Rate pitch with multi-electrode stimulation patterns: confounding cues

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Rate pitch with multi-electrode stimulation

A number of studies have considered the use of multi-electrode stimulation patterns to improve rate pitch perception. For stimulation on single electrodes, CI rate pitch often saturates at around 300 pps, so that above this rate, increases in rate need to be large to be detected. To overcome this, multi-electrode stimulation patterns have been tested. In these, a set of electrodes are stimulated at the same rate, the premise being that rate pitch would then be extracted from multiple cochlear locations. Venter and Hanekom (JARO, vol. 15, 2014, pp. 849-866) sequentially stimulated varying numbers of electrodes in two phase delay conditions, measuring rate discrimination thresholds and pitch ranking resulting from increases in stimulation rate. Penninger et al. (IJA, Early Online, 2015) applied a random order of stimulation in a set of electrodes stimulated at the same rate and measured pitch ranking when rate varied.

A potential problem

A specific consideration comes into play when using multi-electrode stimuli to encode pitch. Increased rate is expected to lead to increases in loudness, so that listeners may attend to this cue rather than to rate pitch changes. It may be necessary to adjust loudness when rate is changed, but this presents a problem, as the levels of multiple electrodes will be adjusted. To maintain the same relative loudness on every electrode, we may adjust each electrode's stimulus amplitude by the same fraction of dynamic range (DR). As electrodes have different DRs, however, this would lead to different current adjustments on each electrode, which could lead to a shift in the stimulus centroid. This is expected to result in a change in place pitch. A similar problem exists when adjusting stimuli by the same amount of current – loudness on each electrodes changes relative to those of other electrodes.

Therefore, it may be undesirable to adjust loudness of multi-electrode stimulus patterns, especially when the intention is to effect changes in rate pitch. Place pitch changes would co-vary with rate, while level roving to mitigate this may cause randomly varying place pitch cues. So, when varying rate in a multi-electrode stimulus, either unintended place pitch or loudness cues may be available, which may interfere with rate pitch perception. These can probably not be controlled simultaneously.

Experiments

The present work probed this in experiments with CI listeners. Earlier data (panels B, C and D in the figures to the right; Venter and Hanekom, 2014) are shown together with data from an experiment that compared pulse rate discrimination of constant rate deviations (5, 10 and 20 %) in different conditions (loudness balanced and two roving conditions).

Earlier measurements (panels B in the figures to the right) determined pulse rate discrimination thresholds (PRDLs; panels B in the figures to the right), loudness differences between the base rate and base rate plus PRDL (panels D), and pitch ranking of single-electrode and multi-electrode stimuli (panels C). Examples of multi-electrode stimuli are shown in Figure 1.

Eighteen conditions were tested. Pulse rate varied from a base rate of 600 pps by 5%, 10% or 20% (or 1%, 3% and 5% for S24). These pulse rates were presented on one electrode, or on 18 electrodes in "spread" condition. Base and probe stimuli were either loudness balanced without roving, or had additional roving of one current unit (CU), or high roving (roving of more than the loudness difference between the two rates).

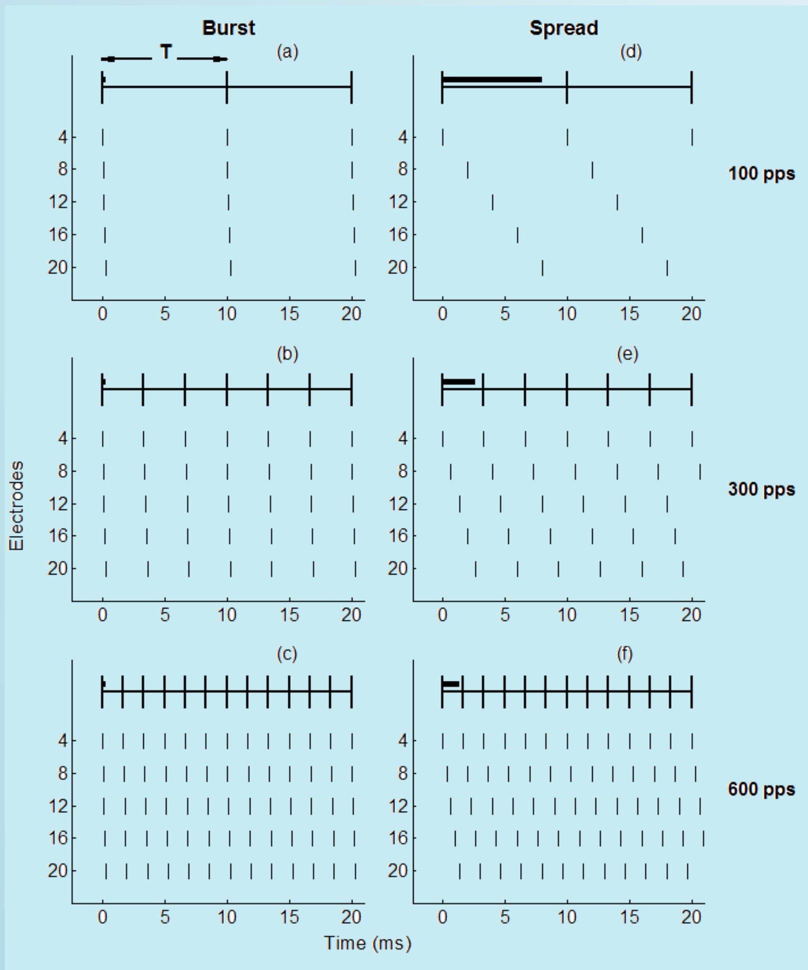

Fig 1. Examples of multi-electrode stimuli.

Results and conclusion

Results of Experiment 5 varied considerably between the three participants, exemplified by participant S5 that scored significantly above chance for only three out of 18 conditions and participant S24 scoring significantly above chance for all conditions tested. In earlier experiments, these three CI users appeared to use rate cues to determine the PRDL. However, present experiments show different trends for each of the participants (Figures 2 to 4).

Seen overall, these three participants appear to be representative of each of the possible outcomes: i.e. the listener listens to any available cue, but if more than one cue is available, different listeners may focus on different cues. Furthermore, it appears that multi-electrode stimuli create a dichotomy: when loudness is controlled for, place pitch cues are created. These are confusing enough so that only one out of three participants (who all did well in earlier experiments) could easily discriminate rate differences, even when these were relatively large. However, when place pitch is controlled for, loudness cues may exist and is probably used in the discrimination task. This results in a dilemma: when attempting to use multi-electrode stimuli to extend rate pitch beyond 300 Hz, it is necessary to control place pitch cues as well as loudness cues, but these cannot both be controlled for simultaneously. The implication might well be that it is not practical to use multi-electrode stimuli to increase the range of rate pitch beyond the often quoted 300 Hz boundary.

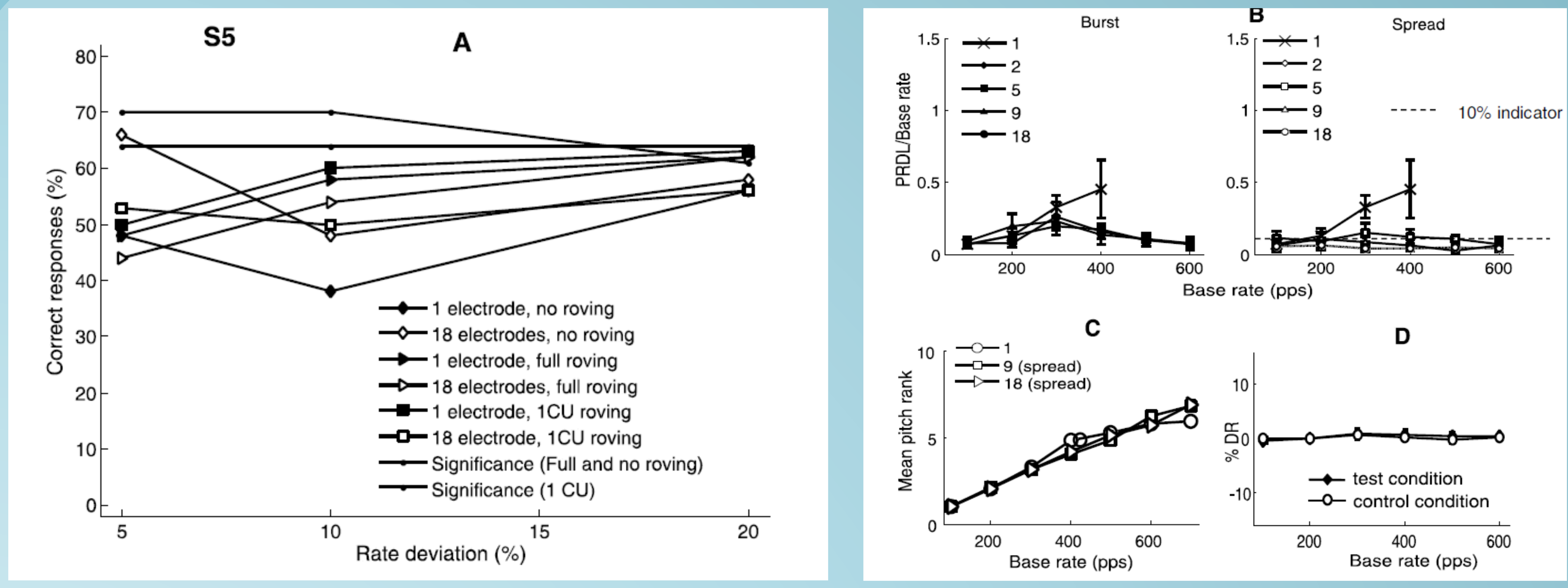

Fig. 2. Participant S5. Rate differences could only be identified when the deviation was high enough (panel A). With roving, the percentage of correct responses increased as the rate deviation increased, suggesting that the listener made use of rate cues. From PRDLs (panel B) we expected scores significantly above chance at a deviation of 10%. D shows very small differences in loudness between base rate and base rate plus PRDL. Still, S5 probably made use of small loudness cues in the PRDL measurements. It appears that without loudness cues rate deviation needed to be higher before it could be perceived. I.e., this listener probably made use of rate cues as well as loudness cues. Panel C (pitch ranking) suggests an advantage for multi-electrode stimuli.

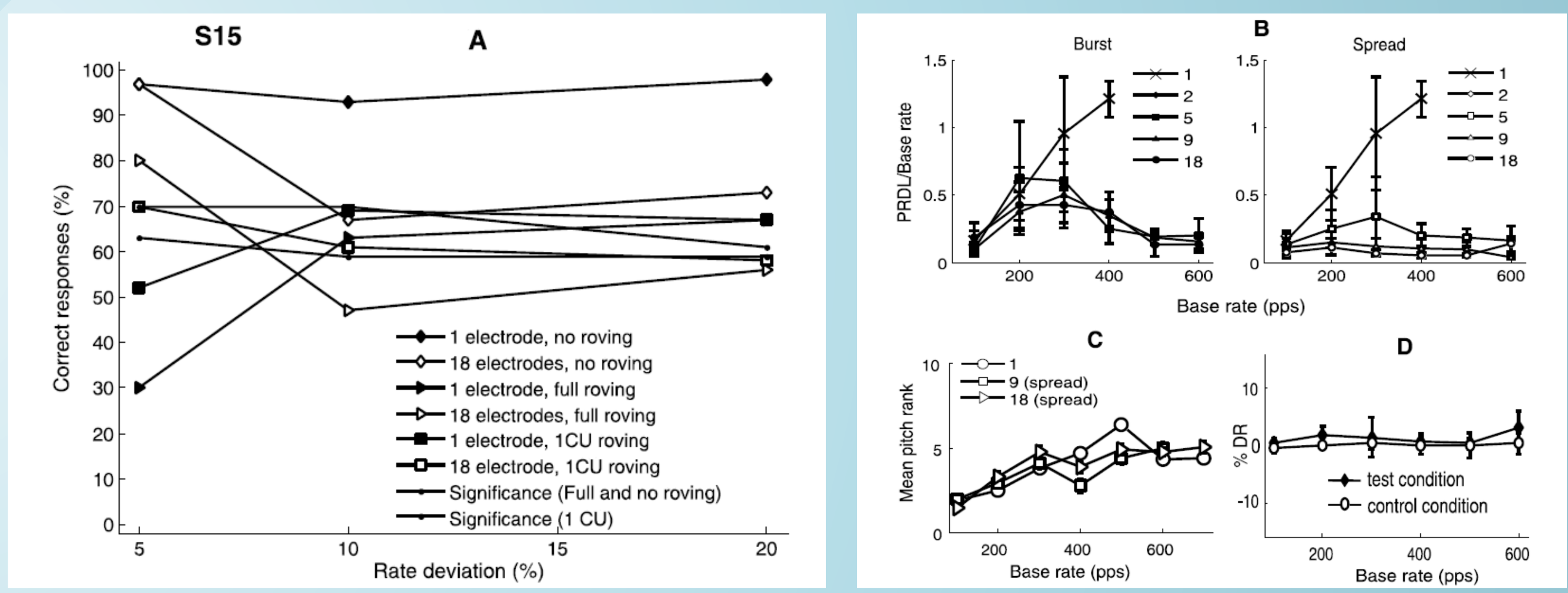

Fig 3. For the multi-electrode conditions, S15 performed better (panel A) for a rate deviation of 5% than for 10% or 20% in loudness-balanced and roving conditions. I.e., this can probably NOT be attributed to loudness effects. Adjustments in stimulation amplitude needed to loudness balance with 5% rate deviation may have been small enough not to cause place pitch cues. For higher rate deviations, the larger adjustment of current amplitudes on electrodes may have caused the centroid position to shift, introducing place pitch cues. Multi-electrode stimuli performance did not improve with increase in rate deviation. S15 may have focused on available place cues rather than rate cues which corresponds to pitch ranking data (panels C). Loudness cues (D) could also have influenced PRDL data.

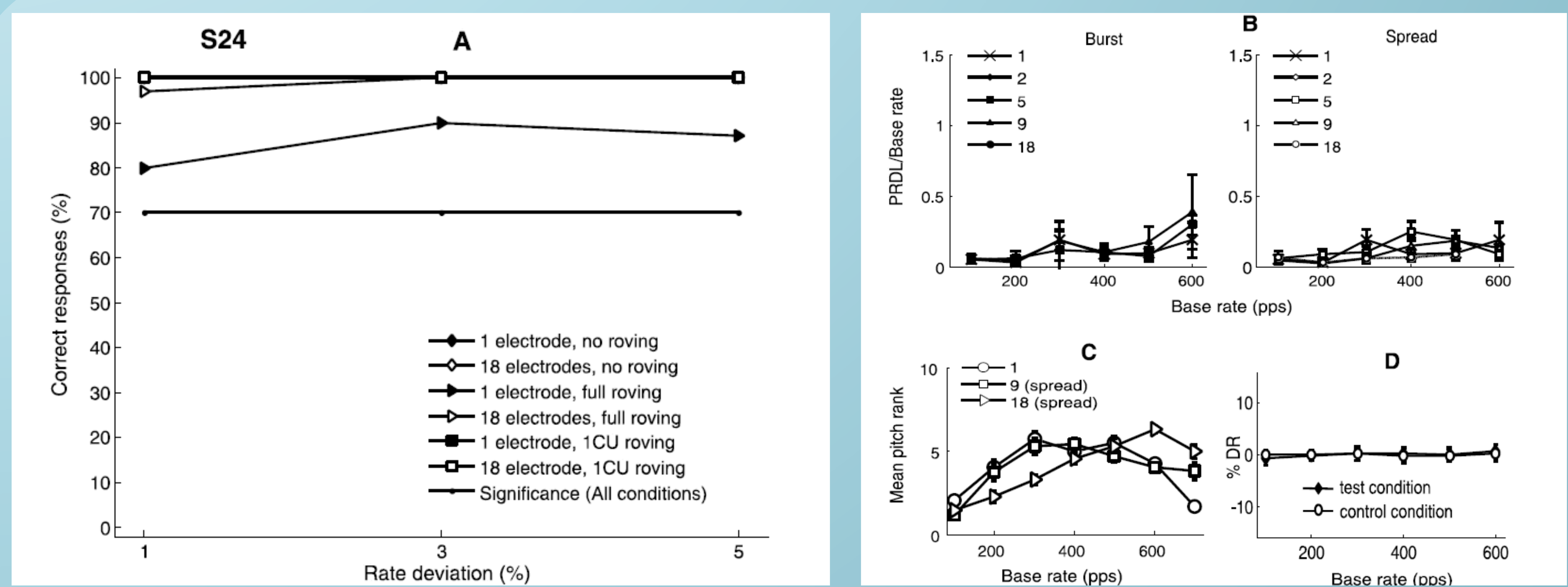

Fig 4. Participant S24 could correctly discriminate small deviations (1%, 3% and 5%; panel A) in all conditions (loudness balanced and roving). Data suggest that neither loudness cues nor place cues had an influence on the PRDLs (panel B). Small PRDLs were measured even for the single electrode condition. Multi-electrode stimulation (18 electrode condition) did result in improved rate pitch sensitivity above 300 pps.

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