Classroom noise and its effect on learning.

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ABSTRACT

The acoustical conditions in a classroom may severely impair listening, which in turn impairs learning. To safe-guard against inferior listening conditions government agencies and professional societies have established building codes and recommendations for acceptable signal-to-noise ratios (SNR) and reverberation times (RT) in classrooms. Codes and recommendations are based on conditions required for speech intelligibility and correct identification of spoken words and isolated sentences.

Correct identification of what was said is a necessary condition for memory and learning, but it is not a sufficient one. There is a gap between speech intelligibility and memory and the size of that gap is a function of the intelligibility of the spoken message and how much the message taxes the individual's limited working memory capacity.

I will discuss how SN, RT and their combinations change speech intelligibility and memory of spoken messages. Although the characteristics of the spoken material and the individual's working memory capacities can be assessed independently of each other, there is a functional equivalence between them. A difficult task and a lack of skill are two sides of the same coin.

In a better world building codes and recommendations for classroom acoustics should be based on memory and learning rather than on speech intelligibility alone.

THE PROBLEM AREA

Poor acoustical conditions severely impair speech communication. Because of this, government agencies and professional societies have established norms and recommendations for acceptable signal-to-noise ratios (SNR) and reverberation times (RT) in classrooms and other places where listening is important (American National Standards Institute 2002; Byggnadsstyrelsen [The Swedish Building Board] 1975; Vallet & Karabiber 2002). These norms have been based on conditions required for correct identification of spoken words or isolated sentences.

Recent research, however, strongly suggests that these criteria are too lenient as they ignore that the acoustic conditions sufficient for speech intelligibility may still impair memory of the spoken information. For instance, listening conditions that allow for complete identification of spoken materials has been shown to render poorer recall of what was said when compared to better acoustic conditions (Kjellberg 2004; Kjellberg et al. 2008; Ljung & Kjellberg 2009; Ljung et al. 2009).

Thus, there is more to learning than just listening. Correct identification of what was said is a necessary condition for memory and learning, but it is not a sufficient criterion. There is a gap between speech intelligibility and memory of the speech, and the size of that gap is a function of to which extent low intelligibility of the spoken message exhaust the limited working memory resources and leaves little, if any, left for elaboration, recoding, storing, and subsequent recall (Kjellberg et al. 2008). Thus, to improve memory and learning it must be easy to identify what was said. Otherwise subsequent recall will suffer, even when speech intelligibility is at an acceptable level.

Because of this, building codes and recommendations for acoustics in classrooms should be evidence-based on how much is learned and remembered, not on speech intelligibility.

SNR and RT - Recommendations for Speech intelligibility

Recommended background noise levels, excluding activity sounds in the room, generally lie between 30 and 40 dB(A) and recommended RT between 0.4 and 0.8 s.

(American National Standards Institute 2002; Byggnadsstyrelsen [The Swedish Building Board] 1975; Vallet & Karabiber 2002)

The basis for these recommendations has generally been studies of the effects of RT and SNR on speech intelligibility (Bradley 1986) where people have been presented with lists of words and sentences. Speech intelligibility in these studies has been defined as the percentage of correctly identified items.

Table 1: Examples of recommendations in the Nordic countries for reverberation times and background noise levels in rooms for teaching.

Country	Reverberation time (s)	Background noise dB(A)
Denmark	≤ 0.6	30-33
Finland	0.5 – 0.6	28
Iceland	≤ 0.9	35
Norway	≤ 0.9	32
Sweden	0.5 – 0.6	30-35

OVERVIEW OF THE RESEARCH

How well founded then are the recommendations when the target is learning and memory rather than speech intelligibility?

SNR. When a teacher speaks at a level of 65 dB(A) (raised voice) in the front of an ordinary classroom with ordinary sound reflections from the surfaces, that level has dropped to ≈ 52 dB(A) 6 m out in the classroom, and further away it does not drop much more thanks to reflections. See Figure 1! This level is only 7 dB(A) higher than an extremely quiet (≈ 45 dB(A)) classroom with a very low activity noise level. A +7 dB SNR-level is not good enough for speech intelligibility. Often it is said that a SNR = +12 is a preferred minimum, but if there is a long RT or the receiver has a hearing impairment, an even better SNR is needed.

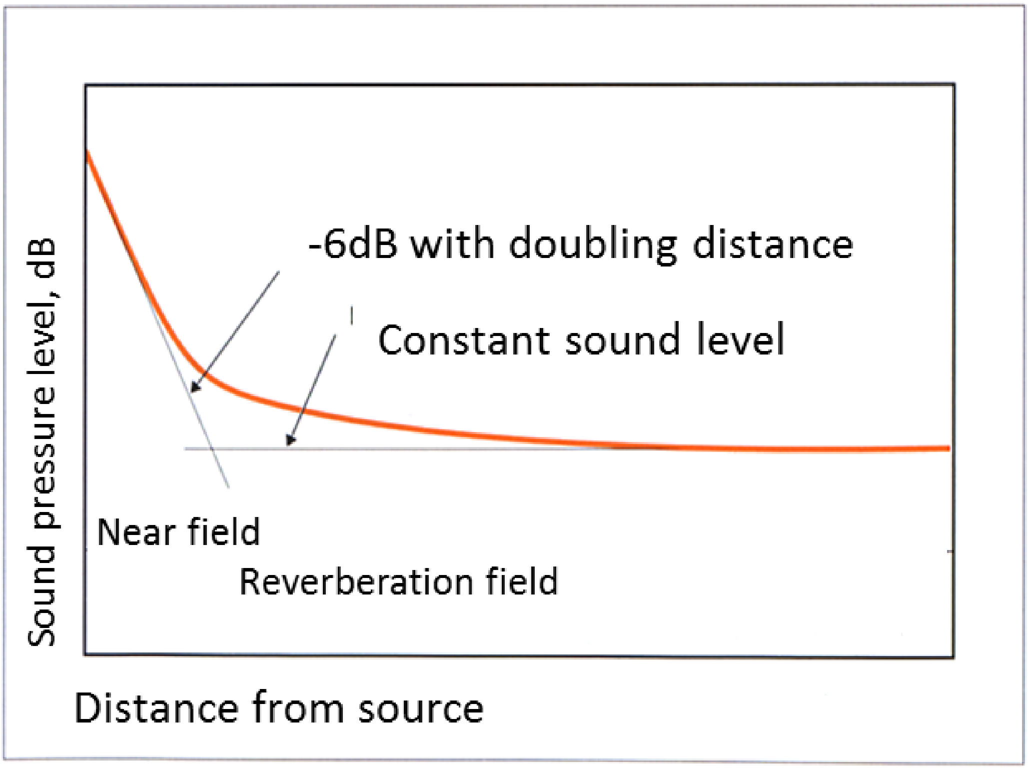

Figure 1: Example of decrease in speech sound level in a classroom

A Swedish survey of the background noise levels from installations (mainly ventilation) in ~ 200 classrooms in southern Sweden (Sjöström 2007) reported that 66% of the classrooms did not meet the criterion of 30 dB(A), (c.f. Table 1). In a related study (Swedish Work Environment Authority 2006) reported that in 19 out of 39 classroom the sound level was ≥ 35dB(A). Thus, the background noise levels in Swedish classrooms do not, on the average, meet criteria for low background levels.

Research studies give support to the importance of low background noise levels. Bad acoustic conditions have effects on speech communication even when they do not prevent immediate identification of the spoken words, but simply render such identification more difficult. (Kjellberg et al. 2008) presented word lists used for audiological testing in good and less good SNR conditions, none of which prevented the participants from identifying the words correctly (they repeated each word aloud). Thus, from that point of view the SNR was acceptable. However, after the presentation when the participants were asked to recall the words they remembered fewer words in the bad listening conditions.

Other recent findings also suggest that criteria based on speech intelligibility are too lenient as they ignore the finding that acoustical conditions that are sufficient for acceptable speech intelligibility, still may hamper memory of the spoken information. For instance, we have shown that listening conditions, which allow for sufficient identification of spoken materials, render comparably poorer retention of the material relative to better acoustic conditions (Kjellberg et al. 2008; Ljung & Kjellberg 2009; Ljung et al. 2009)

In a recent study (Ljung et al. 2013) we have also shown that the speech intelligibility function decreases linearly with increasing background noise levels (SNR levels varied from +12 to +3 in steps of three). However, for the memory of the lists (recall at the end of the list) only the sub-group that had a low WMC showed a decreasing memory performance with lowered SNR. Thus, there was no general mediation by speech intelligibility on recall. In another recent study (Hurtig et al. 2014; Hygge et al. 2013) we used word lists with different SNR (+3 and +12), different languages (English and Swedish), with and without shadowing (repeating the words back orally at presentation). Results for recall of the words indicate very strong expected effects of SNR, Swedish/English and which position the word had in the word list at presentation. However, there were no marked effects of shadowing of the words.

Reverberation time (RT). In the study by Sjöström (2007) 225 classrooms were measured on RT in the year of 2004 and 217 classrooms in 2005-2006. Of these, 46 % and 38 % (respective periods) did not meet a RT criterion of ≤ 0.6 s (c.f. Table 1). A related study (Swedish Work Environment Authority 2006) reported that 24 % out of 50 classrooms had an RT equal to or above 0.6 s. Thus, as well as for the background noise levels, a lot would be gained if schools actually met the acoustical guidelines already in effect.

Studies from our lab suggest that RT manipulations have effects on memory similar to the SNR manipulations. Ljung and Kjellberg (Ljung & Kjellberg 2009) presented words orally in a room with a long (1.2 s) or a short (0.5 s) RT. More words were subsequently remembered in the room with better acoustic characteristics (i.e., with a short RT), even though the participants' ability to identify the words were the same between the two RT conditions. We have also found that memory of continuous stories is similarly impaired by unfavorable listening conditions (Ljung et al. 2009). All this strongly suggests that in the unfavorable listening conditions when more of the limited working memory resources are used up for word identification, less resources are available for the more elaborative memory processes (Kjellberg 2004). Thus, effective learning requires that a message can be heard without excessive effort. Similar results have been reported by (Rabbitt 1966; Rabbitt 1968; Surprenant 1999; Surprenant 2007).

Thus, as with SNR, memory is impaired at RT conditions that allow for reasonable speech identification but at the expense of working memory resources that are needed for elaboration, coding and storage processes.

In a study of Swedish speaking participants' capability to perform the Swedish National test in listening to and understanding English, three RT conditions were employed: 0.3, 0.9 and 1.7 s (Sörqvist et al. 2014). The results suggest that second-language listening comprehension is impaired by increasing RT, and more importantly, listeners with relatively good baseline second-language knowledge were less susceptible to this effect. A strong implication of this finding is that the difference in test performance - and consequently in school grading - between those with high versus low baseline second-language knowledge is exaggerated when acoustical conditions are suboptimal. One unwanted consequence of this finding is that a student may well get a lower grade in English just because of bad acoustics in the classroom.

Interactions between SNR and RT. In recommendations and building standards, SNR and RT are basically treated as independent and *additive* variables, but from a theoretical working memory perspective we would expect them to interact. However, there is a lack of studies of interactions between SRT and RT. However, Klatte, Lachman and Meis (Klatte et al. 2010) is a notable exception. For two RTs at 0.47

and 1.1 s and with different background noise conditions (silence, background speech and classroom noise without speech) they reported that children (1st and 3rd grade) were more impaired than adults by background sounds both in speech perception and listening comprehension. RT had no effect on speech perception in silence but strong impairing effects against background noise. For listening comprehension, the younger the children, the more the impairment, while adults were unaffected.

In the present ICBEN 2014 conference, Hygge et al. (2014) report on a comparison between children in Grade 4 (10-11 years old) and College students. Both groups listened to words lists in English and in Swedish, where two levels of SNR (+3 and 12 dB) were crossed with two levels of RT (0.3 and 1.2 s). The results show a very strong effect of SNR but no main effect of RT. The RT showed up as an interaction SNR*RT*Group to the effect that for Grade 4, but not for the College students, there was a net improvement going from SNR=3 to 12 dB when the RT = 0.3 compared to when RT = 1.3.

A MODEL OF SPEECH INTELLIGIBILITY AND MEMORY

To conceptualize what should happen to speech intelligibility and memory when RT and SNR vary, see Figure 2! In very good acoustical conditions to the right in the figure, speech intelligibility and memory both are at their upper relative limit (=1.0). Both are thought of as sigmoidal functions reflecting a cumulative distribution function, where the area to the left of a given x-value is given by the y-value, which is the probability of perfect speech intelligibility and memory. As the acoustical conditions deteriorate, the two functions separate, and the memory function is expected to have a steeper downward slope than the function for speech intelligibility. The hypothetical reason for this steeper function is that more working memory resources are needed to understand a degraded or distorted speech signal (Rönnberg et al. 2008; Sörqvist 2010; Sörqvist & Rönnberg 2012; Sörqvist et al. 2012) leaving relatively less resources available for subsequent elaboration and storage processes.

A distinction can be made between the physical (sensory) properties of the speech signal (e.g., SNR, RT, Speech Transmission Index, Articulation Index), the characteristics of the spoken material (e.g., redundancy, complexity, difficulty how common words or phrases are), and the individual characteristics of the receiver (e.g., hearing impairment, knowledge of the language, age, cognitive skills, working memory capacity). Although the characteristic s of the spoken material and the individual characteristics can be assessed independently of each other, there is a functional equivalence between them. For instance, task complexity and individual skills are two sides of the same coin.

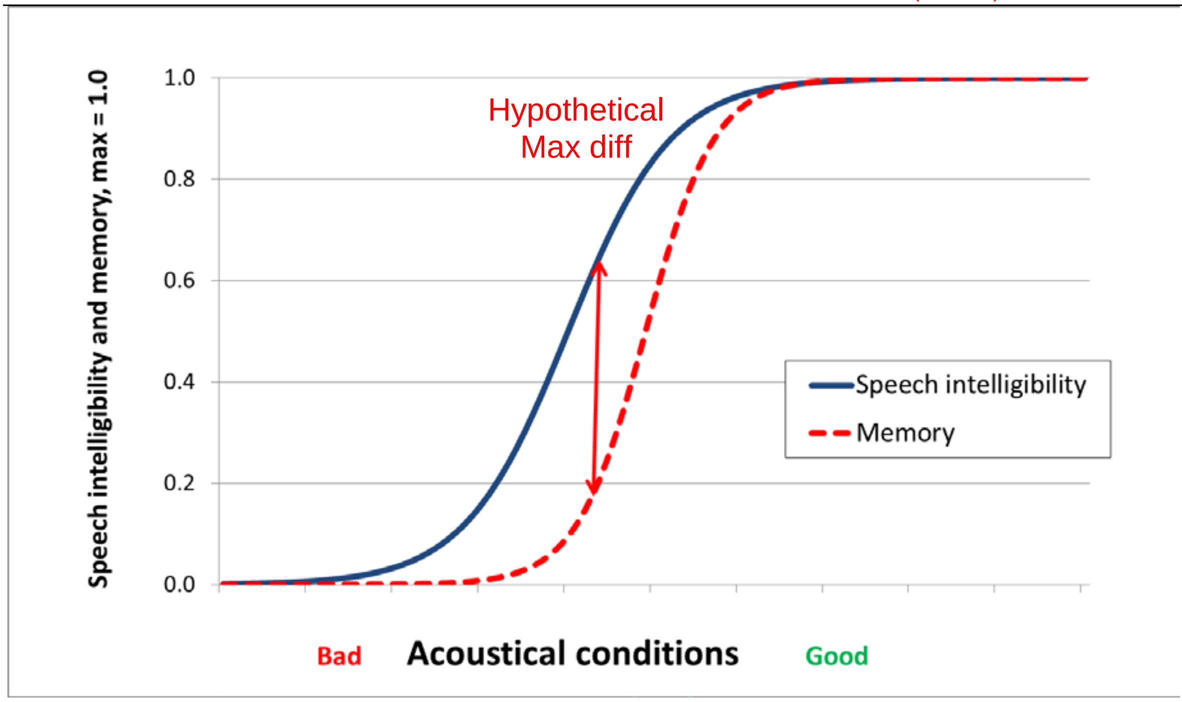

Figure 2: Speech intelligibility and memory as functions of acoustical conditions

From these assumptions, a set of expectations follow:

(1) Memory performance is depends upon speech intelligibility but there is a difference in the slopes for two functions.

(2) The *slope for speech intelligibility* in the mid region of the x-axis should be steeper and drop off earlier and faster when the form or content of the spoken message renders speech intelligibility more difficult, e.g. at a low SNR, a long RT, low redundancy, unfamiliar words or sentences, complex content, subject area unknown to the listener, or the speech is spoken in a foreign language. Poor articulation should also have this effect.

(3) The *difference in slope* between the functions for speech intelligibility and memory should increase when the speech is more difficult to identify, e.g. when heard by children and the elderly, when poorly articulated or in a foreign language. Thus, the difference between the slopes is not expected to be a constant.

(4) Effects on memory is mediated by speech intelligibility, at least when the curves are in the mid-region and not close to 0.0 or 1.0.

(5) A low working memory capacity should also increase the difference between the slopes, as a low working memory capacity implies that the available resources are more easily depleted during the listening process, leaving little resources left for further processing and storage of the information.

CONCLUDING REMARKS

Several studies indicate reliable and strong effects of SNR on recall and memory, but the effects of RT are not as strong and reliable.

The effects on memory from varying RTs also seem to vary with what kind of speech based material is employed. Short stories and sentences are more vulnerable to long RT than single words, the reason being with single word presentations there is no forward masking from one word to the next. Also, the forward shadowing from vowels to consonants will be less frequent with single word presentations.

In terms of the model presented in Figure 2, there is as yet not much to go on. We have seen some studies where there are marked decreases in memory and learning when the acoustical conditions deteriorate, but we are unsure of whether this is accounted for and/or mediated by speech intelligibility.

Also, we do not have as yet have the tools and/or a sufficient amount of relevant research to put a difference between, for instance, SNR +12 and +3 dB on the same x-axis as a difference between RT = 0.3 and 1.2 s.

It should also be borne in mind that the way in which I have treated RT here is not particularly sophisticated. There is, for instance, much more to be said about early and late reflections, which are not handled by the standard procedures to measure RT. Early reflections that reach the listener within the first 50 ms after the direct sound will enhance the speech signal, thereby contributing to speech clarity and speech intelligibility.

But that is another story, which some of us will have to come back to in the near future.

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