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Assessment of adjustment to electrical threshold (T) level and electrical stimulation rate on intensity discrimination and amplitude modulation detection at soft presentation level in adult CI users

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ABSTRACT

A pilot study was conducted to evaluate the influence of electrical stimulation rate and the setting of electrical threshold (T) level on intensity difference limens (IDLs) and amplitude modulation (AM) perception. Participants were ten adult experienced Advanced Bionics cochlear implant (CI) users. The frequency of acoustic sinusoidal stimuli was set at 1076Hz with the intention of stimulating intra-cochlear electrode 7 of the 16 electrode array. Nine experimental maps were created with T levels set at: the threshold of audibility; a level perceived as 'very soft' and 10% of the level judged to produce 'most comfortable loudness'. Rates of electrical stimulation were 905, 1811 and 2750 pulses-per-second (pps). Adaptive 2I-2AFC IDL and AM perception tasks were presented via headphones at soft presentation levels (approximately 50dBSPL). The influence of T Level and stimulation rate adjustments on IDL and AM perception have been explored with the intention of understanding the impact of altering individual parameter settings to optimise detection of acoustic cues at low presentation levels.

Keywords: Cochlear Implant, Amplitude Modulation

1. INTRODUCTION

Cochlear implant (CI) users often show poorer speech perception at low intensity levels (Donaldson et al. 2009; Boyle et al. 2013). Very little is understood about the influence of sound processor fitting parameters on the discrimination of low intensity acoustic cues.

CIs transduce an input acoustic signal to an output electrical signal delivered to the hearing nerve via an intra-cochlear electrode. For the Advanced Bionics CI system, the intra-cochlear electrode has 16 electrical contacts or channels, that encode low frequencies at the apex and high frequencies at the base of the cochlea, analogous to the natural tonotopic organization. When all 16 individual channels are active, each has a fixed bandwidth, with a centre frequency at 383Hz for channel 1 up to 6665Hz for channel 16.

The extracted acoustic energy within each channel is rectified, and low-pass filtered extracting the envelope information. The envelope is used to amplitude modulate the biphasic electrical pulse trains

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delivered to the associated electrical contact. For CI users this envelope information is crucial for delivering speech information (Smith et al. 2002) and it has been demonstrated that poor AM detection is associated with poor speech understanding (Garadat et al. 2013).

Based on patient loudness judgements each electrode is configured to have a maximum current level equivalent to a perception of 'most comfortable' loudness, termed the (M) level, and a minimum current level, termed the threshold or (T) level, which by default for the Advanced Bionics device is set to 10% of M level. This range is the electrical dynamic range (EDR).

This pilot study evaluated three clinical methods for setting T level and used three electrical stimulation rates which span a range commonly offered within clinical practice. The pilot aimed to determine the best approach for setting the T level and the effect of electrical stimulation rate on amplitude modulation (AM) perception and intensity difference limens (IDL). The effect of electrical stimulation rate upon speech perception has been explored (Arora et al. 2011, Battmer et al. 2010, Bonnett et al. 2012, Buechner et al. 2010, Shannon et al. 2011) with a consensus that optimal stimulation rate varies on an individual basis, for speech presented between 60 to 70dBSPL. However, there is a limited understanding of the influence of stimulation rate on cues for speech perception presented at soft intensity. AM was selected as this has been demonstrated to correlate with speech perception (De Ruiter et al., 2015, Gnansia et al., 2014, Won et al., 2011) and AM detection has been shown to improve at lower electrical stimulation rates (Fraser and McKay, 2012; Green et al. 2012; Pfingst et al. 2007) when tested at moderate intensity, 60 to 70dBSPL. The effects of stimulation rate and different methods for setting T level on intensity discrimination and perception of AM were assessed using acoustic stimuli presented at soft intensity.

2. METHODS

2.1 Participants

Ten post-lingually deafened adult CI users were recruited from St Thomas' Hearing Implant Centre. Ethical approval was obtained from Health Research Authority (IRAS number 236017). Participants met the following criteria

Inclusion criteria:

- Over 18 years of age
- Full intra-cochlear electrode insertion
- Users of the Hi-focus 90K or later Advanced Bionics implant system
- Post implant activation experience of more than 9 months
- Post lingual onset of severe/ profound bilateral hearing loss

Exclusion criteria:

- Degenerative neurological diseases or other aetiologies that would limit attendance
- English not first language
- Unable to accurately make the loudness judgements used when setting the M and T levels, standard to cochlear implant programming

Two bilateral users had both ears tested. Eight participants completed tests in one single session lasting 2½ hours. Two required an additional ½ hour session. Participant demographic details are in Table 1.

Table 1 Relevant information about study participants

Participant	Ear	Gender	Aetiology	Age (years)	Duration profound deafness (years)	Device	Surgery (year)	Clinical speech strategy	Clinical IDR	Clinical rate (pulses-per-second)
S001	Right	Male	Otosclerosis	71	30	HRHiFocus 1J	2005	HiResS Fidelity 120	60	3712
	Left				15	HRHiFocus 1J	2008	HiResS Fidelity 120	60	3712
S004	Right	Female	Unknown	75	7	HRHiFocusMS	2014	HiRes OptimaS	70	2062
S005	Right	Male	CLL	60	1	HRHiFocusMS	2017	HiRes OptimaS	60	3375
S006	Right	Male	Unknown	52	8	HRHiFocusMS	2015	HiRes OptimaS	70	3535

S007	Right	Female	Ushers Type III	76	11	HRHiFocus1J	2011	HiResS Fidelity 120	75	3712
	Left				9	HRHiFocus1J	2009	HiResS Fidelity 120	75	3712
S008	Left	Female	Unknown	60	1	HRHiFocusMS	2014	HiRes OptimaS	70	2855
S009	Right	Male	NIHL	69	4	HRHiFocusMS	2017	HiResS Fidelity120	70	3712
S010	Right	Male	Unknown	42	3	HRHiFocusMS	2015	HiRes OptimaS	70	2475
S011	Left	Male	Unknown	37	8	HRHIFocus1J	2011	HiResS Fidelity120	70	2320
S012	Right	Female	Meningitis	54	12	HRHiFocus1J	2007	HiResS Fidelity120	60	1904

2.2 Equipment

Participants used a dedicated Naida Q90 speech processor during testing. It was programmed using SoundWave 3.1 software (version 3.1.18) operating on a standard clinical fitting station. Nine experimental maps were created, which comprised T levels set at: the threshold of audibility; a level perceived as 'very soft', and 10% of the level judged to produce 'most comfortable loudness', factorially combined with three rates of electrical stimulation: 905, 1811 and 2750 pulses-per-second. Standard psychophysical measurement of loudness, using a ten-step loudness scaling chart was adopted; this was familiar to all participants as it is common clinical practice. All measurements were completed by stimulating channel 7, which occupies a mid-cochlear position in a fully inserted electrode array with a centre frequency of 1076Hz.

M level was measured using an ascending electrical current presentation to achieve perceptual response of 'loud, but comfortable' before descending to achieve a current level providing a perception of 'most comfortable' loudness. T level was set in a descending electrical current presentation and marked as the last audible level before inaudibility. Finally, using an ascending presentation, a current level providing a perception of 'very soft' loudness was recorded.

Stimulus presentation and response acquisition were controlled via a MATLAB script. An adaptive 2I-2AFC procedure with feedback for both AM and IDL measurements was used with sinusoids of 1076Hz. Stimuli were presented through Sennheiser HD-414 headphones and all participants used a medium T-mic input microphone, placed in the pinna. For the IDL measurements the respondents had to say which of the two stimuli presented were 'louder' for a fixed reference level of 48dB SPL. A 2-down 1-up adaptive procedure tracking the 71% threshold was used. An initial step size of 4 dB was reduced to 1 dB with a maximum of 6 reversals or 30 trials. IDL was calculated as the mean of levels at the smallest step size. The AM perception task was adapted from a technique developed by Moore et al, (2017). Two successive carrier bursts each lasting 2 seconds were presented with one modulated at an AM rate of 4 Hz and one modulated at 8 Hz AM rate. A 2-down 1-up adaptive procedure tracking the 71% threshold was used. The threshold modulation depth at which the listener could discriminate the difference in modulation rate was defined for the average of the last four reversals and calculated as geometric mean.

Each participant completed two practice runs, before completing a single run for each of the nine test conditions described in Table 2. For this pilot phase the test order was the same for all but two participants. Experimental maps were created and loaded to a research sound processor in the numerical bracketed order indicated in Table 2. The order in which different methods for setting T level were implemented was different to control, to some extent, for order effects. In two participants (S11 and S12) the order of rate of stimulation was reversed. Participants had all parameter settings other than T level setting and stimulation rate configured to those used within their standard clinical sound processing map. Participants with 'Clear Voice' activated in their standard clinical sound processing map had this implemented in the test map. 'Clear voice' is an input noise cancelling algorithm, however at the low presentation levels used, the algorithm would not have been active and consequently would not have had an effect.

Table 2 – Indicates the test order by number in brackets

Rate	Threshold setting method		
900Hz	Threshold at auditory perception (1)	Threshold at perceptually 'very soft' (2)	Threshold at 10% of 'most comfortable' (3)
1800Hz	Threshold at perceptually 'very soft' (4)	Threshold at 10% of 'most comfortable' (5)	Threshold at auditory perception (6)
2700Hz	Threshold at 10% of 'most comfortable' (7)	Threshold at auditory perception (8)	Threshold at perceptually 'very soft' (9)

For each participant, AM measurements were completed before the IDL tests with a short break in between. The responses from three participants, S006, S008 and S009 have been excluded from analysis. Participant S006 and S009 already had their T levels set above 10% of M level within their clinical program and consequently both found stimuli inaudible with T level at 10% of M level. S008 was unable to perform the AM task in any condition and more thorough review of the clinical history and electrophysiological measurements revealed that the individual might have auditory neuropathy (AN). Participants S001 (right ear) and S005 were unable to complete the AM test sequence on the first test date and have been unable to attend for initial follow up dates.

3. RESULTS

Preliminary findings and trends for exploration in future work are reported. Figure 1 shows IDLs for the three methods of T level setting and three stimulation rates. Responses from nine ears and seven participants indicate marked variability with poorer IDLs as rate of stimulation increased from 905 to 1811pps, but not for 2750pps. T levels set at 'very soft' had the smallest EDRs and consequently provided a higher current to represent low intensity acoustic inputs, which when coupled with the lowest rate of stimulation (905pps) resulted in reduced variability and improved IDL.

A two-way repeated measures ANOVA was performed on IDL data with factors of rate of stimulation (3 rates) and T level setting (three approaches). . There was no significant effect of either stimulation rate [$F(2,16) = 1.065$, $p = 0.368$, partial $\eta^2=0.12$] or method of T level setting [$F(2,16) = 0.861$, $p = 0.413$, partial $\eta^2=0.10$], and there was no significant interaction [$F(4,32) = 2.551$, $p = 0.94$, partial $\eta^2=0.25$].

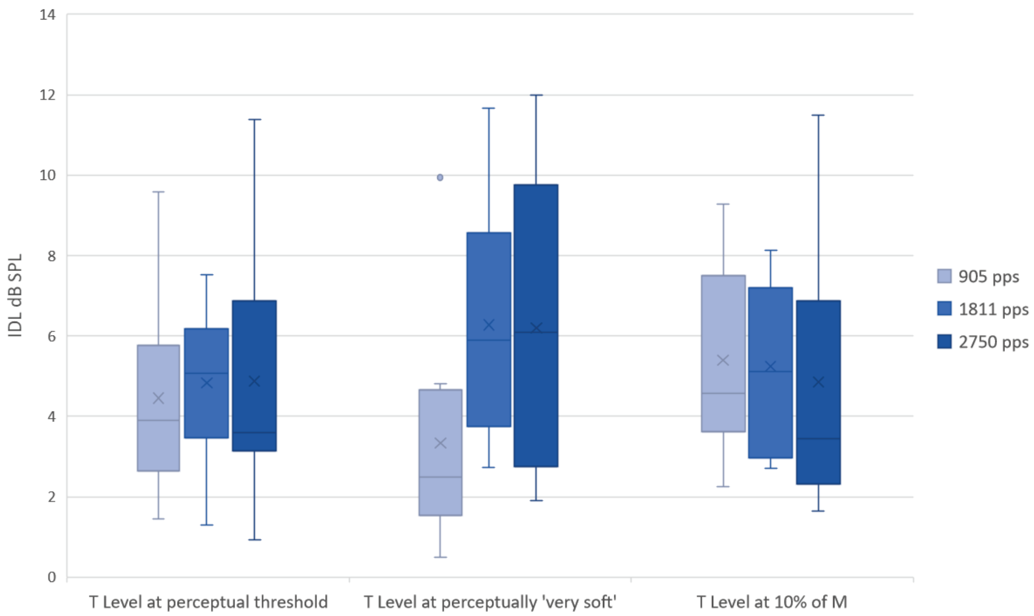

Figure 1 - IDL for stimulation rate as a function of T level by stimulation rate. Boxes indicate 25th and 75th quartile, whiskers indicate the range. Lower IDL values indicate improved ability.

Figure 2 shows AM responses for the three stimulation rates as a function of method of T level setting. Responses from seven ears and six participants were used, and the results showed great variability with no discernable pattern for changing T level approach or stimulation rate. However, there could be a trend for higher rates of stimulation to have a higher geometric mean score for the perceptual T levels and the 'very soft' T level setting.

The ANOVA revealed no significant effect for stimulation rate [$F(2,12) = 3.793$, $p = 0.064$, partial $\eta^2=0.39$], no significant effect of method of T level setting [$F(2,12) = 0.116$, $p = 0.862$, partial $\eta^2=0.02$], and no significant interaction [$F(5,24) = 1.944$, $p = 0.18$, partial $\eta^2=0.25$].

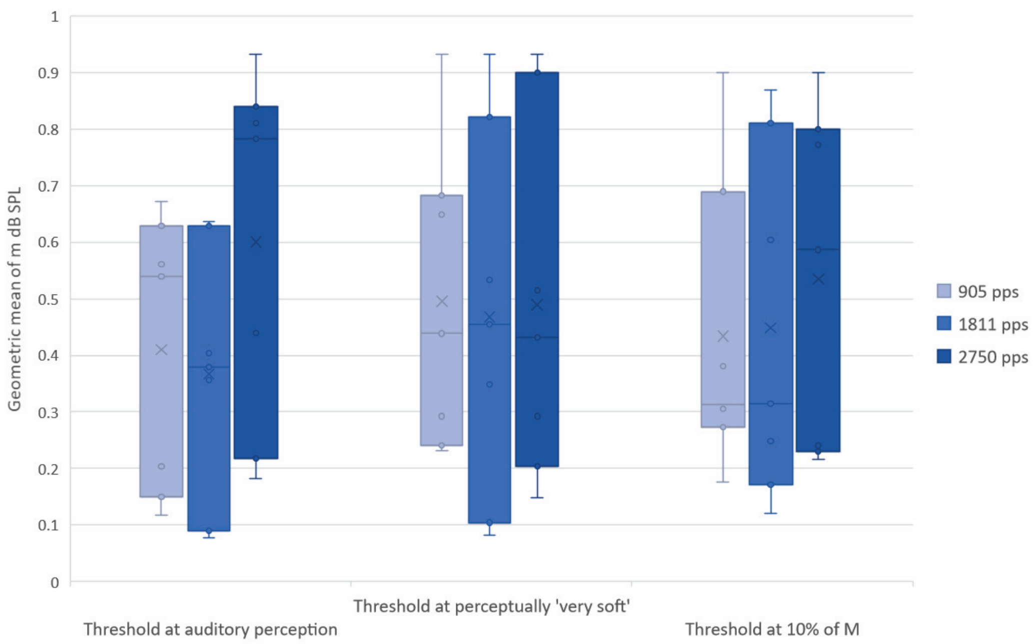

Figure 2 – AM at 48dBSPL by setting of electrical thresholds T level and stimulation rate. Boxes indicate 25th and 75th quartile, whiskers indicate the range. Lower AM values indicates improved ability.

To prevent vetting participants within the main study arm who were observed to have difficulty providing responses in the pilot test phase, the following exclusions within selection criteria will be added.

(i) Clinical indicators of AN
(ii) Only include individuals using T levels automatically set at 10% M level

For AM rate discrimination the effect of stimulation rate was a large effect size ($\eta^2=0.39$), the effect of T level approach was a small effect size ($\eta^2=0.02$), and the interaction was a large effect size ($\eta^2=0.25$). For IDL the effect sizes were large for both factors (rate, $\eta^2=0.12$; and T level approach, $\eta^2=0.10$) and for the interaction ($\eta^2=0.24$). Using $\eta^2=0.25$ and a power of 0.80 for a two-way fixed effects ANOVA results in a sample size of 33 participants for the main study.

4. DISCUSSION

The study performed was a pilot intended to establish the optimal study design and power calculations based on IDL and AM measurements presented acoustically using 'soft' intensity presentation levels. The low presentation levels were used here to determine if testing abilities at the lower end of the dynamic range is appropriate. Study participants generally reported that the IDL and AM measures were challenging but were understandable and could be completed for the nine experimental conditions in one session. In this pilot there was only one run per condition and in the main study all testing would be repeated to give two thresholds per condition. It was decided that all conditions would be retained in the main study although the intention had been to remove some conditions. Variability across participants made it difficult to determine the most critical trends to explore going forwards and consequently all conditions will be retained. To balance the study design across conditions and participants a latin square design will be used in the main study so multiples of 9 participants will be required.

There were a few participants who could not perform the psychophysical measures. This has resulted in the inclusion criteria being adjusted to include the following. Participants using a clinical program in which the T level was not set at 10% M level, because that is the default for AB users and might indicate that there were issues when setting the T levels. Participant notes will be carefully checked and individuals with any suspicion of AN will be excluded.

The procedure for the IDL test was amended for the main study to track 2 down 1 up for the first and every subsequent presentation, which in the pilot phase had been set as a 1 down 1 up until the first reversal. The initial design rationale was to shorten the test time and track fewer reversals before reaching threshold; however following review of a sample of response plots it was apparent that the protocol was too brief for accurate measurement of thresholds.

There was a large variability across participants as expected and this obviously impacts on the power analyses for the main study. For this pilot study there were no significant effects of approach for setting T level or rate of stimulation. However, this was as expected due to the small sample size. From Figure 1, there appears to be a trend towards improved IDLs when using a T level setting at perceptually ‘very soft’, which has a higher stimulus current level and a slower stimulation rate. This was a large sized effect and power calculations indicated that 33 participants would be required for statistical significance. For the AM rate discrimination task, no trends were observed for either T level setting or stimulation rate.

5. CONCLUSIONS

Experienced adult users of the Advanced Bionics CI device were able to perform the IDL and AM rate discrimination tasks that we used at low presentation levels. Notwithstanding the limitations due to sample size of the pilot study there appeared to be trend toward improved IDL response for T level setting at a perceptual equivalence to ‘very soft’ with a slower electrical stimulation rate and a more marginal trend is in the AM data for higher rates of stimulation to have a higher geometric mean score for the perceptual T levels and the ‘very soft’ T level setting.

These elements will be explored further in a main study using refined measurement procedures and a fully balanced study design.

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