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Models and psychophysics of acoustic and electric hearing

by

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KEY WORDS

Cochlear implants, electrical stimulation, modelling, phase-lock coding, frequency discrimination, gap detection, channel interaction, central auditory nervous system

ABSTRACT

Especially important in developing improved cochlear implants is to develop a deeper understanding of the processing of sound in the central auditory nervous system, for both acoustic and electrical stimulation of the auditory system. This thesis contributes to this objective through cochlear implant psychoacoustic research and modelling of auditory system sound processing.

The primary hypothesis of the thesis was that the same underlying mechanisms are responsible for sound perception in both electric and acoustic hearing. Thus, if appropriate models are created for normal acoustic hearing, they should be able to predict psychoacoustic data from electric hearing when the model input is changed from acoustic to electrical stimulation. A second hypothesis was that electrode interaction could be measured by gap detection and that predictions of current spread in the cochlea could be obtained from gap detection data.

Measured gap detection thresholds in three cochlear implant users were a function of the physical separation of electrode pairs used for the two stimuli that bound the gap, resulting in a U-shaped "tuning curve" for this across-channel condition. Models of gap detection in acoustic and electric hearing were created to explain these U-shaped curves. A technique was developed to obtain estimates of cochlear current spread from gap detection data. Predictions of electrode discrimination were obtained from the current spread estimates, and these were compared to data measured in cochlear implant users.

The model for acoustic hearing could predict the U-shaped curves found in acoustic hearing, and when the input spike train statistics were adapted appropriately, the same model could also predict gap detection data for electric hearing. Predictions of current spread exhibited current peaks close to the electrodes and had length constants between 0.5 mm and 3 mm, similar to measured data quoted in literature. Predictions of electrode discrimination correlated well with measured data in one subject, but not in two others.

The primary conclusion from the modelling results is that if the mechanisms of central auditory nervous system signal processing of acoustic stimulation are understood, these same mechanisms may be applied to understand the signal processing in auditory electrical stimulation and to predict psychoacoustic data for electrical stimulation. A second conclusion is that spatial mechanisms, as opposed to temporal mechanisms, may determine gap detection thresholds in the across-channel condition. This is important in cochlear electrical stimulation, where spike trains are strongly phase-locked to the stimulus and temporal mechanisms cannot predict gap detection thresholds. A third conclusion is that gap detection can be used to measure channel interaction and to predict current distributions in the cochlea, although there is still uncertainty about the accuracy of these predictions. However, the gap detection data and predictions for current distributions indicate that electrodes are not discriminable when they are closer than 1.5 mm. The implication of these last two conclusions taken together is that research should focus on obtaining better spatial resolution in cochlear implants.

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Modelle en psigofisika van akoestiese en elektriese gehoor

deur

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Departement : Elektriese, Elektroniese en Rekenaar-Ingenieurswese
Graad : Philosophiae Doctor

SLEUTELWOORDE

Kogleêre inplantings, elektriese stimulasie, modellering, fase-sluit kodering, frekwensiediskriminasie, gapingsdeteksie, kanaalinteraksie, sentrale ouditiewe senuweestelsel

OPSOMMING

Tydens die ontwikkeling van beter kogleêre inplantings is dit besonder belangrik om 'n dieper begrip van die verwerking van klank in die sentrale ouditiewe senuweestelsel te ontwikkel, beide vir akoestiese en elektriese stimulasie van die ouditiewe stelsel. Hierdie proefskrif dra by tot hierdie oogmerk deur psigoakoestiese navorsing en modellering van klankverwerking deur die ouditiewe stelsel.

Die primêre hipotese is dat dieselfde onderliggende meganismes verantwoordelik is vir klankpersepsie in beide elektriese en akoestiese gehoor. Dus, indien toepaslike modelle vir normale akoestiese gehoor geskep word, behoort hulle psigoakoestiese data van elektriese gehoor te kan voorspel indien die modelinset verander word vanaf akoestiese na elektriese stimulasie. 'n Tweede hipotese is dat elektrode-interaksie gemeet kan word met gapingsdeteksie en dat voorspellings van die stroomverspreiding in die koglea verkry kan word uit gapingsdeteksiedata.

Gemete gapingsdeteksiedrempels in drie gebruikers van kogleêre inplantings was 'n funksie van die fisiese afstand tussen elektrodepare wat gebruik is vir die twee stimuli aan weerskante van die gaping en het gelei tot 'n U-vormige "stemkromme" vir hierdie inter-kanaal geval. Modelle van gapingsdeteksie in akoestiese en elektriese gehoor is geskep om hierdie U-vormige krommes te verduidelik. 'n Tegniek is ontwikkel om skattings van stroomverspreiding in die koglea te verkry vanuit gapingsdeteksiedata. Voorspellings van elektrodediskriminasie is verkry uit die stroomverspreidingskattings en is met gemete data van kogleêre inplantinggebruikers vergelyk.

Die model vir akoestiese gehoor kan die U-vormige gapingsdeteksiekrommes van akoestiese gehoor voorspel, en met gepaste aanpassing van die statistieke van die senuwee-impulsreeks op die modelinset kan dieselfde model ook gapingsdeteksiedata vir elektriese gehoor voorspel. Voorspellings vir stroomverspreidings toon pieke naby die elektrodes en het lengtekonstantes van 0.5 mm tot 3 mm, soortgelyk aan data waarna in die literatuur verwys word. Voorspellings van elektrodediskriminasie korreleer goed met gemete data in een proefpersoon, maar dieselfde geld nie in twee ander proefpersone nie.

Die primêre gevolgtrekking uit die resultate van die modellering is dat indien die meganismes van seinverwerking in die sentrale ouditiewe senuweestelsel verstaan word, kan hierdie meganismes toegepas word om seinprosessering in die elektries-gestimuleerde gehoorstelsel te verstaan en om psigoakoestiese data vir elektriese gehoor te voorspel. 'n Tweede gevolgtrekking is dat ruimtelike meganismes eerder as temporale meganismes verantwoordelik kan wees vir gapingsdeteksiedrempels in die inter-kanaal geval. Dit is belangrik in kogleêre elektriese stimulasie waar senuwee-impulsreekse sterk fasegesluit is aan die stimulus en waar temporale meganismes nie gapingsdeteksiedrempels kan voorspel nie. 'n Derde gevolgtrekking is dat gapingsdeteksie gebruik kan word om kanaalinteraksie te meet en om stroomverspreidings in die koglea te voorspel, alhoewel onsekerheid bestaan oor die akkuraatheid van hierdie voorspellings. Nietemin, die gapingsdeteksiedata en voorspellings vir stroomverspreiding wys dat elektrodes nie diskrimineerbaar is as hulle nader as 1.5 mm aan mekaar is nie. Die implikasie van die laaste twee gevolgtrekkings is dat dit nodig is dat navorsing fokus op die verkryging van beter ruimtelike resolusie in kogleêre inplantings.

CONTENTS

LIST OF ABBREVIATIONS

2IFC	two interval forced choice
Δf	just noticeable difference in frequency
ALSR	average localized synchronized rate
ANOVA	analysis of variance
AR	apical reference
BP	bipolar
CF	characteristic frequency
CIS	continuous interleaved sampling
CN	cochlear nucleus
CRLB	Cramer-Rao lower bound
dc	direct current
DCN	dorsal cochlear nucleus
ISI	inter-spike interval
jnd	just noticeable difference
jndf	just noticeable difference in frequency
pdf	probability density function
RS	relative spread
SL	sensation level
SNR	signal-to-noise ratio
SPEAK	spectral peak
SPL	sound pressure level
SR	spontaneous rate