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Review article

Detrimental noise effects on brain's speech functions

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ABSTRACT

Background noise has become part of our everyday life in modern societies. Its presence affects both the ability to concentrate and communicate. Some individuals, like children, the elderly, and non-native speakers have pronounced problems in noisy environments. Here we review evidence suggesting that background noise has both transient and sustained detrimental effects on central speech processing. Studies on the effects of noise on neural processes have demonstrated hemispheric reorganization in speech processing in adult individuals during background noise. During noise, the well-known left hemisphere dominance in speech discrimination became right hemisphere preponderant. Furthermore, long-term exposure to noise has a persistent effect on the brain organization of speech processing and attention control. These results both stress the importance to re-evaluate which noise levels can be considered safe for brain functions and raise concerns on the speech and cognitive abilities of individuals living in noisy environments.

Contents

1. Introduction

The disturbing presence of noise in modern society is a well-known form of environmental pollution. In daily usage, noise refers to an unwanted annoying auditory input. Almost exclusively, noise is experienced as disturbing, and its effects were shown to be negative in a variety of investigations. In the presence of a weak, subthreshold signal, very soft noise may, however, have a beneficial effect (Moss et al., 2004). This phenomenon, termed stochastic resonance, consists of the enhancement of the information content of a weak signal in nonlinear human-made or natural sensory systems. Such enhancement is more likely to occur in the presence of background noise and in correspondence of the threshold crossings near the peaks of the signal (Moss et al., 2004). In the auditory system, stochastic resonance may improve the detection levels of individuals with hearing aids, because of the energy combination of noise and stimulus (Zeng et al., 2000; cf. also Tanaka et al., 2008; Ward et al., 2001). It is important to note that the optimal noise level necessary to induce stochastic resonance in the auditory system is very soft as it corresponds to the absolute threshold for the noise alone. Otherwise moderate noise typically interferes with detection and identification of a suprathreshold signal. This process is called masking (Moore, 2004). Factors such as the loudness or type of noise, or the personal

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characteristics of the individual contribute to the experienced annoyance of noise. For example, continuous noise is usually less disturbing than noise which includes acoustic variation and loud background noise has generally greater harmful effects both physiologically and subjectively than soft noise (e.g., Kjellberg, 1990; Sperry et al., 1997; Stuart and Philips, 1997). Some individuals are more sensitive to noise than others, which is reflected in their subjective ratings of noise annoyance as well as in neural processing during noise conditions (Pripfl et al., 2006).

Harmful effects of background noise on human health, which have been observed in various kinds of everyday environments (Hessel and Sluis-Cremer, 1994; Tubbs, 1995; Kristal-Boneh et al., 1995; Jones, 1996; Chen et al., 1997; Gunderson et al., 1997; Patterson and Hamernik, 1997), pose a growing problem. The most obvious negative consequence of this ubiquitous presence in some recreational and occupational environments is the noise-induced hearing loss. It was recently estimated to be the second most common sensorineural hearing loss after presbyacusis, and the most diffuse irreversible occupational disease in industrialized countries (Alberti, 1992; Lang, 1994; Prasher, 1998). Noise-induced hearing loss is derived from excessive exposure to high-amplitude sounds and it selectively impairs the high-frequency band that carries the majority of information in speech sounds (especially consonant sounds, which contain higher frequencies than vowels). Probably the severest effects of noise on human health can be observed in the so-called vibroacoustic disease (VAD), which can result from long-term presence of loud (above 90 dB SPL) low frequency (below 500 Hz) noise in some occupational settings (for a review, see Castelo Branco and Rodriguez, 1999). Clinical manifestations of VAD involve abnormal behaviors, such as irritability and depression, visual, auditory, and balance disturbances, epileptic seizures, and stroke-like neurological deficiencies. Other main physiological and blood circulation changes such as increased blood pressure and arterial hypertension may also be present in this pathology.

The detrimental physiological effects of high-amplitude noise, causing both functional and structural changes, have been investigated intensively. However, according to recent evidence, even soft-intensity suprathreshold background noise may adversely affect brain function. For instance, background noise in some situations and for certain kinds of individuals may considerably interfere with speech perception. Furthermore, exposure to long-term noise may have persisting effects on brain function and behavior even when the peripheral hearing is intact. We will here review the literature concerning short- and long-term background noise effects on brain processes underlying auditory, and particularly, speech perception.

2. Noise effects on speech processing in various groups of individuals

Both behavioral and brain indices have shown that speech sounds become less discriminable by increasing levels of noise. For example, the hit rate in discriminating syllables /ba/ and /da/ became lower when the background broadband noise level was increased (Martin et al., 1997; Muller-Gass et al., 2001). In evoked brain potentials associated with sound discrimination this effect was reflected as diminished response strengths and slowed processing. Muller-Gass et al. (2001) found that increasing noise level also diminished the amplitude and prolonged the latency of the syllable change elicited mismatch negativity (MMN), which is a pre-attentive cortical discrimination response, elicited 150–250 ms from sound change onset (Näätänen et al., 1978; Näätänen, 1990; Näätänen and Winkler, 1999; Kujala et al., 2007). Neural responses following the MMN when the subject identifies a change in sound stimulation, the N2b and P3 (Donchin and Coles, 1988; Novak et al., 1992; Näätänen et al., 1982; Sutton et al., 1965; Escera et al., 2000), were also found to be diminished and delayed for syllable changes by increasing levels of noise (Martin et al., 1999). Thus, noise affects the early cortical sound discrimination and the following sound identification processes, impairing the perception of sound differences.

For some specific groups of individuals these background noise effects cause overwhelming obstacles in speech perception. For example, hearing-impaired individuals perform worse than normal-hearing individuals in noise in discriminating speech sounds that they can hear without problems in silence (Suter, 1985; Nabelek, 1988). Speech-sound identification is thought to be primarily hampered in these individuals because of the masking effects of noise on the formant transitions and due to time smearing in reverberation. Hearing-impaired listeners require a larger amplitude difference between spectral peaks and troughs for vowel identification as compared to normal-hearing listeners (Leek and Dorman, 1987).

Even when the whole neural apparatus involved in speech perception is intact, background noise may greatly affect speech perception. This situation is faced by individuals using a foreign language. While speech recognition in silence may be equally good in non-native and native speakers, native speakers outperform non-native speakers in degraded listening conditions (Takata and Nabelek, 1990; Nabelek and Donahue, 1984). This has been observed for adverse listening conditions including a babble of voices (Takata and Nabelek, 1990) or room reverberation (Nabelek and Donahue, 1984).

Throughout the normal human development, changes take place in the tolerance of background noise in auditory perception. Hearing becomes increasingly compromised in the advanced ages. Partly this is explained by changes in the cochlea, but even the elderly with a normal audiogram have more difficulties in understanding speech in noise or reverberation conditions than young normal-hearing adults (Nabelek and Robinson, 1982; Nabelek, 1988; Frisina and Frisina, 1997). This suggests auditory brainstem or auditory cortex dysfunctions in temporal processing at the advanced ages (Frisina and Frisina, 1997).

Like the elderly, also children suffer from greater effects of background noise on speech perception than adults (Johnson, 2000). Children need higher sound pressure levels than young adults to obtain maximum scores in word identification (Nabelek and Robinson, 1982). In general, understanding of simple monosyllabic nouns or spondees improves in noise as a function of increasing age (Elliott, 1979).

It has been found that typical acoustic conditions in classrooms do not permit adequate speech recognition (Yacullo and Hawkins, 1987). During both reverberant conditions and multitalker babbler children's sentence repetition is considerably impaired. Comparisons of noisy and relatively quiet school environments have shown a clear detrimental effect of background noise on various physiological, cognitive, and academic-skill measures (Evans et al., 1995,1998; Maxwell and Evans, 2000). The effect of a noisy background on pre-school children's language and pre-reading skills was evaluated by installing sound absorbent panels (Maxwell and Evans, 2000). It was found that after the installation, the children in this environment performed more accurately than matched children in noisy classrooms in pre-reading skills requiring recognition of numbers, letters, and simple words. The children in the quieter conditions also received higher subjective ratings of language skills by their teachers than children in noisy conditions.

Background noise impairs speech perception even more in children with learning disabilities than in their normally devel-