

THE aim of this study was to investigate the human peripheral auditory system in either ear to allow comparison of right and left medial olivocochlear inhibition during contralateral ear stimulation with a broad band noise. The efferent system showed a statistically significant greater right-side activity among 44 young subjects. This laterality appeared to be related to the presence of spontaneous otoacoustic emission but not to gender. This efferent asymmetry and the parallel spontaneous otoacoustic emission asymmetry could explain the lateralization of auditory sensitivity, temporary threshold shift and tinnitus.

**Key words:** Right ear prevalence; Efferent system; Spontaneous otoacoustic emissions

## Functional asymmetry of medial olivocochlear system in humans. Towards a peripheral auditory lateralization

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### Introduction

The results of neuropsychological studies have established that the left superior and middle temporal gyrus are the brain regions involved in language perception.<sup>1</sup> During phonological tasks, activation of the left inferior frontal gyrus regions is highly lateralized in males, but not in females.<sup>2</sup> Moreover right-left asymmetry and a difference in degree of lateralization between males and females have been noted at the central level for language recognition and for sound perception: in particular, the mean amplitude of wave III (auditory brainstem response) is larger when the right rather than the left ear is stimulated.<sup>3</sup>

However, there is also evidence for a peripheral lateralization of the auditory system as well as for the existence of a sex difference in the auditory periphery. Indeed, it seems that tinnitus more often affects the left than the more sensitive right ear.<sup>4</sup> Moreover, the average temporary threshold shifts (TTS) seen after binaural exposition to symmetrical broad-band noise for a maximum of 8 h are higher in the left than in the right ear, this difference being statistically indicative.<sup>5</sup>

This greater hearing sensitivity in females and in right ears appears to parallel the abundance of spontaneous otoacoustic emissions (SOAEs) found in females and in right ears in both adults and full-term neonates.<sup>6</sup> McFadden's hypothesis for both asymmetries is that the strength of the efferent influence on the right ear is less than that on the left ear, and less in females than in males.<sup>7</sup> One means of testing this hypothesis would be to measure medial

olivocochlear (MOC) activity in the left and right ears. MOC activity can be assessed non-invasively through the contralateral attenuation of evoked otoacoustic emissions (EOAEs).<sup>8</sup> The present study aimed to investigate MOC system activity in both ears in young subjects, according to gender and SOAE prevalence, in order to compare the right and left peripheral auditory systems.

### Materials and Methods

**Subjects:** The study involved 44 right-handed subjects (age 19–29 years, mean 22.18), 22 male and 22 female, with no history of auditory pathology and with normal audiometric functions (< 20 dB loss between 250 and 8000 Hz per octave on pure tone audiogram). Half of the subjects in the sample presented SOAEs. Their laterality quotient<sup>9</sup> was positive and the dichotic listening test,<sup>10</sup> performed with a list of words, indicated a greater mean performance of the right ear for word repetition, and no central pathology.

All recordings were performed in a sound-proof room, for both ears of the subjects.

Tonal audiometry was conducted using a Madsen OB822 clinical audiometer. Hearing thresholds were measured at 250, 500, 1000, 2000, 4000 and 8000 Hz.

The Edinburgh Handedness Inventory<sup>9</sup> contains 10 items (activities) for which subjects indicate preference in their use of hand: a strong preference for one hand or no particular preference. The procedure enables a laterality quotient to be calculated.

For SOAE recordings, the ear canal sound pressure

was measured by a low-noise microphone system (Etymotic Research, ER 10-B). The probe was fitted into the external ear canal via an adaptable plastic earplug. The signal was then delivered to a low-noise preamplifier (Etymotic Research) before being sent to a high-resolution signal analyser (Hewlett Packard 3561A) for fast Fourier transform (FFT). The FFT of the acoustic signal was carried out over a frequency span from 0.5 kHz to 8 kHz in steps of 1000 Hz. Ten sweeps were averaged. Whenever a reproducible frequency peak was found recordings were repeated with a 200 Hz span centred on the frequency peak, in order to confirm the presence of the SOAE and to measure precisely its amplitude and frequency. This method has been precisely described in a previous study.<sup>11</sup>

EOAEs were recorded following the method developed by Bray and Kemp,<sup>12</sup> which consists of measuring ear-canal sound pressure variations consecutive to a transient stimulation. The measurement system is composed of an AT286 computer connected to a D/A card, delivering stimulation to the ear canal and recording the subsequent so-called cochlear responses, through a probe equipped with an electric-to-acoustic transducer (BP 1712) and a miniaturized hypersensitive microphone, both embedded in a plastic ear plug. Stimulus presentation, data recordings, averaging and spectrum analysis were carried out using the Otodynamics ILO88 software. The stimuli consisted of clicks of 80  $\mu$ s duration; the click rate was 50 Hz. A total of 300 cochlear responses were averaged for an analysis time of 20 ms.

In order to assess medial olivocochlear feedback in each subject, a stimulus-equivalent attenuation procedure was employed.<sup>8</sup> EOAEs were recorded in each of the two ears, successively with and without a 30 dB-SL broad-band noise stimulation in the other ear. Five different intensities, ranging from -21 to -9 dB gain in 3 dB steps, and presented in random order, were used for the ipsilateral stimulation. The equivalent attenuation (EA) was then calculated as the attenuation of ipsilateral stimulation equivalent to the effect seen with a 30 dB SL white noise contralateral stimulation.

**Statistics:** Comparisons between right ear (RE) EA and left ear (LE) EA were performed using a paired *t*-test or the Wilcoxon T test.

## Results

**EOAE contralateral suppression:** Figure 1 shows RE and LE EA means for 44 subjects. EOAE contralateral suppression was higher in RE than in LE and this difference between the two ears was statistically significant (Wilcoxon T test:  $p \leq 0.01$ ).

Figure 2 shows EA means in RE and LE as a

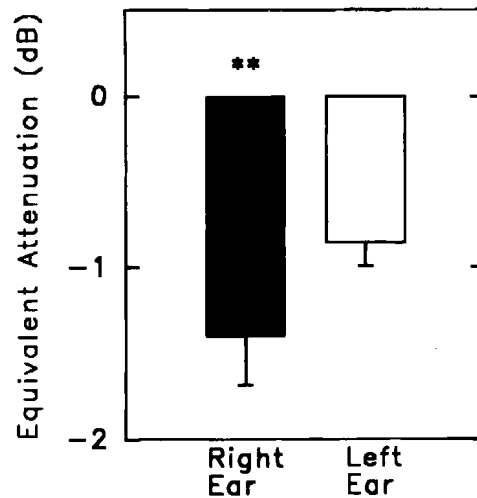


FIG. 1. Mean EA ( $\pm$  s.e.) for each ear of 44 subjects. \*\* $p < 0.01$ .

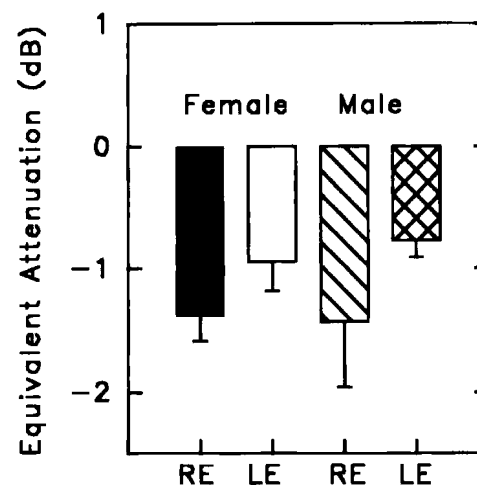


FIG. 2. Mean EA ( $\pm$  s.e.) for each ear of 22 females and 22 males.

function of sex. In females, RE EA was greater than LE EA (Wilcoxon T test:  $p = 0.06$ ). In males, a similar tendency for EA to be greater in RE was found and was also statistically non-significant (Wilcoxon T test:  $p = 0.06$ ).

**EA in subjects with or without SOAE:** Figure 3 shows EA means in both ears for SOAE producers and SOAE non-producers among the 44 subjects. The highest difference between EAs for the two ears EA was found among individuals emitting SOAEs (Wilcoxon T test:  $p < 0.01$ ). In subjects without SOAEs, there was no statistical difference between RE and LE EAs (Wilcoxon T test: non-significant).

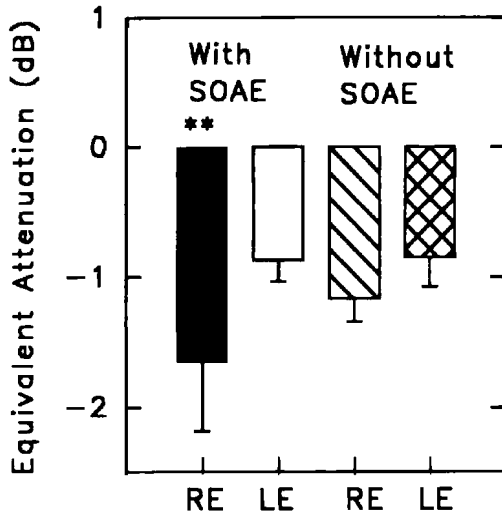


FIG. 3. Mean EA ( $\pm$  s.e.) for each of 22 subjects emitting SOAEs (11 males and 11 females) and 22 subjects without SOAEs (11 males and 11 females). \*\* $p < 0.01$ .

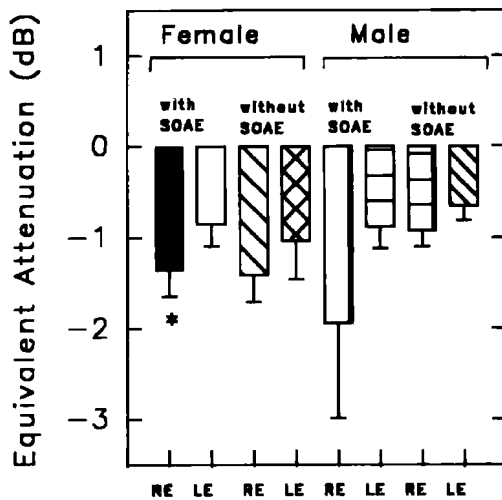


FIG. 4. Mean EA ( $\pm$  s.e.) for each ear of 4 groups of 11 individuals: females with and without SOAEs and males with and without SOAEs. \* $p < 0.05$ .

Therefore, the presence of SOAEs is associated with a RE contralateral inhibition prevalence.

Figure 4 shows EA means in RE and LE in females and in males with and without SOAEs. Females and males with SOAEs both showed smaller LE than RE EAs. The difference was significant in females ( $p < 0.05$ ,  $t = -2.36$ ) and indicative in males. The non-significant RE predominance (68.18% of females and males), equally distributed in females and in males, might become significant with bigger samples. In the absence of SOAE the difference between the two ears was statistically significant in neither males nor females. In summary, the functional activity of the

MOC system proved to be greater in RE, both in the whole sample and in the group emitting SOAEs. Difference between right and left peripheral auditory systems through the medial efferent system clearly appeared and was more marked when SOAEs were present. This difference appeared to be slightly more pronounced in females than in males.

### Discussion

*Peripheral auditory lateralization and SOAEs:* In the present study, the MOC system appeared to be more functional in RE than in LE for all the tested population, the same tendency being found among females and males. There was no significant gender difference in medial efferent lateralization. These results, as those of previous study,<sup>7</sup> indicate peripheral auditory system lateralization in medial efferent fibre functioning. However, contrary to McFadden's hypothesis, the strength of the efferent influence on the RE appeared to be greater than that on the LE. This efferent asymmetry may be understood in terms of a parallel with the suggested functional role of the MOC system (improvement of sound perception in noise<sup>13</sup>) and the greater sensitivity of the RE, together with its lesser susceptibility to noise damage (tinnitus, TTS). Indeed, it has been suggested that the medial efferent system may initiate or regulate a slow contraction of the outer hair cells (OHC)<sup>14</sup> and thus regulate EOAE amplitude. This could help reduce OHC fatigue, particularly during the intense sound exposure of TTS experiments. Indeed, in Pirila's study,<sup>5</sup> LE TTS was slightly higher than RE TTS. The RE may be better protected against noise damage than the LE by greater efferent inhibition.

On the one hand, the MOC system was more functional in RE for the whole sample; on the other, the difference between RE and LE EA was more marked in individuals emitting SOAEs. A link may thus exist between the greater RE contralateral suppression and the more frequent presence of SOAEs in this ear. McFadden's hypothesis was based on this likely link: he suggested that the resting inhibition of the MOC system, especially at high frequencies, could explain SOAE prevalence at low frequencies. In that case, the efferent suppression as well as resting inhibition should be better in the LE, where SOAEs are less frequent. This hypothesis was not confirmed by the results of the present study, which indicated a greater contralateral suppression in the RE, in which SOAEs are more abundant.

These results may suggest a new model. It is possible that the resting inhibition of the MOC system, not being regular along the cochlea, establishes an activity contrast between inhibited and non-inhibited OHCs. Near a zone of OHCs inhibited by the efferent system at rest, OHCs could contract and

cause SOAE emission. The greater the resting inhibition the greater the SOAE frequency. Moreover, according to the proposal that the greater the efferent input the greater the resting inhibition, SOAEs would be more present when the resting inhibition of the MOC system and its activity were strong. Thus, the peripheral auditory system asymmetry consisting of the prevalence of the MOC system in the RE could be linked to SOAE prevalence in the RE.

**Methodological aspects:** Methodology needs to be discussed as the presence of SOAEs might appear to be a technical bias in this study rather than as an argument for a link between the MOC system and SOAEs. Indeed, it might be thought that, when SOAEs are emitted, the EOAEs collected would square with the addition of EOAE and SOAE intensities. Thus, the straight line of click stimulation intensity as a function of EOAE response intensity (input/output function) would be flatter in case of SOAEs. Consequently, for a given intensity of click stimulation, the EOAE curves with and without contralateral stimulation would be more widely separated and thus show greater EOAE intensity difference. Therefore, in the RE where SOAEs prove to be prevalent, the difference between EOAE intensities with and without contralateral broadband noise stimulation would increase, as would the absolute value of the EA. SOAE presence would flatten the two lines used to calculate the EA and would thus increase the efferent inhibition value, simply due to a technical bias in calculation.

In point of fact, however, using a different method of calculating efferent inhibition, such as the euclidean distance<sup>14</sup> between two straight lines, the same tendencies were found as with the EA method.

Moreover, in three subjects emitting SOAEs only in the LE, MOC activity was greater in the RE. Thus,

the presence of SOAE in the left ear was not related to greater efferent inhibition. Despite the small sample of individuals with only left SOAEs, this argument against an SOAE bias may nevertheless be suggestive.

## Conclusion

The central superior lateralization of speech perception in males did not clearly show up in the auditory periphery, where almost equal efferent asymmetry between sexes was found. This study has shown a parallel between greater RE MOC inhibition and RE predominance of SOAEs. Indeed, MOC inhibition may account for the presence of SOAEs. This investigation of efferent bundle functioning supplies a new argument in favor of the physiological importance of this structure and its possible role in SOAE emission. The RE prevalence in hearing sensitivity and LE prevalence of TTS and noise damage seem to parallel a preponderantly RE protective effect of the MOC system. However, medial efferent fibres will need to be further investigated to confirm these results and to explain such physiological asymmetry.

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### General Summary

Unlike handedness and eye dominance, the existence of peripheral auditory lateralization has not previously been clearly demonstrated. In order to address this question, we studied the activity of the medial olivocochlear efferent system in human subjects. The function of this efferent system remains unclear, but could be to protect the ear against noise damage and to improve sound perception in noise. A RE prevalence of olivocochlear bundle functioning was observed in both males and females. This peripheral auditory asymmetry was mainly found when low and middle frequency inaudible sounds, called spontaneous otoacoustic emissions, were emitted by the subjects' ears. Thus, a relationship between right efferent system predominance and right spontaneous otoacoustic emission predominance is suggested. These results lead to a new conception of ear asymmetry and auditory lateralization.