TECHNICAL SPECIFICATION

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Ergonomics of human-system interaction —

Part 620: The role of sound for users of interactive systems

Ergonomie de l'interaction homme-système —

Partie 620: Rôle du son pour les utilisateurs de systèmes interactifs

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Contents

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 4, *Ergonomics of human-system interaction*.

A list of all parts in the ISO 9241 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

In physics, sound is a vibration that propagates as an acoustic wave, through a transmission medium such as a gas, liquid or solid. In human physiology and psychology, sound is the reception of such waves and their perception by the brain. Unwanted sound is referred to as noise and is often perceived as the most serious disturbance factor at office workstations. In many industrial environments, sound can be a serious threat to health in general, not limited to auditory effects alone.

While sound is a measurable physical reality, acoustic noise is a psychoacoustical concept. The main goal of this document is minimizing the impact of noise while operating interactive systems, for example on the behaviour of users, their well-being and/or performance. This can be accomplished by technical measures, organizational means, interventions at the personal level and any combinations thereof.

The overall concept T-O-P (technical – organizational – personal) indicates the reasonable order of measures that can be taken to control the impact of the acoustic environment on human work. In this context, technical solutions have priority over organizational measures and personal protective equipment (PPE).

Psychoacoustics is the branch of psychophysics involving the scientific study of sound perception and audiology – how humans perceive various sounds. More specifically, it is the branch of science studying the psychological responses associated with sound (including noise, speech and music). This document deals with the undesired effects of sound, which can be classified as follows:

— impaired hearing;

— undesired responses of the central and autonomic nervous system;

— hindrance of verbal and other communication;

— reduced performance and cognitive functioning;

— annoyance.

Acoustic satisfaction of a space cannot be guaranteed without consideration of each of the three principle parameters of architectural acoustic design, formalized and established in the early 1900s by Sabine.[28] The three principle parameters are known as the 'ABCs' of architectural acoustics: A for absorption – Sufficient absorption in the built environment; B for blocking – Sufficient isolation of the built environment; and C for control – Control of sound levels in the built environment. For a given space, various measures in combinations can be taken to control the acoustic environment to achieve satisfaction. In ISO 9241-6 such measures are briefly listed and partly explained. Experience now suggests that a more thorough consideration of the acoustic environment is required because of the changes to work organization and tasks.

Controlling the acoustic environment is considered part of the T-O-P concept. It can comprise, for example:

— reducing the rating level

  — insulation in structural components;

  — reducing noise emission from equipment;

  — increasing sound absorption;

 — reducing the ambient noise level;

— optimizing the signal-to-noise ratio

 — reducing the sound level in speech frequencies;

— sound reduction within use environments

 — sound-absorbing ceilings;

 — partitions;

 — adequate distances between workstations;

 — reducing reverberation.

While all these measures are of a technical nature (T of the T-O-P principle, Figure 1), the impact of sound events on persons and work can require organizational measures, such as holding small meetings dedicated to certain tasks outside the workspace. The final argument comprises measures at a personal level, including training to cope with adverse environments.

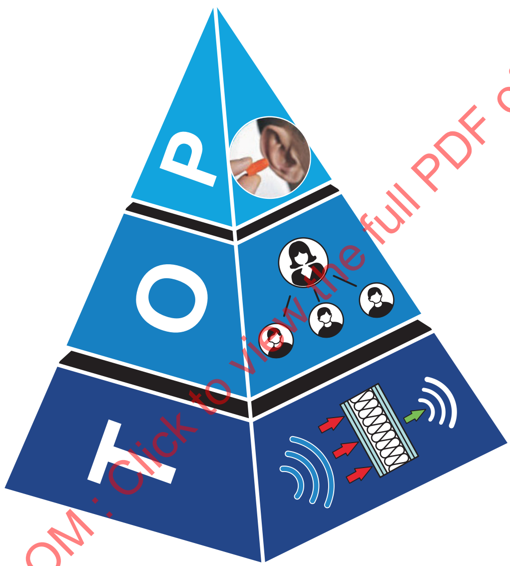


Figure 1 — T-O-P principle for controlling the impact of the acoustic environment on human work

Ergonomics of human-system interaction —

Part 620:
The role of sound for users of interactive systems

1 Scope

This document provides users with a summary of the existing knowledge about ergonomics considerations for the influence of sound in use environments on humans. It describes how unwanted effects of sound (noise) can be controlled. The main goals for controlling the acoustic use environment are reducing the rating level of sound in general, optimizing signal-to-noise ratio and sound reduction within the workspace.

This document also provides users with organizational measures that can be taken if and when technical measures do not help sufficiently. Also included are measures on a personal level.

This document deals with sound events that can cause extra-aural effects. Noise-induced hearing loss prevention and the ways to eliminate or reduce hazardous noise exposure are not covered by this document.

The intended users of this document include:

— developers of systems, products and services;

— public and corporate purchasers;

— occupational health and safety professionals;

— architects and interior designers;

— human resource professionals;

— usability, ergonomics or human factors professionals;

— users of interactive systems.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
irrelevant speech effect
ISE
negative effect of verbal sound level

3.2
rating level
L_{AR}
equivalent continuous A-weighted sound pressure level during a specified time interval plus adjustment for tonal character and impulsiveness

Note 1 to entry: ΔLT = 0 dB or 5 dB according to subjective assessments

where

Δ	is difference;
L	is level;
T	is tonal.

Note 2 to entry: Impulsiveness is specified only if the difference of the measured sound level with and without impulses exceeds 2 dB.

[SOURCE: ISO 9241-6:1999, 3.19, modified — Notes to entry replaced.]

3.3
background noise level
$L_{\mathrm{p,B}}$
A-weighted sound pressure level present at the workstation during working hours with people absent

Note 1 to entry: The A-weighted background noise level $L_{\mathrm{p,B}}$ is expressed in dB.

3.4
total noise sound pressure level
L_{NA}
sound pressure level that contains all noise components affecting the listener during use, such as noise generated by building systems, operating equipment or the audience, and which is determined at ear height for the area in which people are normally located

Note 1 to entry: The A-weighted total noise sound pressure level L_{NA} is expressed in decibels.

Note 2 to entry: If not otherwise specified, noise is determined according to DIN 45641 as the A-weighted equivalent continuous sound pressure level averaged over the time that is representative for the disturbance.

3.5
impulsive sound
sound with a rapid rise and decay of sound pressure level, lasting less than one second and causing an increase in the sound level of at least 6 dB(A)

3.6
reverberation time
T
time required for the sound pressure level in a room to decay by 60 dB once sound excitation has stopped

Note 1 to entry: The reverberation time is expressed in seconds.

3.7
speech transmission index
STI
metric ranging between 0 and 1 representing the transmission quality of speech with respect to intelligibility by a speech transmission channel

[SOURCE: IEC 60268-16:2020, 3.3]

Note 1 to entry: Speech transmission channel can also be the use environment.

3.8
sound pressure level
SPL
logarithmic measure of the effective pressure of a sound relative to a reference value

4 Sound and noise

4.1 How sound and noise impact users

Hearing (audition, auditory sense) is one of the five basic senses used by humans to perceive the physical environment, alongside sight (vision, visual sense), taste (gustation, gustatory sense), smell (olfaction, olfactory sense) and touch (somatosensation, somatosensory sense). Even if its sensor, the ear, seems to function independently from those of the other senses, they all function in concert. Sight and hearing, or those sensory aptitudes that can collect information from a distance (relatively speaking), are called far senses. Hearing is the only sense that can detect objects or events beyond the (optical) horizon.

Evolution has programmed human beings to be aware of sounds as possible sources of danger. The hearing as the far sense gives notice of things that cannot be seen but that could be important. It plays an alerting function. Even if this function is not needed in most use environments, it cannot be switched off or ignored. While the sense of sight is relatively inactive during sleep, hearing remains on. The alert function requires that hearing is almost non-directional compared with sight. It is possible to look away or even close the eyelids, watch certain objects while ignoring others, but there is no mechanism to ignore acoustic events.

The directionality of the human auditory system is limited to sound localization. The brain utilizes subtle differences in intensity, spectral and timing cues to allow sound sources to be localized. Thus, even if someone tries to ignore a certain acoustic event there will be a response. Although people tend to get used to noise exposure, the degree of habituation differs for individuals and is rarely complete.

Adverse effects of sound events can be of a different nature. The simplest effect is characterized as annoyance without further consideration of the genesis and aftermaths. Other effects can be of a physiological and/or psychological nature (see Table 1).

Table 1 — Classification of factors that affect individual annoyance with noise[15]

Factors that affect individual annoyance with noise	
Primary acoustic factors	Sound level
	Frequency
	Duration
Secondary acoustic factors	Spectral complexity
	Fluctuations in sound level
	Fluctuations in frequency
	Rise-time of the noise
	Localization of noise source
	Physiology
Non-acoustic factors	Adaptation and past experience
	How the listener’s activity affects annoyance
	Predictability of when a noise will occur
	Is the noise necessary?
	Individual differences and personality
SOURCE: Canadian Centre for Occupational Health and Safety (CCOHS). *Noise – Non-Auditory Effects.* Available from: https://www.ccohs.ca/oshanswers/phys_agents/non_auditory.html. Reproduced with the permission of CCOHS.	

Recent research supports earlier results regarding the association of ambient sound and heart rate with longitudinal data that demonstrate that the real-world ambient signal-to-noise ratios are associated with lowered heart rates, suggesting that sound conditions which reduce the auditory perceptual load and listening effort de-stress the human cardiovascular system.[16],[27]

If many people work together in close proximity, as is the case in multi-person offices, disturbances to activities and annoyance reactions from staff due to various environmental factors become particularly evident, in particular since working practices often require switching between communicative exchange and focused work.

The resulting annoyance reactions can occur in the following forms:

— disturbance component “annoyance”;

— impairments of well-being, irritation, tension, exhaustion;

— changed communication behaviour (withdrawal, avoiding interactions).

The most disturbing characteristics of speech-specific noise are the information content and the uncontrollability, whereas uncontrollability and unpredictability of the noise play a big role in the case of noises from office environments. Only approximately 30 % to 40 % of the annoyance effects resulting from noise can be explained by technical-acoustic factors. The predominant part originates from moderators of annoyance (see VDI 2569).

4.2 Types of sound events

The type of sound has a bearing on how it is to be measured, what type of sound-level meter setting should be used and what descriptors and other data should be presented.

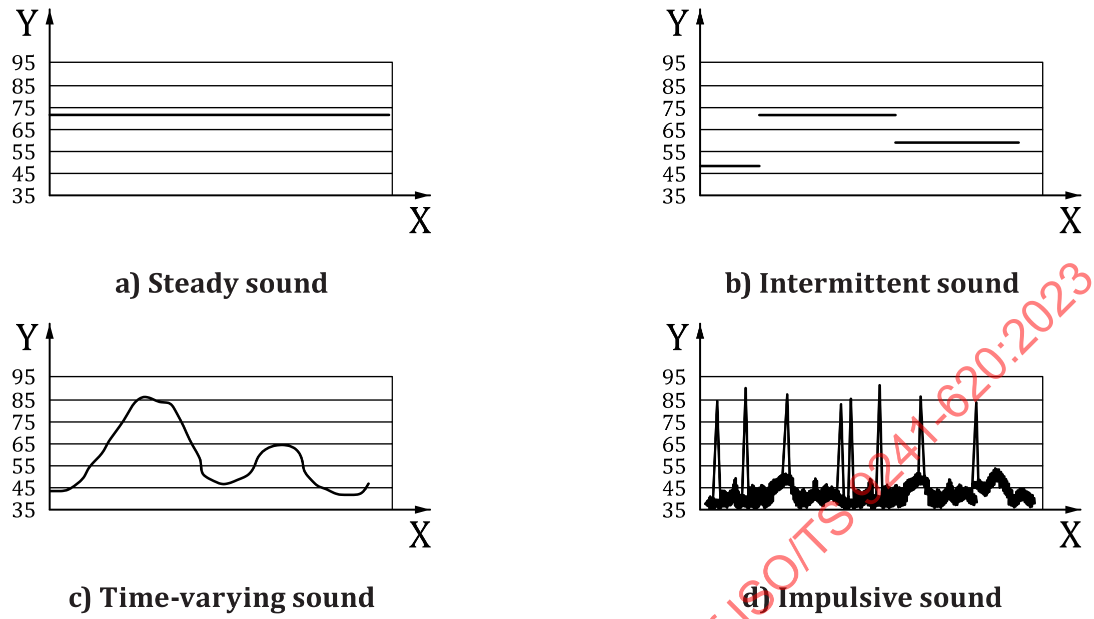
Sound events are generally classified into the following categories (Figure 2):

a) steady sound levels (e.g. air conditioning);

b) steady but intermittent sound levels (e.g. printers that print in bursts);

c) time-varying sound (e.g. traffic sound over a specific time period);

d) impulsive sound signals that can include one or more impulses (e.g. ringing telephones, high-impact printers).



Key

X time

Y sound pressure level, dB(A)

Figure 2 — Types of sound events

Sound level descriptors or metrics differ according to the type of sound events. Most metrics, for example A-weighted sound pressure level, have been developed for non-impulsive sound events. For characterizing impulsive sound levels, different methods are used.

4.3 Interference with the task

The impact of sound from sources other than speech is normally considered by its sound pressure level (L_{pA}) or the equivalent continuous A-weighted sound pressure level (L_{Aeq}). If the sound includes impulse noise, a certain margin is added to the level [e.g. +2 dB(A)].

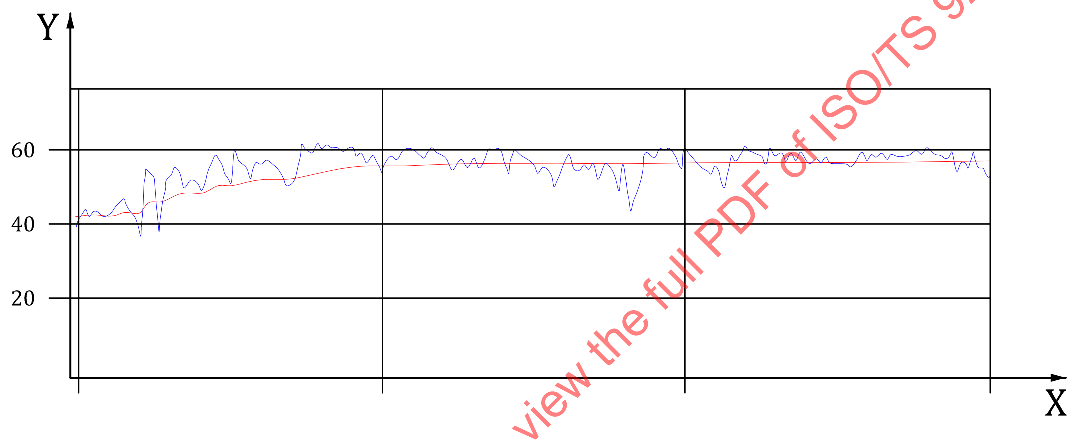
Speech sounds and speech-like sounds lead to losses of performance of the working memory. This effect does not necessitate the understanding of speech; an unknown foreign language or a musical piece can also have adverse effects. In this context, it is essential that the sounds are not mandatorily perceived as noise and that, despite focusing the attention on the material to be memorized, the irrelevant speech effect (ISE) can occur. This disturbing effect can already occur at A-weighted speech levels from 35 dB if they are clear speech signals.[30] The disturbing effect is due to the spectro-temporal structure of the speech or music sound, which results in this sound gaining access to the cognitive system (see VDI 2569)

The interference of speech with the user performance can be a result of the disturbing effect on the “inner speech”. Ambient noise can affect both reading and typing, because most users “speak to themselves” during these tasks. As for the mechanism for such effects, some research indicates that masking the relevant information with ambient sound is responsible.[28] The role of inner speech in human communication has been investigated (see Reference [20]). Inner speech, also called self-talk or internal monologue, is a person’s inner voice that provides a running verbal monologue of thoughts while they are conscious. Inner speech plays several crucial roles in reading.[18],[31] Reading is a complex process that involves the interaction of two levels of processing: decoding individual units and using text as a whole to establish broader meaning. Both can be affected by ambient sound, but the effect seems to be much stronger if the ambient sound is speech or speech-like.

The characteristics of sound events are very different for environments with "normal" noise sources, such as street noise or machine noise, than for those environments dominated by speech sound. While for the first the concept of a sound "level" can hold true (Figure 3), in the latter each sound event is separated from the others (Figure 4). In these studies, the base level without any work activity was 33 dB(A); single events were up to 65 dB(A) in the recorded session. The highest recorded level was 75 dB(A) with a speaker at a distance of 11 m. Whereas in acoustics, mostly a level of 65 dB(A) for normal speech in one meter from the speaker's mouth is assumed.

In real work environments, speakers can emit sound levels between 45 dB(A) and 75 dB(A) while telephoning, depending on the task and the quality of the sound transmission from the opposite side. In contrast to earlier landline phones, mobile networks do not guarantee a certain transmission quality. In addition, users do not speak in rooms with controlled acoustic conditions.

A "silent" train compartment in modern trains has noise levels beyond any recommended environments for acceptable telephone communication. However, those levels are still lower than those in cars or aeroplanes. While communicating with people in such environments, the speaker adjusts her or his speech level to a certain degree to the level of that noisy environment.



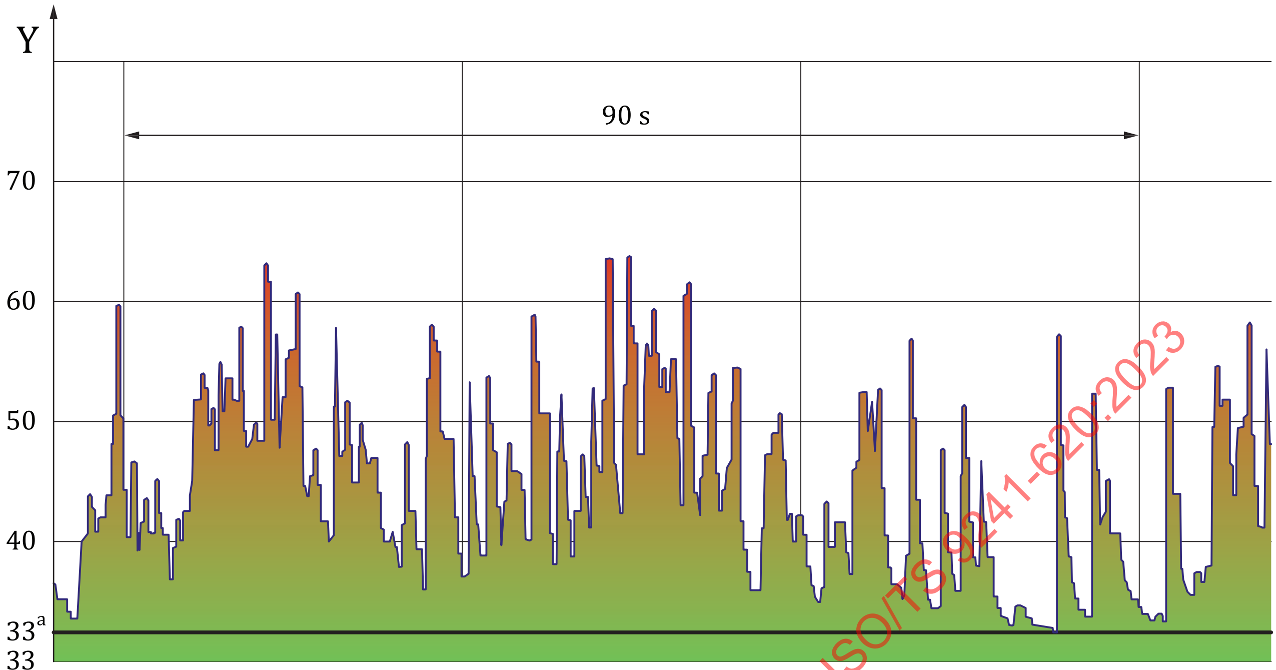
Key

X time

Y sound pressure level, dB(A)

NOTE The red line approximates the sound "level".

Figure 3 — Typical sound event with slow changes in the level



Key

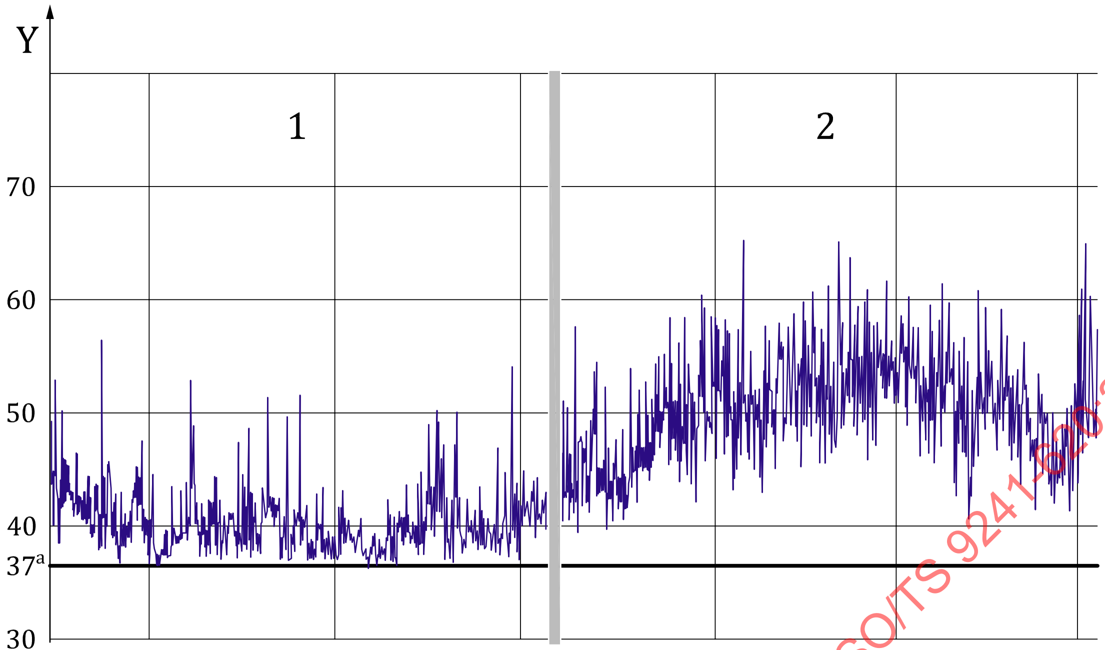
Y sound pressure level, dB(A)

[a] Base level = 33 dB(A).

NOTE The base level is the sound pressure level (SPL) with all users if they are inactive.

Figure 4 — Sound events in an office room within 90 seconds

In a given room with good acoustic conditions, the sound level can be 15 dB(A) higher if many people use a telephone (Figure 5).



Key

Y sound pressure level, dB(A)

1 regular office work with computers

2 office work with intensive telephone conversations

a Base level = 37 dB(A).

NOTE The base level is the SPL with all users if they are inactive. The events do not include ringing telephones.

Figure 5 — Acoustic events in a multi-person room according to type of work

Uncontrolled phoning can heavily interfere with the work of others. One of the mechanisms leading to this level of interference is the Lombard effect.

4.4 Lombard effect

The Lombard effect or Lombard reflex is the involuntary tendency of speakers to increase their vocal effort when speaking in loud noise (total noise sound pressure level) to enhance the audibility of their voice.[24] This change includes not only loudness but also other acoustic features such as pitch and rate and duration of sound syllables. This compensation effect results in an increase in the auditory signal-to-noise ratio of the speaker's spoken words.[33]

It is suggested[24] that the magnitude of the speakers' response to noise is likely to be governed by the desire to achieve intelligible communication, as in noisy conditions speakers would not change their voice level if talking to themselves.

Speech is often considered the primary communicative signal, but it is heavily integrated with signals from the face and body. Visual signals, including hand gestures, are integral to human communication and can play a particularly important role in noisy situations when verbal communication fails.[19]

In noisy environments, noise is not only associated with increased speech intensity but also with enhanced gesture kinematics. Acoustic modulation of the speech signal only occurs when gestures are not present, while gesture kinematic modulation occurs regardless of co-occurring speech. Thus, in face-to-face encounters, the Lombard effect is not constrained to speech but is a multimodal phenomenon where gestures carry most of the meaning[32]. This means that noise modifies the entire behaviour of the users.

4.5 Irrelevant speech effect (ISE)

In work environments such as open-plan offices, users communicate and interact with co-workers verbally, and an open-plan office layout is commonly assumed to facilitate communication and interaction between co-workers, promoting workplace satisfaction and teamwork effectiveness. The assumption reflects the main purpose for selecting such layouts. On the other hand, open-plan layouts are also widely acknowledged to be more disruptive due to uncontrollable noise. As an overall result, the benefits need to overweigh the negative effects.

While most sources of noise can be controlled effectively, human speech is not that easy to control because it is part of communication, although irrelevant to most users by definition.

The irrelevant speech effect (ISE) is the finding that serial recall performance is impaired under complex auditory backgrounds, such as speech, as compared to white noise or silence.[17] The effect refers to the degradation of serial recall when speech sounds are presented, even if the list items are presented visually. The sounds need not be a language the participant understands, nor even a real language; human speech sounds are sufficient to produce this effect. The ISE represents one of the best-investigated disruptions of short-term memory by sound events. Speech and tone are equally capable of disrupting short-term memory.[22]

Analyses of the objective effects of noise on human performance with respect to distribution, temporal stability and the precision of measurement to be attained demonstrate the importance of ISE. Irrelevant words can be disruptive to performance and the frequency of usage of the irrelevant words can affect the magnitude of such disruption.[14]

Both meaningful and meaningless speech disrupts the comprehensive aspect of the task, but the effect of the meaningful speech is significantly greater. Both rehearsal and semantic processing, which are involved in reading comprehension, seem to be susceptible to disruption by irrelevant meaningful speech.[26] Proofreading is disrupted by ISE. The deleterious effects of irrelevant speech depends on the speech being meaningful.[21]

In contrast to intended listening, where familiarity with an attended speaker's voice improves speech comprehension, experiments show that familiarity with an ignored speaker disrupts working memory for target speech.[23] This means that, for work environments, disruption by colleagues' (irrelevant) speech is considered to be higher.

4.6 The importance of the concept of T-O-P

While in private environments the users can select any measures to reduce the annoyance through noise arbitrarily, in organizational contexts other considerations apply. The rationale behind the concept of T-O-P lies in the experience that avoiding sound events that can be considered noise at the source causes fewer issues than fighting their impact. This rationale is in agreement with the principle "freedom from interference between task and environment" of ISO 9241-500.

Where the task at hand of a user can cause impairments or unwanted effects for others and/or the environment, avoiding its effects should begin with technical measures. Organizational measures require a change of the behaviour of others and should therefore be introduced as the next step, because any change in the behaviour of an organization can be the reason for further unwanted effects. Finally, changing the personal behaviour of the user or equipping her or him with, for example, PPE, is the final resort for different reasons but can be necessary under certain circumstances. Giving collective protective measures priority over individual protective measures is a well-established principle in the health and safety domain.

The organizational and personal contributions for noise reduction are indispensable but are not dealt with in technical standards, mostly because organizational measures and changes of personal behaviour are out of scope for them.

5 Measures to control the impact of sound events

5.1 Overview

In ISO 9241-6, space organization and workplace layout are described as the starting point for an acceptable environment (Figure 6). All named aspects, including “artificial and natural light”, can contribute to successfully control the acoustic environment.

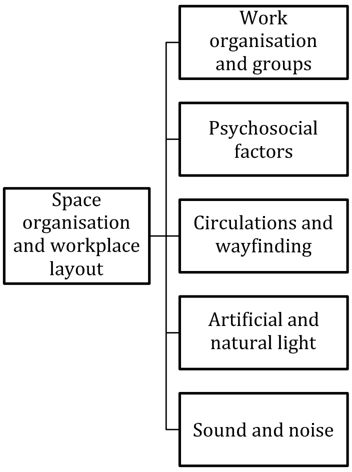


Figure 6 — Space organization and workplace layout as important parameters

A direct contribution is given for “circulations and wayfinding”, for example by avoiding groups and persons moving through work environments with verbal communication. (Type of measure: technical and organizational.)

An appropriate organization of the work, for example the introduction of “silent hours” with no phone use or similar, can help reduce annoyance from sound events. (Type of measure: organizational.)

“Psychosocial factors”, such as respect for the other colleagues’ requirements or learning appropriate speech technologies, usually help more than most technical measures that are feasible. (Type of measure: organizational and/or personal).

Luminaires for artificial lighting can emit noise or enhance noise propagation through the use of hard materials, such as acrylic glass, but can also help reduce annoyance through features such as soft fabric diffusers. Windows are of acoustically hard material (glass) and influence the acoustic environment substantially. If they are also utilized for ventilation, their impact is beyond any acoustic measure. (Type of measure: technical)

For a general strategy to control noise at workplaces containing machinery, ISO 11690-1 includes detailed information.

5.2 Controlling sound and noise

5.2.1 General

The control of the acoustic environment is by far the most complex task for the design of work environments. The main reasons are the conflicting requirements associated with the use of sound for communication (aural interaction) and the impact of acoustic interventions on the other environmental factors.

In rooms dedicated to a single purpose, such as reading rooms of libraries or lecture halls, effective measures can be taken in consideration of the task. In reading rooms, the environment is designed to keep any distraction as low as possible, whereas in lecture halls the propagation of the sound from the speaker to the audience is the ultimate goal. To achieve the goals for such environments, suitable technical measures are usually taken during the planning of the building. Even then, all involved persons' behaviour needs to be controlled.

Use environments are more or less a general purpose space. People in that space do not only perform their tasks. While performing their tasks they emit sound that can be meaningless to others and thus can be considered noise regardless of its level. However, it can also be relevant depending on its content, for example a colleague's phone conversation that has some personal relevance. In the immediate use environment of teams, there will always be intended verbal communication (information), partly interesting communication (information or noise) and noise, i.e. speech without any relevance for a person or group.

The transmission ability of a room or a communication path for speech can be measured through its physical characteristics [speech transmission index (STI)]. STI is a well-established objective measurement predictor of how the characteristics of the transmission path affect speech intelligibility. However, STI depends on various factors such as speech level, background noise level, echoes in the room, reverberation time and masking effects and a variety of technical features of the technical equipment if it is part of the transmission path (see Figure 11). In a general purpose space, a high quality of speech transmission does not form the ultimate goal for all tasks and users. In many respects, a control of the acoustic environment to inhibit the intelligibility of speech can be of higher value.

The control of the acoustic environment requires first an analysis to determine the best trade-off between the achievable benefits and the efforts and disadvantages of a direct or indirect nature. This task requires holistic thinking and acting, because a certain benefit (e.g. better intelligibility of speech) could require measures (e.g. acoustic screens between co-workers) that can impact the work detrimentally but also the intelligibility of speech, because one cannot see the speaker any more.

According to ISO 9241-6, measures to control the acoustic environment can be grouped into three groups of goals (see ISO 9241-6:1999, Figure B1):

— reducing the rating level;

— optimizing signal-to-sound ratio (control of the intelligibility of speech);

— sound reduction within workrooms or immediate environments of workstations.

5.2.2 Reducing the rating level

This group of measures aims at lowering the overall sound level. The rating level (L_{AR}) is the characteristic value for noise emission. The rating level is determined for a specified time interval (see ISO 1996, ISO 9612, ISO 11690). When determining the rating level, no account is taken of acoustic events which serve the purpose of communication between the person at the workplace in question with other persons (conversations, communication signals).

The equivalent continuous A-weighted sound pressure level (L_{Aeq}) is measured to represent a whole shift of 8 hours. L_{Aeq} is a common measurement used in industry to characterize noise levels in loud environments. It is less suitable to characterize the potential of annoyance by impulsive sound or time-varying sound.

Reducing noise emission from the equipment includes a variety of measures, such as silencing telephones or insulating printers. The most recommended intervention is noise control at the source, for example by using equipment with low emissions in the immediate environment.

The main descriptor of the noise emissions from information technology and telecommunication equipment is the A-weighted sound power level (L_{WA}). It is supplemented by another emission quantity, the A-weighted sound pressure (L_{Ap}) at the operator or bystander positions (ISO 7779).

The L_{Ap} at the operator position is relevant for the noise within the immediate environment, whereas L_{WA} helps describe disturbances to other workstations.

Both sets of data are declared according to ISO 9296 and can be found in the product data sheet or the product environmental data sheet.

In office environments, keyboards are among the noisiest equipment due to their use throughout the day. According to ISO 9241-410, the sound emission of keyboards can have three categories:

— C1: suitable for meeting rooms or tasks involving concentration [35 dB(A) to 45 dB(A)];

— C2: suitable for routine office work [45 dB(A) to 55 dB(A)];

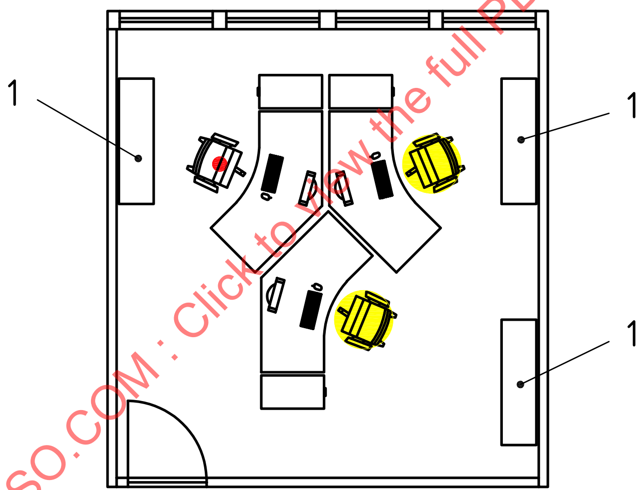
— C3: suitable for industrial workplaces [75 dB(A) to 80 dB(A)].

Selecting C1 is recommended. Since many products are not labelled, the products should be tested for their noise emission before purchasing.

For printers, there is a correlation between the printing speed and the sound emission because the main source is the movement of paper. Thus, purchasing a low-noise printer is not always a good option. For the frequent use of higher-speed printers, the device should either be moved to a separate room or an enclosure should be used. Most printers offer a silent mode, which should be used if possible.

Increasing sound absorption is a usual intervention and gives protection against noise from all sources. All equipment, room surfaces or furniture can be considered for this purpose. The cost involved and the achievable effects are rather different.

Two examples of this type of intervention are given in Figures 7 and 8.[34] The calculation of the efficiency of the measures is valid for a specified position in a workroom (Figure 7). The sound reduction lies between < 0,5 dB and 9 dB for the specified work position (Table 2). For the other work positions, the outcome is similar.



Key

1 Cabinet

SOURCE DGUV Information Akustik im Büro, VBG Hamburg, 2012-09.

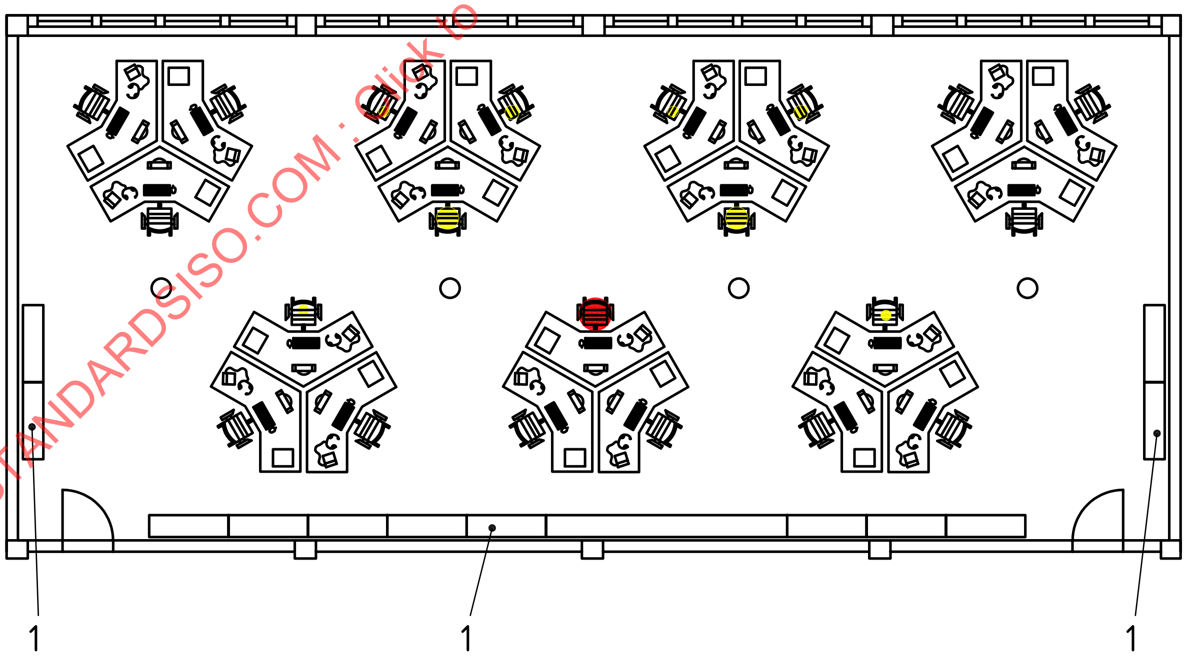
Figure 7 — Workroom and working position

Table 2 — Variants of acoustic interventions and the effects

Sound absorbing product	Variant										
	V0	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10
Carpet											
Absorbing ceiling											
Vertical slat blinds											
Absorbing walls											
Wall panel											
Cabinet fronts											
SPL in dB(A) at the specified workposition	62,8	57,8	62,2	58,9	62,2	60,0	57,5	55,9	55,7	53,8	56,5
Reverberation time in s 500 Hz 1 000 Hz	 1,5 1,0	 0,5 0,4	 1,3 0,9	 0,9 0,6	 1,3 0,9	 0,8 0,6	 0,5 0,4	 0,4 0,3	 0,4 0,3	 0,3 0,3	 0,6 0,4
Reduced SPL in dB(A) at the specified workposition	-	5,0	0,5	4,0	0,5	2,8	5,2	7,0	7,1	9,0	6,1

SOURCE: DGUV Information Akustik im Büro, VBG Hamburg, 2012-09.

The following example depicts a bigger room used for phone conversations, e.g. a call centre. An absorbing ceiling cannot be used because of the chilled ceiling. Instead, baffles can be used. The luminaires can be equipped with acoustic sails (Figure 8, Table 3). The lighting is installed over the workstations.



Key

1 Cabinets

SOURCE DGUV Information Akustik im Büro, VBG Hamburg, 2012-09.

Figure 8 — Multi-person workspace used for regular phone conversation

Table 3 — Variants of acoustic interventions and the effects

Sound absorbing product	Variant									
	V0	V3	V3.0.1	V5	V5.0.1	V5.0.2	V3.1	V5.1	V5.1.1	V5.1.2
Carpet wall-to-wall										
Absorbing walls										
Cabinet fronts										
Acoustic sails lighting										
Baffle ceiling										
Screens 1,20 m high										
SPL in dB(A) at the specified workposition	65,3	63,0	62,3	63,1	62,4	58,9	61,0 [a]	61,1 [a]	60,2 [a]	56,4 [a]
Reverberation time in s 500 Hz 1 000 Hz	2,3 1,4	1,3 0,8	1,1 0,7	1,3 1,0	1,1 0,8	0,5 0,4				
Reduced SPL in dB(A) at the specified workposition	-	3,3	4,0	3,2	3,9	7,4	5,2	5,2	6,1	9,9

[a] Estimated values

SOURCE: DGUV Information Akustik im Büro, VBG Hamburg, 2012-09.

Some elements of this intervention do not cause any negative effects (e.g. wall-to-wall carpet) while baffle ceilings require an additional height of the room. If this is not available, the room impression can suffer. Also, the air circulation in the room can suffer from the baffles, screens and sails. Absorbing walls and cabinet fronts limit the available colours for these surfaces. Once installed, the colours cannot be changed without removing parts of the surfaces. The screens inhibit visual contact between the workers. They also form an obstacle for the daylight. Usual forms of general lighting in regular rows would suffer somewhat when screens are used.

With most of the variants, a comfortable acoustic environment through the technical measures is not achieved. The room for which two different uses and the sound events are shown in Figure 5 can help to evaluate the acoustic environment: the rating level for the general office use would exceed the base level of 37 dB(A) only by about 4 dB(A) to 5 dB(A). If the task includes often telephone conversations, the sound level is increased to about 55 dB(A). Using the same space (Table 3) for tasks where phone conversations dominate will result in sound levels of 65 dB(A) (without intervention) that can be reduced by up to 10 dB(A) with a variety of interventions.

Sound insulation in structural components means that the structural components (walls, ceiling, windows) should be adequately insulated against structure- and airborne sound. Because of the differences in room sizes, activities and interior noise level (background noise level), the acoustic requirements to be met by the components can be adapted to the appropriate conditions (see Table 4) The requirements to be met by the sound insulation system can be selected in relation to the background sound.

Table 4 — Recommendations with regard to the sound insulation of structural components for various office tasks and background noise levels (without activities and equipment) which should not be exceeded

Type of activity	Acoustic recommendations insulation and restrictions	Type of room	Level of background noise L_{Aeq} dB(A)
Tasks with temporary concentration, tasks occasionally repetitive	Good noise insulation from neighbouring offices; very good verbal communication	Single office with normal user requirements	35 to 40
Tasks with temporary concentration, tasks occasionally mechanized	Good noise insulation from neighbouring work areas and adequate screening from neighbouring workplaces; good verbal communication	Multiple office with normal user requirements	35 to 45
Tasks largely mechanized	Adequate noise insulation from neighbouring work areas and low screening from neighbouring workplaces; limited confidentiality, good verbal communication	Multiple office with low user requirements	40 to 45
SOURCE: ISO 9241-6:1999, Table B.1.			

5.2.3 Reverberation time

The reverberation time is an important characteristic for any enclosed space. As can be seen from Table 2 and Table 3, any intervention will affect it. For reasons of good verbal communication and adequate “acoustic comfort”, the reverberation should be as low as possible. A reverberation time of 0,5 s to 1 s in the frequency range from 250 Hz to 4 kHz should be aimed for.

The maximum recommended reverberation time of a work environment depends on its volume. Table 5 sets out the maximum recommended times as a function of room volume, see ISO 9241-6.

Table 5 — Maximum reverberation time as a function of the room volume

Volume of room m^3	Maximum recommended reverberation time s	
	Conversational speech	General purpose
50	n.s.	n.s.
100	0,45	0,8
200	0,60	0,9
500	0,7	1,1
1 000	0,8	1,2
2 000	0,9	1,3

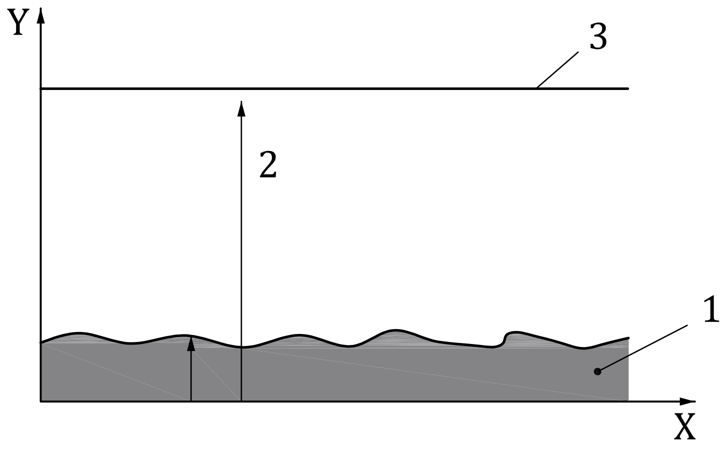
Key
n.s. not specified

5.3 Optimizing signal-to-noise ratio

5.3.1 General

The term signal-to-noise ratio is a concept from technical communication. The word "noise" in this context does not refer to acoustics only. The signal-to-noise ratio is a measure used in science and engineering that compares the level of the desired signal to the level of background noise. Signal-to-noise ratio is defined as the ratio of signal power to noise power, often expressed in decibels. A ratio higher than 1:1 (greater than 0 dB) indicates more signal than noise.

The concept behind the term is depicted in Figure 9. It means the ratio of relevant to irrelevant information in a communication channel (or an interface).



Key

X time

Y power

1 noise floor

2 signal-to-noise ratio

3 received signal

Figure 9 — Principle of signal-to-noise ratio

The primary goal of considering signal-to-noise ratio is to judge or improve speech intelligibility. In many cases, the opposite goal, reducing speech intelligibility, is relevant, for example in open space. The contributors to speech intelligibility in any given room are shown in Figure 10.

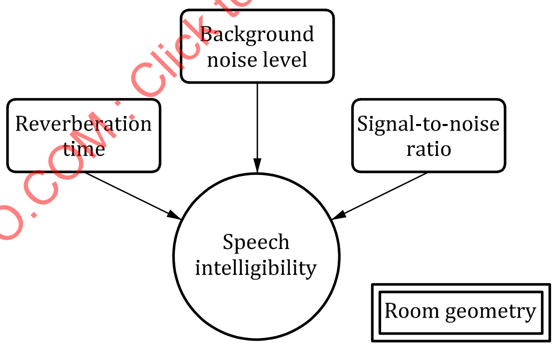
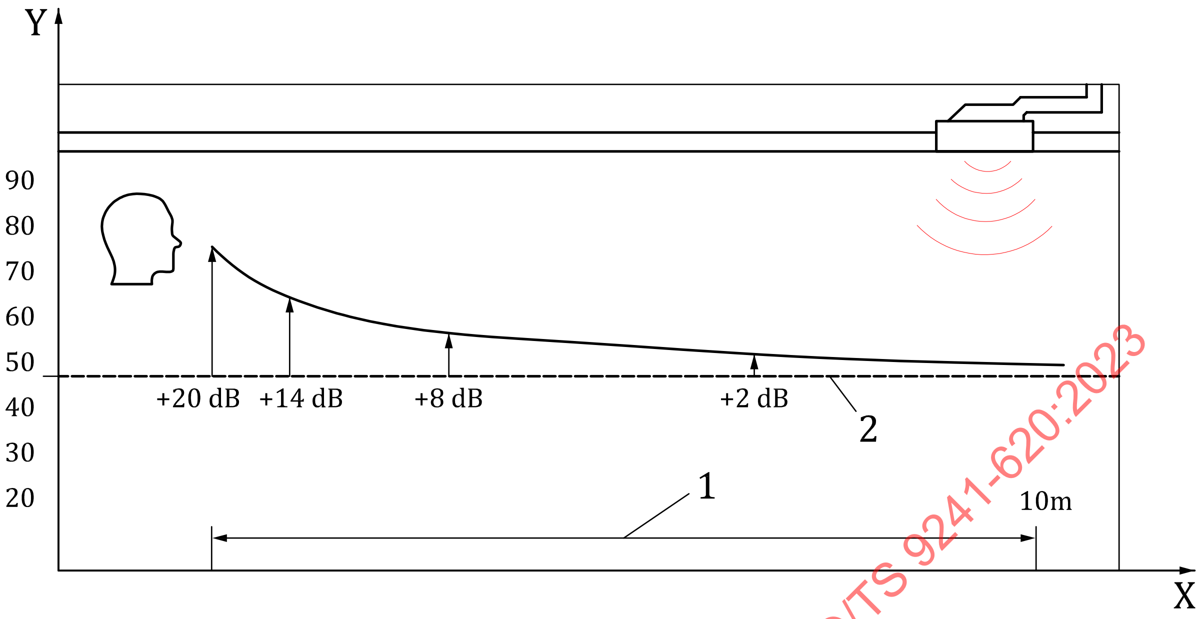


Figure 10 — Contributing factors to speech intelligibility

In a use environment with a noise level of 45 dB(A), a human voice with a level of 65 dB(A) (theoretical assumption) will have a signal-to-noise ratio of +20 dB(A) near to the speaker and 0 dB(A) at a distance of about 11 m (Figure 11).



Key

X distance

Y sound power level, dB(A)

1 distance from speaker

2 background noise level

Figure 11 — Signal-to-noise ratio for the human voice in rooms

5.3.2 Transmission paths for the voice in use environments

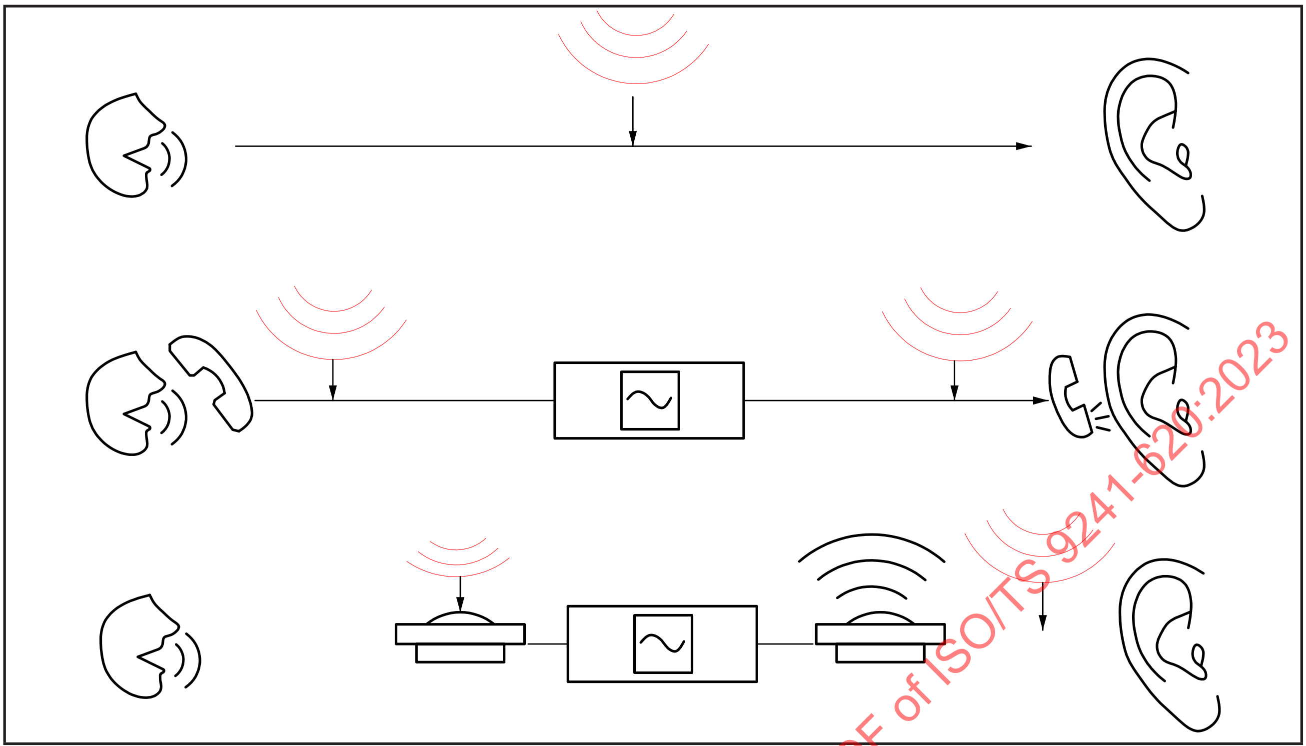
The speaker's voice as the desired signal can reach the target, the ear of the intended listener, through different paths. In face-to-face communication, the likeliest path is air. But communication within teams in bigger rooms (e.g. control rooms) can require the use of technical means, even if both partners can see each other.

In many professional environments, the communication partner is located in another space. Thus, technical means such as telephones, mobile phones or computer equipment need to be used. For meetings or conferences, other type of equipment is used, the input and the output devices of which are not located immediately at the speaker or the listener. Mobile phones used in vehicles are also located at some distance from the user.

This means that human speech can be affected in various ways before it reaches its target. Thus, the task of conveying information from a speaker to a listener has many more facets (Figure 12).

For a given room geometry, the signal-to-noise ratio, the background noise level and the reverberation time are the most relevant contributors.

The concept of signal-to-noise ratio is valid if the transmission path is air only. A more general view is given in Figure 12. While transmitting sound using technical means (Figure 12, middle), ambient sound can affect both ends even if the microphone is located closely to the source (conventional telephone handset, mobile phone, microphone of the headset) and the speaker is also closely located to the ear (conventional telephone handset, mobile phone, speaker of the headset). In many uses, the technical means to capture and reproduce speech are not or cannot be located near to the source or receiving end of a transmission path (Figure 11, bottom). Thus, the ambient sound can affect both ends. This is the case, for example, for conference systems or mobile phones used in cars.



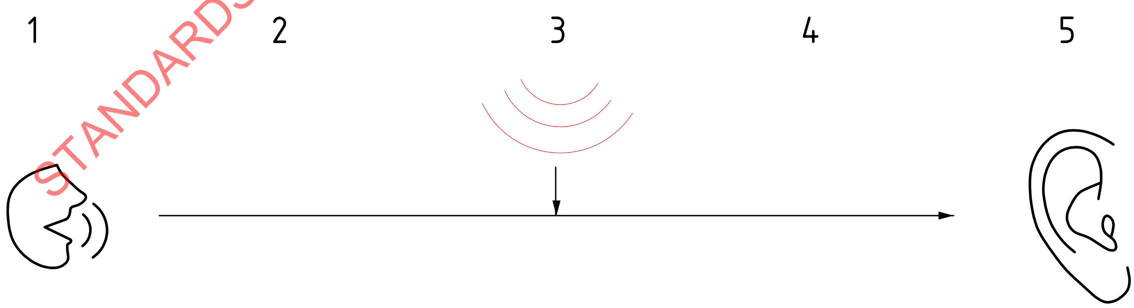
The simplest path is air between speaker and listener (top). For person-to-person conversations, ambient sound can affect the communication on both ends (middle) and the features of the technical equipment play a major role. A communication many-to-many with sensors and loudspeakers in some distance can be affected in various ways (bottom).

NOTE The figures given here for the transmission paths are indicative only and not technology-specific. Their main purpose is to illustrate the range of situations which could be encountered in different interactive systems, and thereby help to identify the best matching situation and select the corresponding recommended intervention solution.

Figure 12 — Transmission paths for human speech

5.3.3 How the communication is affected by unwanted sound

For the transmission path air, the factors in Figure 13 can contribute to the loss of intelligibility of human speech.



Key

1 Lombard effect, change of level, pitch, fundamental tone, voice type

2 room characteristics, reverberation, reflections, etc.

3 unwanted sound, ambient noise, etc.

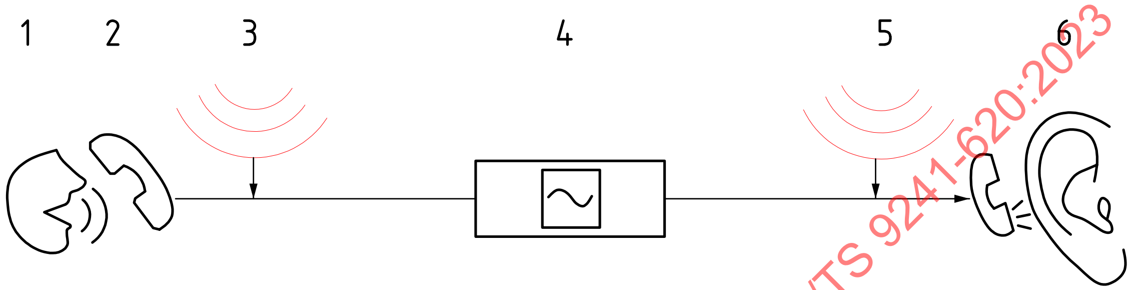
4 distance

5 hearing abilities

Figure 13 — Transmission path air

Interventions to improve the intelligibility of speech are possible at each point, with somewhat different success and using different means.

The communication using technical equipment can be affected at different points from the speaker to the listener (Figure 14). Interventions to improve the intelligibility of speech are possible at each point.



Key

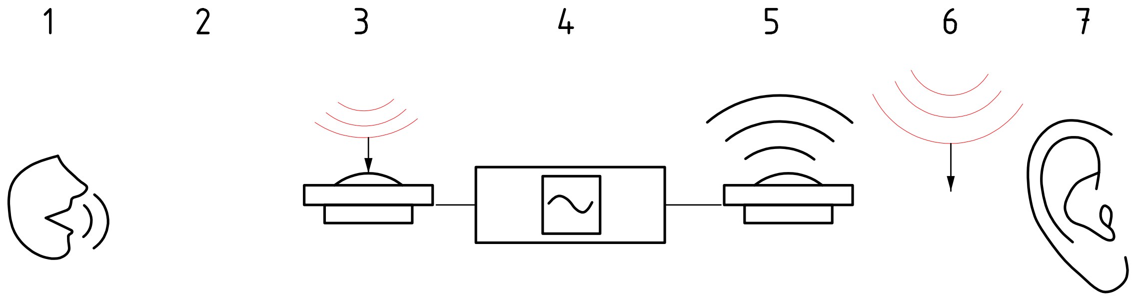
1 Lombard effect
2 characteristics of the microphone, feedback loop for speech
3 unwanted sound, ambient noise, etc. at the source
4 characteristics of the transmission channel (e.g. bandwidth, signal-to-noise ratio, distortions)
5 unwanted sound, ambient noise, etc. at the receiving end
6 characteristics of the earphones, sound insulation, etc.

NOTE Interface elements can include telephones, headsets and mobile phones.

Figure 14 — Transmission path with interface elements near to the user

In use environments, there are different means with extremely different features, from a landline phone (commercial bandwidth 300 Hz to 3 400 Hz) with poor microphone and speaker acoustic quality to a headset capable of transmitting the entire range of speech frequencies, connected to a computer network for which that bandwidth is not a challenge. At the same time, the quality of the acoustic communication can fall well below that of landline phones of earlier times, at least temporarily when mobile equipment is used. In mobile networks, the user can lose control of the communication through different mechanisms.

An even more complex picture is given if the interfaces of the communication system are not located immediately at the mouth or the ear of the user, i.e. using mobile phones in vehicles or conference equipment, the interface of which serves many persons (Figure 15).



Key

1 Lombard effect
2 characteristics of the room (e.g. reverberation), distance to the speakers
3 unwanted sound, ambient noise, etc. at the source, characteristics of the microphone
4 characteristics of the transmission channel (e.g. bandwidth, signal-to-noise ratio, distortions)
5 characteristics of the loudspeaker, unwanted feedback loop, room characteristics
6 unwanted sound, ambient noise, etc. at the receiving end
7 distance to the interface

Figure 15 — Transmission path with distant interface elements on both ends

5.3.4 How to improve the intelligibility of speech

The intelligibility of human speech transmitted by air from a speaker to the ear of a listener (Figure 13) can be improved by applying the possibilities of intervention shown in Table 6.

Table 6 — Recommended interventions to improve the intelligibility of speech for direct communication

Item	Possible interventions
Technical	
Lombard effect	— Reduce ambient noise level (see Table 2 and Table 3) — Optimize reverberation time
Room characteristics	— Adjust the layout of the immediate environment
Unwanted sound	— Same as the Lombard effect — Reduce ambient sound selectively in consideration of speech intelligibility (frequency)
Distance	— Reduce distance between speaker and listener — If not possible, consider using another transmission path
Organizational	
Assignment of space	— Separate groups with different requirements in the acoustic environment (different space, activity-based assignment of space)
Assignment of time	— Separate those work periods with different requirements in the acoustic environment (different time, activity- based assignment of time slices)
Personal	
Training	— Offer voice and speech training
Behaviour	— Encourage mutual respect and understanding

For a technically mediated communication (e.g. telephone or equivalent means with interface elements close to the mouth and ear of the users, transmission path, Figure 14), a bigger variety of technical interventions exists (Table 7).

Table 7 — Recommended interventions to improve the intelligibility of speech for technically mediated communication

Item	Possible interventions
Technical	
Lombard effect	— Reduce ambient noise level (see Table 2 and Table 3) — Optimize reverberation time
Characteristics of the microphone	— Select noise-cancelling microphone — Reduce feedback from speech
Unwanted sound	— Same as the Lombard effect — Reduce ambient sound selectively in consideration of speech intelligibility (frequency)
Characteristics of the transmission channel	— Select wider bandwidth ("HD audio") — Select other codec, e.g. wideband (7 kHz), super wideband (14 kHz) or full bandwidth (20 kHz)
Unwanted sound at the receiving end	— Reduce ambient noise level — Reduce ambient sound selectively in consideration of speech intelligibility (frequency)
Characteristics of the earphones, sound insulation	— Select wider bandwidth (7 kHz) or more — Select noise-cancelling equipment — Select better noise-attenuating equipment
Organizational	
Assignment of time	— Introduce "silent" time periods
Assignment of space	— Allow telephone use in a separate space
Personal	
Training	— Offer voice and speech training
Behaviour	— Encourage mutual respect and understanding

For a technically mediated communication with distant interface elements on both ends – goals and solutions (microphone, loudspeaker, Figure 15), different means can be used to improve the transmission path (Table 8).

Table 8 — Recommended interventions to improve the intelligibility of speech for technically mediated communication with distant interface elements

Item	Possible interventions
Technical	
Lombard effect	— Reduce ambient noise level (see Table 2 and Table 3) — Optimize reverberation time
Characteristics of the room (e.g. reverberation), distance from the speakers	— Same as the Lombard effect — Change distance from the speakers