Spatial hearing advantages in everyday environments

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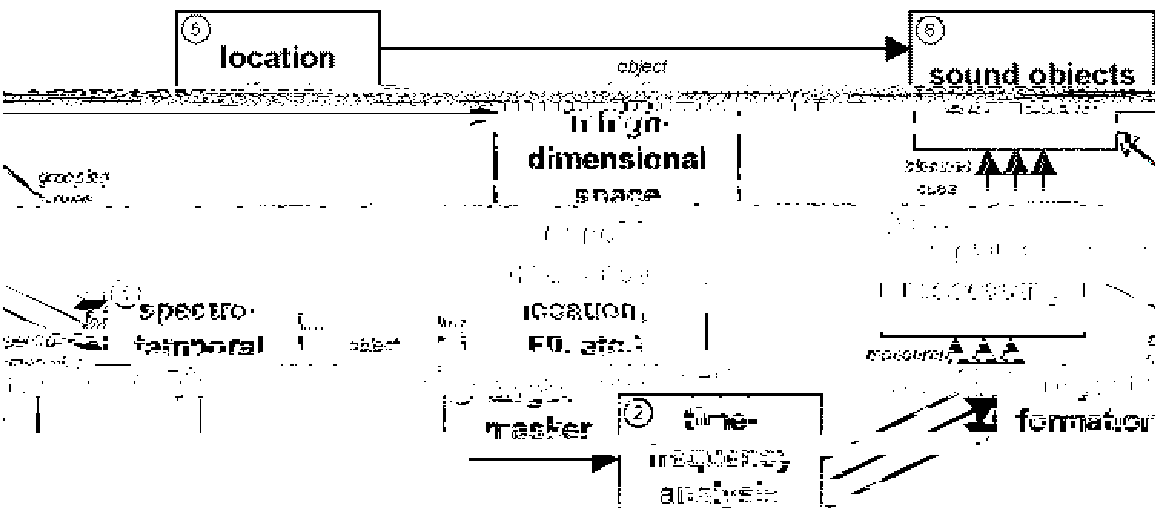
Spatial auditory cues are not a dominant factor in human auditory scene analysis (i.e., in "parsing" the sound reaching the ears to determine the number and spectral content of competing sound sources) [1-5]. However, spatial hearing is very important for *understanding* a target source in an environment that has multiple sound sources [6-9]. Resolving this apparent paradox is critical for understanding how human listeners operate in difficult conditions, for instance when there is a heavy workload and there are competing demands on attention. Such knowledge is very important for designing effective auditory displays and other human-machine interfaces.

Traditional views of the benefits of spatial hearing [10] fail to explain this contradiction as well as other observations, such as the 1) relatively poor ability of hearing impaired listeners to parse and understand speech in situations with competing sources and/or reverberation [11], 2) relatively large inter-subject differences in performance on tasks involving "informational masking" compared to tasks in which the masker is dissimilar from the target [11-13], and 3) very large improvements in speech intelligibility that can arise when similar competing talkers arise from different locations compared to when they are in the same location [6-9, 14, 15]. This short paper provides a preliminary conceptual framework that unifies these seemingly contradictory results by isolating and identifying multiple ways in which spatial hearing impacts the ability to listen to competing, simultaneous sound sources.

It has long been known that spatial separation of a target from an interfering source (a masker) improves a listener's ability to detect and understand the content of the target (a phenomenon known as "spatial unmasking;" e.g., see [16-18]; recent reviews include [10, 19]). Much of this improvement can be attributed to simple acoustic effects: spatially separating the target and masker generally increases the target-to-masker energy ratio (TMR) at one of the two ears. Because speech intelligibility improves with TMR, the improvement in TMR in one ear leads directly to an improvement in performance. The acoustic TMR varies with frequency because the acoustic interaction of the head and body of the listener with an impinging sound wave varies with the sound wavelength. Thus, the TMR changes more with spatial location of target and masker at high frequencies than at low frequencies. In the most extreme cases (i.e., when one of the sources is attending to these components in the face of the masker competition. Under these circumstances, perceived differences in the locations of target and masker can improve the ability to attend to and understand the target message [6-9, 11, 23, 24]. In fact, in these situations, spatial separation can cause extraordinarily large changes in performance that even exceed the effects that have been the focus of traditional study (i.e., changes in the acoustic TMR and the effective TMR). Recent work suggests that this form of spatial hearing advantage arises because a listener can selectively attend to a source from a particular location and ignore a competing source from a different direction.

One final factor that has a large impact on spatial hearing advantages in typical environments is the effect of room acoustics [21, 25-29]. Echoes and reverberation alter nearly all acoustics aspects of the signals reaching the ears (spectro-temporal properties, TMR, binaural cues). As a result, the importance of spatial hearing for spatial unmasking differs in “everyday” environments compared to the anechoic conditions under which many psychophysical tests have been performed. Reverberation and echoes degrade spatial unmasking advantages for many traditional test conditions, but are less detrimental on tasks that involve similar-quality, simultaneous talkers and spatial attention. Further, while existing binaural processing models predict spatial unmasking under certain circumstances (e.g., a speech target in the presence of a steady-state, noise masker in anechoic space), they cannot account for the effects of reverberation on speech intelligibility or spatial unmasking.



In order to gain insight into how spatial hearing influences task performance in everyday listening conditions, it is helpful to consider how sound is processed in the auditory system. The spatial auditory pathway is organized in a very hierarchical manner. Even a cursory consideration of its structure suggests that spatial hearing may influence auditory processing at many different stages of processing, and that the importance of spatial hearing for a particular task depends on the nature of the stimuli being presented and the task being performed. The figure above presents our conceptual framework for understanding how spatial hearing influences the ability to listen to a target in the presence of a masking source.

Spatial separation first influences the acoustic TMR through physical interactions, external to the listener (1). Acoustic information is then analyzed neurally to extract spectro-temporal content in the monaural signals reaching the ears (2). This information is processed binaurally in the brainstem (3). We hypothesize that this low-level binaural processing provides information to two parallel processing stages. In one stage, spectro-temporal content of the signals reaching the listener are grouped into acoustic objects by combining spectro-temporal features of the signals reaching the ears (4). We believe binaural processing contributes to this process by revealing spectro-temporal features of a masked signal that may not be audible in a monaural representation (3)-(4). In the grouping stage (4), cues such as harmonicity, common onset, and other features determine how auditory objects are formed. The resulting grouping rules in turn

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