MIDDLE EAR STAPEDIUS MUSCLE ACOUSTIC REFLEX AND LARYNGEAL AMPLITUDE RESPONSE*

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1. Introduction

This study describes the ascending auditory pathway of the middle ear stapedius muscle acoustic reflex. The purpose is to localize the reflex's role in transmitting complex speech sound, specifically, resonant and prosodic elements — stress and syllables — produced in the laryngeal-pharyngeal region of the vocal tract. The corresponding acoustic components are amplitude and intensity. The processing locale of these speech elements apparently differs from that of segment processing which occurs in the peripheral auditory system. Acoustic and psychoacoustical data[1,4] suggest a system which, in addition to the peripheral auditory system, operates in sound identification; moreover, this system creates some form of representation of the laryngeal and prosodic elements in the human speech signal.[3] These observations are summarized here in reference to selection for a laryngeal and prosodic inventory in natural language.

Stevens asks how constraints imposed by the auditory system shape the inventory of sounds used in language. A second question, beyond this paper's scope, is how auditory processing imposes a classificatory structure on the phonetic sounds of language. The present, informal study contributes to deriving a system of non-peripheral bioacoustic constraints on the auditory representation of language.

2. Rapid change in the spectrum and its amplitude characteristics

Production of laryngeal-pharyngeal complexity occurs in the posterior region of the vocal tract, at/near the larynx. In addition to the resonant low-frequency spectral energy, and within a 50msec duration, this segment may contain periodicity within the same spectral region due to vibration of the vocal cords.[2] The rapid spectrum change which occurs corresponds to a consonantal sound produced with a narrow constriction along the midline of the vocal tract.[3]

In an utterance containing a laryngeal-pharyngeal consonant segment, rapid-spectrum change occurs at the segment's onset in the low-frequency area corresponding to an articulatory movement from relative constriction into that of vowel production, an unconstricted vocal tract;[3:64] rapid decrease in the first formant accompanies a decrease in the size of the constriction in the oral cavity.

There also may be an abrupt rise (or fall) in an utterance's amplitude; this if it occurs is independent of any spectral change. The class of speech sounds in effect are *interrupted* segments, mainly stops but also affricates and resonants. Studies remain inconclusive over whether there is a natural perceptual boundary when this relative amplitude, i.e., interrupted segment reaches a particular value; or, whether some other acoustic attribute forms the primary cue for distinguishing, for example, nasal resonants from stop plosives.[3:69]

Pharyngeal resonants occurring at syllable onsets and relative to stressed vowels are comprised of a relatively low first formant (200-600Hz) and within that a low db; nevertheless the amplitude energy and changes in that are present throughout the spectral range present during the pharyngeal's production. Difficulties arise in defining the perceptual effects acting on amplitude characteristics within the 200-600Hz frequency range. For example, rise-time is indeterminant; amplitude gain and slope are not measured psychoacoustically. Though conservation of amplitude gain can be resolved linguistically in laryngeal segmental and prosodic categories, e.g. syllable and stress, formal work is required in the parameterization and accompanying measurement of the amplitude change, i.e., amplitude gain, in the low-frequency spectrum. Further, how the amplitude is managed and its energy conserved is unclear, though there are suggestions of a transformation and significant diversion from the peripheral pathway.[1,3]

3. Peripheral System

The lower brain stem auditory pathway is a system of olivocochlear efferent tracts in a bundle, (OCB). It responds to phonetics segments, discriminating in terms of instant-by-instant speech perception. However, the response is not constant to adjacent pairs of phonetic sounds differing only by a fixed, specified distance along an acoustic dimension defined by a phonetic category, i.e., a limited acoustic range of stimuli. Responses are unpredicted by the physical quanta; they correspond instead to linguistic features — that is, natural classes of segments. This linguistic-perceptual disparity is unexplained by the OCB and its related responses.[1,3]

The OCB efferent system has an influence on the cochlea's response to sound. Further, the acoustic middle ear reflexes comprised of the stapedius (St) and tensor tympani (TT) muscles are important regulators of the auditory input to the cochlea. Relations between the middle ear reflexes — in particular, the St — and the OCB appear non-monotonic however, though it is widely held that the acoustic middle ear reflexes constitute one of the feedback loops controlling activity throughout the afferent auditory system.[1:101] The response to each of these as registered in the cochlear is nonlinear;[2,3] also, as described above, psychoacoustical data show the lack of a constant in subjects' ability to discriminate ordered pairs of phonetic categorical stimuli.

The following paragraph is from Borg's description of the stapedius reflex pathway.[1:115-9] The first neuron — the primary acoustic neuron from the haircells to the cochlear nucleus (CN) — synapses with the second-order neuron. This the first synapse of the St reflex pathway and is situated in the ventral cochlear nucleus (VCN). For pure tones, the dorsal cochlear nucleus (DCN) and posteroventral nucleus' neurons are not involved in the reflex. No primary fibres pass the cochlear nucleus (CN) in the trapezoid body (TB) to higher centres (in the auditory cortex), therefore, the VCN is the only possible location of the first synapse.

The second neuron passes in the TB and has contact directly with the ipsilateral St motoneurons in the nucleus of the facial nerve VII, (Nc7). Via interneurons in, or near, the medial superior olive (MSO), the second neuron relays to the third neuron, to the ipsi- and contralateral facial nucleus, Nc7. The 3rd neuron and the 4th, the motoneuron in Nc7, follows the facial nerve to the St in the middle ear.

There is no indication that the stapedial reflex, which in effect regulates sound transmission to the cochlea, occurs on a pathway directly between the auditory cortex and the cochlea, i.e., the peripheral auditory system. In fact, the facial nerve innervates the St. The observations point to the involvement of another system.[1,4] This system which may operate temporally as a parallel process to that occurring along the pathway in the OCB is similar to the OCB due to its function as an inhibitor. This, as Borg demonstrated could be the extrapyramidal system.[1] This, more so than the descending auditory system, may be involved in co-activating the middle ear muscles found in a number of motor reactions such as vocalization and body movements.[1:119]

4. Non-peripheral System

The extrapyramidal system might at best be derived formally.[5] Here, its description is preliminary only, from data on systematic observations. First, that cochlear potentials, in guinea pigs under light anesthesia, were changed in magnitude at the moment of a "spontaneous contraction" of only the TT (tympanic) muscle's reflexes. The change was greatest for low tones, and in the region of 100Hz amounted to a reduction of 35 to 40 db, with the reduction becoming progressively less as frequency was raised (to 0 db at about 1kHz). Further, transmission was enhanced from 1.3 to 1.8kHz (4 db @ 1.5kHz) and there was no effect at 2+kHz.[4] Wever & Bray, cited in the same study, experimenting on the cat, but on the stapedius muscle, indicated similar systematic changes in sound transmission, i.e., the cochlea potential changed as a result of tension in the normal direction of action on the tendon of the stapedius muscle. A new design corrected for the reduction in transmission being the result of a damping action by the muscle, more-so than as an effect of tension, i.e., neurological inhibitory action; excitation slightly above the threshold for each the TT and St reflex showed a reduction in the transmission of low tones, but with the reduced effect diminishing progressively and disappearing at around 600 Hz and enhanced between 600-1000Hz. A present concern is whether the spectrum's amplitude component and any gain at the slightly above-threshold intensities and in the low frequency range from 200 to 600 Hz is managed and conserved by the non-peripheral system. As mentioned, the amplitude change in this range is resolved linguistically, in feature detection according to natural classes of resonants (vs. stops) and in syllable and stress structure.

5. Concluding remarks

Conservation of the amplitude slope in the ascending, not only the lower brain stem auditory pathway is a problem of sound identification. The problem also arises in binaural localization using cues of interaural time and intensity differences. After Borg, it is likely that the lower brain stem organization of somamotor reactions to sound can be studied best as a function of the middle ear reflex system, e.g. the pathways at the VCN and the SOC, at least when pure tones are used as stimuli. With respect to complex stimuli and monaural localization, higher auditory pathways are involved.[5] In terms of sound transmission for identification, on the other hand the middle ear muscles and specifically the stapedius muscle is less connected to the descending auditory system than is generally assumed and appears more related to the extrapyramidal, non-peripheral system.

6. Notes & References

* Support for this research by the Strathy Language Unit, Queen's University, Kingston and by the American Philosophical Society, Phillips Fund is gratefully acknowledged.

1. Borg, E. 1973. "On the Neuronal Organization of the Acoustic Middle Ear Reflex. A Physiological and Anatomical Study," *Brain Research* 49:101-123.
2. Orser. 1992a,b; 1993. "Application of *FIR* Digital Filters ..." *Canadian Acoustics* 20:9-10,"'FIR' Digital Filter Modelling of Linguistic Pharyngeals Transmission ..." *Working Papers of the Linguistics Circle* (U Victoria), 11:133-42; Thesis, U Victoria, Canada.
3. Stevens, K.N. 1983. "Constraints Imposed by the Auditory System ... Data from Phonology, Acoustics and Psychoacoustics," in, T.Meyers, et al. (eds), *The Cognitive Representation of Speech*, New York: North-Holland 61-74.
4. Wever, G.& J. Vernon 1955."The Effects of the Tympanic Muscle Reflexes Upon Sound Transmission," *Acta Otolaryngology* 45:433-39.
5. Zakarauskas, P. & M. Cynader (1993) "A computational theory of spectral cue localization," ms., Victoria.