INFERIOR COLLICULUS RESPONSES TO SINGLE AND DUAL SITE STIMULATION IN THE VENTRAL COCHLEAR NUCLEUS USING A PENETRATING AUDITORY BRAINSTEM IMPLANT

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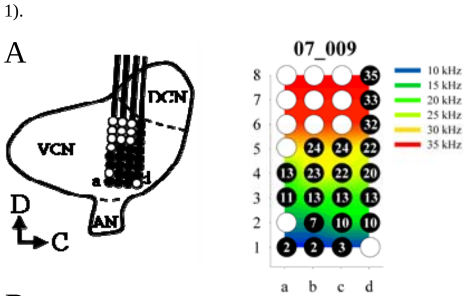
INTRODUCTION

The Auditory Brainstem Implant (ABI) is used to restore hearing in patients who are unable to benefit from a cochlear implant (CI), however, clinical success has been limited. This has been attributed mainly to the lack of a penetrating electrode array to access the tonotopic organisation of the ventral cochlear nucleus (VCN). In a recent study performed by our group[1], we demonstrated that stimulation of single VCN sites is not always frequency specific and in some cases does not elicit a response in the central nucleus of the inferior colliculus (CIC). This suggests a great need for the ABI design to incorporate redundancy by having several electrodes in each VCN isofrequency lamina. This might enable stimulation of multiple sites within an isofrequency lamina to further improve speech performance. In this study we explored the feasibility of dual site stimulation of two VCN sites in an isofrequency lamina and its effect on CIC responses.

METHODS

Experiments were performed on seven adult male Hooded Wistar rats anaesthetised with Urethane. Following a craniotomy, the cerebellum was aspirated to expose the brainstem. Multichannel electrodes were then visually guided into the VCN and the contralateral CIC. In order to assist in histological verification of the electrode sites, both electrodes were dipped in fluorescent DiI stain prior to insertion in the brain. After pre-determining the frequency regions corresponding to each electrode site in the two structures, each individual VCN site as well as pairs of VCN sites within similar frequency regions were electrically stimulated using biphasic charge balanced pulses (Bipolar configuration, 120 μs per phase, 1-54 μA, 2 Hz). Positions of the electrodes in the VCN were determined by histology, and maps depicting the tonotopic organisation of the VCN were constructed (example shown in Fig. 1).



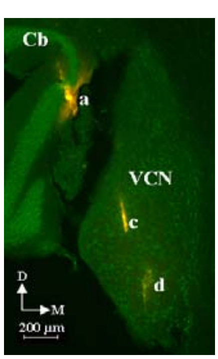


Figure 1. VCN electrode placement and tonotopic map. (A) Parasagittal representation of the cochlear nucleus along with electrode shank placements for one of the experiments. Shown beside is the tonotopic map (low frequencies, blue; high frequencies, red; Key). Each of the four shanks is represented by a letter (a-d) and the electrode sites are numbered from 1-8. Each circle represents a recording site on the electrode. The numbers in the circles correspond to the characteristic frequency (CF) of the multiunit cluster of that site. (B) Photomicrograph (x4) of a coronal brain section showing the VCN and part of the cerebellum (Cb) Electrode tracks for three of the four shanks are clearly discernable and marked with fluorescent DiI stain.

RESULTS

A total of 58 VCN sites were used for single site stimulation from 224 possible sites. The other VCN sites either did not have any multiunit activity or did not have any other VCN site with a similar CF, to be paired with for dual stimulation. In total, 39 pairs of VCN sites with similar CFs were chosen for dual stimulation. Data in response to VCN stimulation was obtained from 164 CIC sites that exhibited acoustic response areas.

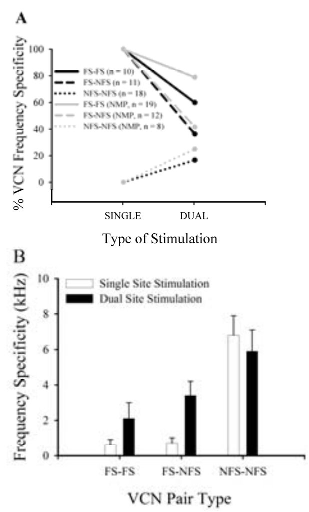


Figure. 2 Effect of dual site stimulation on frequency specificity. (A) Change in the number of frequency specific VCN sites/pairs from single site to dual site stimulation (NMP: Multiple-peak Tuned CIC sites removed from dataset. (B) Mean CF difference (frequency specificity) between a stimulated VCN site/pair and the corresponding lowest threshold CIC site. Both the FS-FS (n = 10) and FS-NFS (n = 11) dual stimulation pairs exhibited a reduction in frequency specificity from dual site stimulation, while the NFS-NFS pairs (n = 18) showed a slight benefit from dual site stimulation.

For each individual VCN site of a dual VCN pair, the CIC site that responded with the lowest threshold was found. In cases where the lowest threshold CIC site had a CF difference less than or equal to 1/8 octaves from the CF of its corresponding VCN site, the VCN site was deemed to be frequency specific (FS). Remaining VCN sites were classified as "NFS" or non-frequency specific. Dual site stimulation was performed with three types of VCN pairs (FS-FS, FS-NFS and NFS-NFS). Overall, dual site stimulation brought about changes in frequency specificity (Fig. 2), spread of activation (Fig. 3), and thresholds, saturation points and dynamic ranges of CIC responses (Fig. 4,5) as compared to single site stimulation. Maximum benefit from dual site stimulation was seen with stimulation of NFS-NFS pairs while stimulation of FS-FS pairs showed significant reduction in benefit.

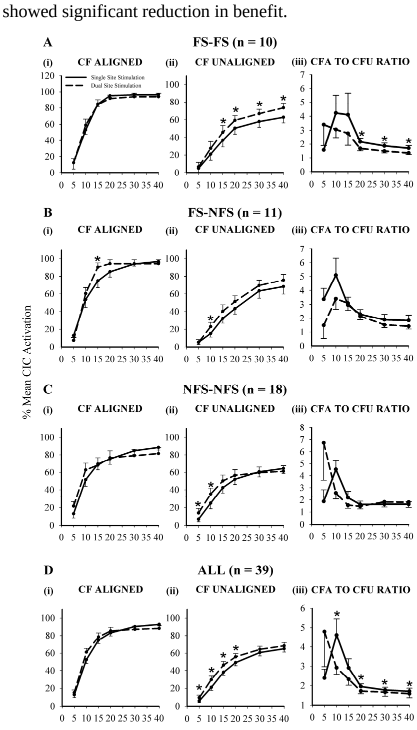


Figure 3. Effect of dual site stimulation on CIC spread of activation. Spread of activation in the CIC was measured by the ratio of all responding CIC sites to the total number of CIC sites, for each stimulated VCN site/pair at various current levels. Mean CIC activation in CF aligned sites generally rose more sharply and was always higher than the activation in unaligned sites. However, dual site VCN stimulation mostly brought about the same increase in spread of CIC activation compared to single site stimulation.

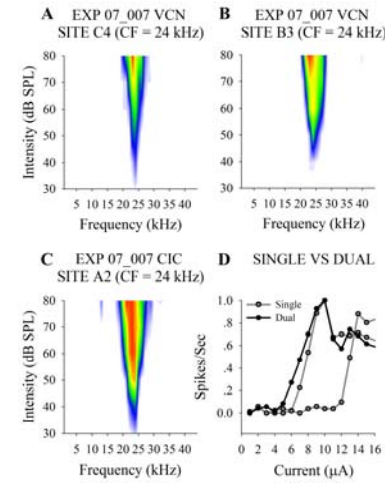


Figure 4. Benefit with dual site stimulation on CIC response threshold. (A) & (B) Acoustic response areas of two VCN sites (c4 and b3) with same CFs (24 kHz). (C) Acoustic response area of a CF aligned CIC site (a2) from the same experiment. (D) Rate-level functions at CIC site a2 in response to individual stimulation of VCN sites c4 and b3 (Gray lines/circles) and in response to dual stimulation of the VCN sites (Black line/circles). Note reduction in threshold of response from dual site stimulation.

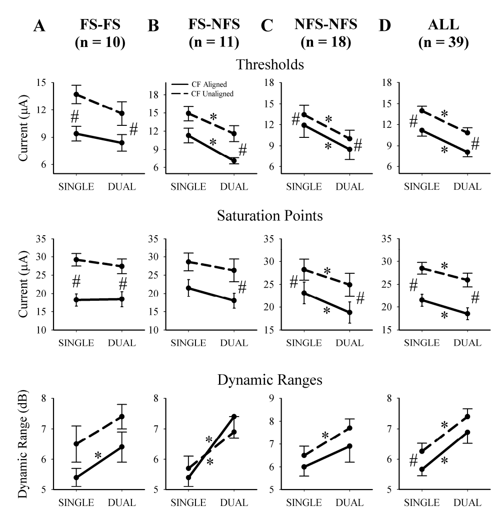


Figure 5. Effect of dual site stimulation on CIC response thresholds, saturation points and dynamic ranges. Mean thresholds (± S.E) of CIC sites were found to significantly reduce with dual site stimulation compared to single site stimulation (*, Wilcoxon Signed Rank Test, $p < 0.05$). In addition, significant differences in thresholds were found (#, Wilcoxon Signed Rank Test, $p < 0.05$) between CIC sites that were CF aligned to the stimulated VCN sites/pairs compared to the CIC sites that were CF unaligned. In most cases, dynamic ranges were found to increase significantly (*, Wilcoxon Signed Rank Test, $p < 0.05$) for dual site stimulation compared with single site stimulation while saturation points were mostly found to decrease with dual site stimulation.

DISCUSSION

We have shown that dual bipolar stimulation of two sites in a single VCN isofrequency lamina can provide some benefit, especially in cases where two VCN sites that were not frequency specific individually, became frequency specific when stimulated together. Furthermore, the reduction in thresholds and increase in spread of activation in CF aligned CIC sites indicates the possibility of more convergent information travelling to the CIC as a result of dual site stimulation. Our results suggest that in patients where placement of the ABI electrode array is not optimal, incorporating dual site stimulation may enable higher order auditory structures to code frequency information, resulting in increased speech understanding.

1. Shivdasani MN, Mauger SJ, Rathbone GD, Paolini AG. (2008) Inferior colliculus responses to multichannel microstimulation of the ventral cochlear nucleus: implications for auditory brain stem implants. *Journal of Neurophysiology* 99:1-13.

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