The Acoustics of places for social gatherings

Jens Holger Rindel
Multiconsult AS, Oslo, Norway

Summary

A well-known but also very complicated problem in room acoustics is the ambient noise when many people are gathered for a reception or in a restaurant, a bar, a canteen or a similar place. In such social gatherings people want to speak with each other, but for the same reason the place can be very noisy, and verbal communication can be difficult or even impossible, especially for people with reduced hearing capacity. A general observation says that the noise depends on at least the following parameters; the volume, the reverberation time, the number of people, and the type gathering. Other parameters to consider include background music, and consumption of alcohol. Verbal communication in a noisy environment has been studied and this led to the introduction of the concept 'Acoustic Capacity' of a facility, defined as the maximum number of persons in order to avoid insufficient quality of verbal communication. The influence of background music and the influence of noise level on the consumption of alcohol and on the taste of food is discussed. The new concept, the acoustic capacity of a room, has proven to be well understood by architects and other non-acousticians – much better than the reverberation time or the sound pressure level. However, in order to avoid poor acoustics in restaurants and similar places, it is necessary to design with bigger volume and more absorption material than usual in current practice.

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1. Introduction

Noise from people speaking in restaurants and at social gatherings in closed spaces is often a nuisance because it can be very loud, and a conversation may only be possible with a raised voice level and at a close distance. Because of the noise and the difficulties associated with a conversation the visitors may leave the place with a feeling of exhaustion, and people using hearing aids may find that verbal communication is impossible.

In many countries there is a growing awareness of the concept called universal design, which means accessibility for all in public buildings, and this is not limited to the physical access but includes also that the acoustical conditions should be suitable for the use of the building. Recently an investigation was made in Norway with the aim to throw some light on the problems due to the acoustical conditions in various kinds of rooms and spaces for people with reduced hearing or sight abilities [1]. It was found that particularly in canteens, restaurants and cafés the acoustical problems were very pronounced and 52% of the hearing impaired people were severely or much disturbed by noise. Also foyers and similar assembly areas in cultural buildings were rated as places with great difficulties of verbal conversation. The data in Table 1 shows that 51-54% of the hearing impaired people have often or always difficulties to have a conversation in these places, and if "sometimes" is included, the percentage increases to 86–88%. For the group of visually impaired people the percentage having difficulties with conversations in the same kind of places is often/always or sometimes 48–51%.

Table 1. Statistics of replies to the question: How often is it difficult to have a conversation due to noise from speech? Data from [1].

	Hearing impaired		Visually impaired	
	Canteens, restaurants and cafés	Foyers and assembly areas	Canteens, restaurants and cafés	Foyers and assembly areas
Often / always	51 %	54 %	23 %	21 %
Sometimes	37 %	32 %	28 %	27 %
Seldomly	9 %	9 %	16 %	20 %
Never	3 %	5 %	33 %	32 %
Total	100 %	100 %	100 %	100 %
Number of replies	251	243	212	174

2. Speaking in noise, the Lombard effect

The vocal effort is characterized by the equivalent continuous A-weighted sound pressure level (SPL) of the direct sound in front of a speaker in a distance of 1 m from the mouth. A description of the vocal effort in steps of 6 dB is given in ISO 9921 [2], see Table 2. Thus normal vocal effort corresponds to a sound pressure level around 60 dB in the distance of 1 m. Speech at levels above 75 dB may be more difficult to understand than speech at lower vocal effort. By shouting the SPL can reach 84–90 dB, and in private communication in dwellings (whispering or soft speech) typical levels are 35–50 dB.

Table 2. Description of vocal effort at various speech levels (A-weighted SPL in a distance of 1 m in front of the mouth) after ISO 9921 [2].

$L_{S,A,\ 1m}$ dB	Vocal effort
54	Relaxed
60	Normal
66	Raised
72	Loud
78	Very loud

It is a well-known phenomenon that many people speaking in a room can create a high sound level, because the ambient noise from the other persons speaking means that everyone raises the voice, which again leads to a higher ambient noise level. This effect is called the Lombard effect after the French otolaryngologist Étienne Lombard (1869 – 1920), who as early as 1909 was the first to observe and report that persons with normal hearing raised their voice when subjected to noise [3].

The increase of the speech level as a function of the A-weighted ambient noise level is described by the rate c (the Lombard slope). Lazarus [4, 5] made a review of a large number of investigations, and he found that the Lombard slope could vary in the range c = 0.5 to 0.7 dB/dB. The Lombard effect was found to start at an ambient noise level around 45 dB and a speech level of 55 dB. Assuming a linear relationship for noise levels above 45 dB, the speech level can be expressed in the equation:

$$L_{S,A,1m} = 55 + c \cdot (L_{N,A} - 45), \quad \text{(dB)} \tag{1}$$

where $L_{N,A}$ is the ambient noise level and c is the Lombard slope. The valid range for this relationship is limited to speech levels above 55 dB or noise levels above 45 dB.
The Lombard slope c = 0.5 dB/dB was found already in 1962 by Webster & Klumpp [6] and again by Gardner in 1971 [7] based on several cases of dining rooms and social-hour type of assembly, and studying a wide range of number of individuals present in each facility. In his overview paper, Bronkhorst [8] also confirms the Lombard slope of 0.5 with reference to a study by Lane and Tranel [9].

3. Hearing in noise, the cocktail party effect

Listening to voices at a social gathering is a very interesting situation that challenges our hearing system. Due to the ability of a normal hearing person to localize a sound source in the surrounding 3D space, it is possible to focus on one out of many voices, and at least to some extend to catch what one person says, while the other voices are suppressed as background noise.

This may work at signal-to-noise levels far below 0 dB. The phenomenon is called the "Cocktail party effect" and was first described in 1953 by Cherry [10] and further analyzed by MacLean [11]. He concluded that in a party there is a certain critical number of participants, and when this number is exceeded the party suddenly becomes a loud one. An overview of later research in the cocktail party effect is found in [8].

4. Prediction models for ambient noise

Applying simple assumptions concerning sound radiation and a diffuse sound field in the room a calculation model for the ambient noise level was derived in [12]. The prediction model was verified by comparison with measured data for a varying number of persons between 50 and 540 in two large foot courts and in a canteen [13, 14]. In the comparison with these data it became clear that the Lombard slope had to be c = 0.5 dB/dB; this was the only value that made a reasonable good fit between the experimental data and the simple prediction model.

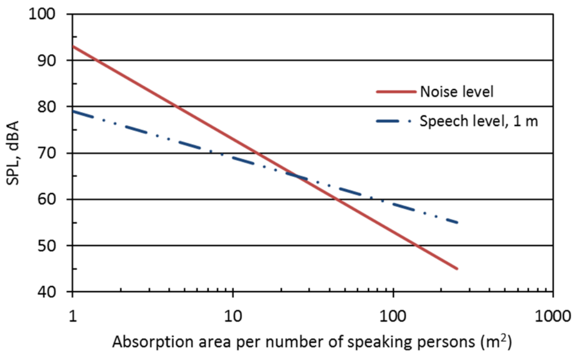

Figure 1. Ambient noise and vocal effort as functions of absorption area per number of speaking persons.

The suggested prediction model can be expressed in the equation:

$$L_{N,A} = 93 - 20\log\left(\frac{A}{N_S}\right) = 93 - 20\log\left(\frac{0.16 \cdot V \cdot g}{T \cdot N}\right), \text{ (dB)} \quad (2)$$

where A is the equivalent absorption area (in m^2) of the room and N_S is the number of simultaneously speaking persons. In the second equation the volume V and the reverberation time T are inserted by using Sabine's equation and the group size g is introduced. Since normally only the total number of people N present in the room is known, it is convenient to introduce the group size, defined as the average number of people per speaking person, $g = N / N_S$.

The interesting consequence of (2) is that the ambient noise level increases by 6 dB for each doubling of number of individuals present. The same result was found by Gardner [7].

If the room has the volume V (m^3), the reverberation time in unoccupied state is T (s), and assuming a diffuse sound field, the Sabine equation gives the following estimate of the equivalent absorption area including the contribution from N persons:

$$A = \frac{0{,}16 \cdot V}{T} + A_p \cdot N\,, \quad (\text{m}^2) \quad (3)$$

where A_p is the sound absorption per person in m^2. This depends on the clothing and typical values are from 0.2 to 0.5 m^2. The contribution of absorption from persons is negligible if the ambient noise level is not too high. Below 73 dB, it follows from (2) that the equivalent absorption area per person is around 10/g, i.e. approximately 3 m^2, and bigger in less noisy conditions.

4.1. The group size

It is obvious that in general noise from speech where many people are gathered cannot be predicted with a high accuracy, simply because there are unknown parameters related to individual differences and how much people actually want to talk. This may depend on the type of gathering, which can be more or less lively, how well people know each other, the age of the people, the consumption of alcohol, and other social circumstances.

With the suggested prediction model (2) it is possible to calculate the expected noise level from the volume, reverberation time and number of people gathered in the room. The uncertainty is mainly related to the group size, and from the cases that have been studied it appears that a group size of 3 to 4 is typical for most eating establishments and a value of g = 3.5 is recommended for the noise prediction.

The accuracy of the prediction depends on how close the assumed group size is to the actual group size. If the actual group size varies between 2.5 and 5, it means a total variation of 6 dB. This in turn means that the prediction method may have an uncertainty of ± 3 dB.

The prediction model is based on statistical conditions meaning that it should not be applied to small rooms with a capacity less than, say 50 persons.

4.2. Case 1: Reception at a conference

In connection with the Forum Acusticum meeting in Krakow, September 2014, a welcome party and a farewell reception were both held in the main building of AGH University of Science and Technology. The main foyer is a high room with volume approximately above 8000 m^3 and reverberation time around 4 s at mid frequencies. At the welcome party the room was crowded and very noisy do to speech from several hundreds of people and additional background music (voice and piano). It was extremely difficult to have a conversation during this gathering. The sound pressure level was not measured at that time, but at the farewell reception in the same room, the sound level was measured, and within a typical time of 15 minutes the $L_{A,eq}$ was 77 dB.

Table 3. Calculated and measured ambient noise during social gatherings in the AGH hall.

Volume V, m^3	8265		
Reverberation time, s	3.9		
Number of people N	250	500	1000
Calculated $L_{N,A}$, dB	78	82	85
Measured $L_{A,eq,\ 15\ min}$, dE	77	-	-

Just before there had been a closing ceremony with 260 participants, so it is assumed that the number of people attending the farewell party was around 250. Using equation (2) and (3) with A_p = 0.35 m^2 yields 78 dB, i.e. very close to the measured level. With the same equation, and estimating the number of people at the welcome party to be between 500 and 1000, the SPL would have been around 82 – 85 dB, see Table 3.

4.3. Using a computer model and a dynamic sound source

In many cases the volume is not well defined, and it may be necessary to replace the simple prediction equation (2) by a computer simulation; this can lead to a surprisingly accurate estimate even in apparently complicated cases where a diffuse sound field cannot be assumed. Instead of assumptions of the room volume and reverberation time, the room geometry is modelled and appropriate absorption data are assigned to the surfaces according to the materials. The principle is to calculate a transfer function from a surface source that covers the total area with speaking persons to a receiver grid covering the same area. This transfer function is the response of the room to the speech noise. Assuming a certain number of people (and the group size 3.5) the ambient noise can be calculated. For further information about this method, see [15]. This is the method used in the following case.

4.4. Case 2: DTU dining in different rooms

Acoustical measurements were made May 2011 at the Technical University of Denmark on the occasion of the annual celebration with a lot of people dining in different rooms. Three rooms with very different acoustical conditions were monitored with sound level measurements during the evening, and the results were compared with the prediction method, see Table 4. The predicted noise levels in the three different halls deviate less than 1 dB from the measured noise levels.

Table 4. Measured Measured ambient noise and results of calculations in three dining halls at DTU using different assumptions on vocal effort. $L_{W,A,1}$ is the assumed sound power level of one speaking person, and $L_{N,A,1}$ is the corresponding calculated median sound pressure level in the receiver grid.

Hall	**Hall A**		**Hall B**		**Hall C**	
Reverberation time, s	2,5		0,8		1,0	
Number of people N	480		530		380	
Measured $L_{A,eq,\ 2\ h}$, dB	**87,3**		**82,5**		**82,9**	
Vocal effort	Raised	Loud	Raised	Loud	Raised	Loud
$L_{W,A,1}$, dB	75,5	82,6	75,5	82,6	75,5	82,6
$L_{N,A,1}$, (50%) dB	57,6	64,6	54,6	62,0	56,1	63,3
Calculated $L_{N,A}$, dB	87,9	87,7	82,8	83,4	82,9	83,1
Deviation, dB	**0,6**	**0,4**	**0,3**	**0,9**	**0,0**	**0,2**

5. The acoustic capacity and quality of verbal communication

The above findings can be used for a room with known absorption area to estimate the maximum number of persons in order to keep a certain quality of verbal communication. So, it is suggested to introduce the concept "Acoustic Capacity" for an eating establishment, defined as

the maximum number of persons in a room allowing sufficient quality of verbal communication between persons.

Sufficient quality of verbal communication requires that the ambient noise level is no more than 71 dB, which means that the average SNR in a distance of 1 m is at least -3 dB, see Table 5. A simplified approximation derived from (2) yields that the number of persons in the room should be limited to:

$$N_{\max} \cong \frac{V}{20 \cdot T} \tag{4}$$

where V is the volume in m^3 and T is the reverberation time in seconds in furnished but unoccupied state at mid frequencies (500–1000 Hz). N_{max} is the suggested Acoustic Capacity for an eating establishment or a space for social gatherings.

For the evaluation of acoustic quality in such spaces it is suggested to consider the quality of verbal communication which can be related to the signal-to-noise ratio (SNR), see Lazarus [5]. Thus a SNR between 3 dB and 9 dB is characterized as "good", the range between 0 dB and 3 dB is "satisfactory", and SNR below -3 dB is "insufficient", see Table 5.

A simple approach is suggested here, namely to define the signal-to-noise ratio as the level difference between the direct sound from a speaking person in a distance of 1 m and the ambient noise in the room. Thus, the SNR_{1m} in the distance of 1 m is the difference between the two curves shown in Figure 1. This can be expressed in terms of the absorption area per person and the group size:

$$\begin{aligned} SNR_{1m} &= L_{S,A,1m} - L_{N,A} \\ &= -14 + 10\log\left(\frac{A \cdot g}{N}\right), \text{ (dB)} \end{aligned} \tag{5}$$

This applies to A-weighted ambient noise levels between 45 dB and 85 dB, or a range of speech levels between 55 dB and 75 dB. The corresponding SNR range is from – 10 dB to +10 dB.

Table 5. Quality of verbal communication and the relation to SNR (signal-to-noise ratio) as suggested by Lazarus [5] and the corresponding levels of vocal effort and ambient noise.

Quality of verbal communication	SNR dB	$L_{S,A,1m}$ dB	L_{NA} dB
Very good			
	9	56	47
Good			
	3	62	59
Satisfactory			
	0	65	65
Sufficient			
	-3	68	71
Insufficient			
	-9	74	83
Very bad			

Figure 2 shows how the SNR in a distance of 1 m depends on the volume and reverberation time, and the importance of sufficient volume per person is obvious. Figure 3 shows the ambient noise level as function of the number of persons relative to the acoustic capacity. The applied absorption per person is 0.35 m^2.

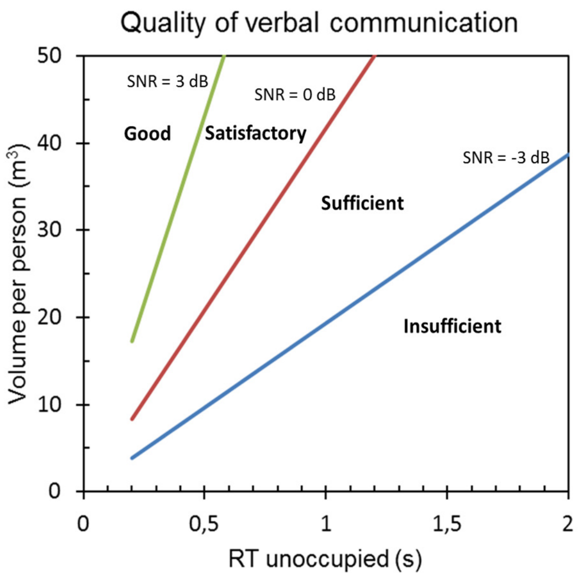

Figure 2. Quality of verbal communication as function of room volume per person and reverberation time.

While these considerations may be valid for normal hearing people, ISO 9921 [2, section 5.1] states that *People with a slight hearing disorder (in general the elderly) or non-native listeners require a higher signal-to-noise ratio (approximately 3 dB)*. This improvement is relative to that

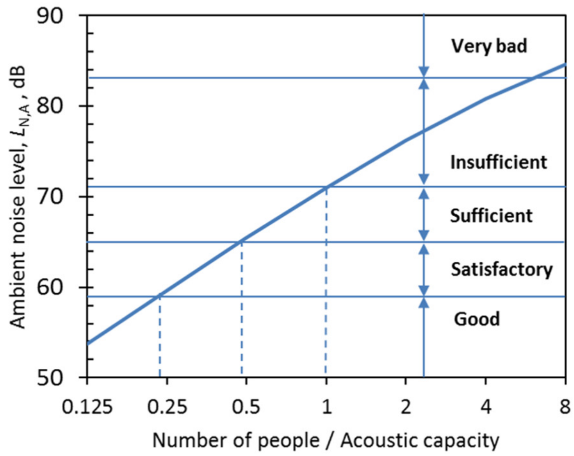

Figure 3. Ambient noise level as a function of the number of people relative to the acoustic capacity of the room. The corresponding quality of verbal communication in a distance of 1 m is also indicated.

required for normal hearing listeners, and thus for this group of people a SNR ≥ 0 dB should be applied to represent "sufficient" conditions, and SNR ≥ 3 dB to represent "satisfactory" conditions. The SNR and thus the quality of communication can be improved if the listener can come closer to the speaking person. Reducing the distance from 1 m to 0.7 m means a 3 dB better SNR, and coming as close as 0.5 m yields another 3 dB improvement. So, this is the obvious solution for maintaining communication in a too noisy environment, but it doesn't change the noise level.

6. Background and foreground music

Background music is typically instrumental music played at a low level. It is not meant to be in the focus of an audience, but rather to fill the gaps of silence, that might occur. When used in restaurants and at social gatherings it should be played at a sufficiently low sound level, so it is not disturbing for normal vocal communication. Background music can have a masking effect, which contributes to a feeling of privacy in the meaning that a private conversation is not easily overheard by other people in the room. Thus, it may happen that people stop talking if the background music is stopped. Recommended maximum sound pressure level of background music is around 60 – 65 dB(A).
Foreground music is played at higher levels than background music, and is meant to be noticed and enjoyed as entertainment [16]. The audience is not supposed to talk during the music. Recommended maximum sound pressure level of foreground music is in the range 75 - 90 dB(A).

In a restaurant or at a social gathering the music contributes to the ambient noise level, which means an increase of vocal effort in conversations. Thus the Lombard effect is activated by the total noise level due to music and speech. Solving the problem leads to the following equation for the total noise level:

$$L_{N,Total} = 10\log\left(E_M + 0.5 \cdot E_N\left(1+\sqrt{1+\frac{4\cdot E_M}{E_N}}\right)\right), \text{ (dB)} \qquad (6)$$

where the average SPL of the music is 10 log(E_M) and the SPL of ambient noise from speech without music is 10 log(E_N). The latter is the SPL given in eq. (2). From this result, it is straightforward to estimate the vocal effort (1) and the SNR with background music or other background noise.
Figure 4 displays the SNR as function of the ambient noise level without music, but with the sound level of the background music as a parameter. If the level of the music does not exceed 65 dB the quality of vocal communication can be sufficient (SNR > -3 dB), but of course only when the room is not too crowded (actually if $N < 0.7 \cdot N_{max}$). For a satisfactory quality of verbal communication, the background music should not exceed 60 dB.

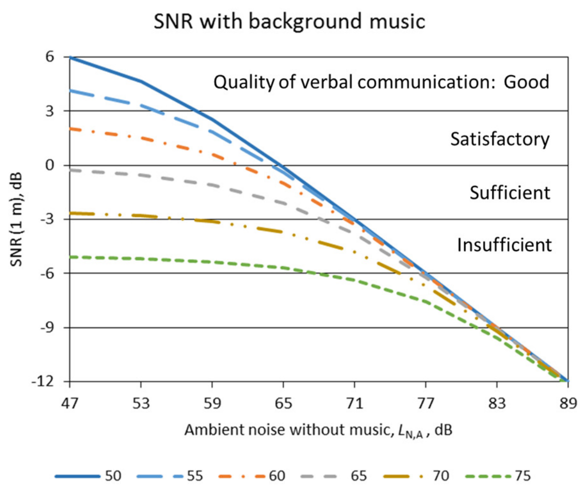

Figure 4. The influence of background music on the quality of verbal communication. The curves represent levels of music from 50 to 75 dB in steps of 5 dB.

7. Drinking and eating in noisy environments

Although it is a widespread assumption that the noise level of a party increases with the amount of alcohol consumed, no proof of this is found in the scientific literature. However, there is no doubt that there is a relation between noise and alcohol consumption. Guéguen et al. [17] studied the drinking behavior in bars as function of the sound level of music, either at "usual" level, 72–75 dB, or at a typical level of "foreground" music, 88–91 dB. With the high sound level, significantly more drinks were consumed, the mean value for 60 persons being 3.7 versus 2.6 drinks at the usual level. The authors have suggested an "arousal" hypothesis to explain the findings; the high sound level leads to higher arousal, which stimulates *to drink faster and to order more drinks*. In a later follow-up study [18] it was confirmed that the average time spent to drink a glass of beer decreased from 14.5 ± 4.9 minutes with usual level (72 dB) to 11.5 ± 2.9 minutes with high music level (88 dB).

Recently Stafford et al. [19] have found that music and other forms of distraction leads to increase in alcohol consumption. In addition they found that sweetness perception of alcohol was significantly higher in the music compared to no music and other distraction conditions. The study gives support to the general distraction theory that *noise disrupts taste and smell*.

The effect of noise on food perception was studied by Woods et al. [20]. Test persons were exposed to white noise at levels of 45-55 dB (Quiet) and 75–85 dB (Loud), in addition to a no-noise condition. The ratings of sweetness and saltiness were influenced by the noise, and *the food was reported to taste less intense in the noisy condition*. This might be interesting news for owners of good restaurants, and it certainly gives a new twist to the discussion of the importance of good acoustics in restaurants.

Fiegel et al. [21] have found that background music can alter food perception, and that the effect depends on the music genre (classical, jazz, hip-hop, rock). They used the same sound pressure level of the music in all cases, namely 75 dB. Especially in the presence of jazz stimulus, flavor pleasantness and overall impression of the food stimuli increased.

8. Conclusions

For the characterization of the acoustical conditions in restaurants and similar environments, the quality of verbal communication is applied in addition to the ambient noise level. A signal-to-noise ratio of -3 dB for a speaker in a distance of 1 m corresponding to an ambient noise level of 71 dB is suggested as a realistic basis for design criteria. This leads to a combined requirement for the reverberation time and the volume; the volume per person should be at least $T \cdot 20$ m^3, where T is the reverberation time. Thus, the reverberation time should be as short as possible, but still a sufficient volume is a physical necessity for satisfactory acoustical conditions. It should be noted that for hearing impaired people and non-native speakers the acoustical needs are stronger and a better SNR is needed for an acceptable quality of verbal communication.

It is obvious that the acoustical problems depend strongly on the number of people present in the room. So, in addition to the design guide for the acoustical treatment of rooms, it is suggested to introduce the Acoustic Capacity of a room as a way to label, what number of persons should be accepted in the room in order to obtain sufficient quality of verbal communication. In other words, if the number of people in the room exceeds the labelled Acoustic Capacity, the ambient noise level may exceed 71 dB and the quality of verbal communication is characterized as insufficient.

Both a simple prediction model and an advanced computer-based model for the ambient noise due to speech have been derived. The models take the Lombard effect into account, and have been verified for several test cases. In the design stage when alternative solutions for the acoustic design of a restaurant or similar facility are considered, the acoustic capacity may be a good parameter to present to architects, in addition to the calculated reverberation time or ambient noise level. This has already been used successfully in several projects, and it is clear that the maximum number of persons to allow sufficient acoustical conditions is much easier to understand for non-acousticians than noise levels or reverberation times.

For the owners of restaurants it may be interesting to know that the perception of food and drink is influenced by the ambient noise in the room. However, the results go in opposite directions. In a fine restaurant the noise should be kept at a low level in order to maintain the taste qualities in the food. But for the owner of a bar, where the guests mainly come for drinks, a noisy environment means that more drinks are consumed in a shorter time. So, the quality of verbal communication might be less important in bars and a higher noise level (and thus a higher level of arousal) acceptable or maybe even wanted.

When music is played in restaurants or at social gatherings, it is necessary to distinguish between background music and foreground music. While foreground music is meant to catch the attention, background music should not interfere too much with the quality of verbal communication, and a sound level up to 60 dB is suggested.

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