FROM ACOUSTICS TO COGNITION: SOME SUPRISING RESULTS

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When the acoustics are poor, a listener's ability to navigate an auditory scene, communicate within it, or learn while immersed in it, is adversely affected (see, for example, Picard & Bradley's, 2001 analysis of classroom acoustics). Moreover, when poor acoustics are combined with virtually any kind of auditory problem (even those which would not normally merit clinical attention), all of these listening and learning difficulties are considerably exacerbated. For example, a number of studies have demonstrated that older adults with clinically normal hearing are considerably more disadvantaged than normal-hearing younger adults in adverse listening conditions (e.g., Schneider, Daneman, Murphy, & Kwong See, 2000). Indeed, hearing status in older adults is, arguably, the best predictor of their performance on a number of different cognitive tasks. For example, in the 1994 Berlin Aging study (Lindenberger & Baltes, 1994), the hierarchical model that provided the best account of age-related declines in cognitive functioning was one in which age effects on cognitive tasks were mediated, in large part, by age-related changes in auditory function. Because the proper functioning of higher-order cognitive processes can be highly dependent on the integrity of the information supplied by the sensory systems, it is not unreasonable to expect that cognitive functions dependent on sensory input might be adversely affected by poor acoustics. Hence, acousticians, audiologists, psychologists, and cognitive scientists need to understand how acoustics and cognitive functioning are related.

1.0 AN INTEGRATED MODEL OF INFORMATION PROCESSING

Both sensory and cognitive scientists study how humans detect, encode, process, store, and recall information. However, they concentrate on different aspects of this process. Sensory scientists typically study how information available in the pattern of energy falling on the sensory receptors is used to build up a representation of the external world. Cognitive scientists typically begin to study how information is processed *after* a perceptual representation has been achieved, and neither group, until recently, has been concerned with the nature of the interaction between sensory and cognitive processing. In other words, both groups tend to treat perception and cognition as separate modules (or boxes in a flow chart) with the perception module feeding the cognitive module. A more reasonable approach is to consider them as a unitary information-processing system, in which those processes we call sensory occur relatively early in the processing sequence, whereas those that are labeled cognitive are considered as elaborations of these early processes. Moreover, such an approach would have to explicitly recognize that, in addition to the upward (more central) flow of information, there is also a considerable amount of top-down control exerted over the upward flow of information.

2.0 HOW THE LISTENING ENVIRONMENT AFFECTS COGNITION

Evidence is accumulating that the acoustical environment determines not only how well we can hear but how well we can think. For example, Murphy, Craik, Li, and Schneider (2000) showed that the ability to memorize word associations is affected by background noise. These investigators assessed performance of young adults in a paired associates memory task in which listeners heard sets of five paired words, either in quiet, or in a moderate level of background noise (12 speaker babble). After each set, the first member of one of the paired-associates was presented to the listener, who was asked to supply the other word in the pair. When the paired associate tested was one of the last two presented (positions 4 & 5), performance was quite good and did not differ between noise and quiet conditions. Consistent with the memory literature, performance declined as the serial position of the word became more remote from the time of testing (positions 1, 2, & 3). However, the decline in performance was more severe for those listeners tested in a moderate level of noise than for those tested in quiet, indicating that background noise, even though it may have little or no effect on our ability to hear, can interfere with memory, and that the degree of interference depends on the serial position of the word to be recalled.

As a second example, we will consider the effect that source separation has on speech comprehension. It is well known that separating the position of a noise masker from that of the target stimulus improves our ability to detect, identify, and process the information coming from the target stimulus. In natural environments, much of this improvement comes from increases in signal-to-noise ratios that occur when the target and noise sources are physically separated. However, Freyman, Helfer, McCall & Clifton (1999) have recently shown that when the precedence effect is used to achieve a perceived separation between target and noise source (without substantially altering the signal-to-noise ratio), perceived separation alone can significantly improve listeners' ability to recognize target words in a nonsense sentence. However, this release from masking with spatial separation only occurs when the masker consists of nonsense sentences spoken by other people, but not when the masker is speech-spectrum noise. Speech maskers, in addition to the masking effect that they produce along the cochlea, also interfere with speech recognition by eliciting activity in the semantic and linguistic (i.e., cognitive) systems. This elicited activity, if not cognitively inhibited or suppressed, competes with that elicited by the target, thereby adversely affecting target word recognition. Hence, a speech masker, because it produces cognitive interference in addition to peripheral masking, should reduce word recognition more than a noise masker, which provides the same degree of peripheral masking, but does not interfere on a cognitive level with the processing of the targeted speech. Shifting the perceived location of the masker away from that of the target helps to perceptually distinguish the target from the masker, thereby making it easier for the listener to cognitively suppress the competing activity elicited by a speech masker. Interestingly, Li, Daneman, Qi, & Schneider (in press) have shown that this release from informational masking is the same for young as it is for older adults in the early stages of presbycusis, indicating that this level of cognitive processing in older adults remains unaffected by aging.

We can also show that features of the acoustical environment can have a surprisingly large effect on the ability to encode and recall information from monologues and dialogues (Schneider et al., 2000), and can influence working memory (Pichora-Fuller, Daneman, & Schneider, 1995). In short, there may be very good reasons why people often say that "It is so noisy that I can't think straight."

3.0 THE ACOUSTIC ENVIRONMENT AND TOP-DOWN CONTROL.

A number of studies (e.g., Dai, Scharf, & Buus, 1991) have shown that listeners can "tune" their hearing to a particular frequency, and can "set" the degree of signal amplification in an auditory channel (e.g., Parker, Murphy, & Schneider, 2002). In other words, there is emerging evidence that auditory system is under top-down control, and that both the flow of processing and the emphasis given to certain kinds of processing may change according to context and task demands. For example in the absence of noise there may be little need to tune the auditory system to select the frequency regions that are required for source identification and for information extraction. However, as the listening situation becomes more difficult, we would expect increases in the degree of top-down control exerted over the upward flow of information. The imposition of a greater degree of top-down control would be expected to produce performance decrements in higher-order tasks because more processing resources would be allocated to controlling and improving lower level functions, to the detriment of higher-order cognitive processes such as working memory (e.g., Pichora-Fuller et al., 1995). Thus, within an integrated model of sensory and cognitive processing, the quality of the auditory environment and the status of a person's auditory system may have far-reaching consequences for cognitive performance. In particular, some portion of the age-related decline in cognitive functioning may be a direct consequence of age-related deterioration in hearing, and of the poor acoustic environments that older adults must function in.

Finally, the strong connections between acoustics and cognitive processing provides another argument as to why we need to be concerned about the auditory environment within which we function. We need environments that not only are "hearing friendly" but "thinking friendly". We need to ensure that students in learning situations need not "strain" to hear what is being said. For if they have to "work at" hearing, their ability to take in information, integrate it with past knowledge, and store it in memory for future use, is likely to be compromised, with the situation being even worse for those with any kind of hearing impairment.

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