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Presentation is available at:
https://akustiikka.turkuamk.fi/en/speech-level-reduction/

Acoustic classification of booths – and science behind

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Orgatec, Cologne, Germany
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- What is office noise?
- Noise effects on human
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- Benefits of booth insulation on human
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My short biography

- Master in Physics
- Doctor in Acoustics
- Docent in Noise Control
- Docent in Environmental Psychology
- > 90 peer-reviewed scientific articles
- > 200 other scientific articles
- Leader of 13-person research group
  - Acoustics lab
  - Air conditioning lab
  - Psychophysics lab
  - Vibration lab
  - Underwater acoustics lab
- Leader of ISO/TC43/SC2/WG34 responsible for “office acoustics standards:” ISO 3382-3, ISO 23351-1, and ISO 23351-2

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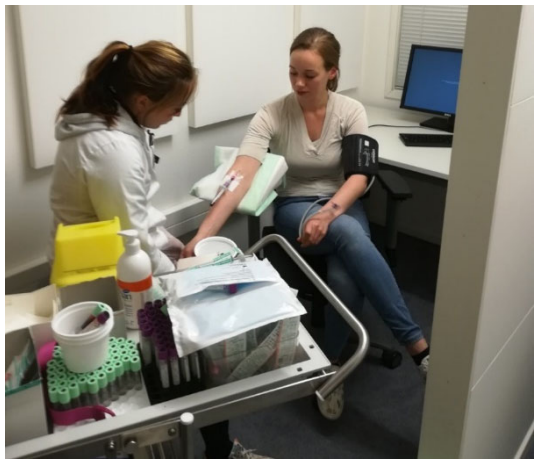
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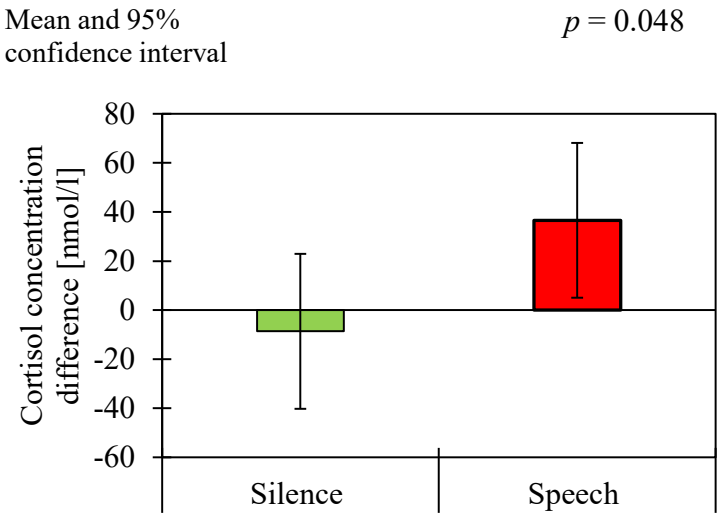
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Irrelevant speech harms the body, work &mind

- Stress refers to an elevated state of bodily arousal.
- Prolonged stress can impair health.
- Irrelevant speech is the main noise source in offices

- Our medical experiment investigated the effects of speech on working persons.
- Two conditions:
  - Speech at 65 dB L_{Aeq}
  - Silence at 35 dB L_{Aeq}
- 20 participants per condition
- Exposure lasted 45 minutes





Physiological stress increased:
- Plasma cortisol concentration*
- Heart rate variability (LF/HF of ECG)*

Work performance declined:
- Digit span memory***
- 3-back accuracy*

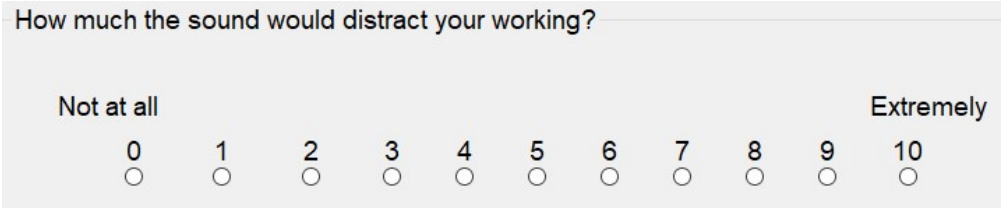
Psychological strain increased:
- Annoyance***
- Workload*

*p<0.05; ***p<0.001

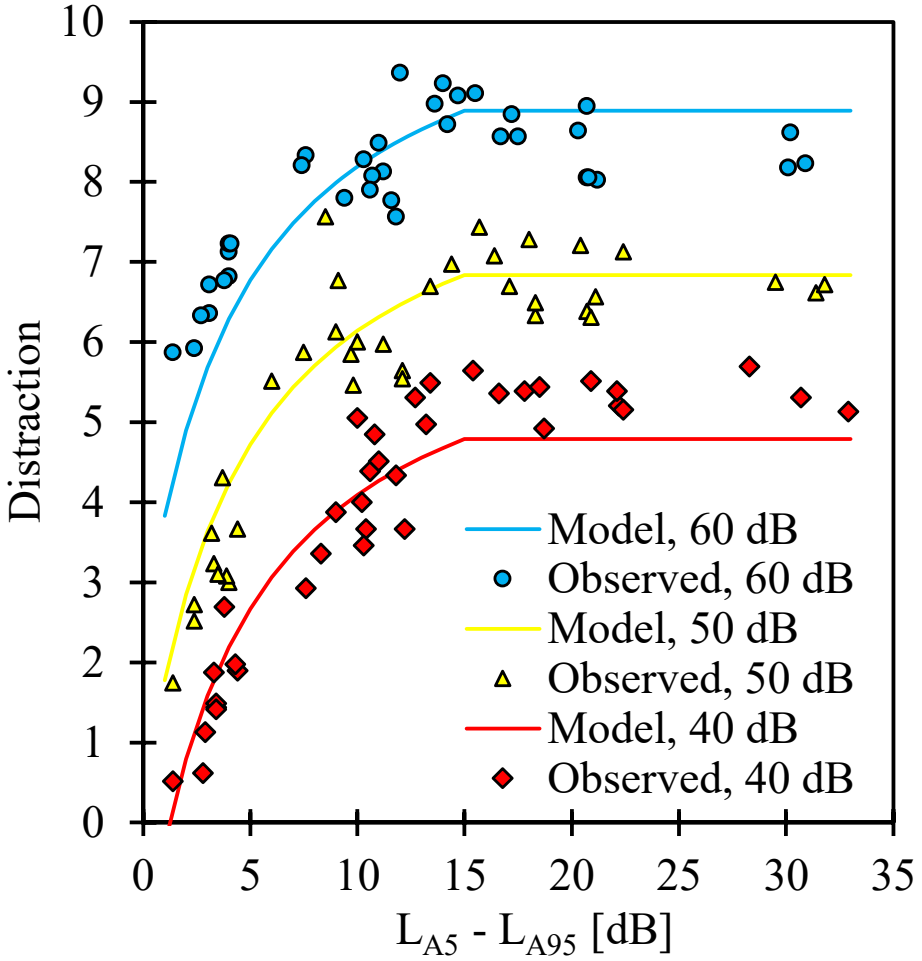
Distraction is mostly explained by variability of sound level

Hongisto et al. 2025 **Build Environ**

- We conducted an experiment with 40 subjects
- They rated the distraction of 23 different speech scenarios presented at 40, 50, and 60 dB L_{Aeq}
- The scenarios varied with number of simultaneous speakers (0-12) and signal -to-noise ratio (-5…+15 dB)



- We found a model (D_p) that predicted the mean distraction ratings almost perfectly **(r_P=0.96)**
- Distraction incresed with
  - increasing overall level **L_{Aeq}**, but even more with
  - increasing variability V (V=**L_{A5}-L_{A95}**)



L_{Aeq}=60 dB
V=30 dB

V=2.9 dB

V=1.4 dB

$$D_p = 0.205 \cdot L_{Aeq} + 8.63 \cdot \frac{V}{V + 4.65} - 10$$

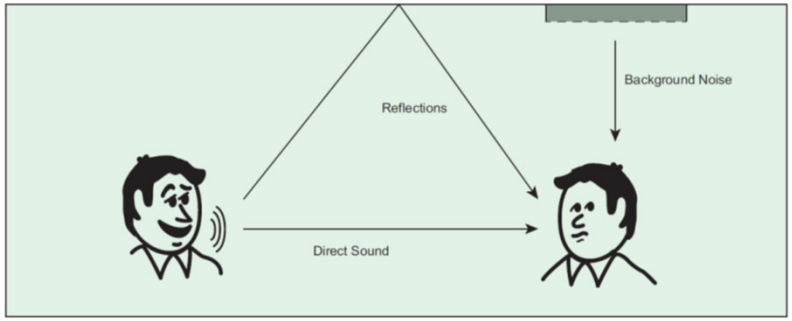
Speech Transmission Index, STI

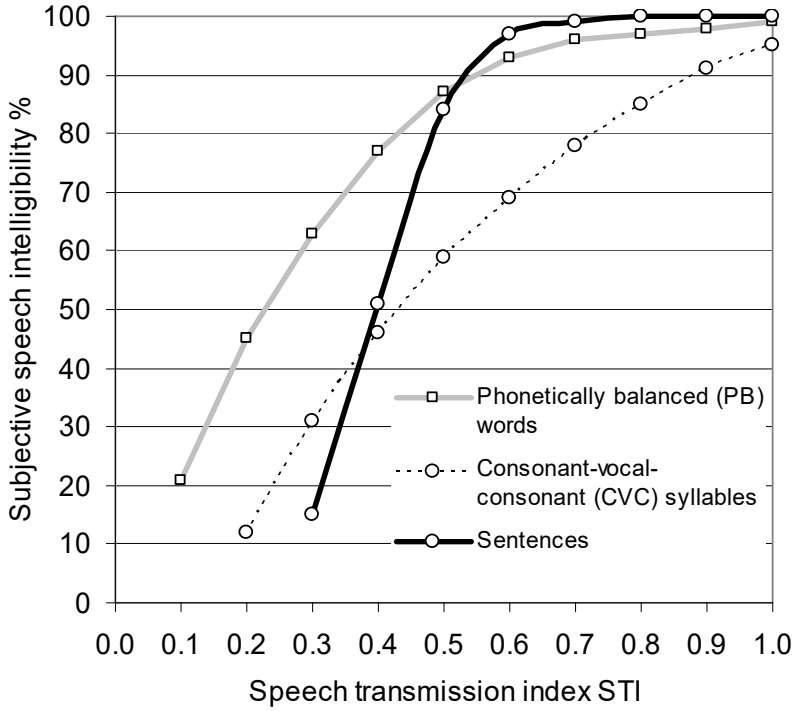
- Subjective speech intelligibility, SSI, describes how many percent of speech is correctly heard
- Listening tests are used to find SII but they are slow and expensive
- SSI can be well predicted measuring STI (IEC 60268-16)
- STI is measured in a room between one speaker and one listener

STI range	Speech intelligibility
<0.30	Useless
0.30-0.45	Poor
0.45-0.60	Reasonable
0.60-0.75	Good
>0.75	Very good

STI range	Speech privacy
0.00	Very good
0.00-0.10	Good
0.10-0.20	Reasonable
0.20-0.35	Poor
>0.35	Useless

- **STI range: 0.00 - 1.00**
- High STI is appropriate for for presentation spaces
- Low STI is appropriate for open-plan offices, libraries, hospital patient rooms, etc.

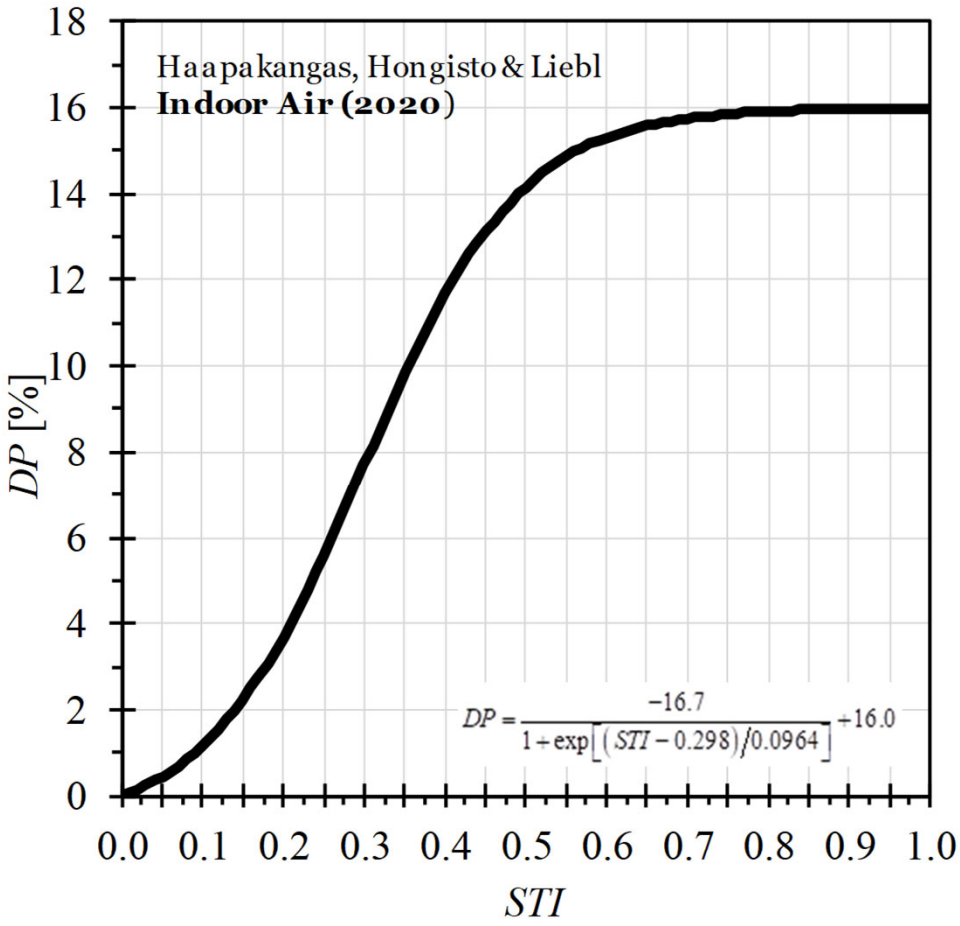




Hongisto, 2005 *Indoor Air*
IEC 60268-16:1998 2nd edition

Decrement of performance (DP) declines with increasing STI

- Colle (1977): DP is more than 15% during speech compared to silence
- Task-irrelevant words arriving to hearing organ are automatically coded to short-term memory and the current cognitive tasks, which also process words, are disturbed
- Colle studied loud speech with STI=1.00.
- STI in offices vary between 0.0 and 1.0
- Hongisto (2005) proposed that STI could explain DP due to speech
- Haapakangas *et al*. (2020) found that DP depends on STI, and reaches even 15 %, when STI exceeds 0.50.
- Therefore, STI is used in room acoustic measurements of offices



DP = Decrement of performance, työsuorituksen heikkeneminen
STI = Speech Transmission Index, puheensiirtoindeksi

Hongisto, 2005, *Indoor Air*
Haapakangas et al., 2020, Indoor Air

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Noise control methods in the open-plan office

Room acoustics

Simultaneous use of these three means is necessary to reduce STI:

A. Maximum ceiling absorption (class A)
B. High screens >140 cm
C. Sound masking 42 dBA

Additional benefits:
- Wall absorbers
- Curtain absorbers
- Screen absorbers
- Soft carpet

Architectural methods
- Soundproof rooms (D_{nTw} >40 dB)
- Isolation of coffee rooms and stairways (D_{nTw} >40 dB)
- Sufficient workstation distances
- Pods or booths ($D_{S,A}$>25 dB)

Organizational methods
- Activity-based office
- Office noise etiquette
- Team grouping according to task
- Silent and communication zones
- Offering qualified headsets
- Crowd-indicating displays
- Remote work contracts

Individual or behavioral methods
- Choosing soundproof workstation
- Notifying colleagues
- Remote working
- Hearing protectors
- Local sound masking
- Choosing a task type insensitive to noise
- Choosing another workplace

Who pays what?

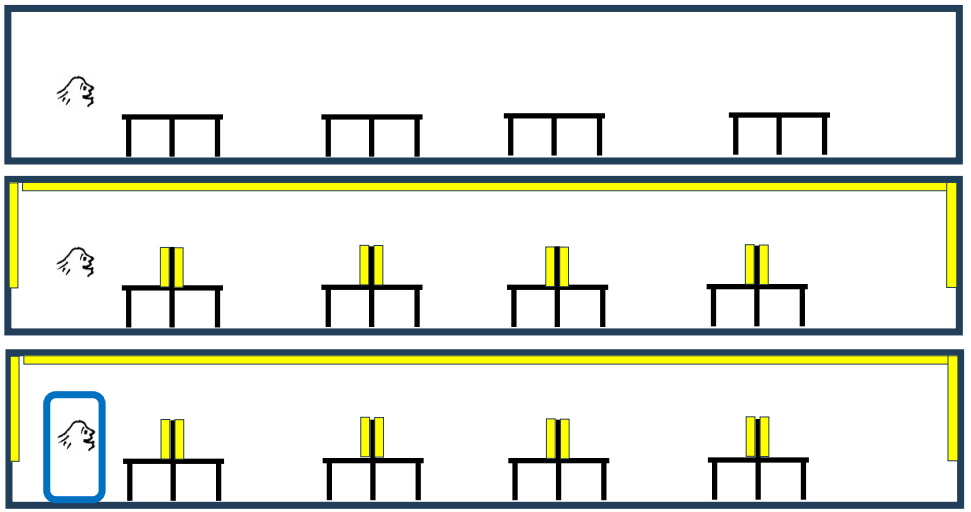
BUILDING OWNER: ”The space”

- Ceiling absorption, coverage >80 %
  - Sound absorption class A
- Wall absorption coverage >30 %
  - Sound absorption class A
  - Alternatively vertical absorbers
- Sound masking system in workstation area
  - level 40-44 dBA
  - A loudspeaker grid of 2.5-3.0 m in the ceiling
- Textile floor covering
- Isolation of workstations from noise
  - aisles, coffee areas, meeting rooms

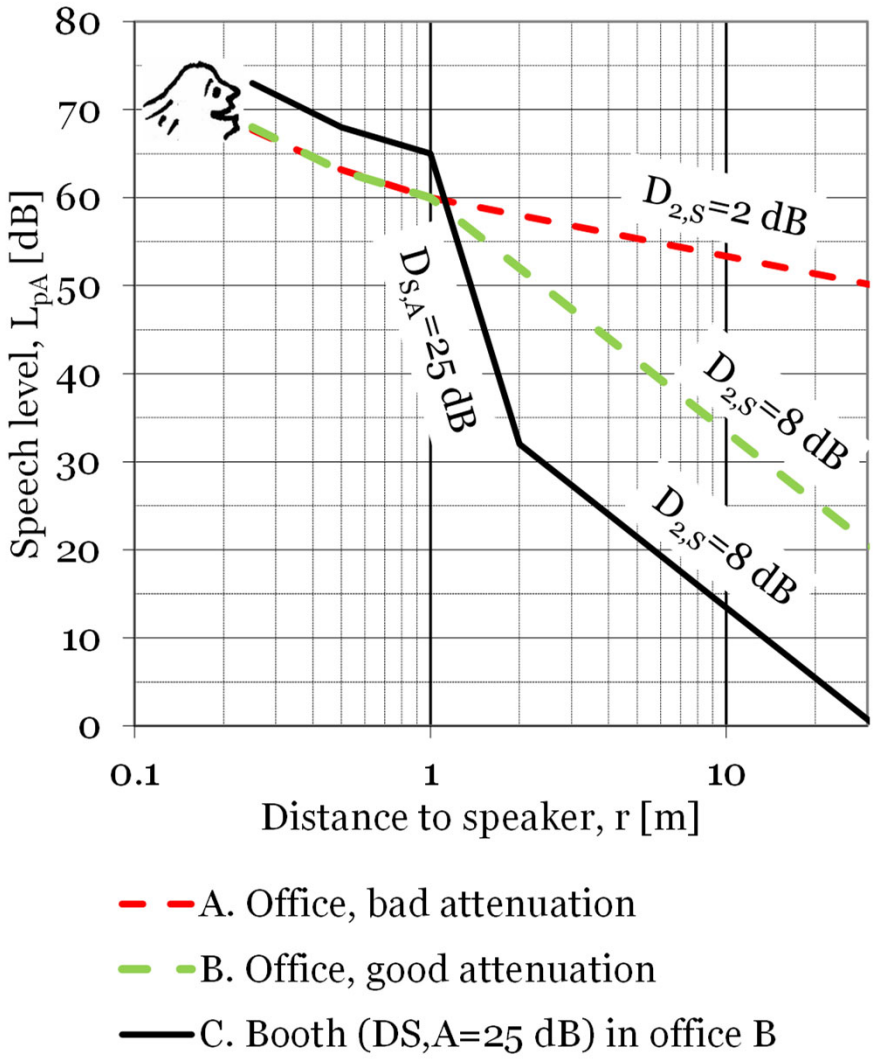
USER: ”Furniture & behavior”

- Acoustic screens and storage units
  - Height 130–170 cm
  - Sound absorption class B
- Sound isolating booths (pods)
  - Tested by ISO 23351-1
- Workstation distances > 2.5 m
- Sound-absorbing curtains
- Headsets
  - Headphones with microphone
  - Either closed or on-ear model
  - High quality means high utilization rate
- Team-level etiquette
  - Silent, communication zones

How to reduce STI in open offices?



- ISO 3382-3: room acoustics is good, if STI declines fast from speaker (small distraction distance)
- This is achieved by three simultaneous means:
  - Strong room absorption in ceiling & walls
  - High screens with sound-absorbing faces
  - Sound masking
- These means are inefficient close to speaker!
- **Office booths work at all distances from speaker!**







Why booths and not rooms?

Advantages over fixed rooms

- No construction work
- No municipality building permission needed
- Cheaper & faster to erect
- No landlord's permission needed
- Easy to sale further (recyclable)
- Flexible to move to other place
- Includes everything: electricity, furniture, reservation systems
- Can be purchased flexibly, according to needs and money

Applications, e.g.

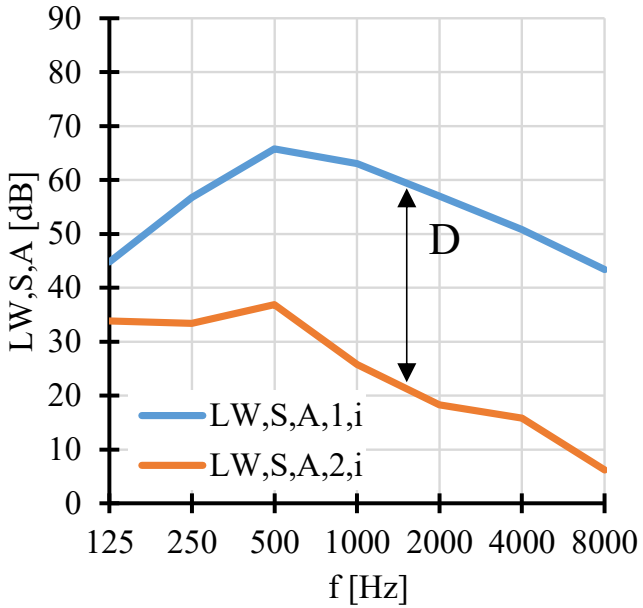
- Offices
- Schools
- Public spaces
- Health-care sector
- Studios
- Factories
- Outdoor café´s

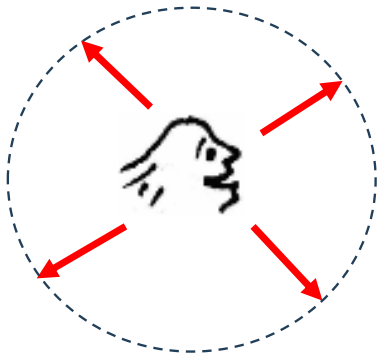




Speech level reduction, $D_{S,A}$

- It expresses how many decibels the A-weighted sound power level of speech is reduced
  - First, level reduction D is measured within 125 – 8000 Hz.
  - Thereafter, D is applied to standard speech and A-weighted
- $D_{S,A}$ values are reliably comparable between products and the trade becomes fair





Sound power level of a sound source

- describes the total radiated energy;
- is independent on test environment and source orientation

Sound power level of speech is 68 dBA

Sound pressure level is the same as sond power level at 28 cm distance from midpoint of the source

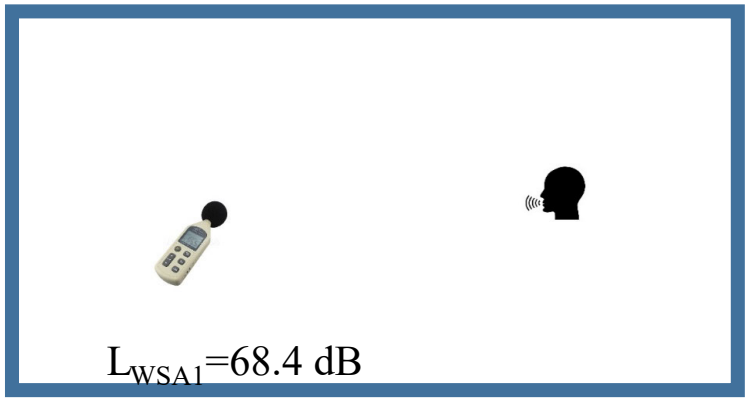
If speaker is inside a booth with $D_{S,A}$=30 dB, the sound power level reduces by 30 dB, and the sound pressure levels measured at all distances from the booth also reduce by 30 dB!

Principle of the lab test ISO 23351-1:2020

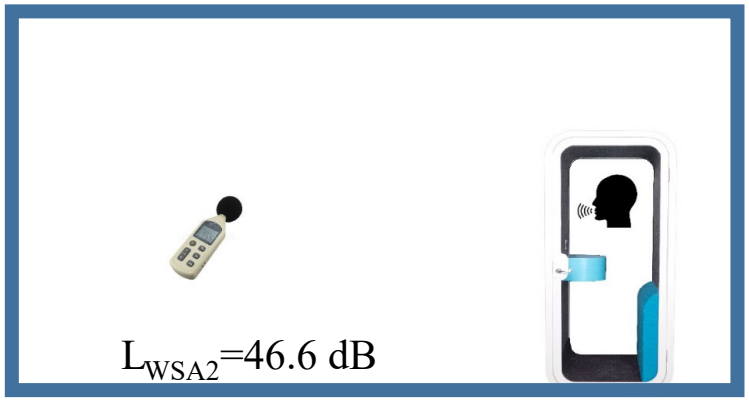
- Reverberation room is required
- ISO 3741 is applied to determine the sound power level in scenarios 1 and 2
- Measurement uncertainty is ±1 dB (Hongisto et al., 2026)
- Classification scheme is also available

EXAMPLE: a booth with $D_{S,A}$=21.8 dB

Scenario 1: Sound power level measurement of speaker alone



Scenario 2: Sound power level measurement of speaker inside test object



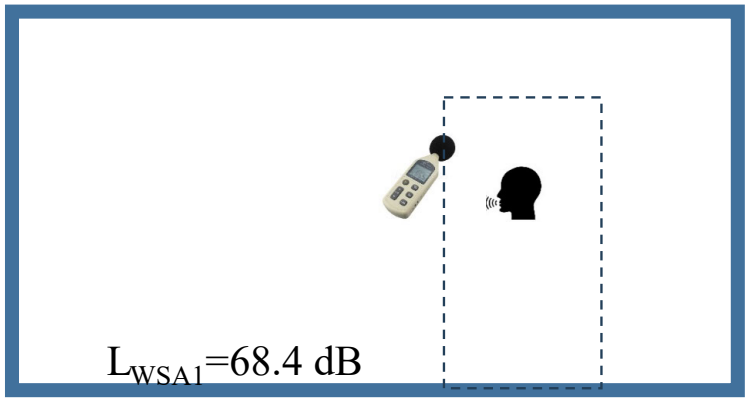
$D_{S,A}$ [dB]	Class
>33	A+
30-33	A
25-30	B
20-25	C
15-20	D
<15	unclassified

Principle of the field test ISO 23351-2:2026

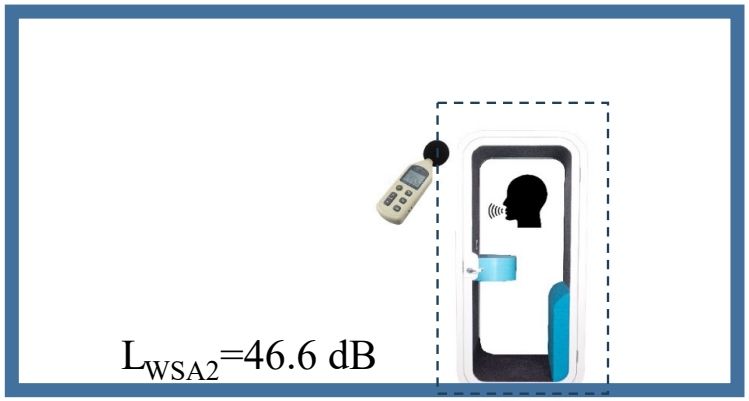
- Test can be conducted in any room which is so large that the distances from the test object to room boundaries exceed 1.5 m
- **ISO 3744** is applied to determine the sound power level in scenarios 1 and 2
- Measurement surface is located at 50 cm distance from envelope (scanning)
- Measurement uncertainty is ±1 dB (Hongisto et al., 2026)
- ABCD classification is not allowed

EXAMPLE: a booth with $D_{S,A}$=21.8 dB

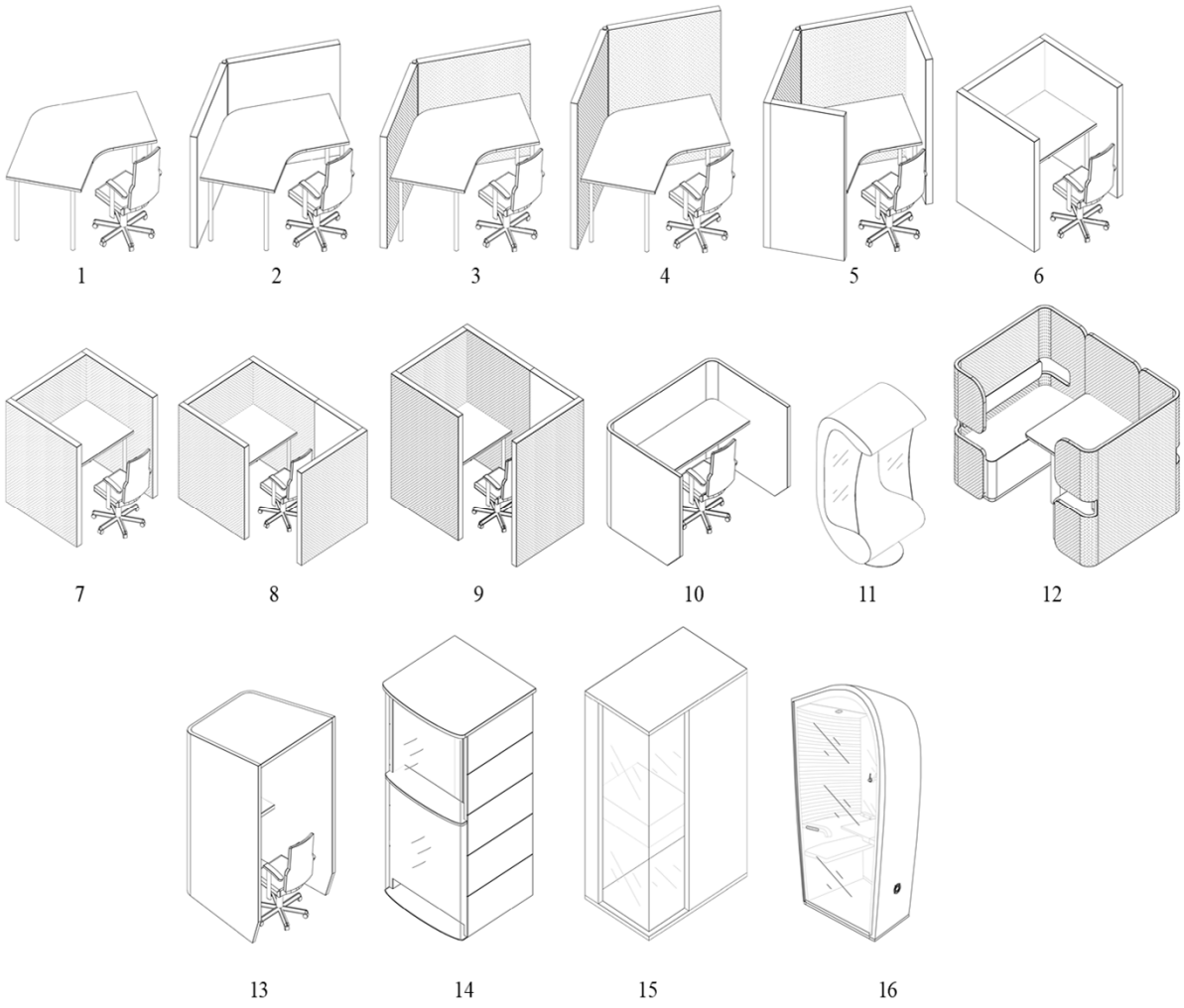
Scenario 1: Sound power level of speaker alone on surface S

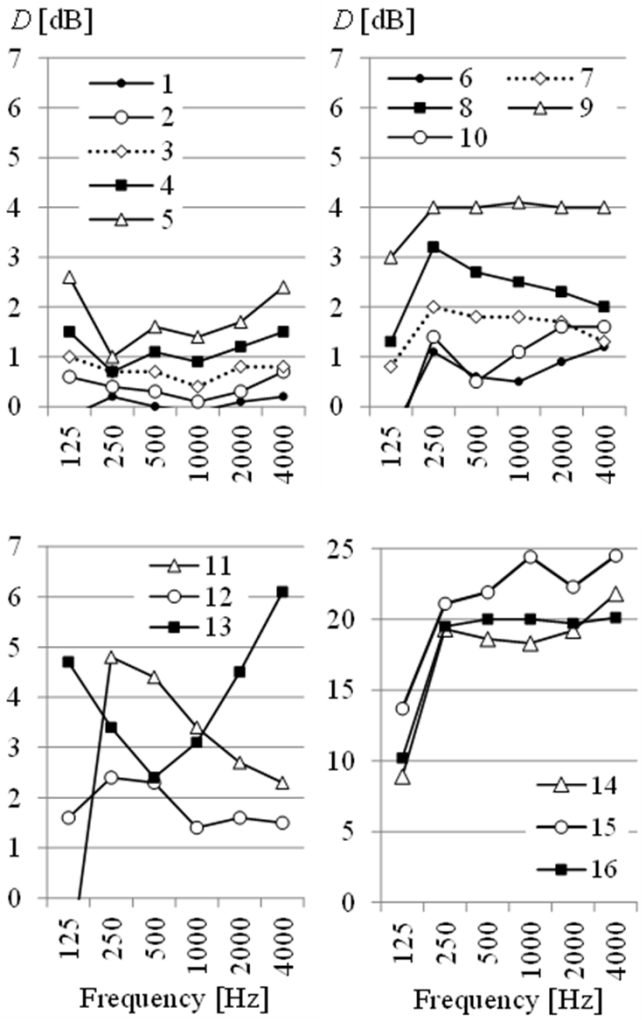


Scenario 2: Sound power level of speaker inside test object, on surface S



Examples of test results by ISO 23351-1





Specimen	$D_{S,A}$ [dB]
1	0.0
2	0.2
3	0.6
4	1.0
5	1.5
6	0.6
7	1.8
8	2.6
9	4.0
10	0.8
11	3.9
12	1.9
13	2.8
14	18.5
15	22.4
16	19.8

Hongisto et al. (2016) **Acta Acust Acust**

Survey of commercial booths

- Large differences were observed between products
- Products were available in all classes A-D

Booth	$D_{S,A}$ [dB]
A	30.3
B	28.3
C	26.4
D	26.0
E	24.9
F	23.4
G	19.3
H	18.9
I	18.6
J	17.0
K	15.0

$D_{S,A}$ [dB]	Class
>33	A+
30-33	A
25-30	B
20-25	C
15-20	D
<15	unclassified



Hongisto and Keränen (2020) **Res. Rep. Turku Univ. Appl. Sci.**

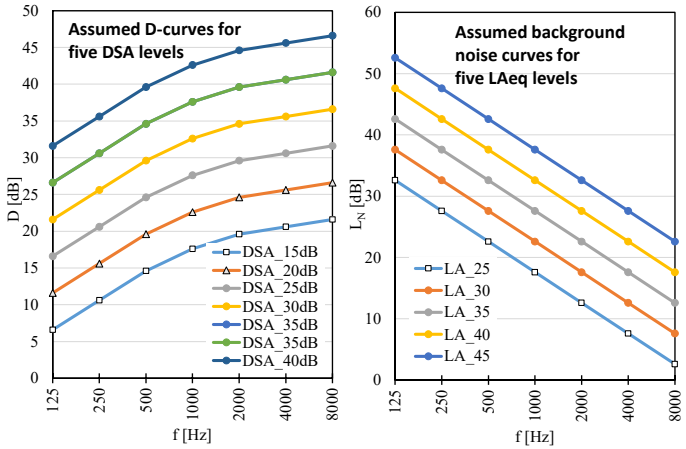
Which factors increase $D_{S,A}$?

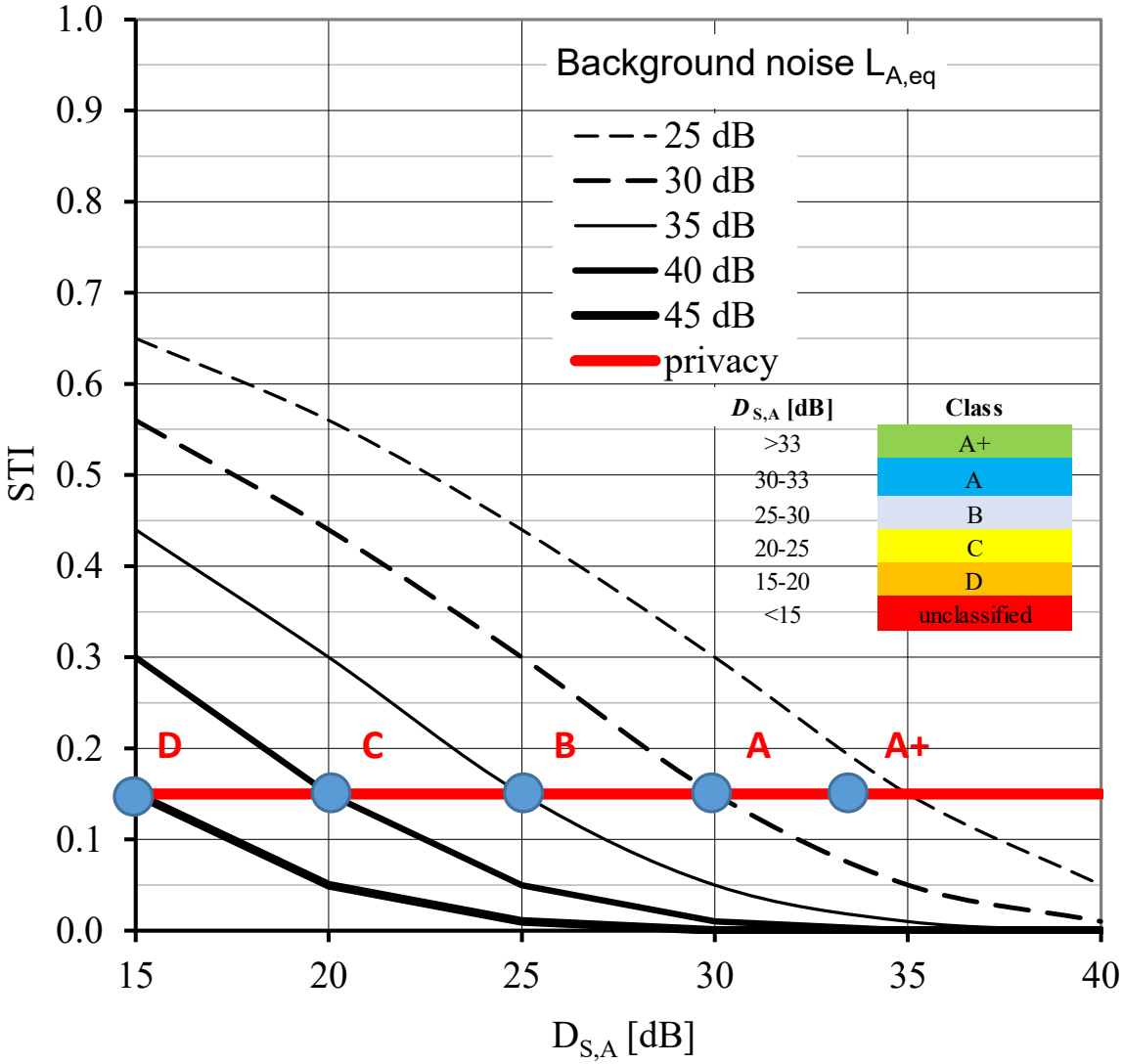
- 100% enclosed structure (no holes, ceiling)
- Air-tight sealing of door & junctions
- High sound reduction index of impervious panels (glazing, wall, ceiling, door leaf)
- Silenced ventilation inlets and outlets
- High sound absorption of interior surfaces
  - The effect on $D_{S,A}$ is even 15 dB!
- Positioning of interior absorbers
- Positioning and absorption of furniture

- Test result is only valid for the tested object with specified
  - Dimensions
  - Constructions
  - Absorbers
  - silencers, and
  - furniture
- Result are not applicable for another booth size of the same product family despite of similarities

Speech privacy depends on booth and background noise

- STI =0.15 means good speech privacy
- ISO 23351-1 classes are based on STI calculated under different background noise levels, L_{Aeq}
- Calculations assume that
  - listener is right behind the booth (1 m)
  - Frequency dependencies of D and background noise are “typical”





Why booths cannot be tested by airborne sound insulation?

- ISO 16283-1 and ISO 717-1 (R'_w, $D_{nT,w}$) are traditionally used for sound insulation tests in Europe between rooms
- Many consultants want to apply them for booths
- However, they are intended only for two nearby standard rooms sizing at least 8 m^2 (20 m^3)
- Mandatory requirements of ISO are always violated in rooms below 8 m^3 (most booths)
- $D_{nT,w}$ depends on measurement direction →
- R'_w did not depend on direction in this lobby accidentally but in most rooms it does!
- R'_w and $D_{nT,w}$ depend on room absorption, room size, absorption, microphone, loudspeaker positions
- R'_w and $D_{nT,w}$ are inequal
- Declarations are wild and not repeatable by others!

ISO 717-1 values measured for a booth ($D_{S,A}$=31 dB) located in a lobby

Measurement direction	$D_{nT,w}$ [dB]	R'_w [dB]
From booth to room outside	44	37
From room outside to booth	23	36

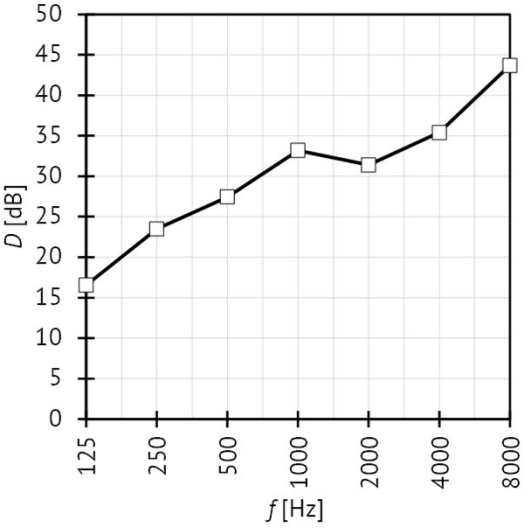
ISO 23351 test services in Turku

- Accredited test laboratory for ISO 23351-1
- Experience since 2013
- Testing of booths up to 15 m^3
- We also provide other associated services
  - consultation services for RDI
  - tests for absorbers, silencers, and elements
  - noise level tests of ventilation
- Price is customized for clients needs

- Booths larger than 15 m^3 must be tested by ISO 23351-2, it will be accredited in 2026
- Part 2 also allows to test in manufacturer's (RDI) and clients' premises (reclamations)

f [Hz]	*D* [dB]
125	16,6
250	23,5
500	27,5
1000	33,2
2000	31,4
4000	35,4
8000	43,7
$D_{s,A}$ [dB]	28,0
Class	B

f [Hz] is the 1/1-octave frequency band
D [dB] is the level reduction
$D_{s,A}$ [dB] is the speech level reduction



FINAS
Finnish Accreditation Service
T293 (EN ISO/IEC 17025)

Reijo Alakoivu
research engineer
test performer





The first psychological experiments on booth benefits

Psychological experiments on booth sound reduction on human outcomes

Experiment 1

- How the level reduction of irrelevant speech by class A booth affects human?
- Experimental conditions:
  - 1a: bare speech
  - 1b: speech attenuated by 30 dB (class A)

$D_{S,A}$ [dB]	Class
>33	A+
30-33	A
25-30	B
20-25	C
15-20	D
<15	unclassified

Experiment 2

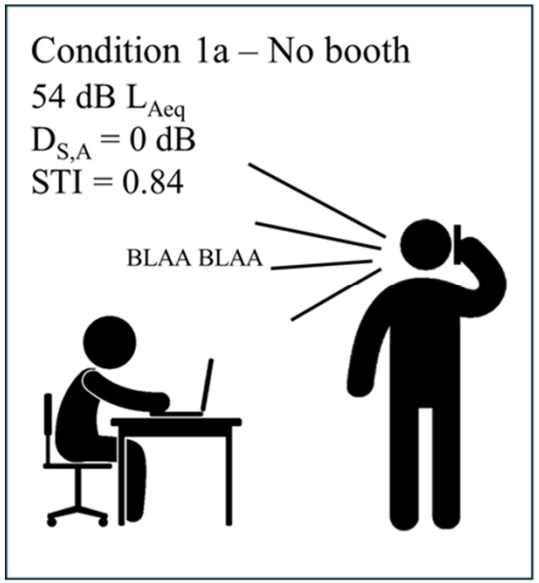
- Does the class matter?
- Experimental conditions:
  - 2a: speech attenuated by 23 dB (class C)
  - 2b: speech attenuated by 30 dB (class A)

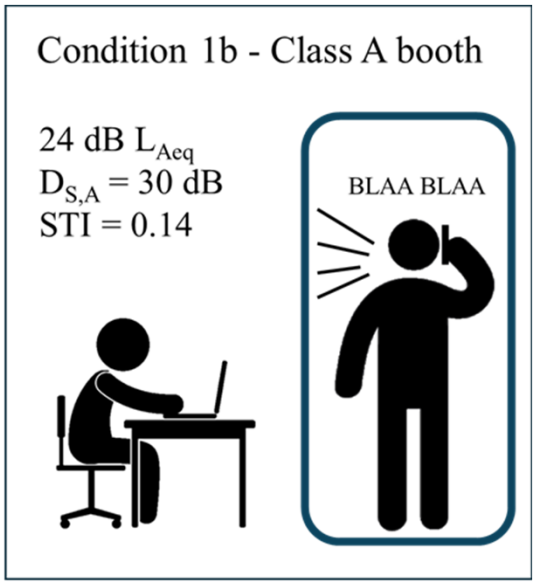
Methods in experiments 1 and 2

- Sounds were produced by headphones
- Speech was random sentences
- Background noise was 33 dB L_{Aeq}
- Exposure was 25 min per condition
- Number of participants was 40 in both

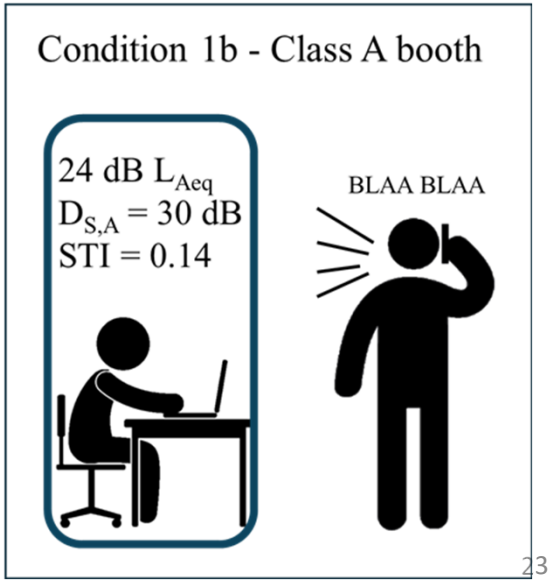
Experiment 1: Effect of class A booth

	Expt 1
OBJECTIVE WORK PERFORMANCE	
Visual serial recall accuracy	X
3-back accuracy	
SUBJECTIVE EXPERIENCE	
Task-related experiences	
Workload	X
Tiredness	
Lack of motivation	X
Lack of energy	
Acoustic experiences	
Annoyance of speech	X
Pleasantness of sound environment	X
Influence on work performance	X
Influence on attention	X
OBJECTIVE PHYSIOLOGICAL STRESS	
Heart rate variability - LF	X
Heart rate variability - HF	X
Heart rate variability - LF/HF	



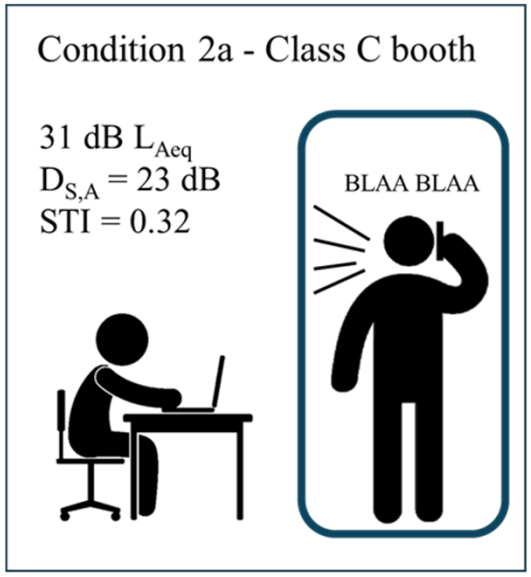


OR

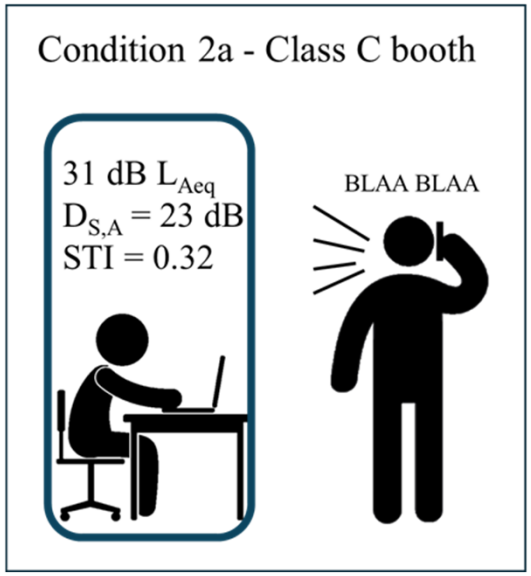


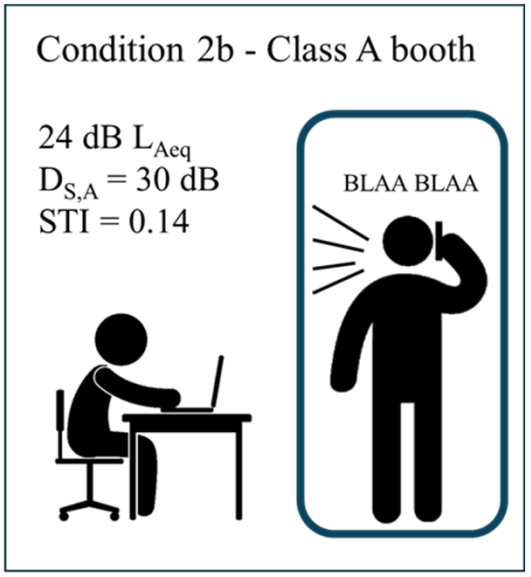
Experiment 2: Differences of class A and C booths

	Expt 2
OBJECTIVE WORK PERFORMANCE	
Visual serial recall accuracy	
3-back accuracy	X
SUBJECTIVE EXPERIENCE	
Task-related experiences	
Workload	X
Tiredness	
Lack of motivation	
Lack of energy	
Acoustic experiences	
Annoyance of speech	X
Pleasantness of sound environment	X
Influence on work performance	X
Influence on attention	X
OBJECTIVE PHYSIOLOGICAL STRESS	
Heart rate variability - LF	
Heart rate variability - HF	
Heart rate variability - LF/HF	

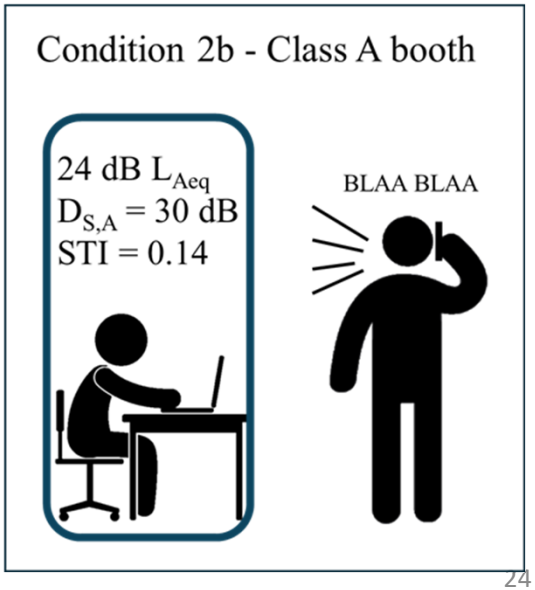


OR





OR



Conclusions

- **Experiment 1:** Reducing speech level by Class A improves the user experience and performance, while also lowering stress levels.
- **Experiment 2:** Upgrading level reduction from Class C to Class A improves employee experience and performance.
- Limitations of lab experiments are many:
  - Focused on a scenario involving a single, continuous speaker—the worst-case scenario.
  - Does not account for all other effects that booths have in an office environment.
  - Does not examine the benefits regarding speech privacy.
- Therefore, we did also a field study.

- Greater satisfaction
- Lower stress
- Better work efficiency

→ **Increased resources**



The first field study on booth benefits

Objective

- The aim was to study the effect of the addition of office booths on employees' experiences of the workspace and work

- A natural experiment - the workplace had an inherent problem with insufficient speech privacy
- Booths were chosen as the only means to solve the problem
- We monitored how the office change (addition of booths) affected employees using **quasi-longitudinal experimental design**

Study site



- Activity-based office Unit of Educational Services at the University of Oulu.
- Administrative staff (not researchers).
- 58 employees, 38 workstations
- Renovated in 2020.
- High-quality of indoor air and acoustics
- "A standard Finnish office"

Methods – Timeline of the study & change

Year	2023				2024				
Month	9	10	11	12	1	2	3	4	5
Surveys/Phase	1					2			3
Booth installation									
Booths fully in use									
Sound level measurement									
Indoor environment measurements *									

Survey respondents
- Phase 1: 49
- Phase 2: 42
- Phase 3: 32

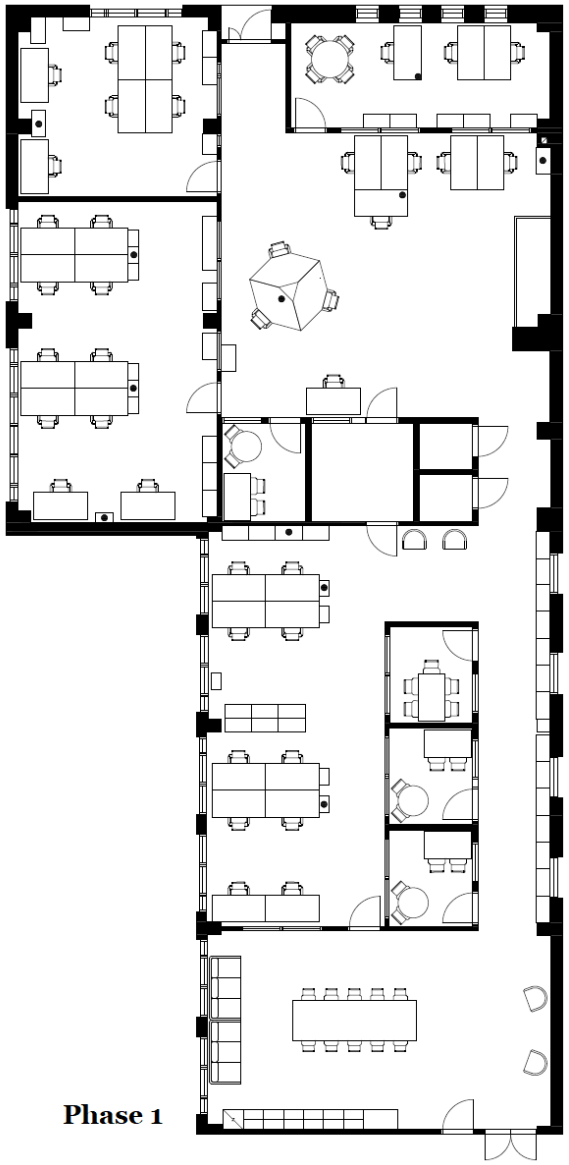
* Room acoustics, sound insulation, lighting, CO_2, temperature.

Methods – Office change

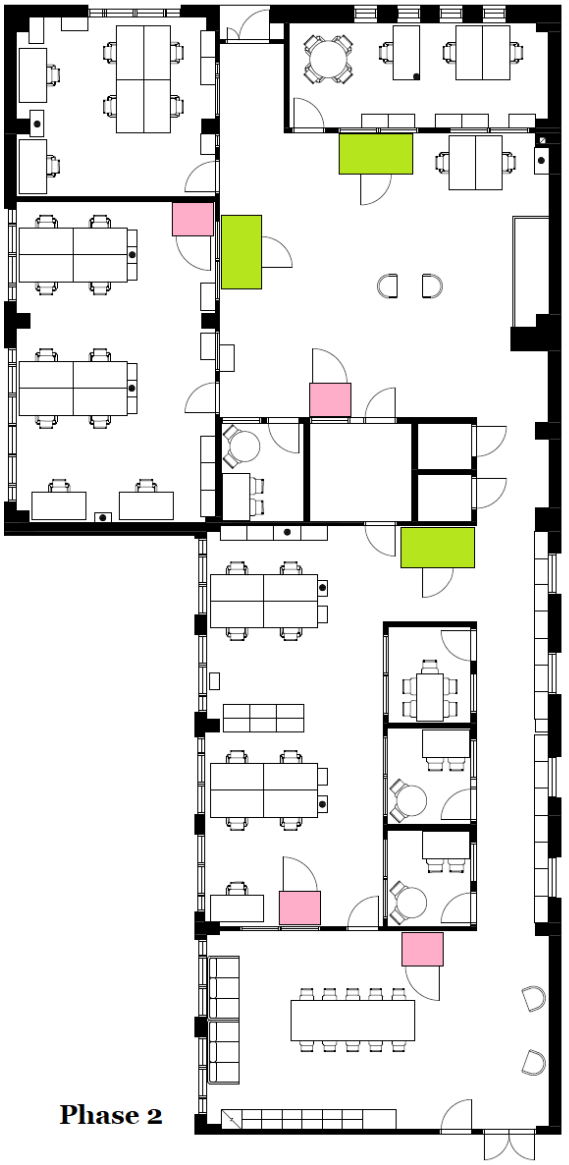
- **Before:**
  - 38 workstations
  - 5 retreat spaces
- **Change:**
  - 7 office booths added
    - 4 x phone booths of class A
    - 3 x meeting booths of class B
  - Some workstations were removed
- **After:**
  - 30 workstations
  - 11 retreat spaces







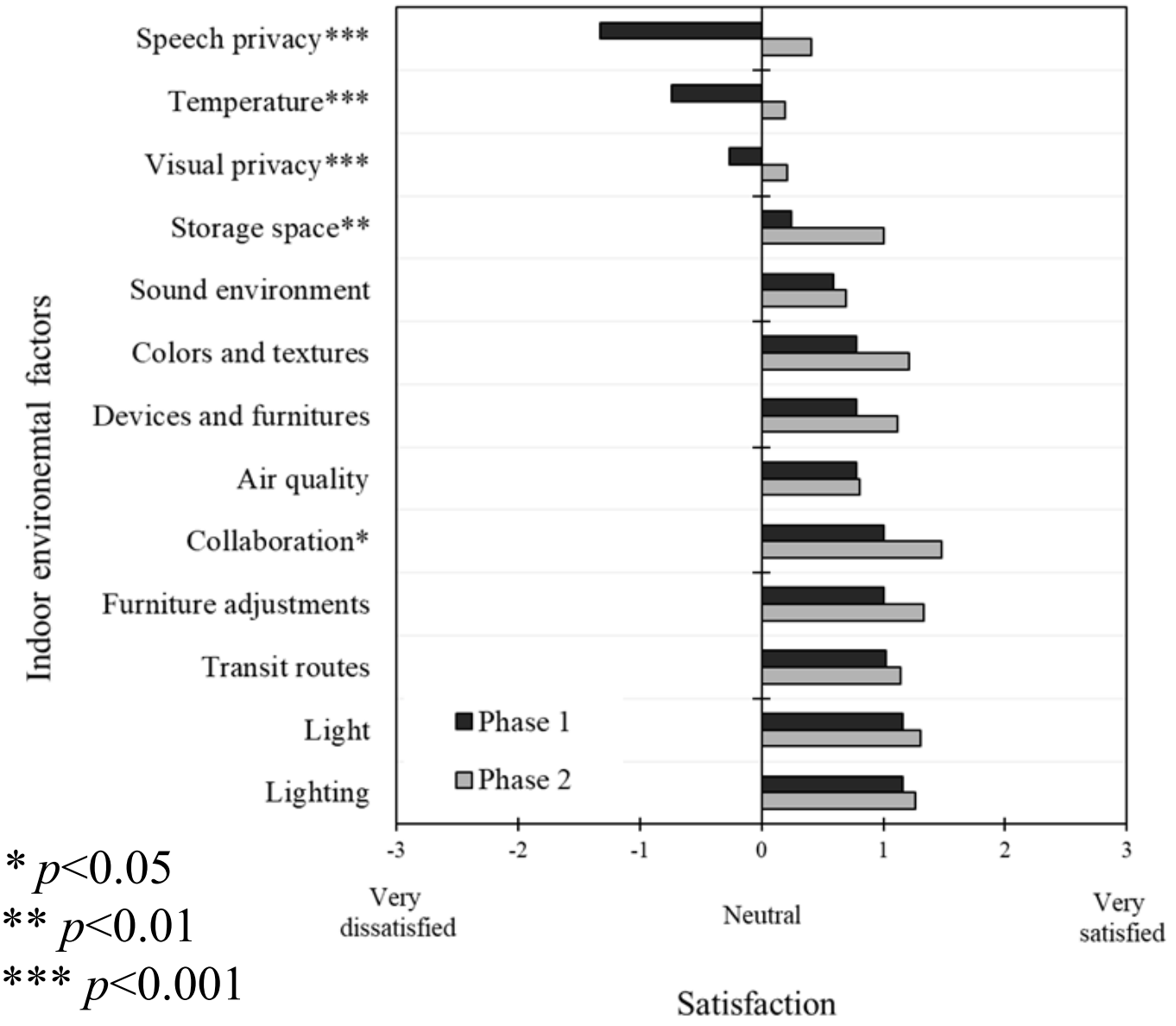
Phase 1



Phase 2

Results – Satisfaction with many indoor environmental factors improved

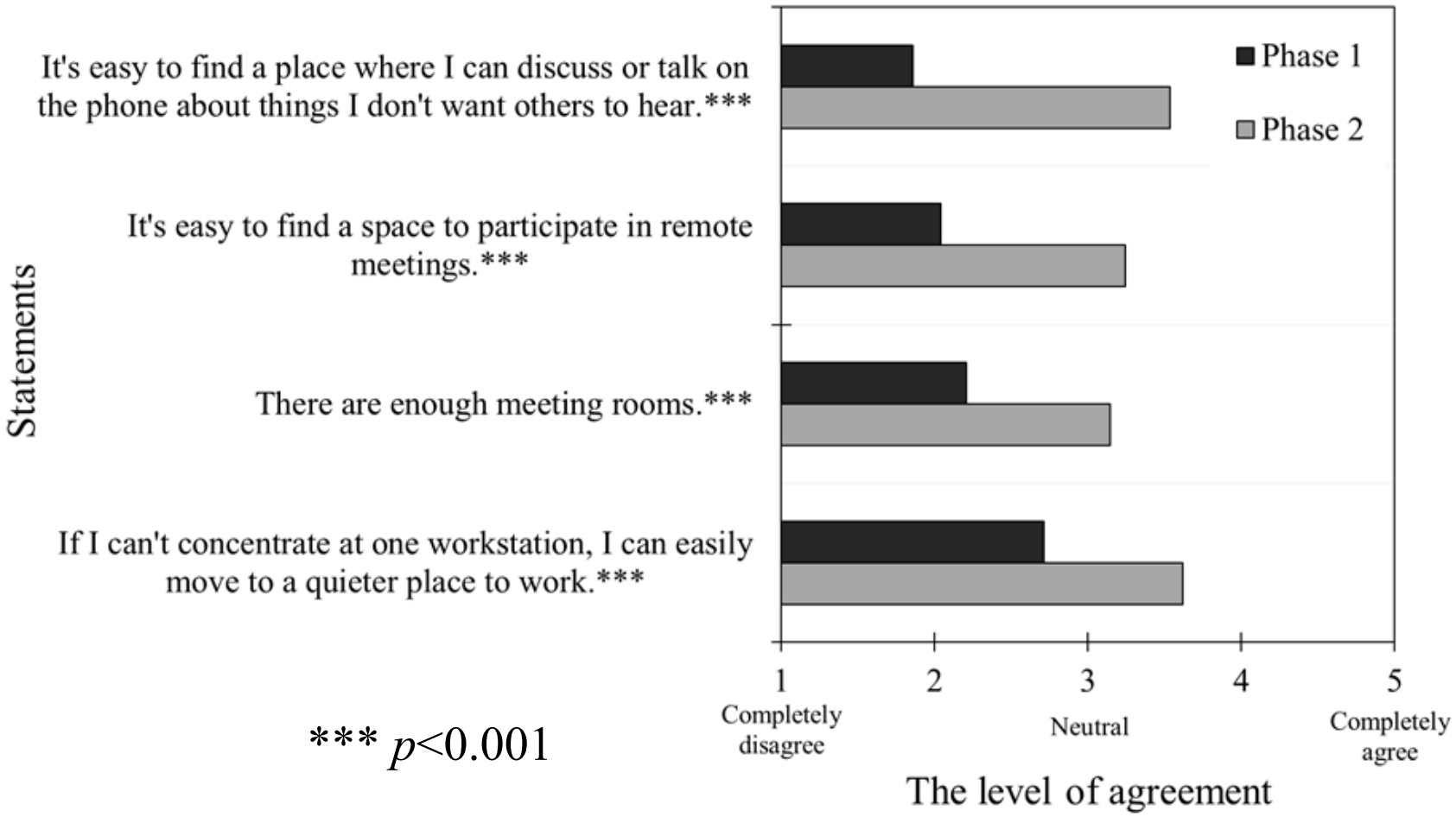
"How satisfied are you with the following factors in your workplace?"



* $p<0.05$
** $p<0.01$
*** $p<0.001$

Results - Availability of workspaces increased

"What do you think of the following statements about your workplace?"

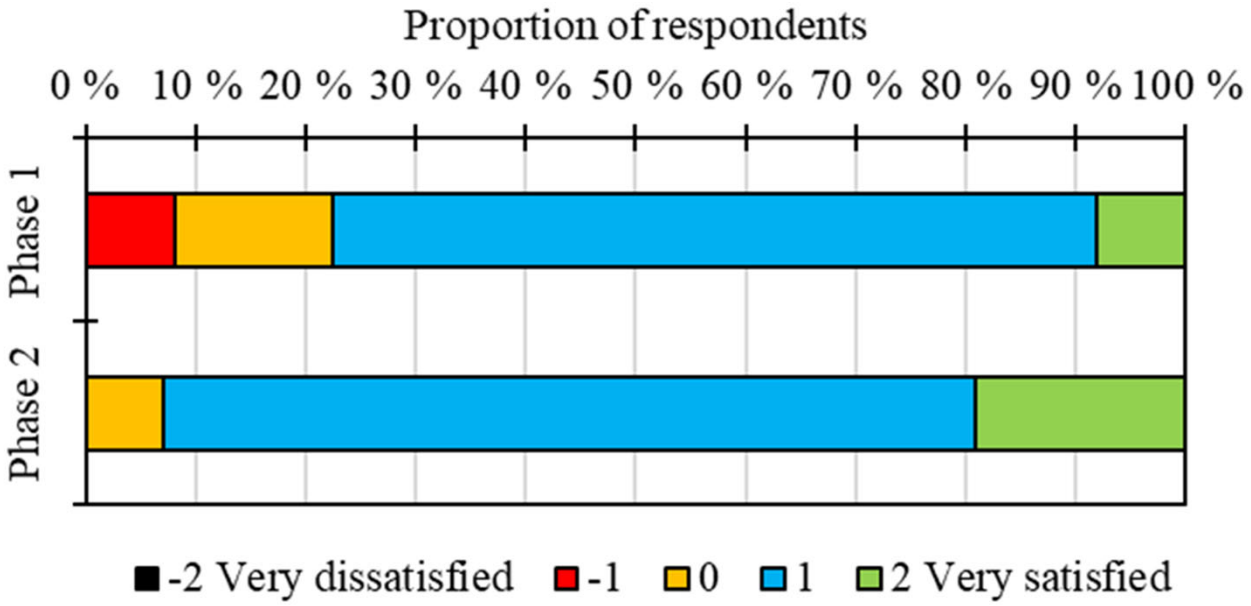


*** $p<0.001$

Results - Job Satisfaction

- Job satisfaction increased ($p<0.01$)
- Increment was permanent (Phases 2 and 3 equal)
- Small changes do not usually affect job satisfaction
- Now it happened since
  - booths solved the main problems in the office
  - employees felt that they had been listened (perceived control)
  - trust towards supervisors increased

"How satisfied you are with your job?"



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Presentation is available at:
https://akustiikka.turkuamk.fi/en/speech-level-reduction/

Thank you for your attention!
Q&A?

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29th October 2026