Using the mosaicOne electro-haptic device to improve pitch perception for cochlear implant users

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Overview

Pitch is a key feature of music and speech perception that can be difficult for cochlear implant user to discern. A potential method to improve pitch perception is electrohaptic stimulation - recent work has shown that combining electrical stimulation from a cochlear implant with congruent haptic stimulation on the wrist can lead to improved hearing performance for cochlear implant users, particularly in areas such as speech recognition, speech-in-noise performance and sound localization (Fletcher, In press; For an in-depth overview, please attend the **"Mixing it up" session talk "*Enhancing music perception in cochlear implant users by providing missing sound-information through tactile stimulation*"** by Mark Fletcher).
This study details the development and evaluation of a new wrist-worn haptic device (the mosaicOne_B). The device and accompanying signal processing strategy are used to extract and map the pitch of an audio signal to an array of motors, arranged spatially along the participant's forearm.

Aims of current work

1. Evaluate the use of the mosaicOne_B and accompanying signal-processing strategy for improving pitch discrimination performance for tone-complexes
2. Assess the robustness of the approach to added inharmonic noise

The mosaicOne_B

Device design and signal processing

The mosaicOne_B was designed as an in-lab device that could be readily adapted to a real-world intervention. The device comprises of 12 DC motors spaced equally on the upper and underside of the forearm.

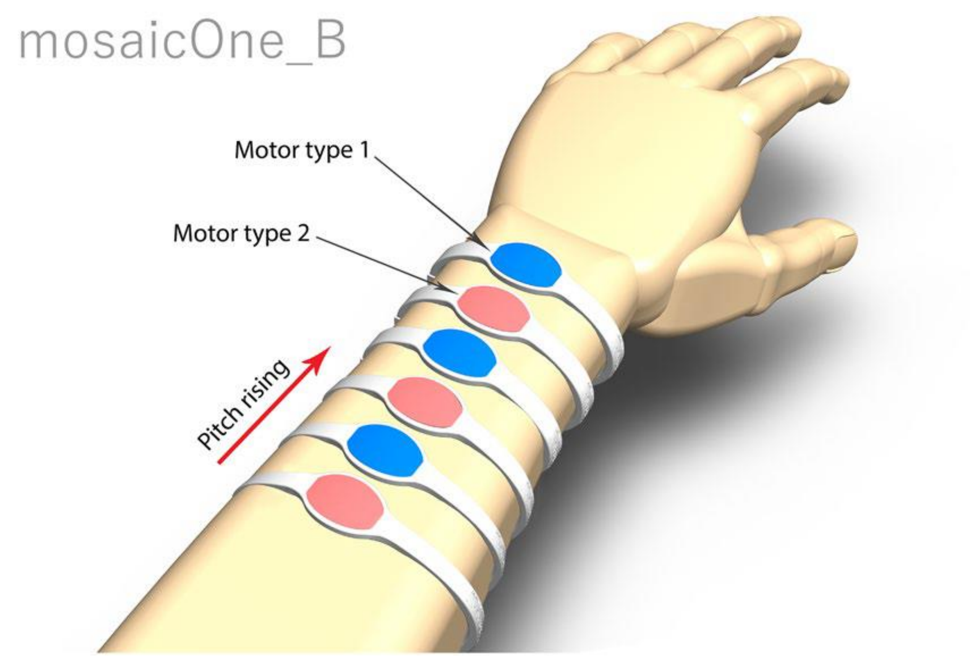

Figure 1: Schematic illustration of the mosaicOne_B

The accompanying signal processing strategy was developed to extract the F0 of audio and intuitively map this to haptic feedback. The strategy consisted of the following steps:

1. Estimate the absolute fundamental frequency using the YIN algorithm
2. Wrap the extracted frequency by octave (a "chroma wrap") so that frequencies an octave apart produce the same value (For example an F0 of 440, 880 or 1760 Hz would yield the same result).
3. Split the chroma wrapped range into 12 bands, with each activating one of the 12 motors on the mosaicOne_B
4. Apply a smoothing function to reduce the effects of erratic channel selection in noise (caused due to artefacts in the F0 estimator) estimator.

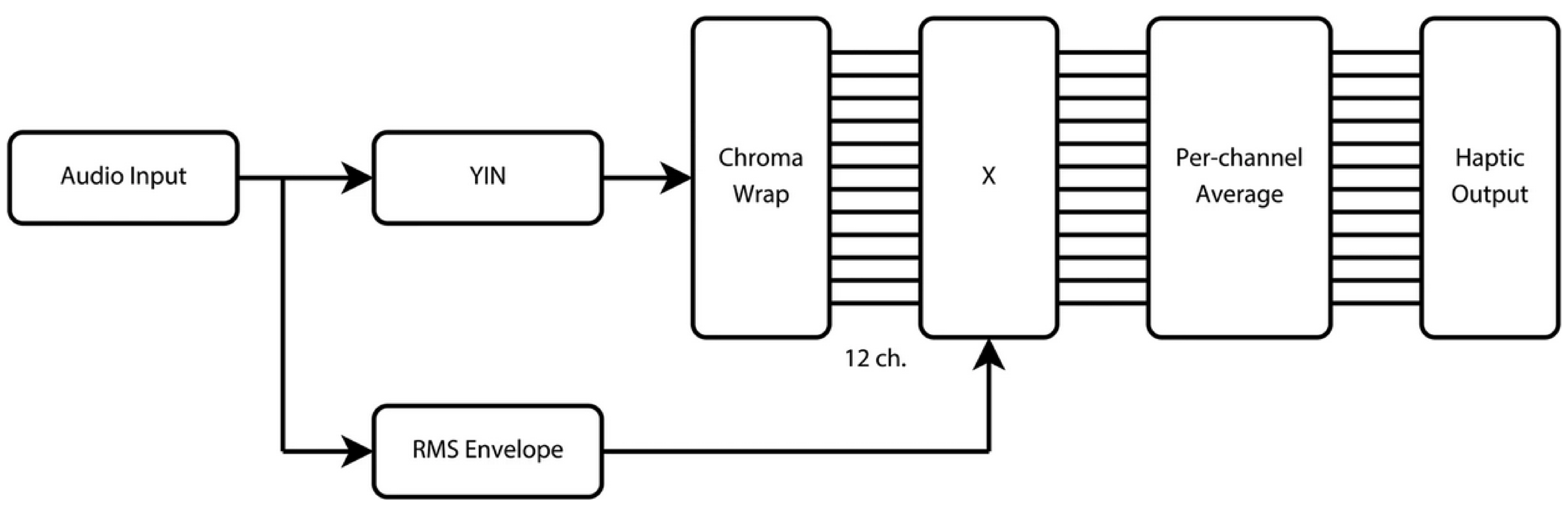

Figure 2: Overview of the signal processing strategy used to convert audio to haptic stimulation

This strategy provided a representation of the input's pitch relative to within an octave – this allowed for a much higher resolution when representing small changes in pitch, whilst removing absolute pitch information. Cochlear implant users are typically able to discriminate pitch differences of more than one octave. This design therefore aimed to provide sub-octave pitch information that is may not be well represented.

Procedure

A pitch discrimination task was used to assess the viability of the mosaicOne_B:

- 12 simulated cochlear implant users (normal hearing listeners using the SPIRAL cochlear implant simulator)
- Two tone complexes presented sequentially – reference tone at 300 Hz ±5% and target tone with varying F0 based on an adaptive track
- Two-alternative forced choice paradigm used – participants asked to state if the first or second stimulus was higher in pitch
- Track measured for complex in quiet, at -5 dB SNR white noise and at -7.5 dB SNR white noise
- 3 conditions were measured for each noise:
  1. Audio only
  2. Haptic only
  3. Audio-haptic

Results

Wilcoxon signed-rank tests showed significantly better pitch discrimination performance with Audio-haptic enhancements than audio alone ($T = 78$, $p = .001$, $d = 3.76$) - on average from 43.4% to 1.5% without noise, from 85.3% to 2.5% at -5 dB SNR and from 82.2% to 2.4% at -7.5 dB SNR.

No effect of noise was found for audio-haptic stimulation, assessed using a Friedman ANOVA ($\chi^2(2) = 2.09$, $p = 0.35$) (Fletcher et. al, 2020a)

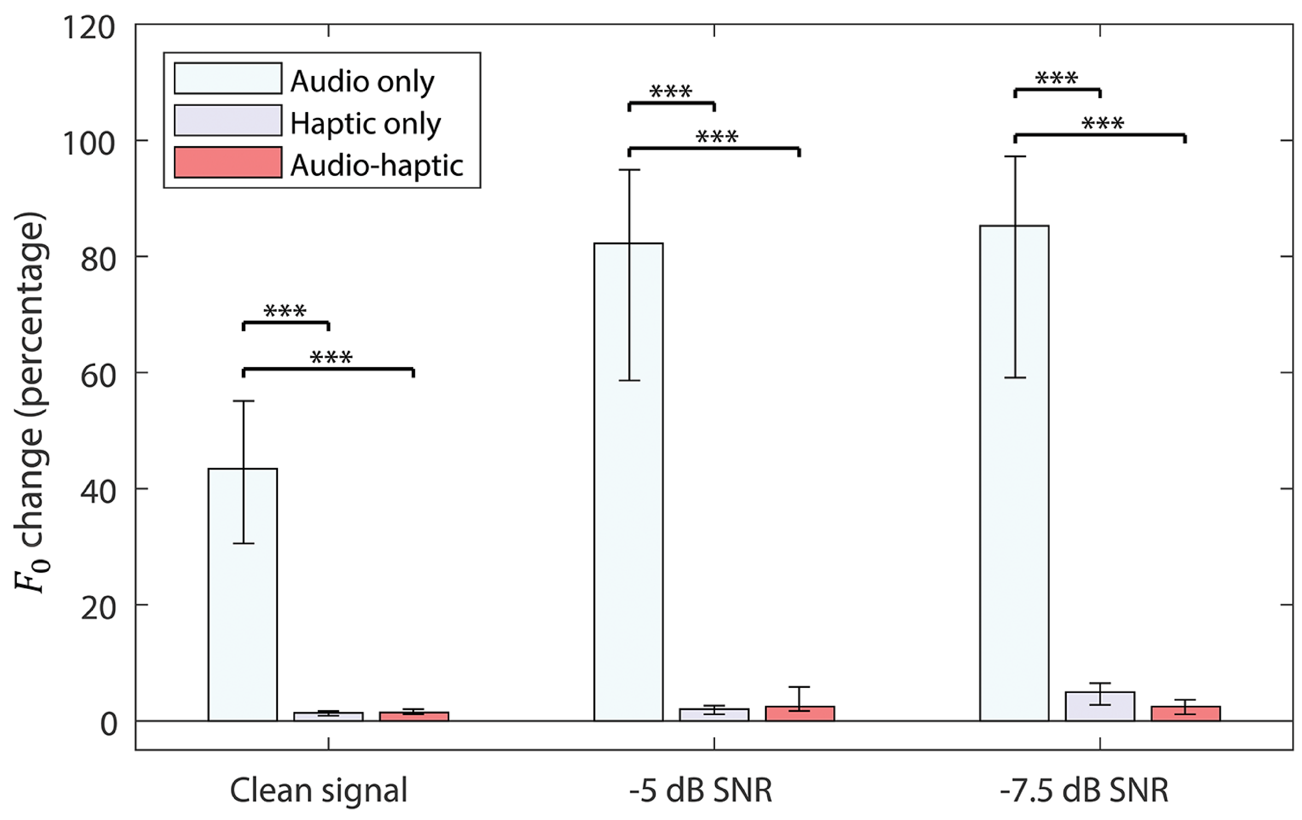

Figure 3: F0 discrimination thresholds for the Audio only, Haptic only and Audio-haptic conditions for each noise level (clean, -5 dB and -7.5 dB

Future work

- Verify results in cochlear implant users, and explore benefits provided when using more ecologically valid stimuli (e.g. music or speech)
- Design a more compact device for real-world applications
- Explore the use of wireless streaming from behind the ear devices to electrohaptic device (Fletcher et. al, 2020b)
- Use of automatic motor calibration and individualised fitting to maximise benefits

Figure 4: 3D render of a potential future iteration of the mosaicOne

References

Fletcher, Thini, and Perry, (2020a) "Enhanced Pitch Discrimination for Cochlear Implant Users with a New Haptic Neuroprosthetic." Sci Rep.

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