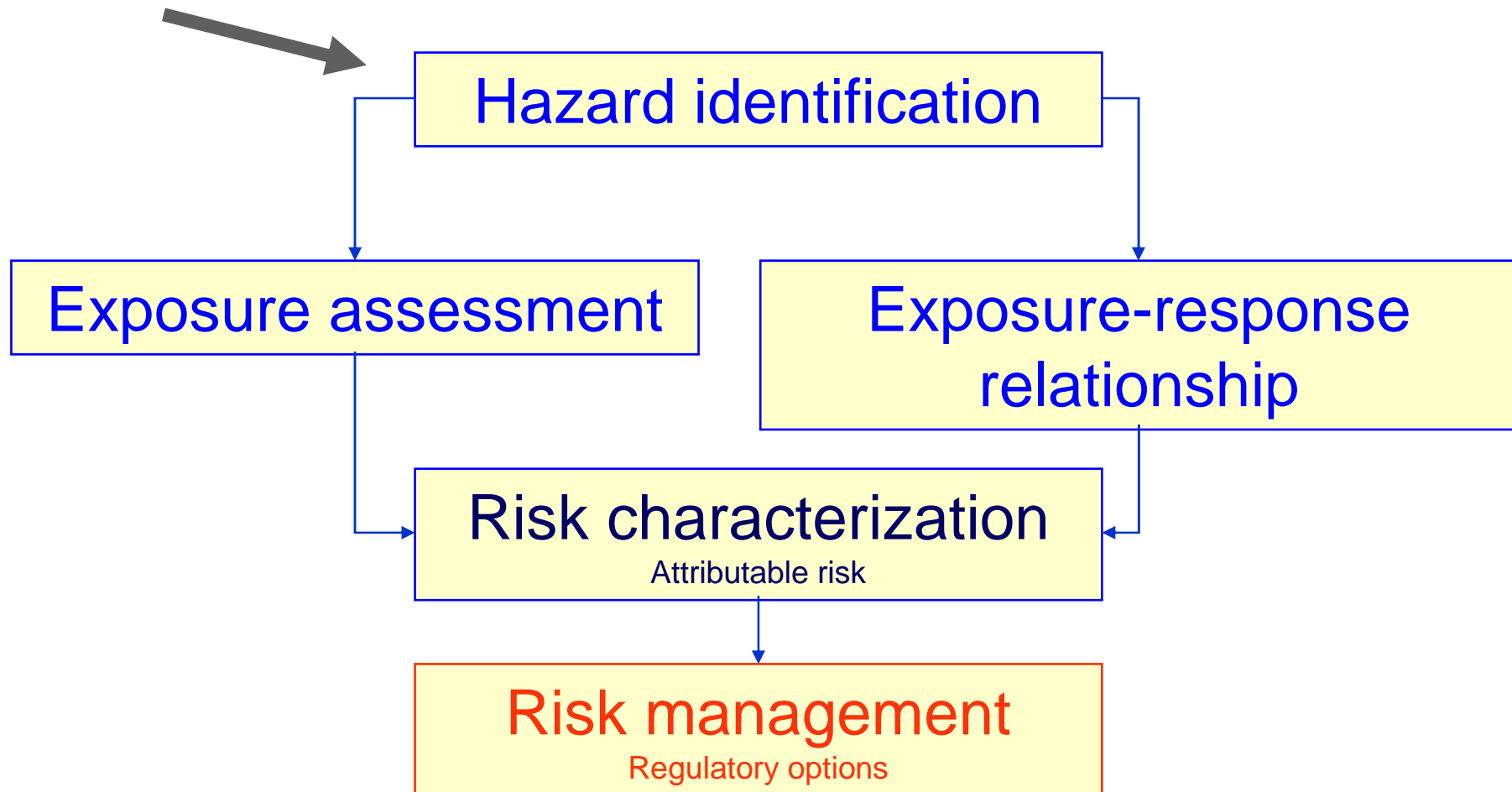


Image: Maschke (2004), Spreng (2001)

Quantitative Risk Assessment

Health Impact Assessment



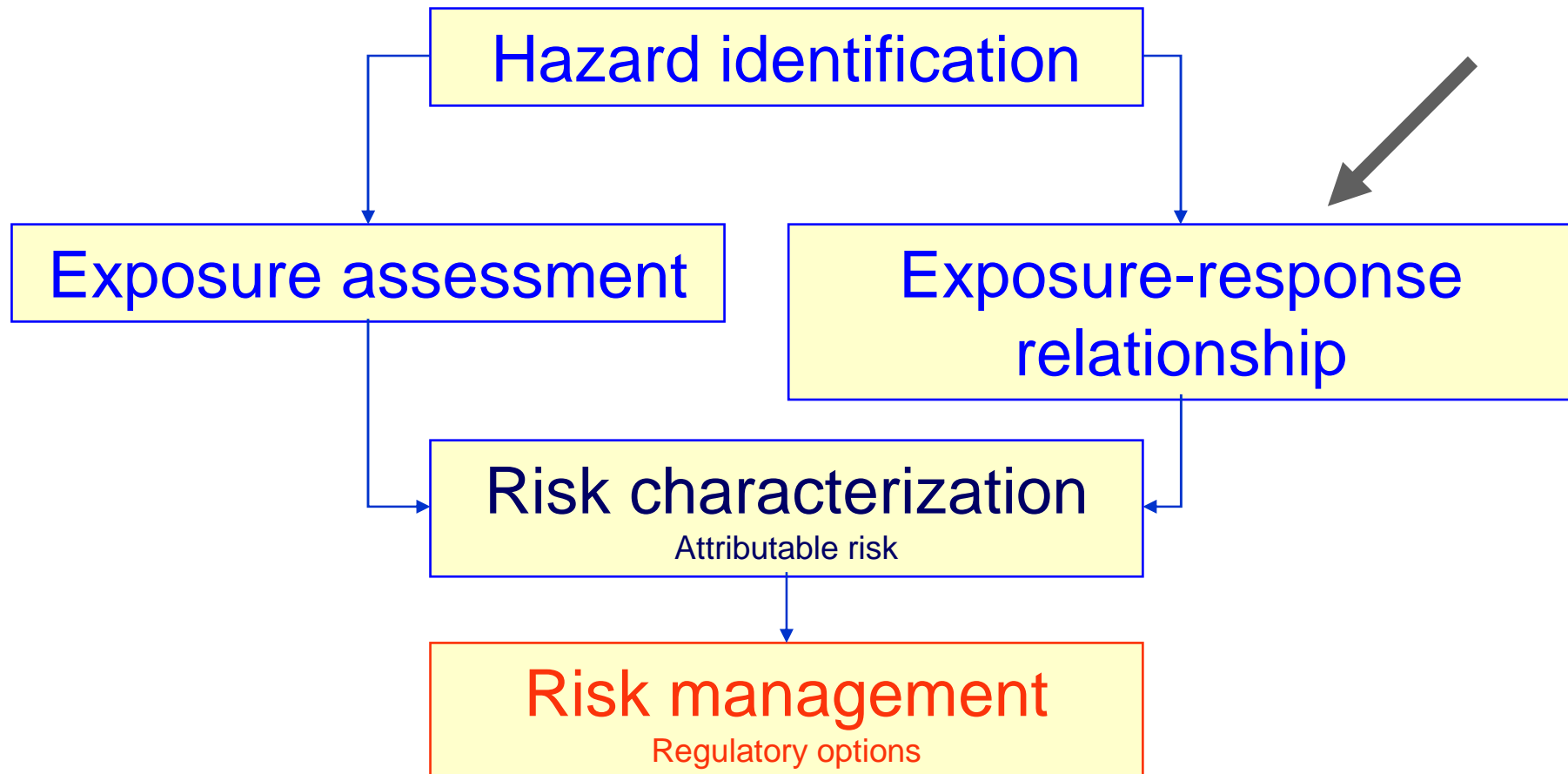
Health Endpoints

Environmental Noise

- ~~Hearing loss~~
- Annoyance
- Sleep disturbance
- Cognitive impairment
- Physiological stress reactions
- Cardiovascular risk

Quantitative Risk Assessment

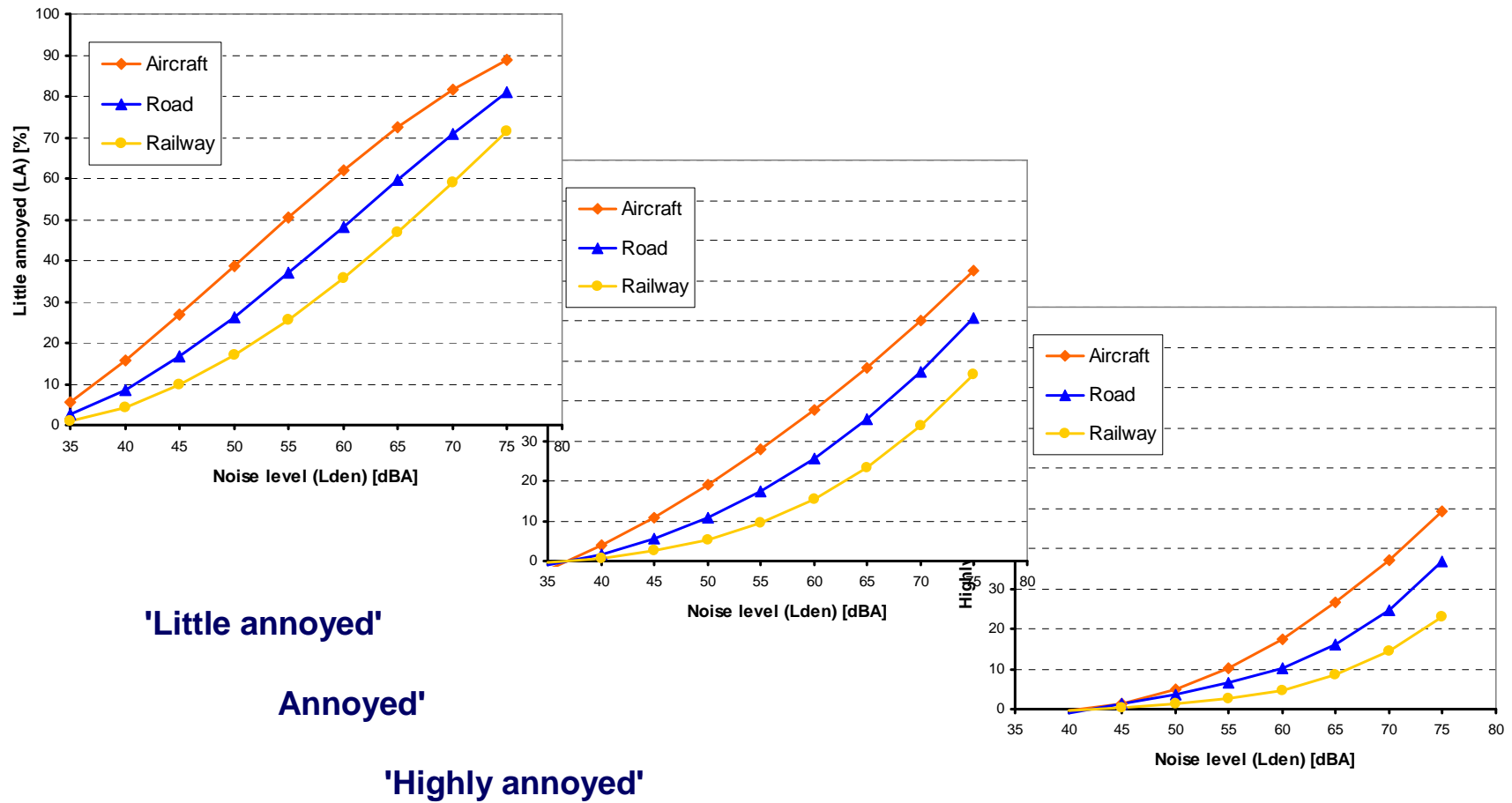
Health Impact Assessment



Noise Annoyance

Noise Annoyance

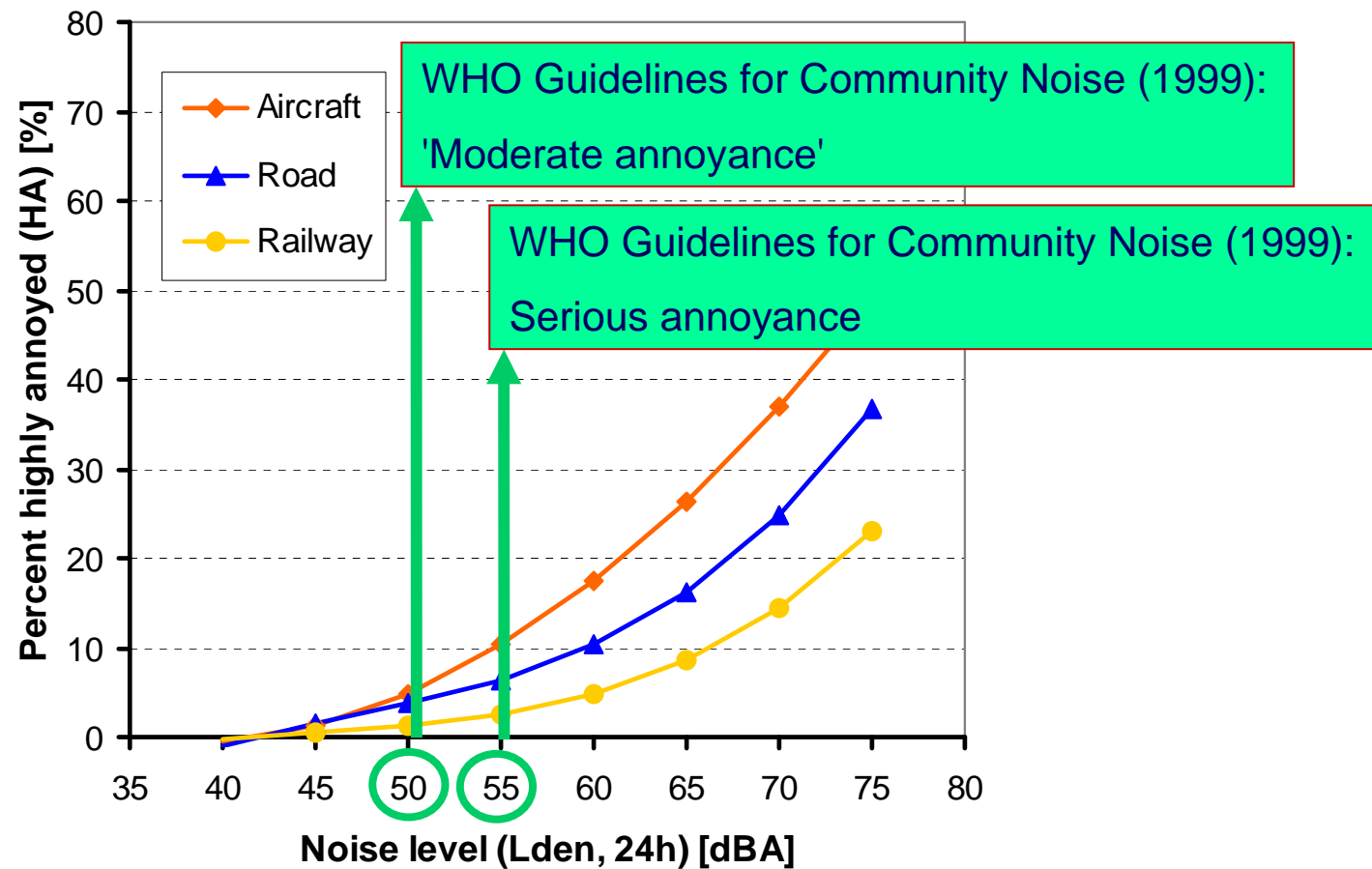
EU Standard Curves



Source: European Commission Working Group on Dose-Effect Relations (2002)

Relationship Between Noise Level And Annoyance

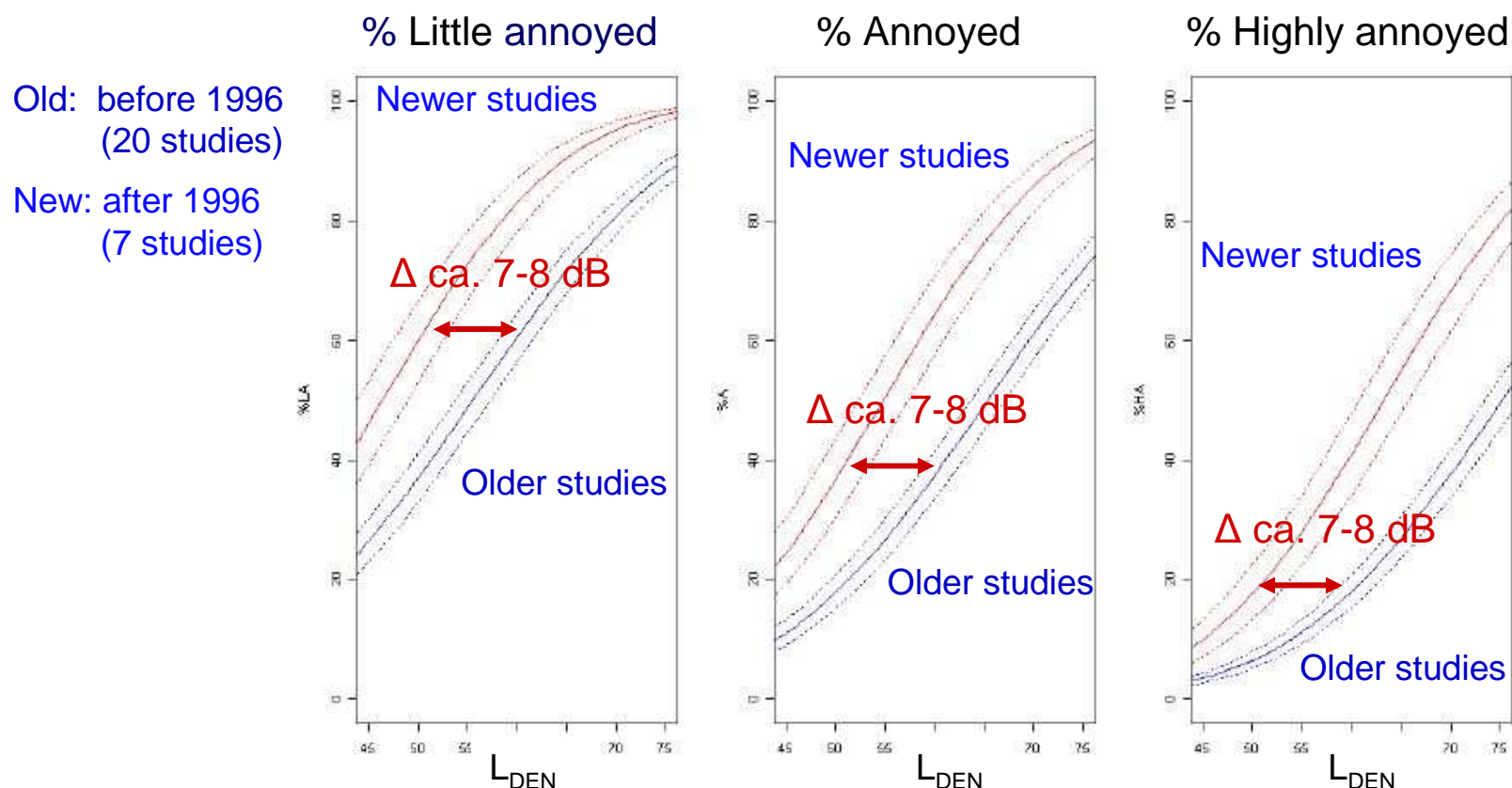
Percentage "Highly Annoyed"



Source: European Commission Working Group on Dose-Effect Relations (2002)

Annoyance Due To Aircraft Noise

Update



WHO 'serious annoyance': noise level during daytime < 55 dB(A) \rightarrow < 47 dB(A)

WHO 'moderate annoyance': noise level during daytime < 50 dB(A) \rightarrow < 42 dB(A)

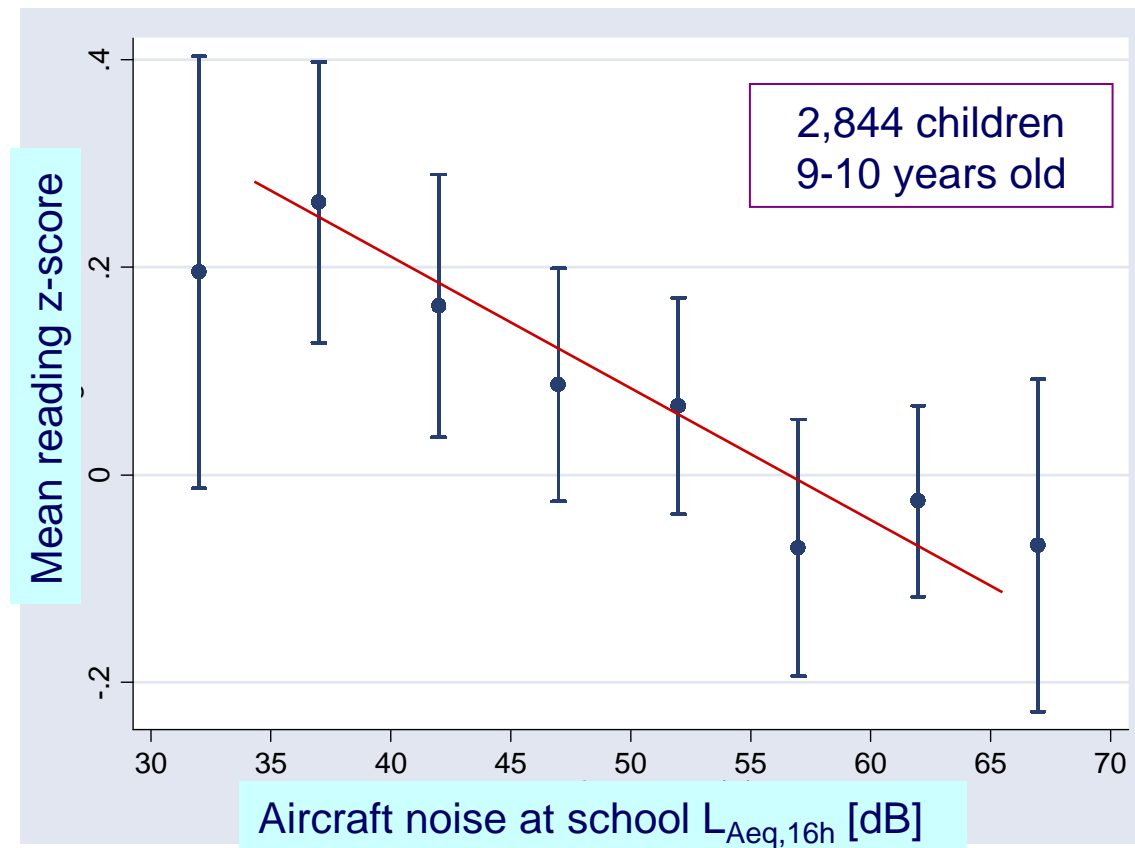
Sources: INO (2009), Janssen et al. (2011)

Cognitive Impairment

Cognitive Performance

'Ranch Study'

Aircraft noise associated with deficits in reading comprehension and recognition memory
Per 5 dB(A) increase of the noise level reading comprehension was 1-2 months delayed

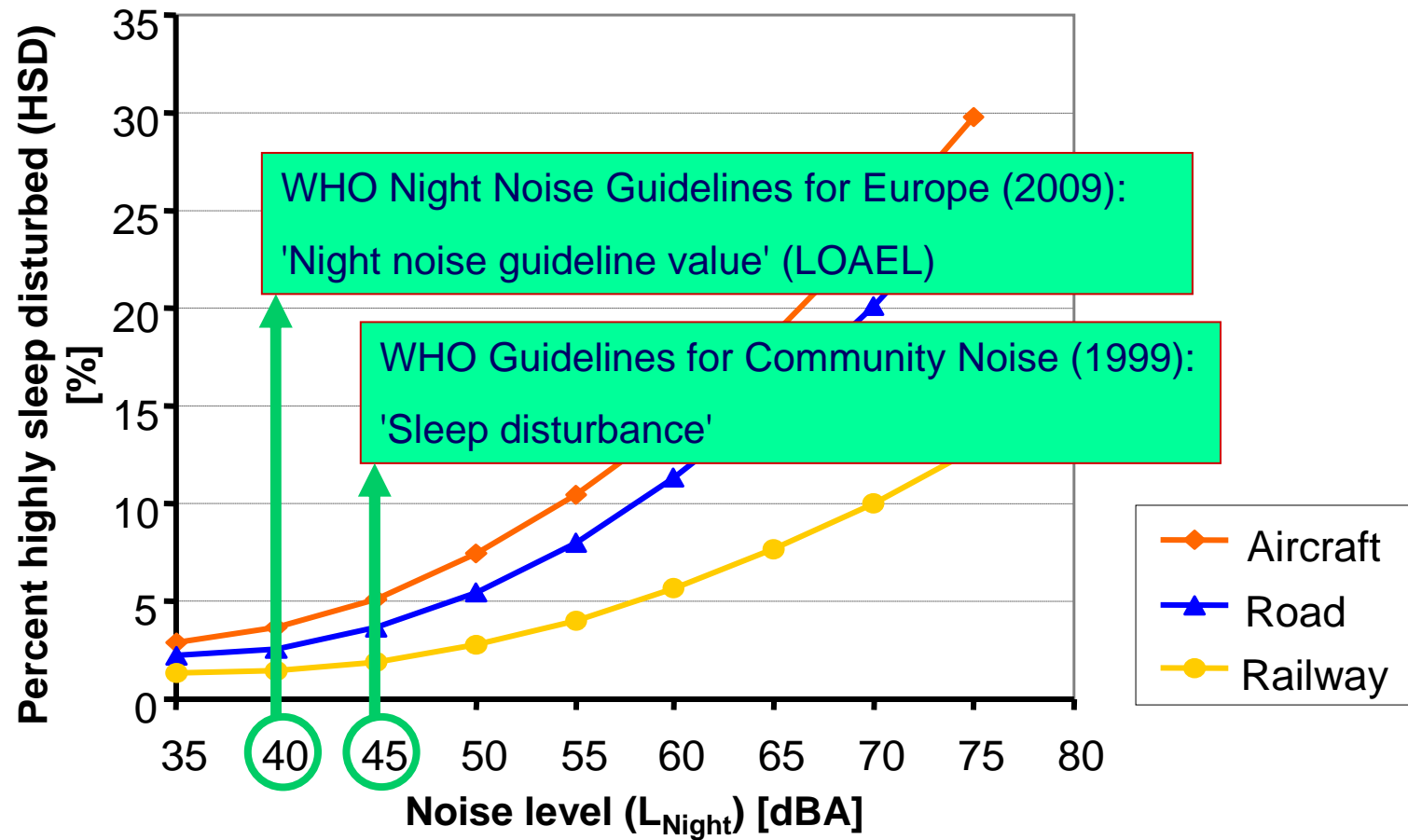


Source: Stansfeld et al. (2005)

Sleep Disturbance

Reported Sleep Disturbance

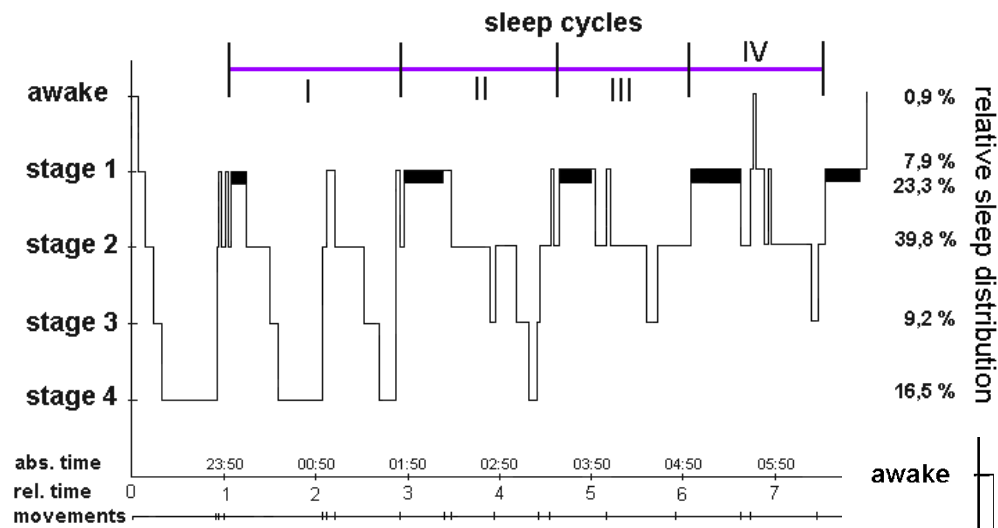
Percentage 'Highly Sleep Disturbed'



Sources: Miedema and Oudshoorn (2001), European Commission Working Group on Health and Socio-Economic Aspects (2004)

Disrupted Sleep Profile

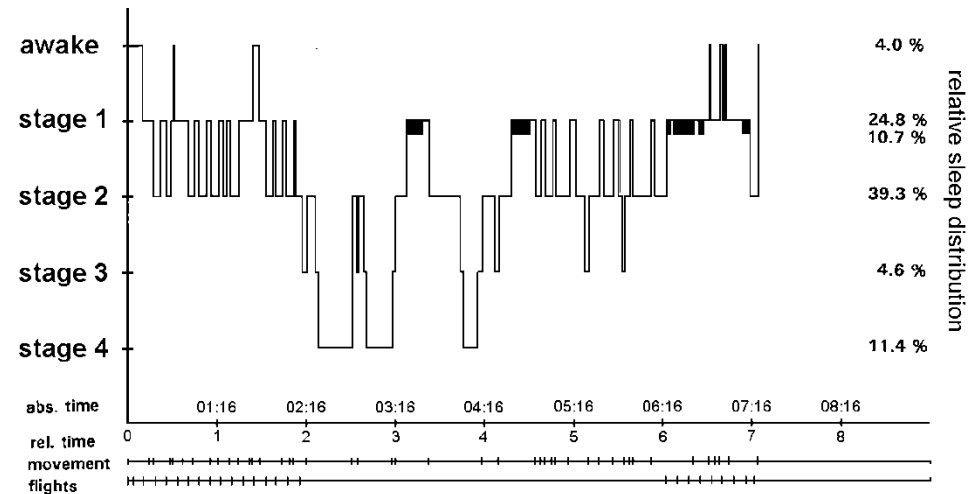
Sleep-Stage Changes (EEG Recordings)



Normal sleep

Disturbed sleep

- reduced deep-sleep
- reduced "dream"-sleep (REM)

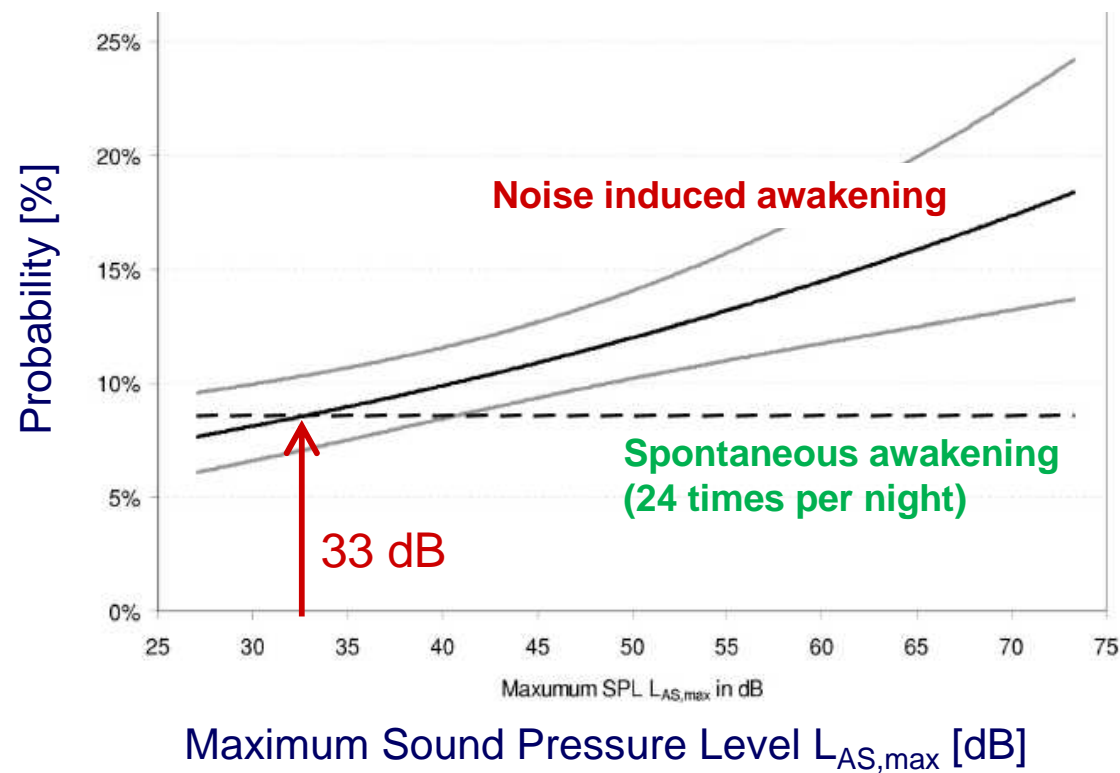


Source: Maschke et al., (2000)

EEG Awakenings (Polysomnography)

Single Aircraft Flyover – "DLR Laboratory Study"

Change to awake or sleep stage S1 for at least 15 seconds within a time window of 90 seconds after the onset of the noise event



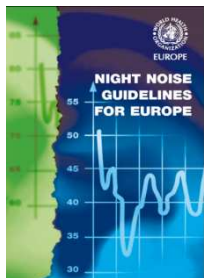
Source: Basner et al. (2006)

Night Noise Guidelines For Europe

WHO 2009

Recommended Guidelines for Night Noise

Interim Target (IT)	$L_{\text{night, outside}} = 55 \text{ dB}$
Night Noise Guideline (NNG)	$L_{\text{night, outside}} = 40 \text{ dB}$



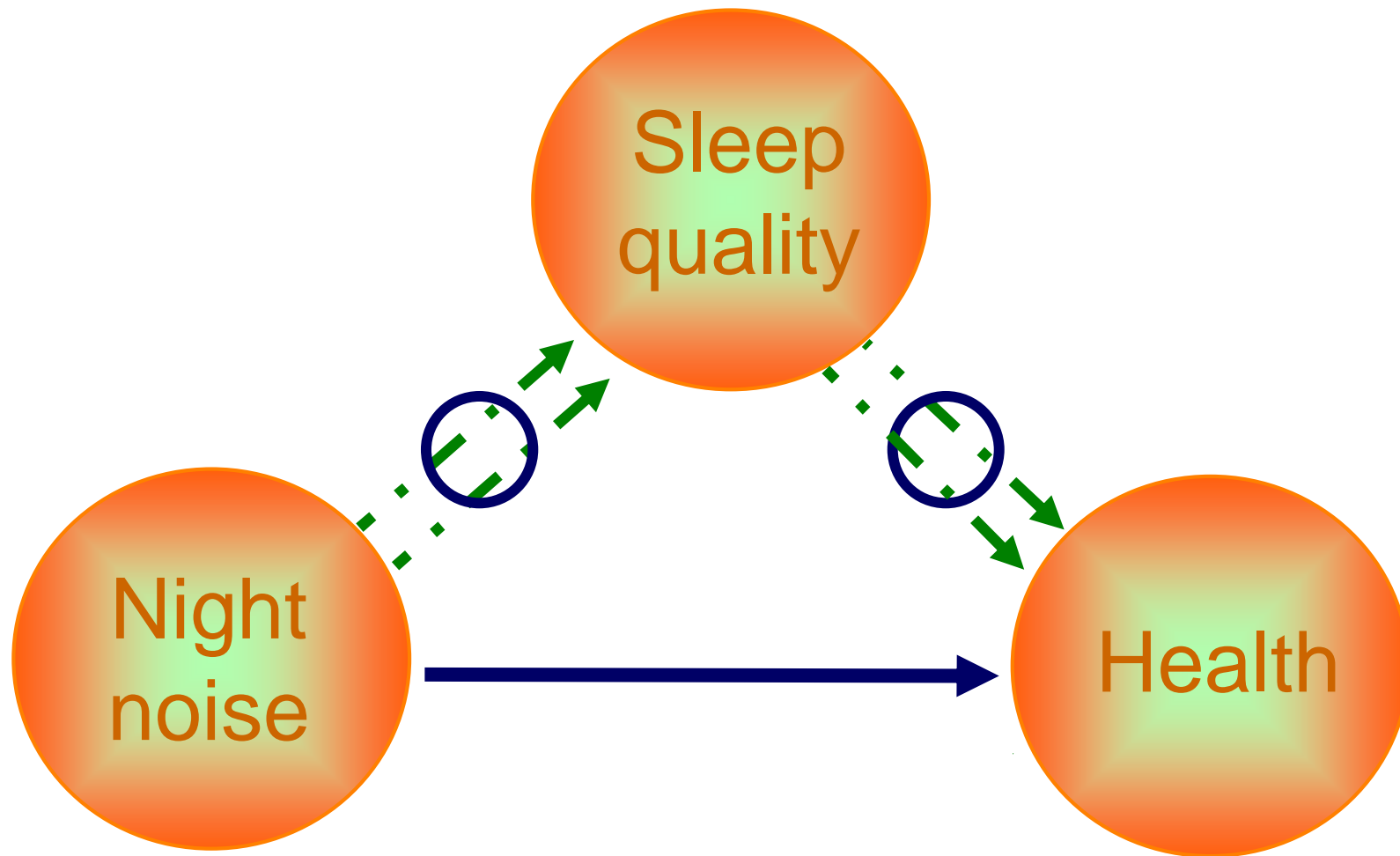
30 dB: No observed effect level (NOEL).

40 dB: For primary prevention of sub-clinical adverse health effects, Lowest observed adverse effect level (LOAEL).

55 dB: The situation is increasingly dangerous for the population. Recommended in the situations where the achievement of NNG is not feasible in the short run.

WHO European Centre for Environment and Health, 2009

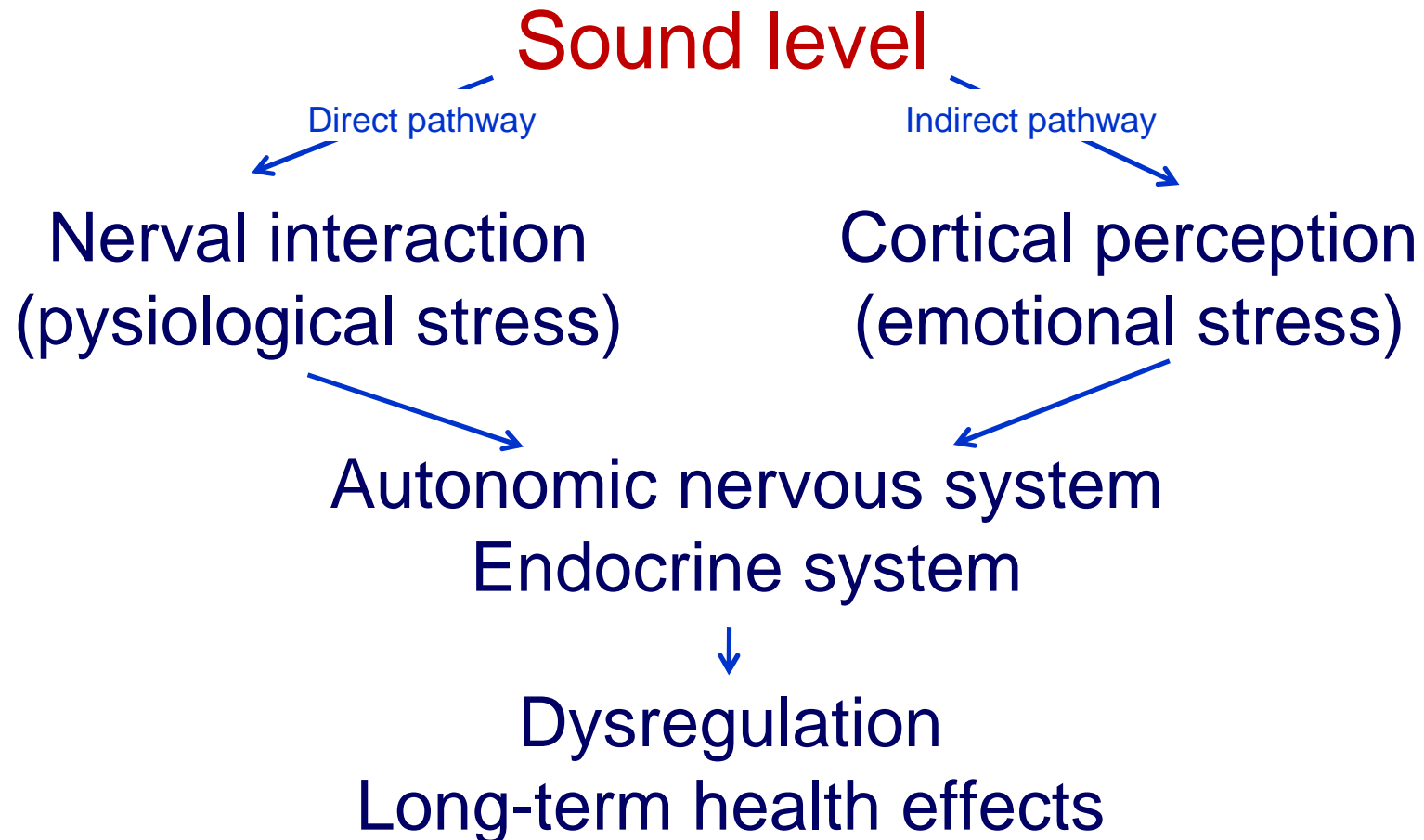
Noise, Sleep And Health



Source: WHO (2009)

III-Health

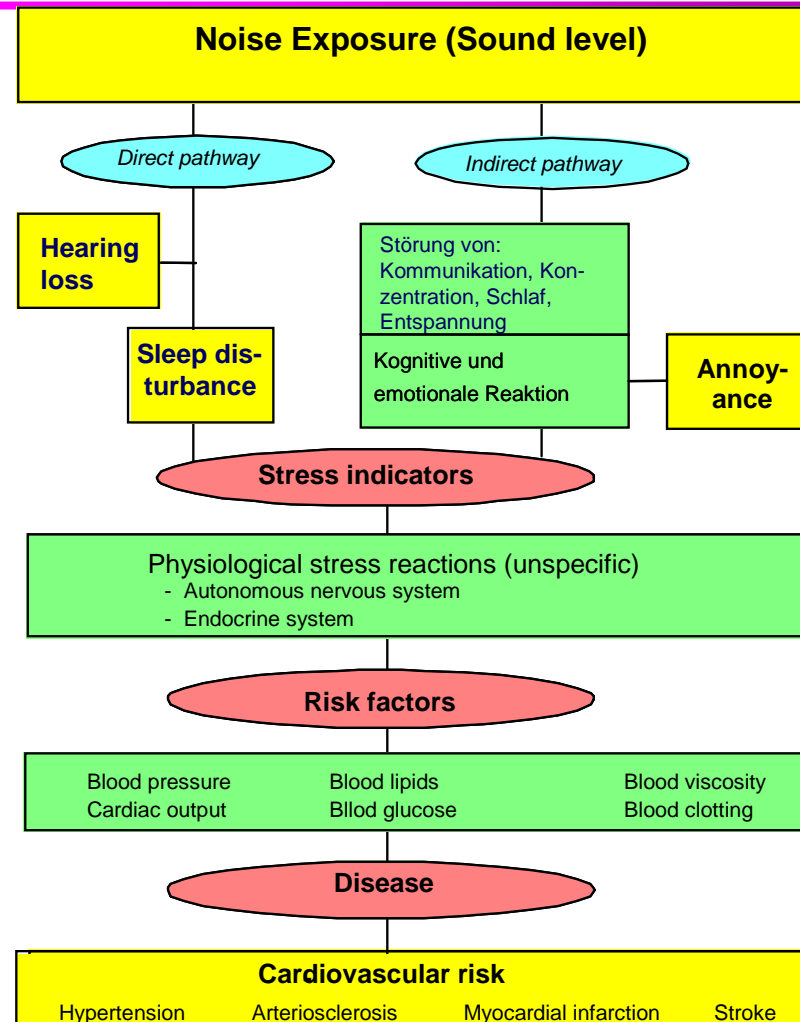
Cardiovascular Effects Of Noise



Cardiovascular Diseases

Simplified Reaction Model

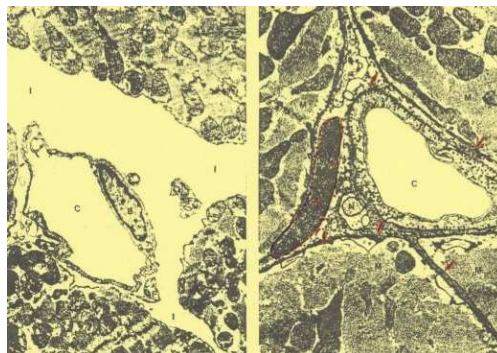
Sound exposure
↓
Disturbance of
intended activities
↓
Stress indicators
↓
Biological
risk factors
↓
Cardiovascular
diseases



Source: Babisch (2002)

Animal Experiments

- Circulation (peripheral blood vessels and arteries)
- + Chronic blood pressure increase
- + Collagen (connective tissue) in heart muscle
- + Aging of the heart



Occupational Noise Studies

Reviews – Hypertension

Thompson (1993): prevalence ratios ranged from 2.0 to 2.8

v. Kempen et al. (2002): meta-analysis (9 studies)

OR_{10 dB(A)} = 1.30 (95% CI = 1.02-1.66)

range $L_{Aeq8h} \sim 55-116$ dB(A)

Tomei et al. (2010): meta-analysis (15 studies)

prevalence ratio 2.56 (95% CI = 2.01-3.27)

high (92 ± 7 dB(A)) vs. low (62 ± 29 dB(A))

Studies – Myocardial Infarction / Coronary Heart Disease

Davies et al. (2005): >100 dB(A), no hearing protection
incidence rate ratio 1.2 to 1.5 (length of exposure)

Gan et al. (2011). **prevalence ratio 2.04 (95% CI = 1.16-3.58)**

Occupational Noise Studies

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$OR_{10 \text{ dB(A)}} = 1.30$ (95% CI = 1.02-1.66)

range $L_{Aeq,8h}$ 55-115 dB(A)

Tomei et al. (2010): meta-analysis (15 studies)

prevalence ratio 2.55 (95% CI = 2.01-3.27)

high ($L_{Aeq,8h} = 72 \pm 23$ dB(A)) vs. low (62 ± 29 dB(A))

Studies – Myocardial Infarction / Coronary Heart Disease

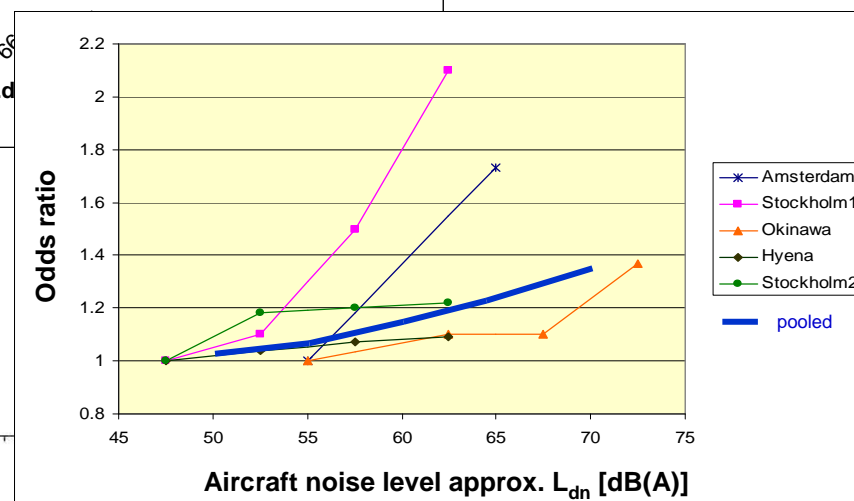
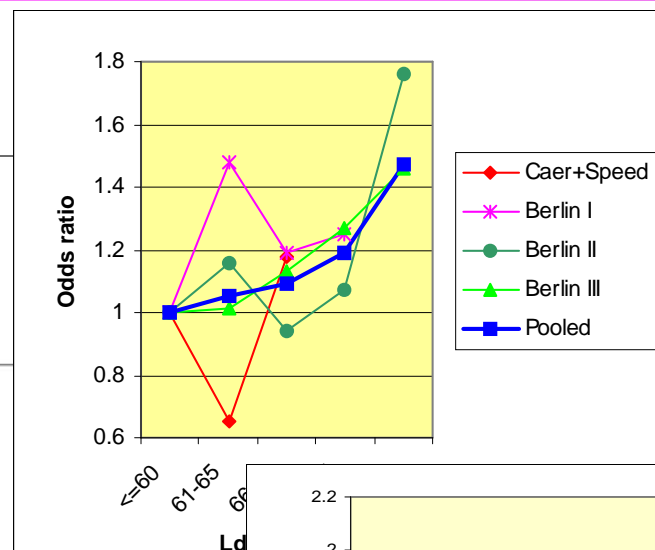
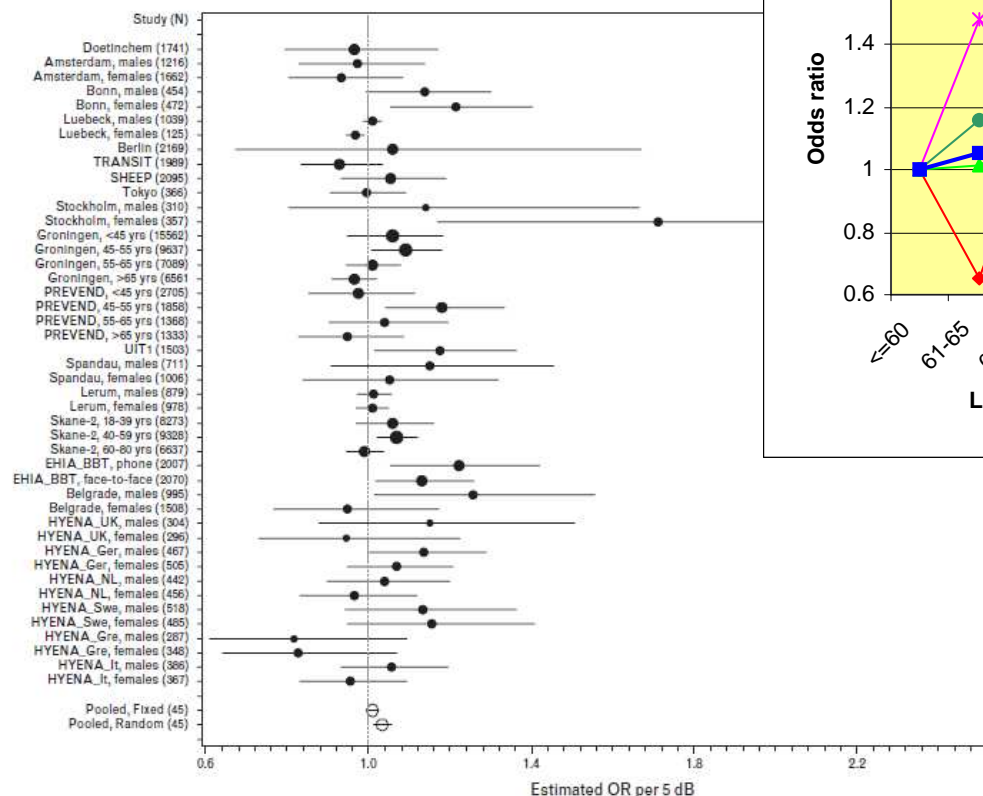
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Environmental Noise Studies

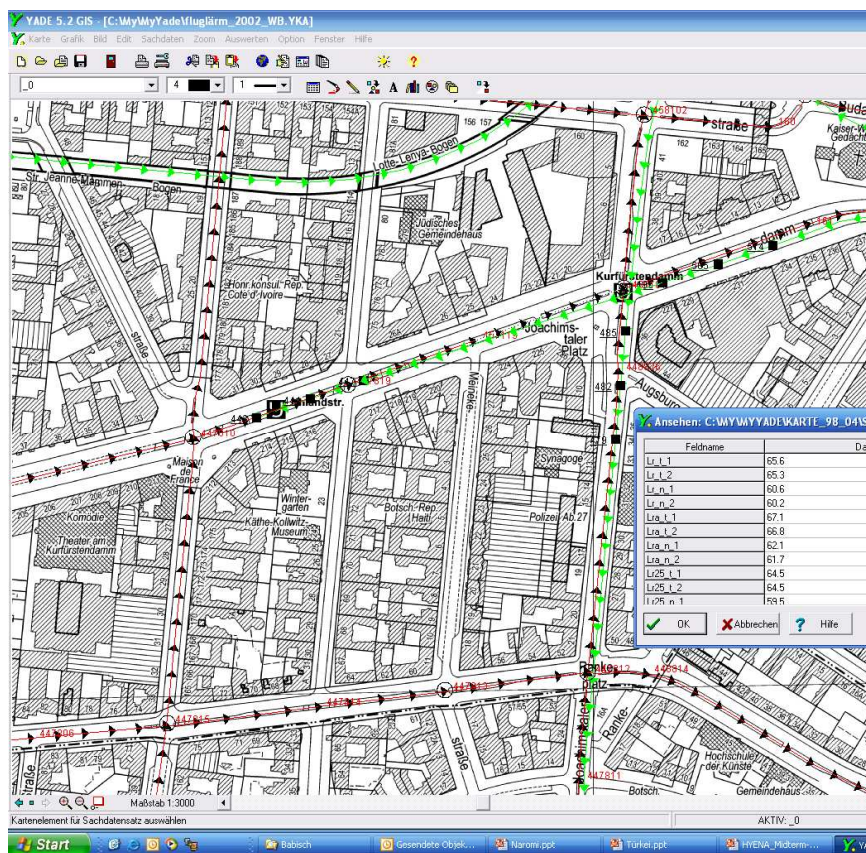
Meta-Analyses



Sources: van Kempen and Babisch (2012), Babisch (2008), Babisch and van Kamp (2009)

Road Traffic Noise

Noise Maps



Berlin noise map



Augsburg noise map

Road Traffic Noise - Cardiovascular Diseases

Meta-Analyses

Hypertension (24 studies)

L_{Aeq16h} : range ~ 45-75 dB(A), OR = 1.07 (95% CI = 1.02-1.12)

- **7%** increase in risk per 10 dB(A) increase in noise level

Myocardial Infarction (6 studies)

L_{Aeq16h} : range ~ 55-75 dB(A), OR = 1.17 (95% CI = 0.87-1.57)

- **17%** increase in risk per 10 dB(A) increase in noise level

Stroke (1 study)

L_{DEN} : range ~ 50-75 dB(A), RR = 1.14 (95% CI = 1.04-1.25)

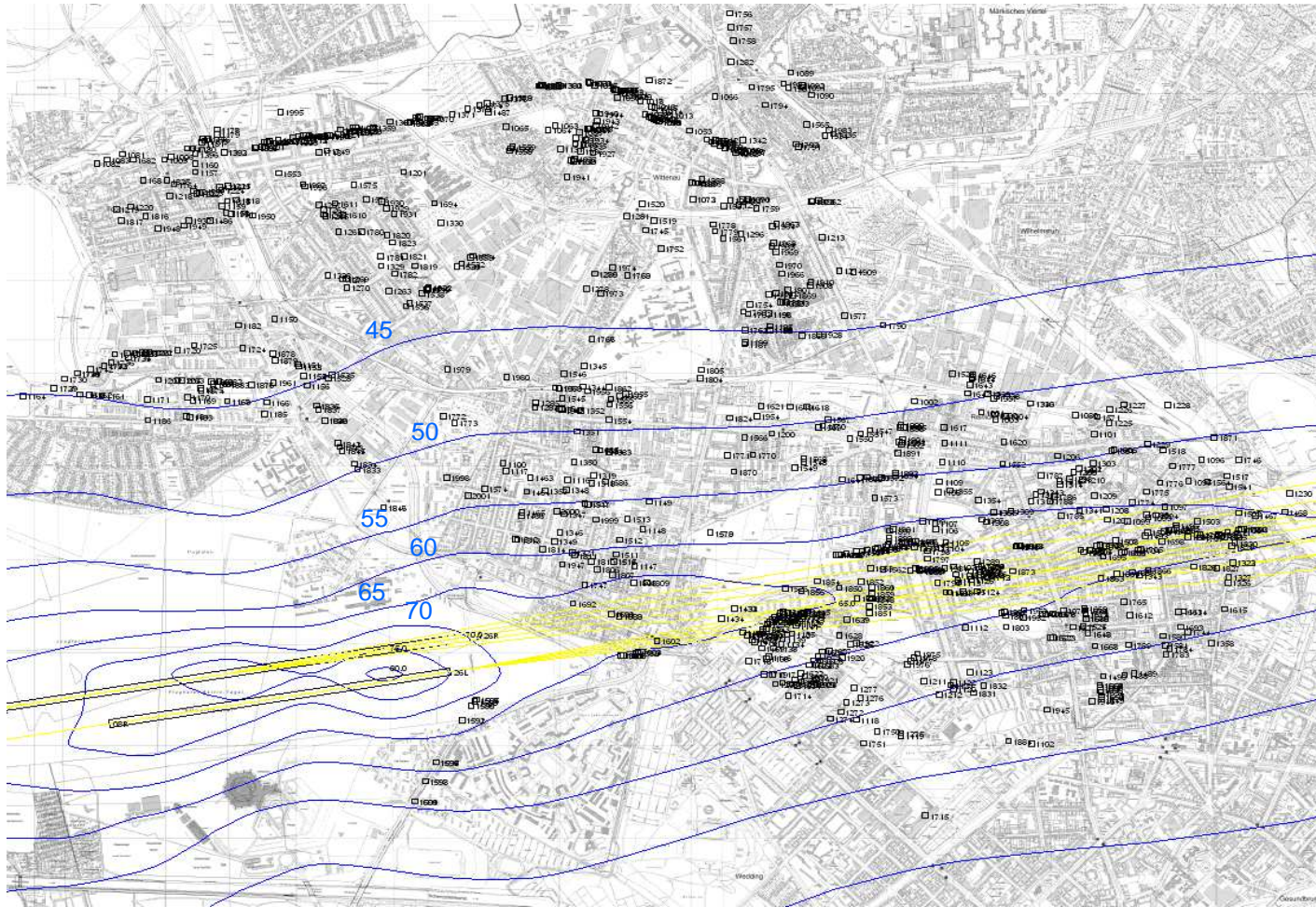
- **14%** increase in risk per 10 dB(A) increase in noise level

OR = Odds ratio = estimate of the relative risk

Sources: van Kempen and Babisch (2012); Babisch (2008); Sørensen et al. (2011)

Aircraft Noise

Noise Contours



Berlin-Tegel airport

Aircraft Noise - Cardiovascular Diseases

Meta-Analyses

Hypertension (6 studies)

L_{DN} : range ~ 45-65 dB(A), OR = 1.13 (95% CI = 1.00-1.28)

- **13%** increase in risk per 10 dB(A) increase in noise level

Myocardial Infarction (1 study)

L_{DN} : range ~ 45-65 dB(A), HR ~ 1.07 (95% CI = 0.94-1.23)

- **7%** increase in risk per 10 dB(A) increase in noise level

Cardiovascular Diseases

Meta-Analyses

Road traffic noise – Hypertension (24 studies)

L_{Aeq16h} : range ~ 45-75 dB(A)

- 7% increase in risk per 10 dB(A) increase in noise level

Road traffic noise – Myocardial Infarction (6 studies)

L_{Aeq16h} : range ~ 55-75 dB(A)

- 17% increase in risk per 10 dB(A) increase in noise level

Road traffic noise – Stroke (1 study)

L_{DEN} : range ~ 50-75 dB(A)

- 14% increase in risk per 10 dB(A) increase in noise level

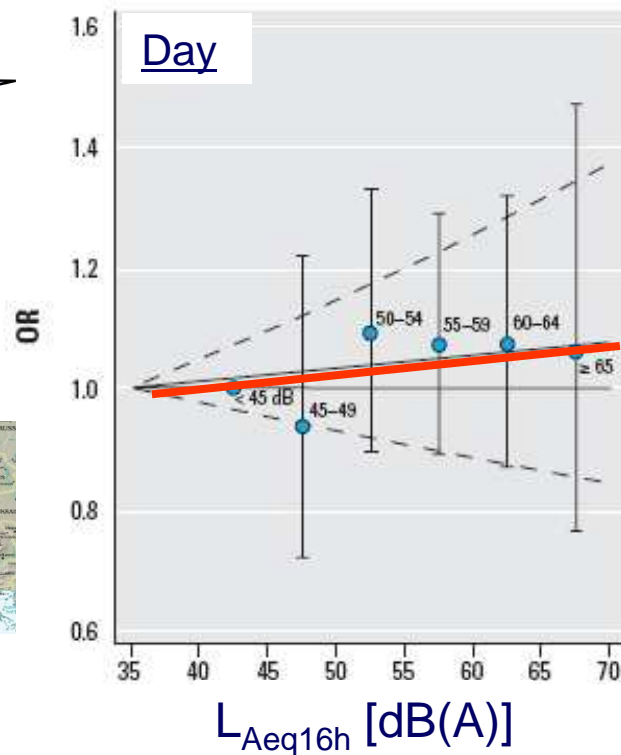
**$L_{DEN} \geq 65$ dB(A):
20-40 % increase in risk**

Day / Night

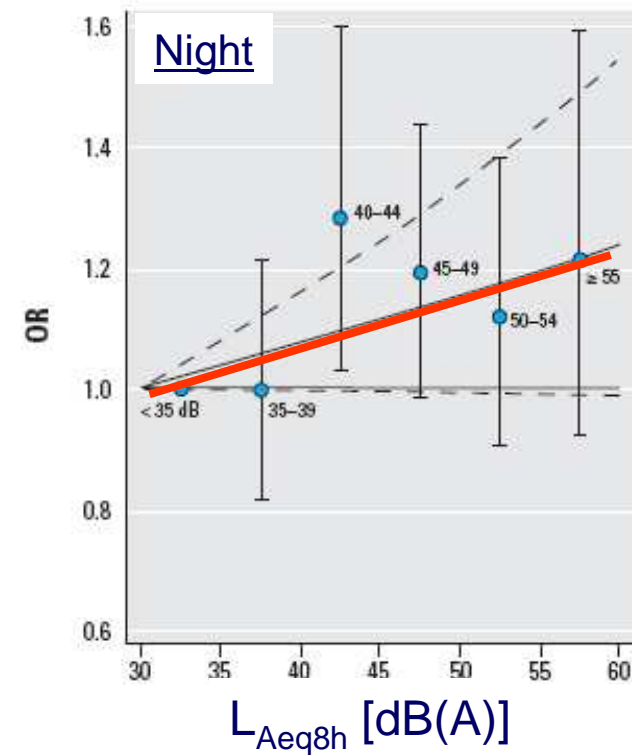
Six Airports Study ('HYENA')

Cross-sectional study, 4861 males+females, aged 45-70 yrs
Prevalence of high blood pressure

Per 10 dB(A): $OR_{Day} = 1.02 (0.95-1.10)$



$OR_{Night} = 1.07 (1.00-1.15)$



OR = Odds ratio = estimate of the relative risk

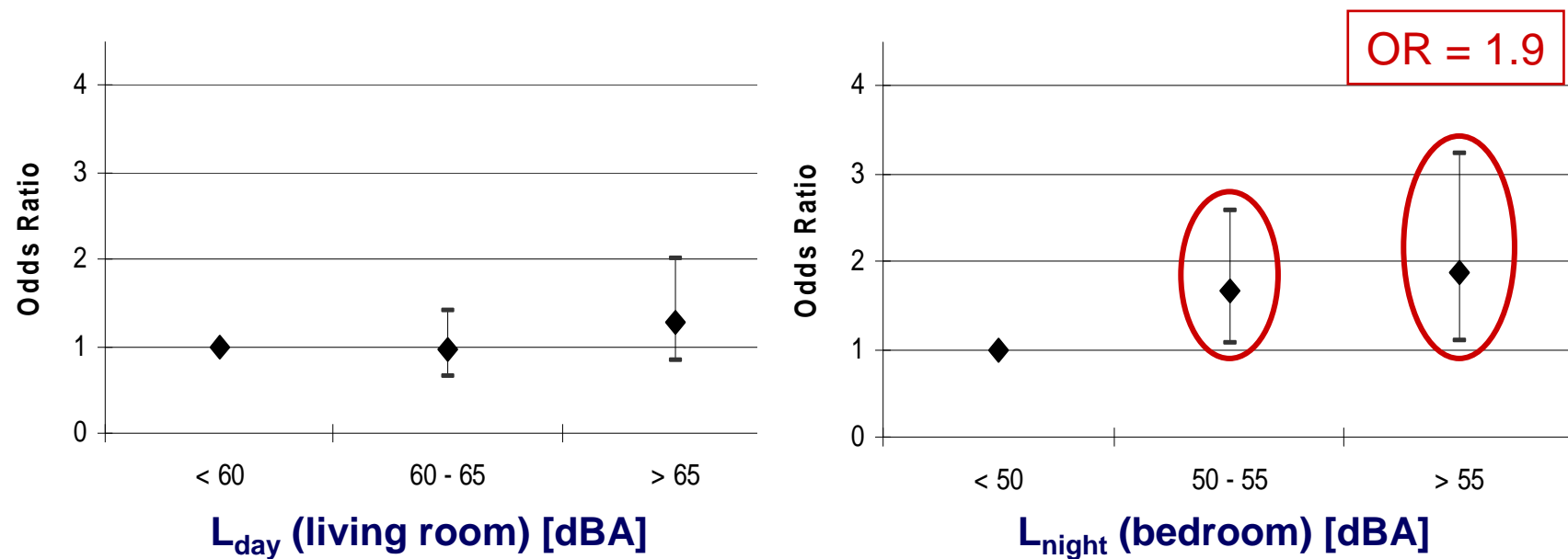
Source: Jarup et al. (2008)

Day / Night

'Spandau Health Survey'

Cross-sectional study, 1718 males and females, aged 18-90 yrs
Prevalence of treated high blood pressure by road traffic noise level

Significant effects (only) with respect to the exposure of the bedroom

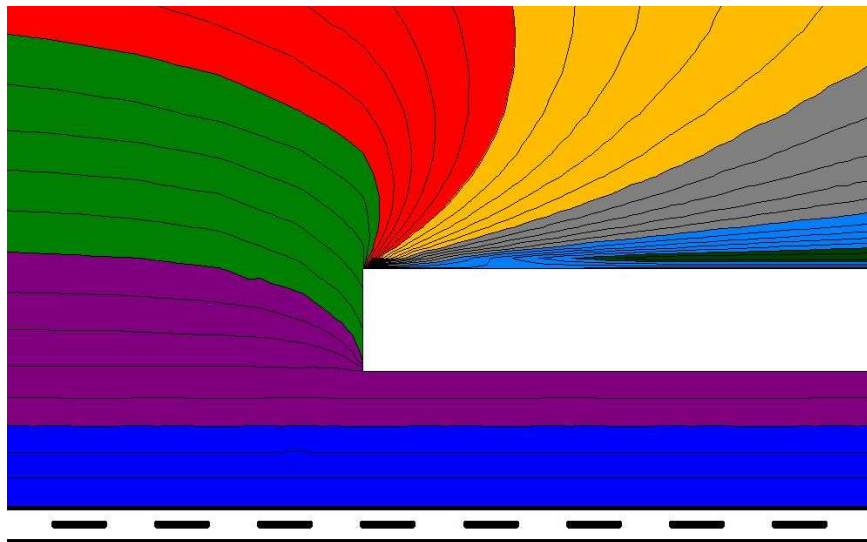


OR = Odds ratio = estimate of the relative risk

Source UBA, Maschke et al. (2003)

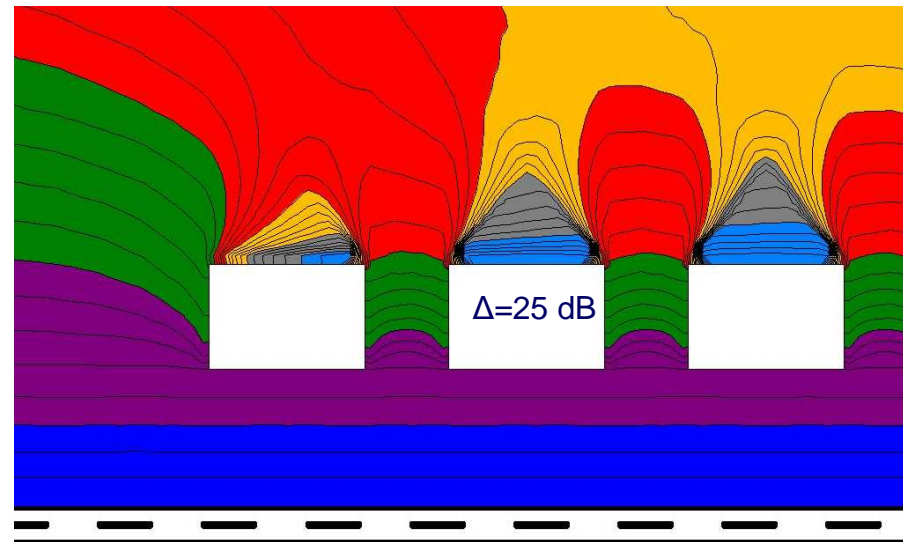
Location Of Rooms (Shielding)

Terraced houses



←→ 10 meter

Detached houses



Roadside

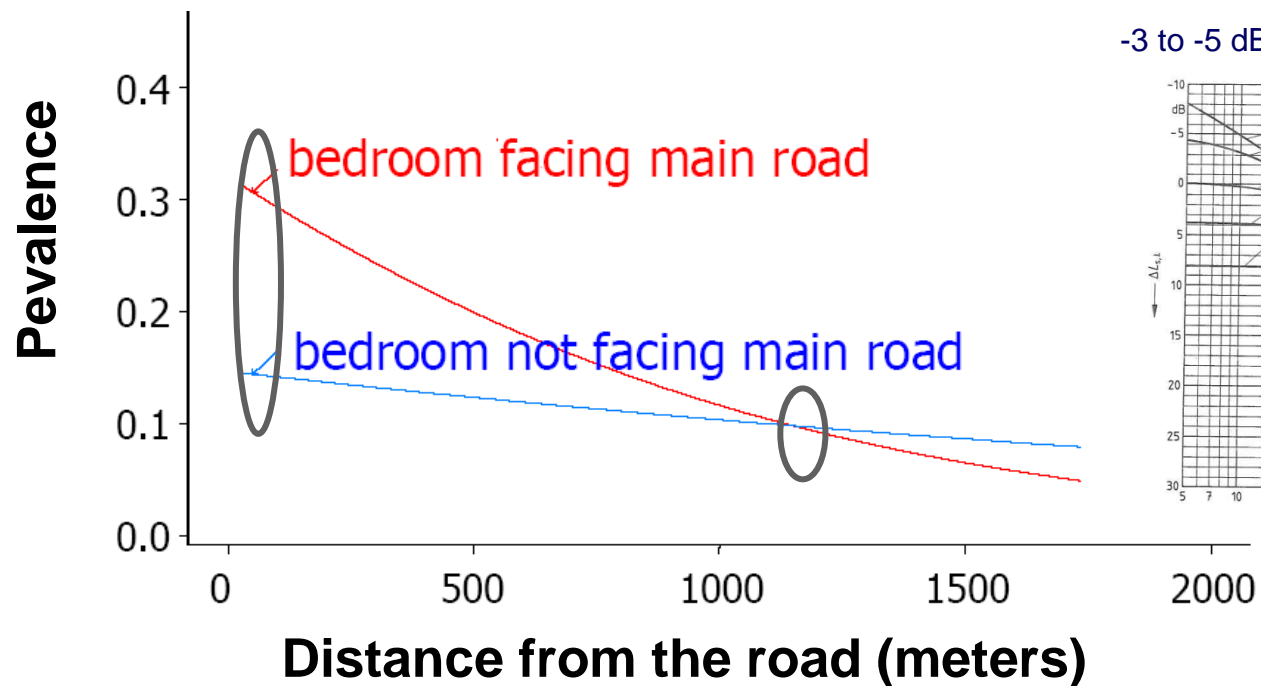
Objekte	Raster
Straße	> 40.0 dB
Haus	> 45.0 dB
	> 50.0 dB
	> 55.0 dB
	> 60.0 dB
	> 65.0 dB
	> 70.0 dB
	> 75.0 dB

Software: Cadna

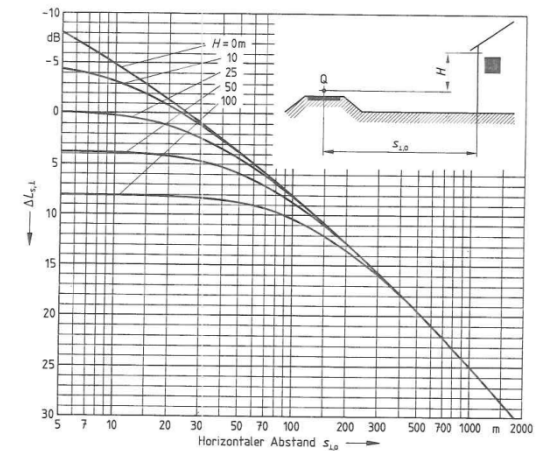
Bedroom Location

'Inn Valley Study'

Cross-sectional study, 1989 males+females, aged 25-64 yrs
Prevalence of high blood pressure by road traffic noise



-3 to -5 dB per doubling of the distance

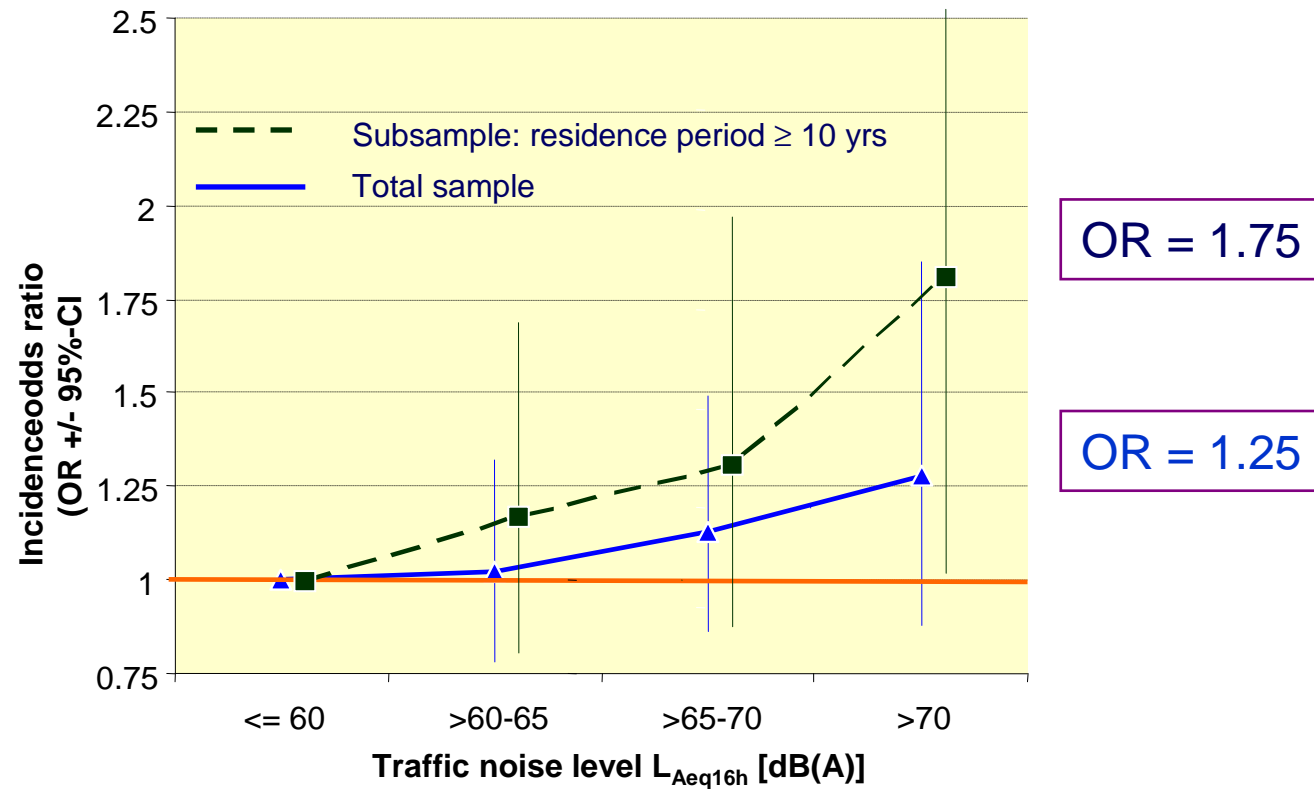


Source: Lercher et al. (2000)

Length Of Residence

'Berlin Road Traffic Noise Study'

Prospective hospital-based case-control study, 4035 males, aged 20-69 yrs
Relative incidence of acute myocardial infarction by road traffic noise level



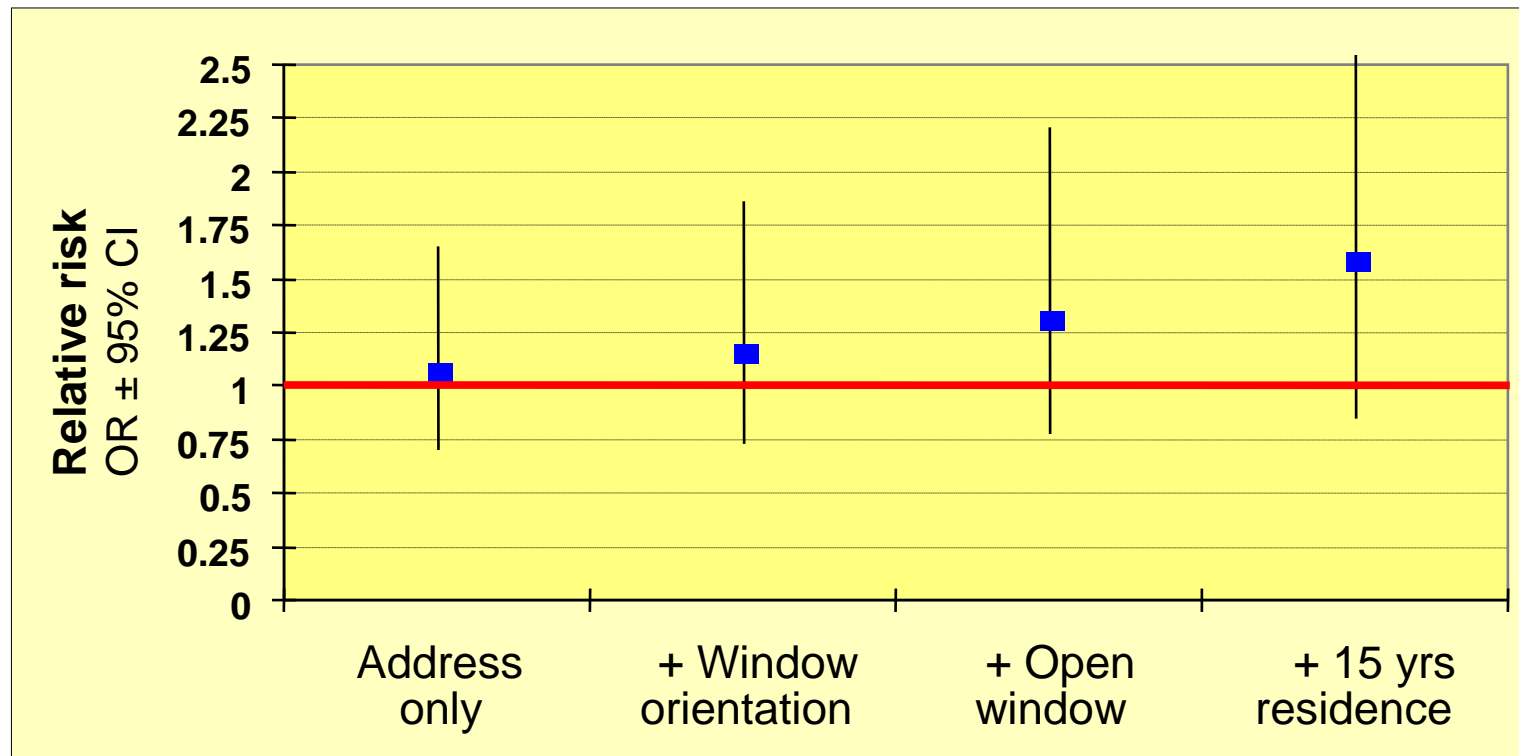
OR = Odds ratio = estimate of the relative risk

Source: Babisch et al., (2005)

Exposure Modifiers

'Caerphilly & Speedwell Studies'

Prospective cohort study, 3950 males, aged 45-63 yrs
Extreme group comparison: L_{Aeq16h} = 66-70 dB(A) vs. 51-55 dB(A)
Incidence of major ischaemic heart diseases by road traffic noise



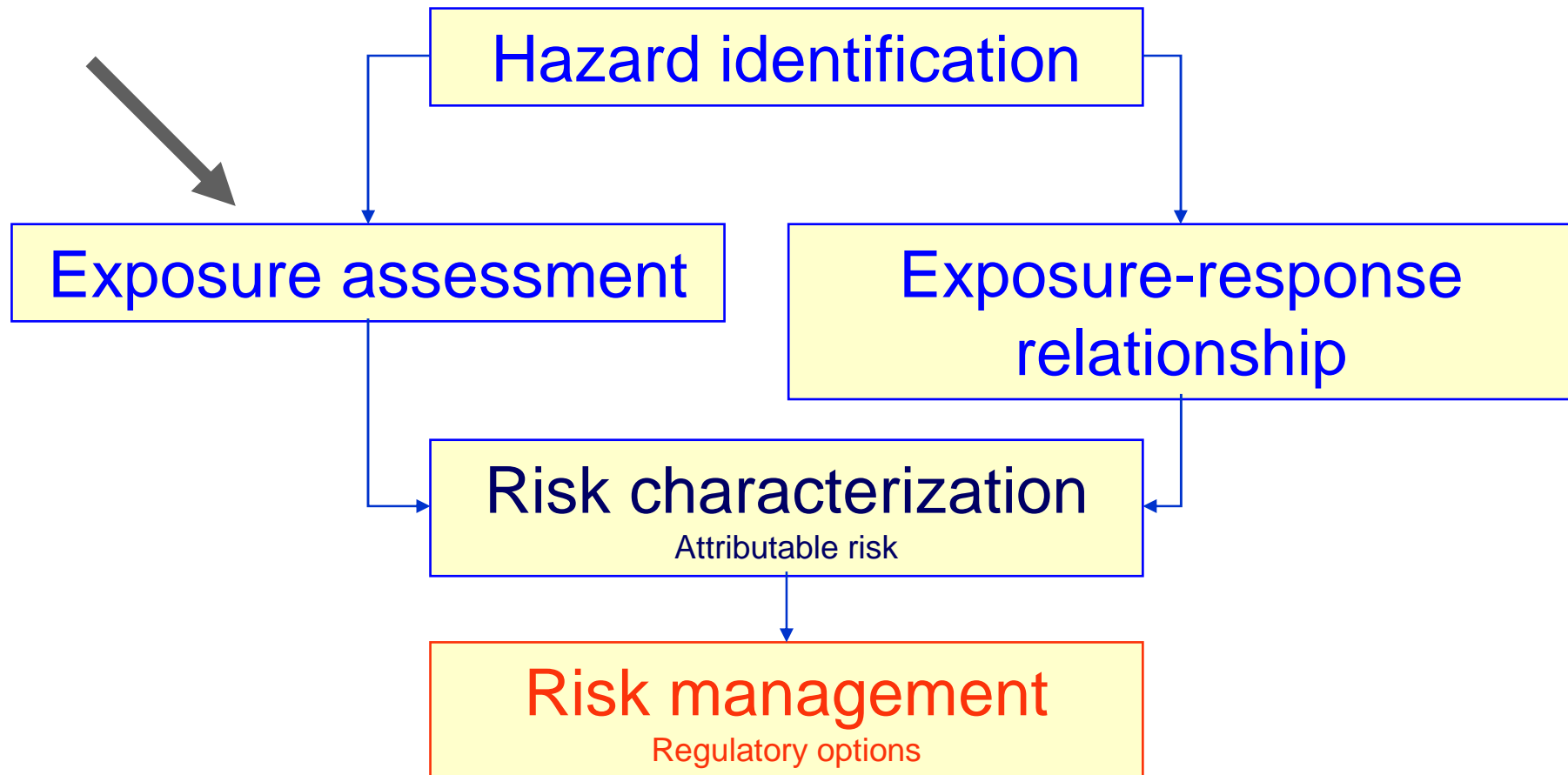
OR = Odds ratio = estimate of the relative risk

Source: Babisch et al. (1999)

Quantification Of The Risk

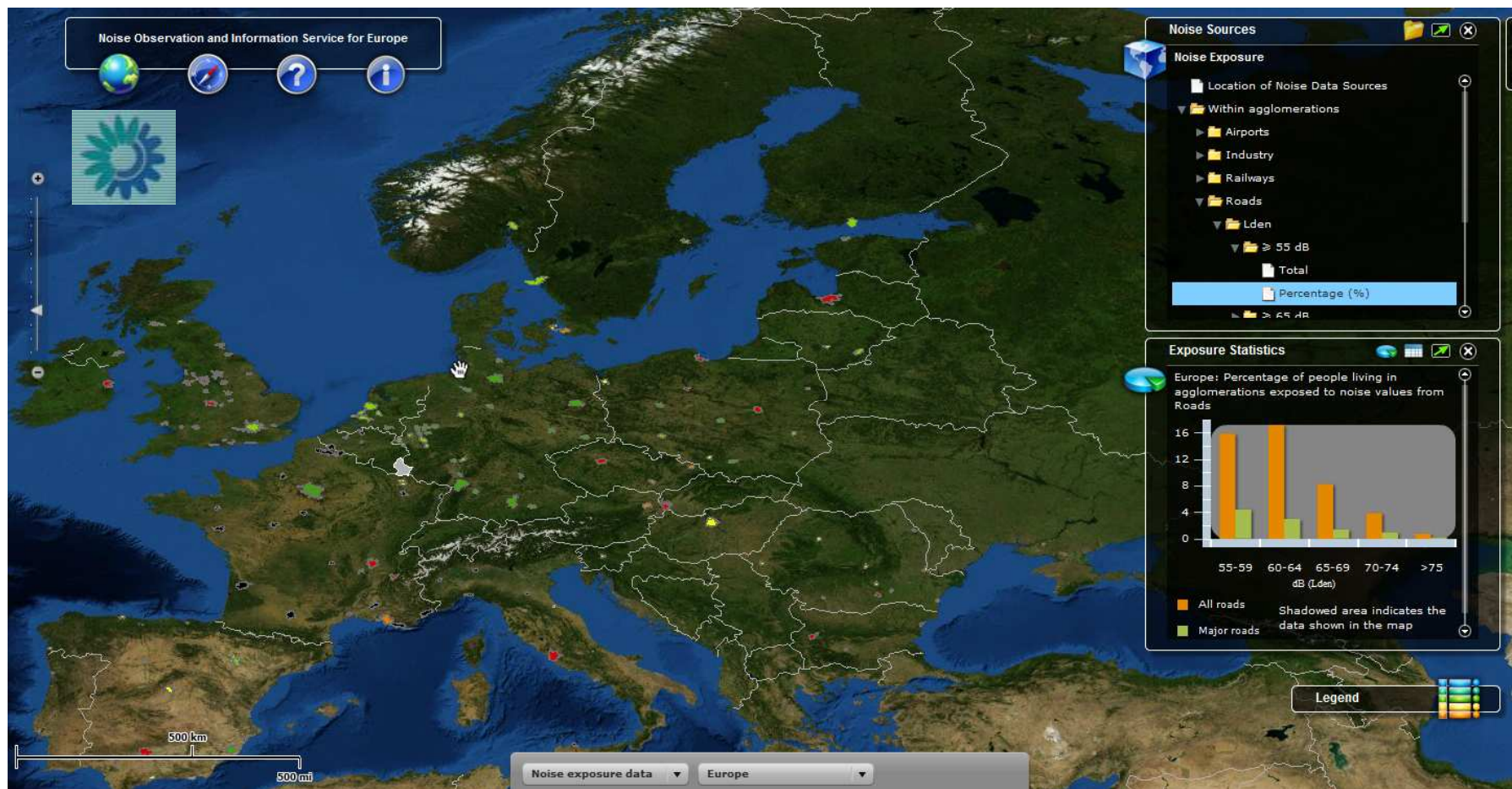
Quantitative Risk Assessment

Health Impact Assessment



Noise Observation And Information Service

For Europe (EEA, ETC-SIA) – Year 2011



<http://noise.eionet.europa.eu/viewer.html>

Noise Exposure In Europe

Large Agglomerations > 250,000 Inhabitants

131 Agglomerations:
103,715,627 Inhabitants (21% of EU-27 population)

$L_{DEN} \geq 55 \text{ dB(A)}$: 54%

$L_{DEN} \geq 65 \text{ dB(A)}$: 15%

$L_{Night} \geq 50 \text{ dB(A)}$: 39%

$L_{Night} \geq 55 \text{ dB(A)}$: 18%



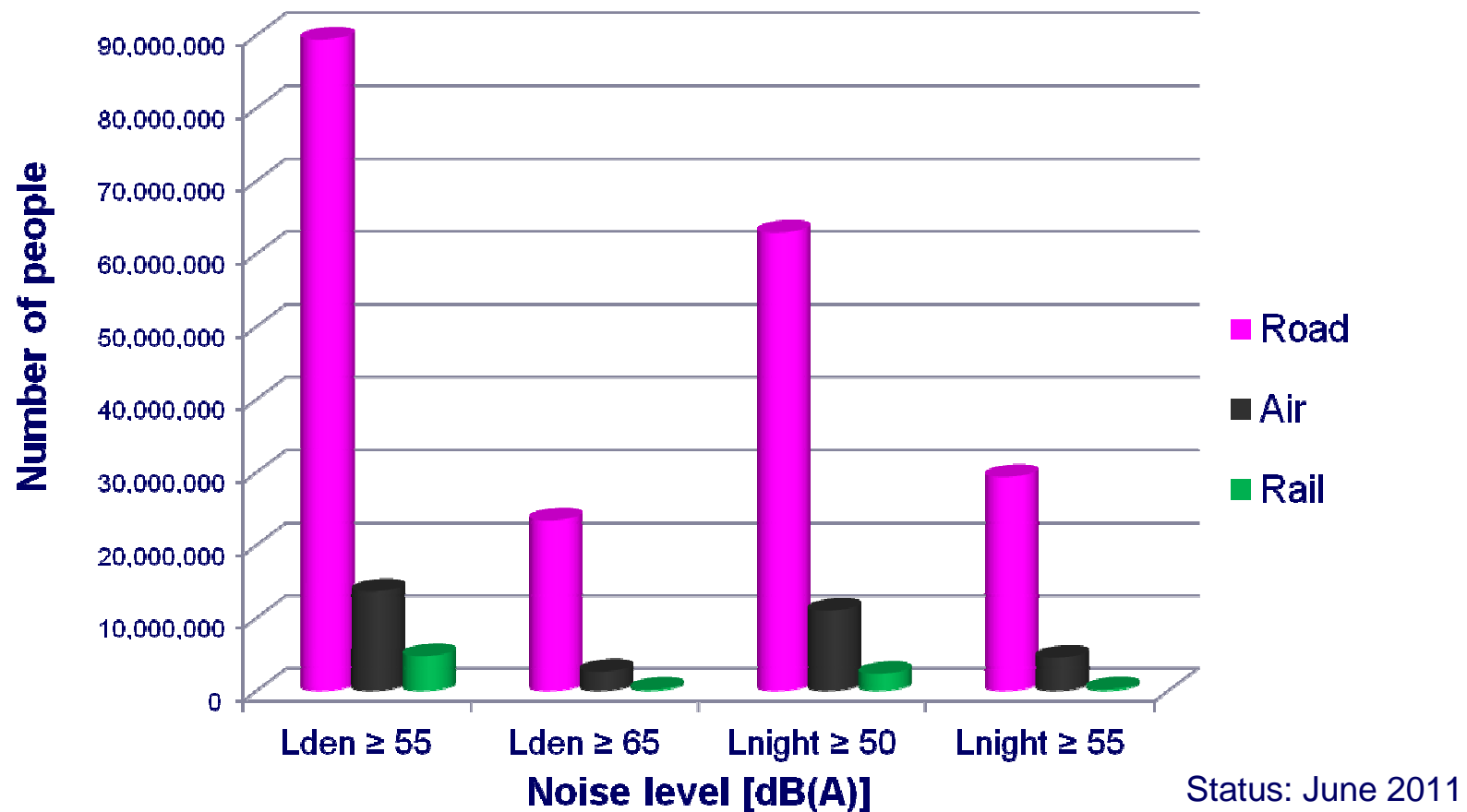
Status: June 2011

Source of raw data: http://eea.eionet.europa.eu/Public/irc/eionet-circle/etccte/library?l=/2009_subvention/113noise/data&vm=detailed&sb=Title

Noise Mapping In Europe (EU-27)

Large Agglomerations + Major Roads Outside Agglomerations

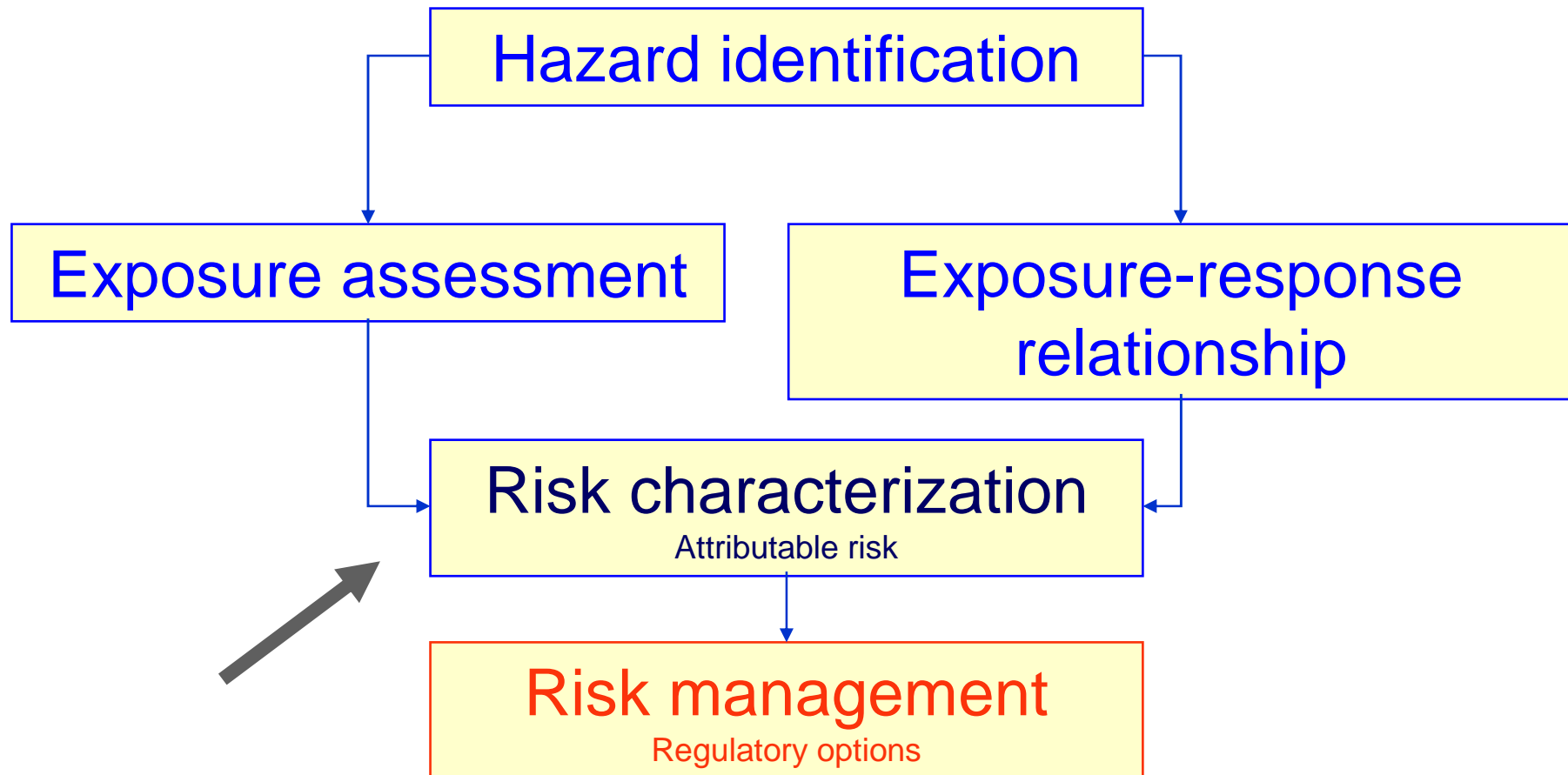
Road traffic is the major source of transport noise



Source of raw data: http://eea.eionet.europa.eu/Public/irc/eionet-circle/etccte/library?l=/2009_subvention/113noise/data&vm=detailed&sb=Title

Quantitative Risk Assessment

Health Impact Assessment



WHO: Disability Adjusted Life Years

"DALYs"

- Idea: One figure to aggregate different levels of severity
Quantification unit, priority setting, DALYs as a public health currency
- $DALY = YLL + YLD$
The sum of years of potential life lost due to premature mortality and the years of productive life lost due to poor health or disability
 $YLL = ND$ (number of deaths) x DW (disability weight) x LD (standard life expectancy at age of death in years)
 $YLD = NI$ (number of incident cases) x DW (disability weight) x LI (average duration of disability in years)
- Severity weight factors (disability weights)
Expert rating

Disability Weights

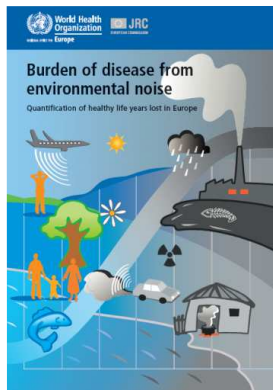
Environmental Noise Burden Of Disease (EBD)

- Mortality: 1.000 (WHO EBD)
- Non-fatal acute myocardial infarction: 0.405
- Ischaemic heart disease: 0.405 (WHO EBD), 0.350
- Hypertension: 0.352
- Primary (non-organic) insomnia: 0.100
- Sleep disturbance: 0.070 (WHO NNGL)
- Noise annoyance: 0.020 (WHO EBD)
- Cognitive impairment: 0.006 (WHO EBD)
- Tinnitus: slight 0.010; moderate, severe 0.111 (WHO EBD)

Sources: Mathers et al. (1999), de Hollander et al.(1999), WHO (2011)

Environmental Noise Burden Of Disease

WHO 2011



Every year in the EU cities, at least:

- 61 000 DALYs for ischaemic heart disease
- 45 000 DALYs for cognitive impairment
- 903 000 DALYs for sleep disturbance
- 22 000 DALYs for tinnitus
- 654 000 DALYs for annoyance

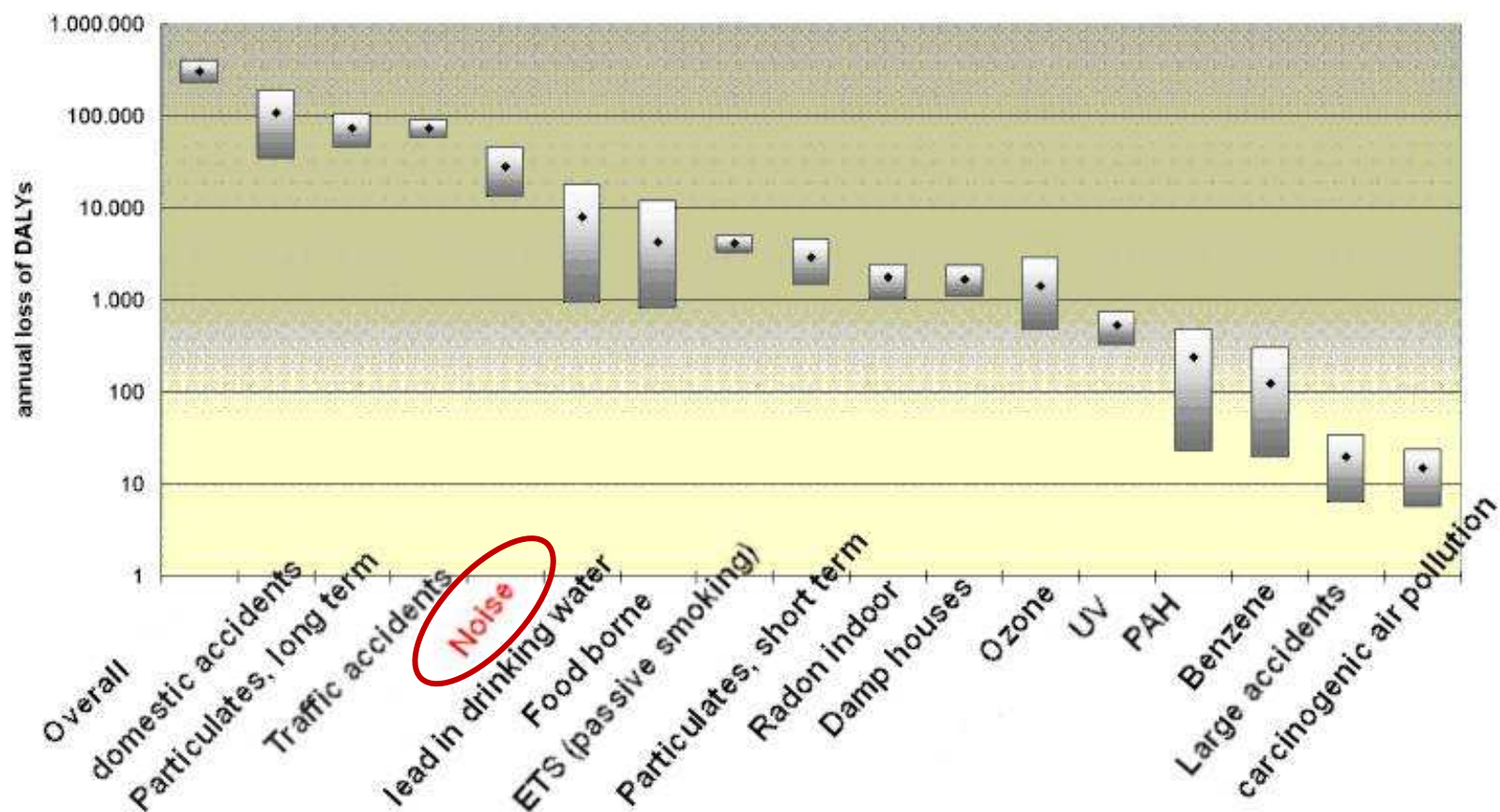
1~1.6 million healthy life years are lost every year from traffic noise in the EU cities.

Sleep disturbance and annoyance related to road traffic noise comprise the main burden.

WHO European Centre for Environment and Health, 2011

Environmental Burden Of Disease

Example: The Netherlands (Complete Noise Assessment Available)



Source: de Hollander (2004), EEA (2010)

Economic Valuation

Cost-Benefit

Valuation of healthy life years lost (VOLY):

One healthy life year has been valued at 40,000 to 80,000 Euro in previous studies in the health sector (air pollution research).

1 Million DALYs \Leftrightarrow 40 Billion Euro loss

Crude estimate (includes uncertainties, use with caution)

Willingness to pay (WTP):

25 Euros per household per decibel per year
(for $L_{den} > 50-55$ dB(A))

1.1 Billion Euro per 1 dB(A) per year

Sources: Navrud (2002), De Hollander et al. (2004), Needs report (2007), EU Commission (2009), Joris et al. (2010), EEA (2010)

Summary

History Of Noise Effects' Research

Begin of systematic research:

- ~ 1950: Laboratory experiments with humans
- ~ 1960: Animal experiments
- ~ 1970: Occupational epidemiology
- ~ 1980: Environmental epidemiology
- ~ 2000: Quantitative risk assessment
- ~ 2005: Combined effects (e. g. air pollution)

Evidence

- Laboratory experiments on humans
(acute effects, high and moderate noise levels)
- Animal experiments
(long-term effects, high noise levels)
- Occupational noise studies
(long-term effects on humans, high noise levels)
- Environmental noise studies
(long-term effects on humans, moderate noise levels)

Epidemiological Reasoning (Causality)

- Hypothesis
- Biological plausibility (coherence)
- Consistency of study results
(different populations, different methodology)
- Exposure-response relationships
- Magnitude of effect is of public health relevance

Statement

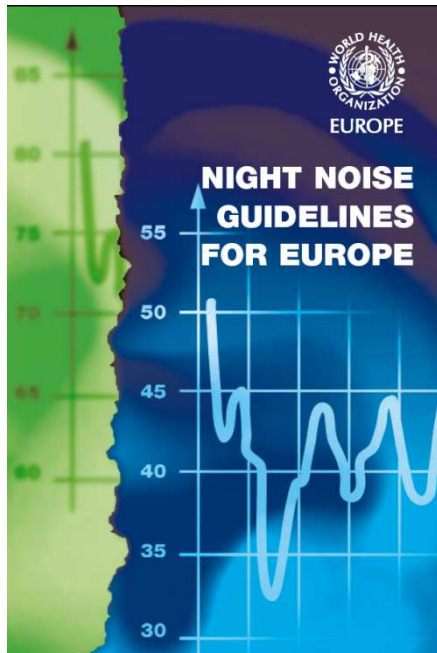
The question nowadays is no longer whether community noise causes adverse health effects, the question is rather as to what extent:

- Slope of the exposure-response relationship (magnitude)
- Onset of the exposure-response relationship (threshold)

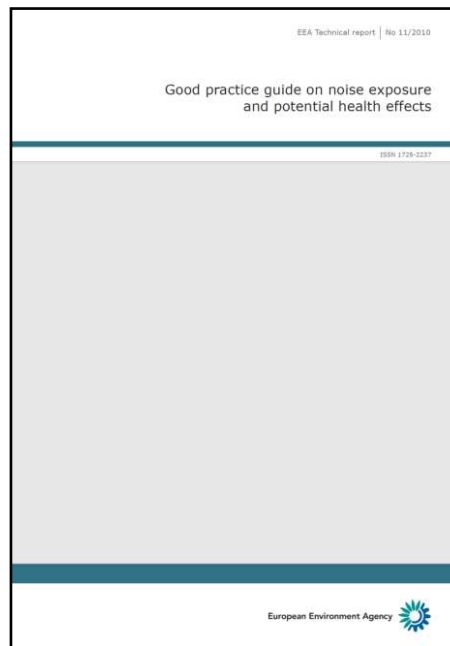
Research Needs

- Refining exposure-response curves
- New / unexplored noise sources
(e. g. railway noise, noise from windfarms)
- Combined effects
 - different noise sources
 - noise and other agents
- Modifying factors (acoustical and non-acoustical)
- Quality targets

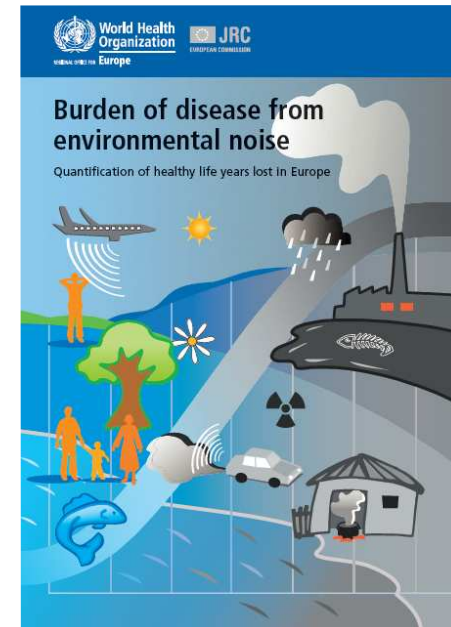
Important Documents



WHO, 2009



EEA, 2010



WHO, 2011

Thank You For Listening

“Calling noise a nuisance is like calling smog an inconvenience”
(W. H. Steward, former Surgeon General of USA)



Contact:
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Discussion Points

Environmental Quality Targets

Outdoors:

Cardiovascular: $L_{\text{day}} \leq 60\text{-}65 \text{ dB(A)}$

Serious annoyance: $L_{\text{day}} \leq 55 \text{ dB(A)}$

Moderate annoyance: $L_{\text{day}} \leq 50 \text{ dB(A)}$

Cardiovascular: $L_{\text{night}} \leq 50\text{-}55 \text{ dB(A)}$

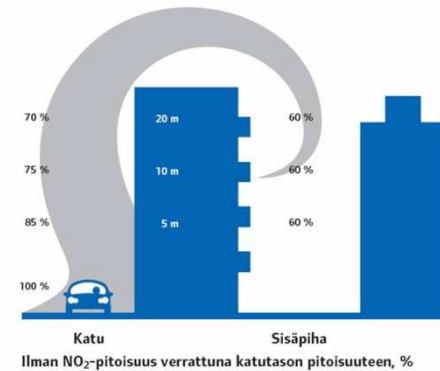
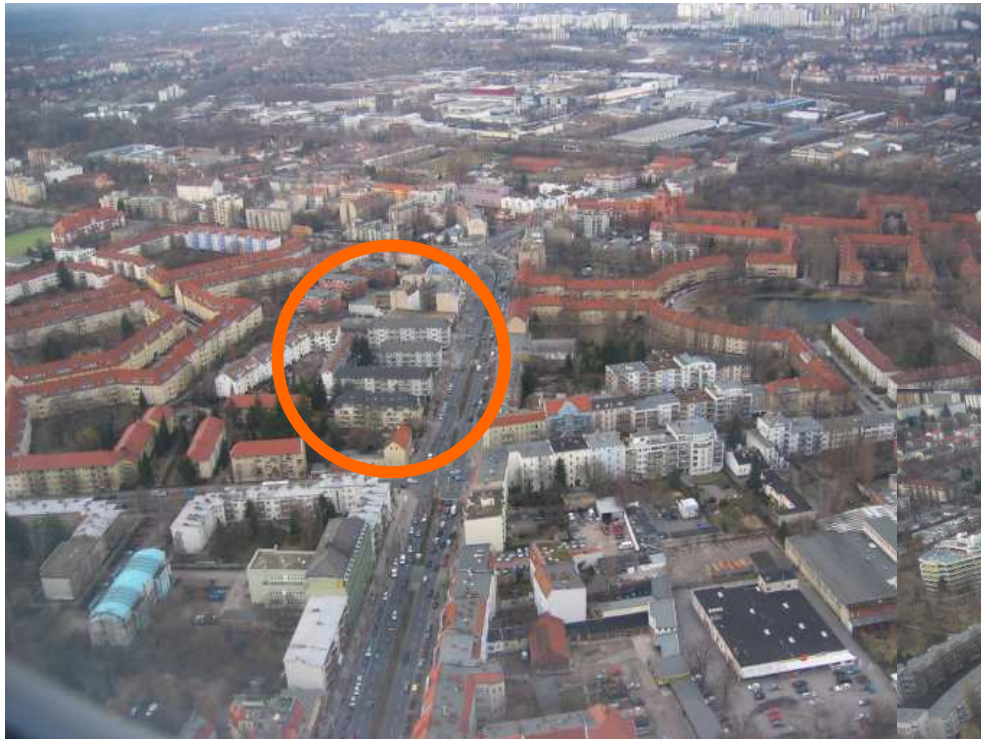
Sleep disturbance: $L_{\text{night}} \leq 40\text{-}45 \text{ dB(A)}$

Noise Versus Air Pollution

- Small scale (individual) exposure vs. spatial exposure
- Shielding (orientation of rooms) very effective
- Independent of meteorology
- Well defined physical propagation rules
- No accumulation in the atmosphere ("no cars, no noise")
- Effects were found with respect to sound sources other than road traffic (aircraft noise, occupational noise)
- Day-night differences (stronger effects for night noise / less air pollution)
- Window opening
- No day to day variations

Combined Exposures

Noise + Air Pollution



Access to a quiet side



Images: Babisch, Pesonen

Noise And Air Pollution (1)

"Prevent / Groningen Studies": Hypertension

Road traffic noise (L_{den}) and air pollution (PM_{10})

Age group 45-55 yrs

Groningen sample

cross-sectional (N=40,856)

self-reported HBP

OR = 1.08 (0.97-1.29) per 10 dB

including PM_{10}

OR = 1.19 (1.02-1.40) per 10 dB

Prevent sample

cross-sectional (N=8,592)

self-reported + clinical HBP

OR = 1.27 (1.08-1.49) per 10 dB

including PM_{10}

OR = 1.39 (1.08-1.77) per 10 dB

Source: de Kluizenaar et al. (2007)

Noise And Air Pollution (2)

'Stockholm County Study' (SHEEP): Myocardial Infarction

	Controls		All cases	
Road traffic noise #	<i>n</i>	<i>n</i>	<i>OR</i> *	95% <i>KI</i> *
Dichotomous				
<50	1369	923	-	
≥50	683	543	1.12	0.95-1.33
Categorical				
<50	1369	923	-	
50-54	384	312	1.15	0.95-1.39
55-59	214	161	1.05	0.81-1.36
60-64	75	60	1.21	0.81-1.79
≥65	10	10	1.26	0.48-3.30

#Time weighted average of road traffic noise ($L_{Aeq,24h}$) from 1970 to 1992-1994.

*Odds ratio and 95% confidence interval adjusted for matching variables (gender, age and catchment area) and for smoking, physical inactivity, diabetes, air pollution (NO_2) and occupational noise.

Source: Selander et al. (2009)

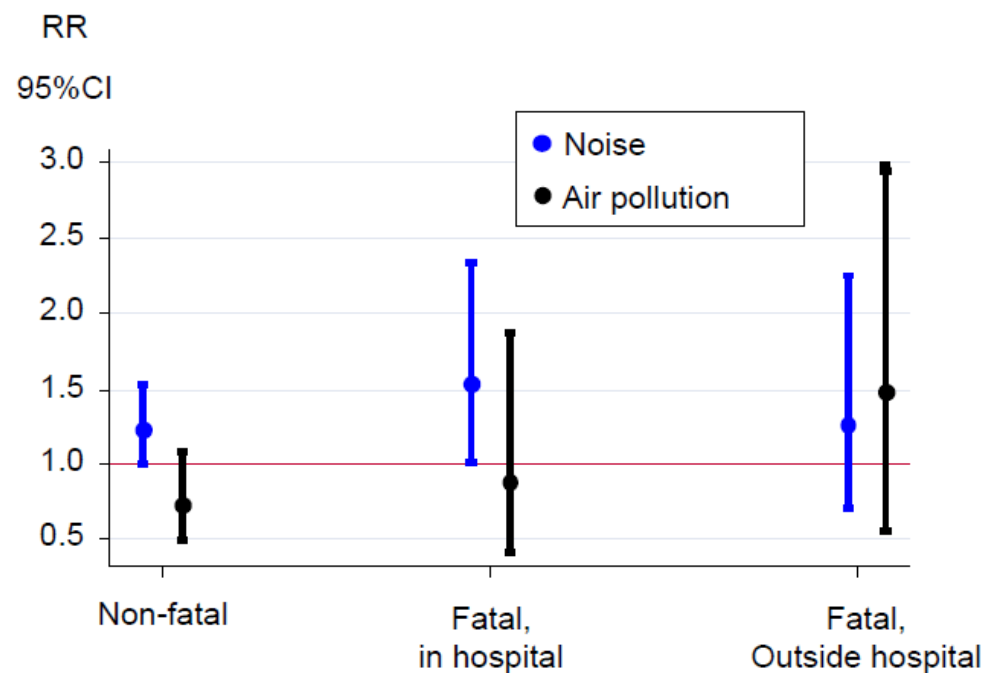
Noise And Air Pollution (3)

"Stockholm County Study" (SHEEP): Myocardial Infarction

Noise ($L_{Aeq,24h}$): ≥ 50 vs. < 50 dB
Air (NO_2): ≥ 20 vs. < 20 $\mu g/m^3$



Relative risk for myocardial infarction related to exposure to road traffic noise or air pollution



Sources: Pershagen, at DEFRA (23/02/2012) , Selander et al..(2012)

Augsburg Noise Maps

House at a close distance to a major road

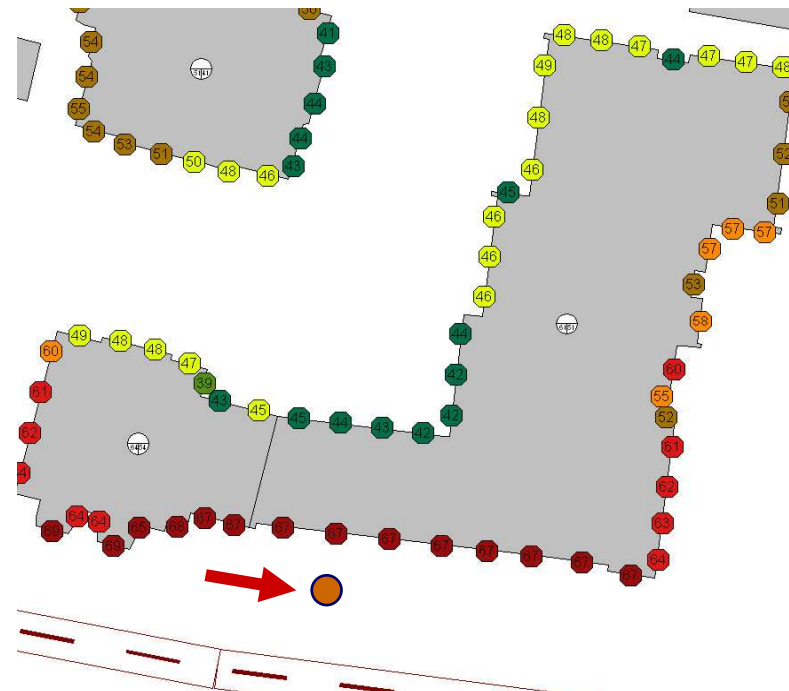
Improved Map



Front / back side

$L_{\text{day, 16h}}$: 70/50 dB(A), $\Delta = 20$ dB(A)

END Map



Front / back side

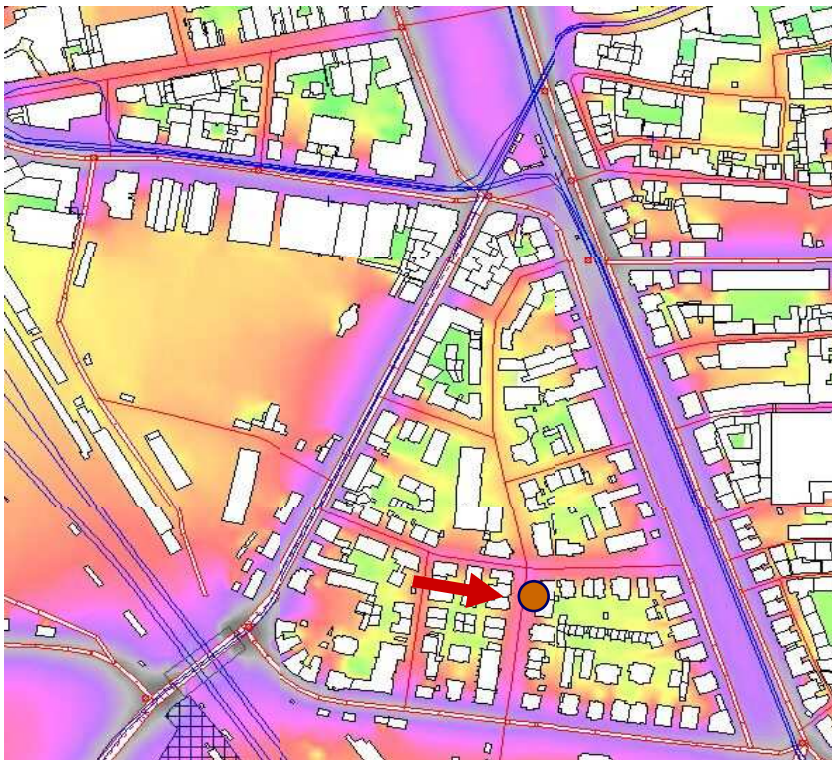
$L_{\text{day, 12h}}$: 67/44 dB(A), $\Delta = 23$ dB(A)

Software: Cadna

Augsburg Noise Maps

House at a far distance to a major road

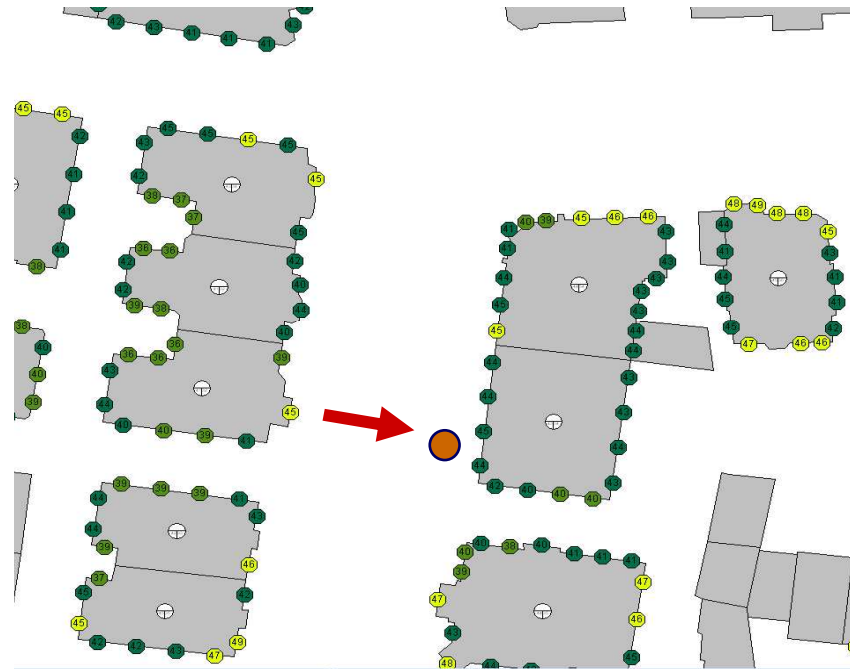
Improved Map



Front / back side

$L_{\text{day, 16h}}$: 62/46 dB(A), $\Delta = 16$ dB(A)

END Map



Front / back side

$L_{\text{day, 12h}}$: 44/43 dB(A), $\Delta = 1$ dB(A)

Software: Cadna