Encoding signal intensity with stimulation rate: Forward masking measures

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Abstract: In today's cochlear implant systems, the signal intensity is usually encoded directly into the stimulation level of the charge-balanced biphasic stimuli. One of the main factors limiting the spatial resolution is the electric field spread. This resolution is further compromised with increasing stimulation intensity, since the electric field spread is expected to increase accordingly. One possible alternative to minimize the electric field spread would be to use the stimulation rate to encode the signal intensity, while keeping the stimulation level constant.The present study investigates the accompanying change in the electric field spread when using either the stimulation rate (at a constant stimulation level) or stimulation level (at a constant stimulation rate) to achieve the same change in loudness, with the hypothesis that the former results in less changes in the electric field spread compared to the latter. Psychophysical forward masking functions were measured for three masker rate/level combinations: Firstly, the masker (e11, 500ms) was loudness matched at a comfortable level for either 250Hz or 2000Hz (at stimulation levels L250 and L2000 respectively, typically L2000 < L250). Additionally, the masker was set at 250Hz and L2000, corresponding to a lower loudness percept. The masked thresholds of a 250Hz 20ms probe, presented 4ms after the end of the masker, were then measured for locations either side of e11, in an adaptive 2down-1up 3IFC task.Results with 5 CI subjects indicate a greater increase in the amount of forward masking when the stimulation level was changed from L2000 to L250 (both at 250Hz), compared to when the stimulation rate was changed from 250Hz to 2000Hz (both at 2000Hz), supporting the hypothesis. The implications of these results will be discussed.

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Encoding signal intensity with stimulation rate: Forward masking measures

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Introduction

One of the main factors limiting the spatial resolution of electric stimulation with a cochlear implant is the electric field spread. In today's cochlear implant systems, the signal intensity is usually encoded directly into the stimulation level of the charge-balanced biphasic stimuli (Vandali et al. 2000). To aggravate the situation, the spatial resolution is further compromised with increasing input signal level, since the stimulation leveland the corresponding electric field spread is expected to increase accordingly. The stimulation level, however, is not the only means available for controlling the signal intensity. Changing the stimulation rate will also change the perceived signal intensity accordingly. Thus, one possible approach to minimize the electric field spread with increasing input signal intensity could be to use the stimulation rate instead to encode the signal intensity, while keeping the stimulation level constant.

Before embarking on a full implementation of such an approach, it is necessary to investigate whether encoding the signal intensity using the stimulation rate will actually result in reduced electric field spread compared to when using the stimulation level. To accomplish this, a study investigating the accompanying change in the electric field spread when using either the stimulation rate (at a constant stimulation level) or stimulation level (at a constant stimulation rate) to achieve the same change in loudness was conducted. The hypothesis is that the former will result in smaller changes in the electric field spread compared to the latter. Forward masking in the manner employed by Kwon & van den Honert (2006) was used to measure the extent of the electric field spread.

Method

Figure 1: *Psychophysical functions were measured using a 500ms masker (e11, 500ms) at(a) 250Hz& L250, (b) 2000Hz & L2000 and (c) 250Hz & L2000 followed by a 250Hz 20ms Probe presented 4ms after the end of the masker.*

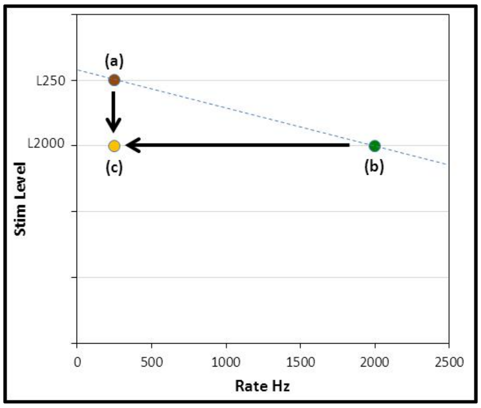


Figure 2: *Diagram illustrating the 3 rate/level combinations, where conditions (a) and (b) are at the same loudness level while condition (c) is softer, such that the transitions (a)-(c) and (b)-(c) represent the same change in loudness percept when the stimulation level or stimulation rate is changed respectively.*

Psychophysical forward masking functions were measured for three masker rate/level combinations as follows:Firstly, a 500ms masker (alone) presented in the middle of the electrode array on e11, was loudness matched at a comfortable level for either (a) 250Hz or (b) 2000Hz. The corresponding stimulation levels are denoted L250 and L2000 respectively, with typically L2000 <L250, yielding the first two rate/level combinations. The third rate/level combination (c) consisted of 250Hz at L2000, which corresponds to a lower loudness percept.

For all three masker rate/level combinations (a), (b) and (c), the masked thresholds of a 250Hz 20ms probe, presented 4ms after the end of the masker, were then measured for locations either side of e11, in an adaptive 2down-1up 3IFC task.

5 experienced adult CI subjects were assessed in this manner.

Results

Figure 3 below shows the forward masking functions from each of the 5 subjects with all three rate/level combinations. The brown curve corresponds to condition (a), the green curve to condition (b) and the orange curve to condition (c). The results from subjects AB, WH and CE show that the (a) curve has clearly higher probe detection thresholds compared to the (b) and (c) curves, which are very similar to one another. The results from subject CE, however, were more erratic, partly due to her having difficulty performing the adaptive detection task. The data point at e13 for condition (a) is probably due to a measurement error but has been left in the data set.

This was not so clearly observed with the results from subjects TB and GR, where all three (a), (b) and (c) functions were much more similar to one another. Subject GR also showed a shift in the peak of all three forward masking functions to e7, away from the expected central stimulation site e11. The reason for this is unclear, and could be possibly an indicator of inhomogeneous neural survival. There is, however, no such indication in clinical speech processor map levels.

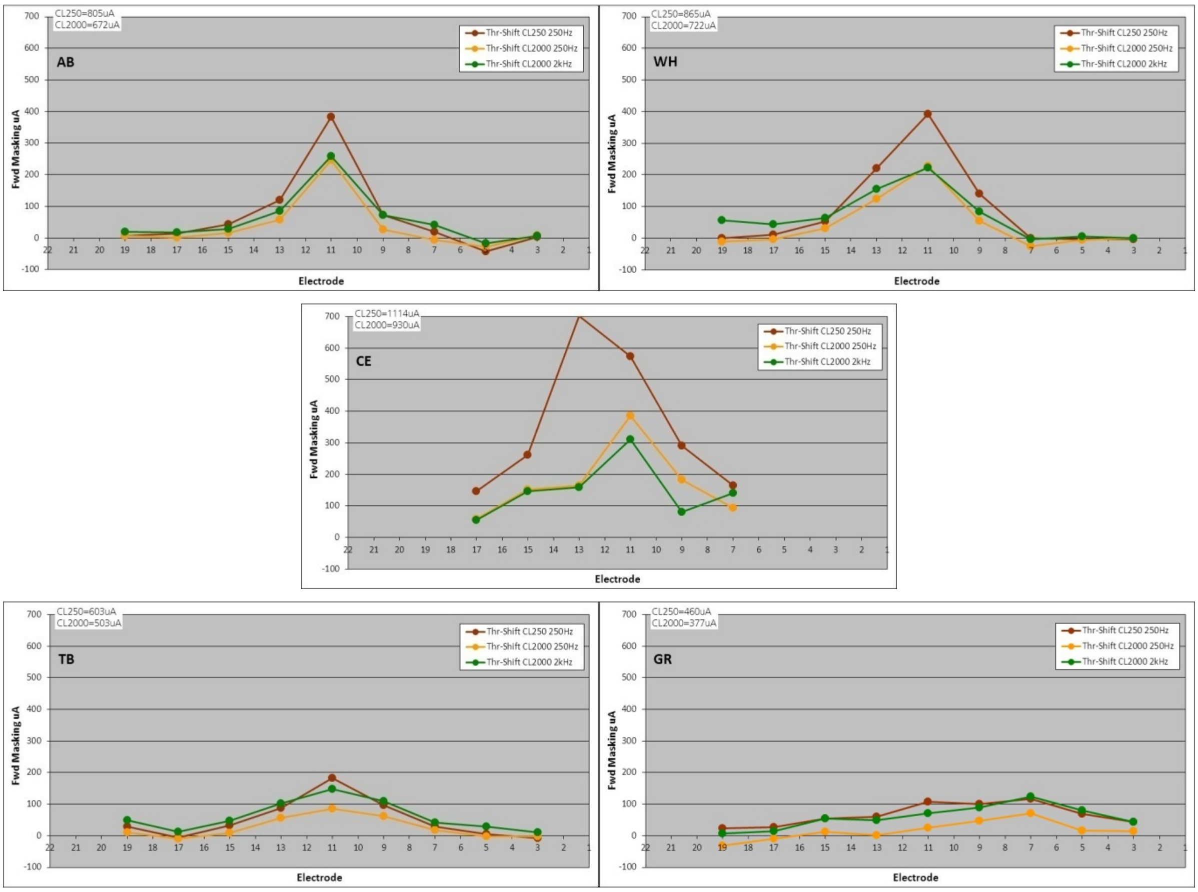


Figure 3: *Probe detection thresholds (forward masking curves) with the masker at e11 for all 5 subjects and all 3 conditions. All curves have been plotted using the same vertical scale to illustrate the differences between subjects.*

Additionally, the difference in the probe detection threshold at the masker stimulation site e11 between conditions (a)-(c), as well as between conditions (b)-(c), are summarized in Figure 4 below. Subjects AB, WH and CE clearly show a larger change in the probe detection thresholds for (a)-(c) compared to (b)-(c). Although the difference was not so large for subjects TB and GR, there is a general agreement in their results as well.

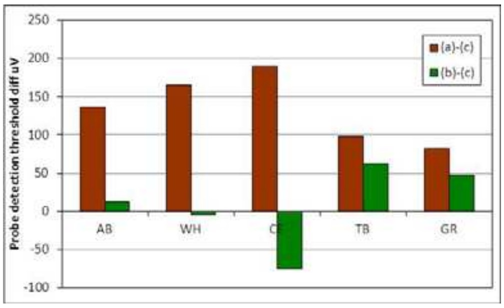


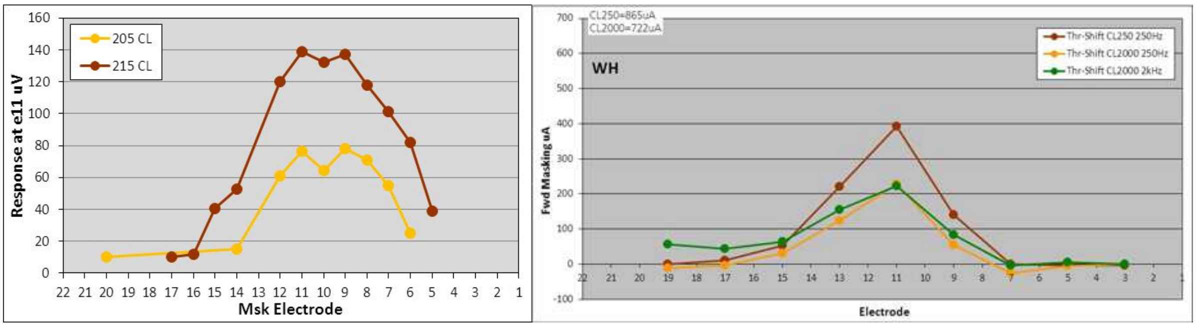
Figure 4: *The difference in the probe detection thresholds at e11 between conditions (a)-(c) are clearly larger than their counterparts for (b)-(c) for all 5 subjects.*

Discussion

Despite the individual variability between subjects, the results above generally suggest that there is reason to believe that using the stimulation rate to encode loudness will result in less electric field spread compared to the conventional approach of using stimulation level to encode loudness. This would imply thatusing the stimulation rate to encode loudness may result in reduced channel interaction and thereby lead to clearer sound percepts in general. This in turn could more specifically be useful for improving the clarity of musical sounds provided to CI-listeners.

The variations in the results we observed with the small number of subjects above indicate that there are still individual variations that we need to understand before being able to generalize such a conclusion. As such, the study will be extended to include a greater number of subjects.

One related point of interest is whether the spread of excitation (SoE) function as measured using NRT is in any way related to the forward masking functions measured above (Cohen et al. 2004).Although no such SoE data was explicitly collected for this study, some SoE data on e11 at the exact same stimulation levels from a single participating subject WH from a separate study were available and these are shown below in Figure 5a. The data shows how the SoE function expanded when the stimulation level was increased. However, the SoE functions were somewhat different in shape compared to the corresponding forward masking functions (Figure 5b).



(a) *(b)*

Figure 5: *The (a) SoE and (b) forward masking functions above were measured using the same probe stimulation levels, but at different times. The resulting functions are quite different in there shapes.*

Care should be taken when comparing NRT SoE functions with psychophysical forward masking functions as they involve different approaches respectively. The SoE functions are measuredusing a fixed probe location while the location of the (constant amplitude) Masker is varied along the array. The forward masking functions presented here, on the other hand, varied the probe location while the masker location was fixed. In addition, the SoE functions are based on the (averaged) neural response to a single pulse, in contrast to forward masking functions that involve an entire pulse train. As such, the SoE functions cannot be directly extrapolated to infer the effects of a train of pulses whose rate/level are to be altered according to conditions (a), (b) and (c) above.

Summary

The results of this (pilot) study imply that using the stimulation rate (at constant stimulation level) to change the loudness level between (b) and (c) results in less changes to the electric field spread, compared to when using the stimulation level (at constant stimulation rate) between (a) and (c). This would support the proposed hypothesis. The variations in the results which were observed in the small number of subjects, however, make it difficult to draw clear conclusionsabout the influence of individual factors. Consequently, further testing with more subjects is needed.

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