# Enhanced Modiolar Stimulation Effects in the Inferior Colliculus.

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*Abstract*- **This preliminary study quantifies and provides one explanation for the extent of modiolar stimulation observed as a function of current level as recorded in a population of Inferior Colliculus units. . The Inferior Colliculus units were driven by scala tympani bipolar charge balanced stimulation**.

*Keywords:* **Cochlear Implant, Inferior Colliculus, Modiolar Stimulation**

## I. Introduction

Cochlear implants are used to provide hearing sensation to the sensoneurally deaf. Bipolar electrical stimulation of a scala tympani cochlear implant produces a localized stimulus which has been measured to diminish at about 9dB/octave [1].

Blamey et al. (1994) describes both a perceived low frequency shift by cochlear implant patients in response to high stimulus levels and a perceived lower pitch for place of electrical stimulation when compared with acoustic stimulation on the opposite side. Modiolar stimulation is likely the cause. Frijns (1995) and Briaire (2000) have modeled the field excitation patterns for scala tympani bipolar electrical stimulation and predicted excitation of the modiolus at higher current levels.

This preliminary study aims to quantify and explain the extent of modiolar stimulation as a function of current level as recorded in a population of IC units driven by scala tympani bipolar charge balanced stimulation.

## II. Methodology

Cats (2-4kg) were anaesthetized with Ketamine$^{TM}$ (40mg/kg, i.p) and RompunTM (30mg/kg, i.p). The anaesthetic level was maintained by supplementary doses of Nembutal (5-10mg/kg, i.v). Feline versions of the multichannel bipolar Melbourne/Cochlear scala tympani electrode array were implanted into a Neomycin$^{TM}$ deafened cochlea. The contralateral cochlea was Neomycin deafened, implanted and electrically stimulated whilst the ipsilateral cochlea was left intact. A craniotomy was carried out rostral to the tentorium, and the inferior colliculus exposed by aspirating the overlying occipital lobe. Recording microelectrodes were placed in the inferior colliculus. Stimuli were 40ms bursts of biphasic charge balanced (l00µs/phase) electric pulses (250 pulses/s). Electric stimuli were presented as pulse trains at constant current levels.

Unit threshold was established. If no driven response was detected at a particular current level the current was increased in 1 dB steps up to a maximum of 2.5mA. If a driven response was detected the current level was decreased in 1 dB step to establish response threshold. At each threshold point the measurement was repeated until two reproducible threshold values were obtained. Threshold determining stimuli were bursts of electric pulses or a single electric pulse. The firing rate in the interval 0-120 ms post stimulus onset was compared with the firing rate in the 120 ms prior to stimulation. These firing rates were summed over the 10 bursts in each stimulus packet. A driven response was defined, either as a 10 % increase in firing in the driven interval compared to the non driven interval or, for very low or zero spontaneous rate units, an increase of 5 spikes per stimulus packet for the driven region as compared to the non driven region of the response. For a small number of units the automated program failed. In such cases a manual procedure, based on a visual assessment of an increase in firing rate, was used. Automated threshold measurements were checked manually for each unit and recorded to an accuracy of $\pm$1 dB respectively.

The care and use of animals reported on in this study were approved by the University of Melbourne Animal Experimentation Ethics Committee and the Royal Victorian Eye and Ear Hospital Animal Research Ethics Committee.

## III. Results

Figure 1 upper plot shows as a function of stimulus level the number of contralaterally electrically driven units (n=66), expressed as a fraction of the control acoustic population in each bin, versus their CF. Stimulus level is measured as a dB attenuation re a 2.5mA current level. Electrodes were located in the 2-5kHz bin. For attenuation levels less than 12dB there is evidence of modiolar stimulation in the 0.5-1 kHz CF bin. The contralateral acoustic plot was obtained from 116 IC units recorded using contralateral acoustic stimulation of an intact cochlea. For electrical stimulation there is a relatively localized stimulation from threshold up to 6-9dB of attenuation (with some localized modiolar stimulation). At higher stimulus levels most IC units representing most of the cochlea or its projections are being driven by either modiolar stimulation or by stimuli local to the electrode pairs.

Figure 2 shows, compared acoustic unit type distributions, there is a new sharp peak (0.5-1 kHz bin) in the electric driven EO unit CF distribution. Each peak corresponds to the immediate cochlear turn above the stimulating electrode pair.

## IV. Discussion

There are short distance relatively low impedance current paths, for example, via the habena perforata from the stimulating electrodes to the modiolus in which are located spiral ganglion cells from lower CF upper turns of the cochlea (Figure 3). In the

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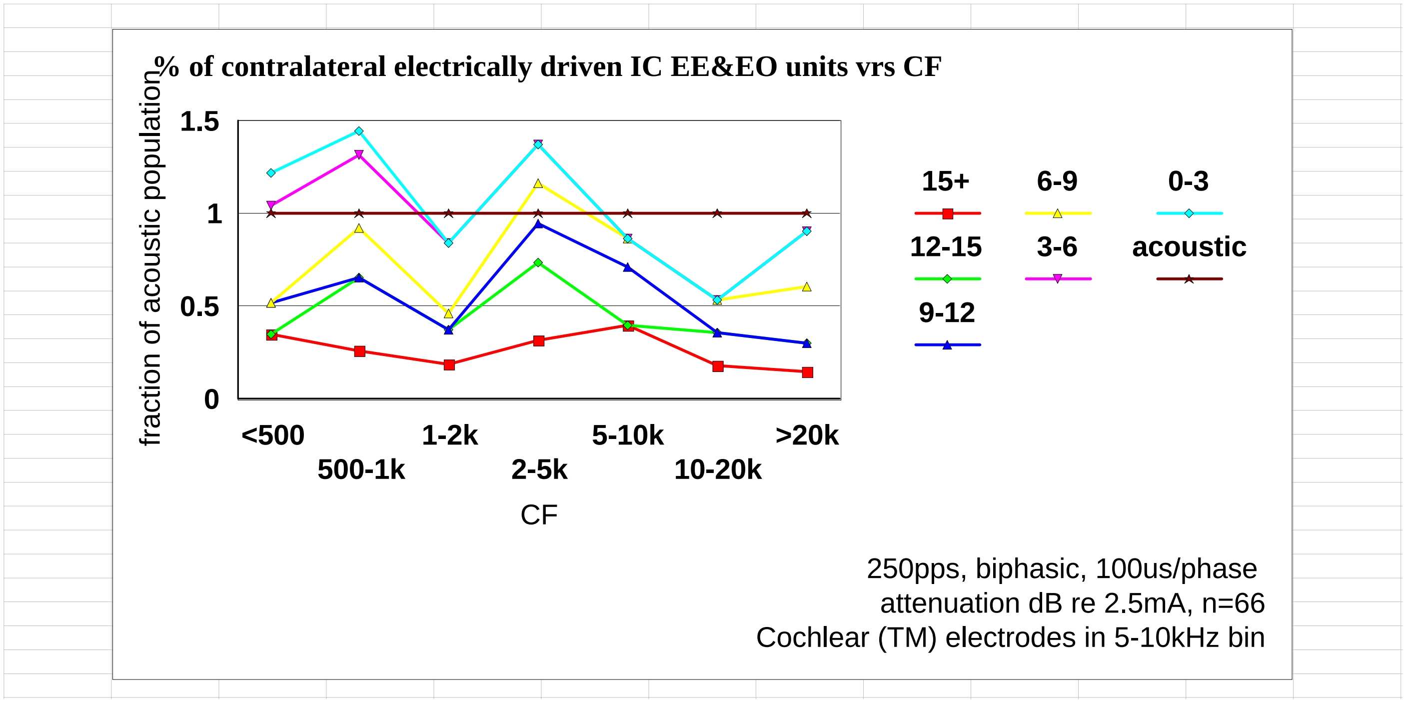


**Figure 1** shows the number of units expressed as a population percentage (n=66) of contralateral driven units that showed a driven response to the applied electrical stimulus versus their CF.

modiolus the spiral ganglion cells of the immediate cochlear turn above the stimulating electrodes are nearest the stimulating electrodes [5]. If modiolar stimulation was responsible for generating a driven response from low CF units, cochlear implant patients would note a low frequency shift at high current levels, the average latency of these low CF units might be shorter than middle to high CF units and, for electrically driven units, theremodiolar stimulation evoked peak in the unit distribution as a function of CF. This peak should correspond to the immediate cochlear turn above the stimulating electrode pai
r. All these observations are seen in figures 1 and 2 and from Blamey et al. [2] and Lithgow [8].

Why is there an apparent enhanced response to electrical stimulation when compared to that evoked by acoustic stimulation proximal to the electrodes and at the site of peak modiolar stimulation (figure 1)?

Silverman and Clopton (1977) suggest that the relative efficacies of ipsilateral and contralateral projections to the IC are mediated by acoustic activation and established on a competitive basis. In a monaurally deafened situation the spontaneous input would be lower from the deafened side. This may result in the unit becoming more depolarised prior to stimulat
ion (ie. a pre-stimulus threshold shift). Möller (1995) proposes a

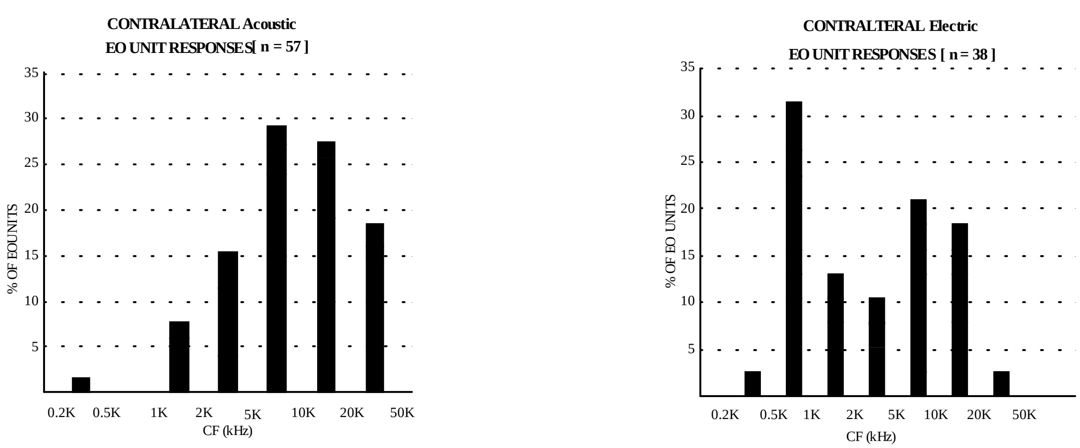


**Figure 2.** Plot of acoustic driven EO unit population versus CF (left) and contralateral electric driven EO unit population versus CF (right).

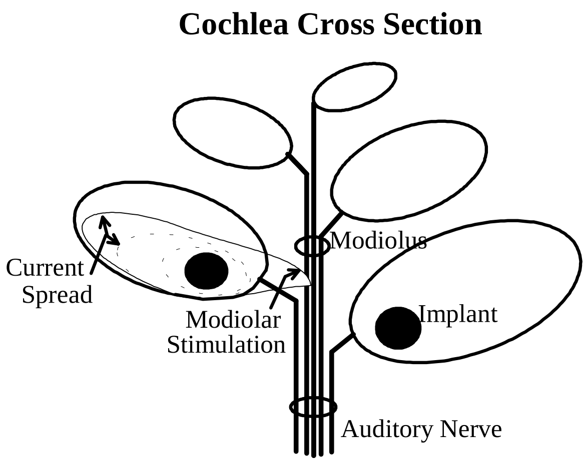


**Figure 3.** Diagram shows the anatomical relationship of the modiolar fibres of upper turns to the site of electrical stimulation. The diagram is a diagramatic representation of the spread of current to the modiolus at various increasing stimulus levels.

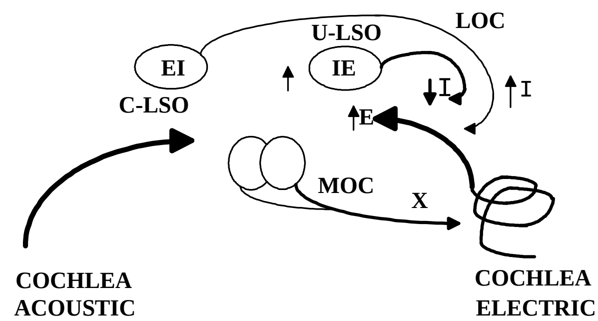


**Figure 4.** The proposed superior olive efferent influences prior to stimulus onset. Unit types are EI (crossed) or IE (uncrossed). {Arrows above projections indicate either an increase or decrease in inhibitory (I) influence on outer hair cells for medial olivocochlear projections (MOC) and on afferent fibres projecting from the cochlea in the case of lateral olivocochlear projection (LOC). The C-LSO and U-LSO are respectively the crossed and uncrossed Lateral Superior Olives. The overall effect on the excitatory (E) afferent ascending projection is shown.

similar model. This may mean a "weak" excitatory stimulus normally unable to evoke an excitatory response might be capable of doing so.

There is a body of evidence that supports the concept of a pre-stimulus threshold shift [6], [12]. Keeping in mind the fundamental difference between neonatal cochlear ablation and neomycin deafening, the Kitzes and Semple (1985) study showed

An alteration in the spontaneous rate of units underlies the concept of pre-stimulus threshold shift. However, spontaneous rates are low in anaesthetised compared to non anaesthetised a nimals [9], [10] and may be even low er for inhibitory compared to excitatory inputs [11]. Consequently, caution must be exercised before adopting the pre-stimulus threshold shift hypothesis. This issue is addressed below by considering the mechanism of pre-stimulus threshold shift.

An ICC unit pre-stimulus threshold shift could be mediated locally, on a competitive basis, by inputs to the ICC unit [7]. These inputs can be effected by efferent feedback paths. Most efferent fibres in the olivocochlear bundle originate in the medial and lateral ovilocochlear regions [13]. These fibres are believed to have inhibitory terminals on the bases of outer hair cells and on the dendrites of afferent Type I spiral ganglion cells respectively [13], [14]. Liberman and Brown (1986) have shown 89 % of their sample (predominantly monaural units) of medial olivocochlear efferents had zero spontaneous rate. This lack of spontaneous activity means medial olivocochlear efferents are unlikely to play a major role in facilitating a pre-stimulus threshold shift upon outer hair cells. (The electric stimulus bypasses this inhibitory effector). In contrast lateral superior olive units (Figure 4) are predominantly IE (ipsilateral) or EI (contralateral) and have a robust spontaneous discharge in decerebrate cats (Brownell, 1979). Compared to C(acoust)I(acoust) stimulation, for contralateral or ipsilateral electric stimulation with the opposite side intact (Figure 4), the crossed lateral superior olive, as a result of the reduction in relative spontaneous rate to the inhibitory input of its EI units could output a stronger inhibitory projection onto afferent fibres prior to stimulus onset. Similar arguements suggest the inhibitory effects of the dominant ipsilateral lateral superior olive efferent projection on afferent cochlear projections may be diminished. The overall result will be a slightly reduced inhibitory influence on afferent cochlear projections. This may mean a lower stimulus level may be required to evoke an excitatory response and this may be reflected as a less inhibited response for ICC units receiving input from these projections.

Why is there an apparent reduced response to electrical stimulation when compared to that evoked by acoustic stimulation basal to the electrodes (figure 1)?

The anatomy of the cochlea is such that the physical distance from the scala tympani to the modiolus is much larger at the extreme basal end of the cochlea than in the basal or mid regions of the cochlea. This would limit modiolar stimulation.

## V. CONCLUSION

Modiolar stimulation can evoke responses in IC units at low stimulus levels. Modiolar stimulation is often more effective apical to the electrode pair. A consideration of cochlea anatomy and pre stimulus threshold shift might provide one explaination for this finding.

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