Electro-haptic hearing: Improving speech-in-noise performance in cochlear implant users by presenting sound information through vibration on the wrists

Mark D. Fletcher[1], Amatullah Hadeedi[1], Robyn O. Cunningham[1], Sean R. Mills[1], Sam W. Perry[1], Tobias Goehring[2], Carl Verschuur[1]

[1] Faculty of Engineering and Physical Science, University of Southampton, University Road, Southampton, SO17 1BJ, United Kingdom
[2] MRC Cognition and Brain Sciences Unit, University of Cambridge, 15 Chaucer Road, Cambridge, CB2 7EF, United Kingdom

Background

Many cochlear implant (CI) users achieve excellent speech understanding in quiet listening conditions, but most perform poorly in background noise. It has been observed that CI users who have residual low-frequency acoustic hearing ["electro-acoustic hearing" (EAS)] perform better in noise than those with no residual hearing. However, only ~9 % of CI users have access to EAS.

The tactile system is most sensitive in the frequency range in which EAS has provided benefit (~20-500 Hz). In this work, we tested whether speech envelope information presented via tactile stimulation can improve speech-in-noise performance for in CI users.

Two recent studies have explored the possibility of augmenting CI hearing by providing speech information through tactile stimulation (Huang et al., 2017; Fletcher et al., 2018). The results from Fletcher et al. (2018) are shown in Figure 1 and a comparison of the features of Huang et al. and Fletcher et al. is given in Table 1.

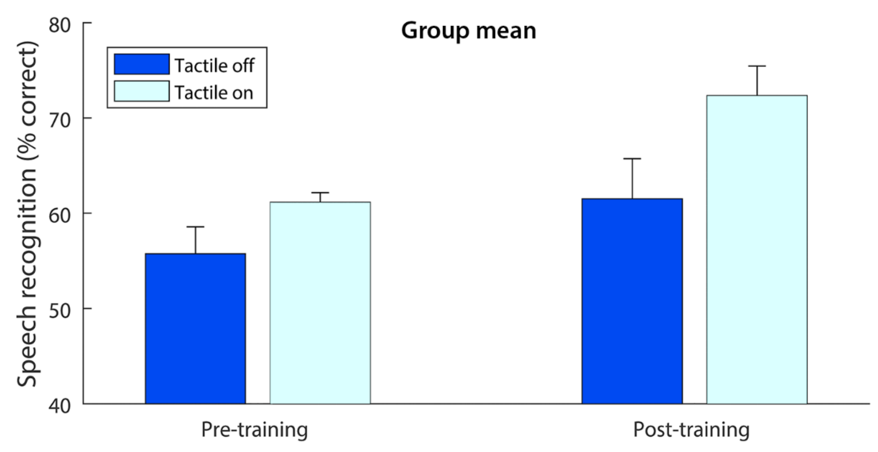

Figure 1: Results from Fletcher et al (2018). Eight normal-hearing participants listened to CI simulated speech-in-noise both with and without concurrent tactile stimulation of their fingertip. Error bars show the standard error of the mean

	Huang *et al.* (2017)	Fletcher *et al.* (2018)	Current study
Tactile signal extracted from speech-in-noise signal?	✗	✓	✓
Signal extraction suitable for real-time processing?	✗	✓	✓
Tactile signal that could be produced by portable device	✓	✓	✓
Stimulation site suitable for real world use?	✗	✗	✓
Conducted in real cochlear implant users (not simulated)?	✓	✗	✓
Speech testing with multi-talker noise?	✗	✓	✓
Assessment before and after training?	✗	✓	✓

Table 1: Comparison of the key features two previous studies and the current study.

Aims of the current study:

We aim to replicate the findings of Fletcher et al., but:

1. Use real CI users (not normal hearing participants listening to simulations)

2. Present tactile stimulation to the wrist (a more suitable site for real-world application)

Methods

Participant

Participant number	Gender	Age	Speech in quiet	Years since Implantation	Implant type
1	F	65	85	9.3	MEDEL Sonata
2	M	56	89	3.4	AB Hi Res 90k
3	M	69	99	1.5	AB Hi Res 90k
4	F	68	98	3.7	Cochear Nucleus 512 (CA)
5	M	68	94	1.0	AB HiRes ultra
6	F	70	96	2.7	Cochear Nucleus 512 (CA)
7	M	70	92	9.1	Cochlear Nucleus Freedom contour
8	F	44	98	1.6	Cochear Nucleus 512 (CA)
9	F	41	93	7.7	Cochlear Nucleus Freedom contour (bilateral)
10	F	52	100	10.9	AB Hi Res 90k

Set up & protocol

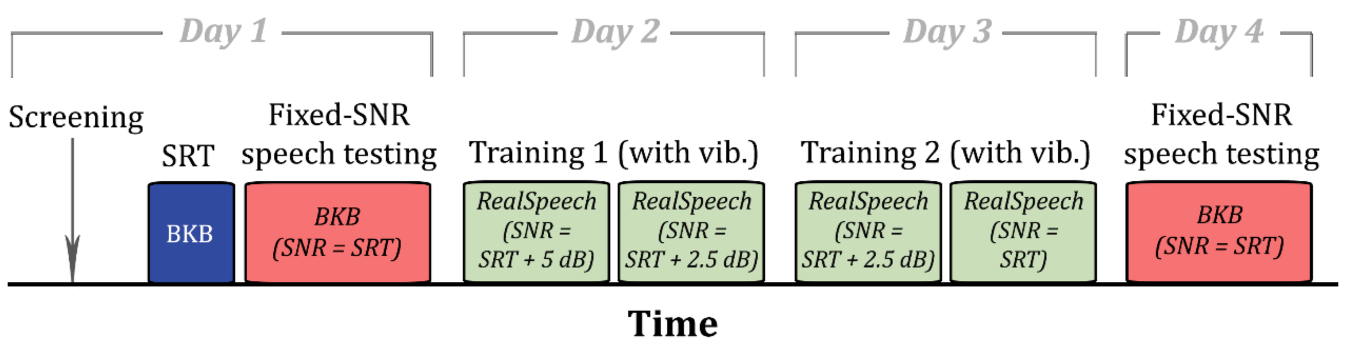

Figure 2: Schematic (not to scale), showing the timeline of the experiment

Testing sessions 1 and 2 (days 1 and 4)

1. *Measure speech-reception threshold (SRT) without vibration (only session 1):* IHR-BKB sentences and National Acoustics Laboratories "party noise"; criteria = 1 out of 3 key words correct.
2. *Fixed SNR speech testing with and without vibration to both wrists:* Percentage correct for speech-in-noise at SNR equal to participant's SRT. When vibration is on, participants are told they are getting "vibration enhancement", and when it is off "audio enhancement".

Training sessions 1 and 2 (days 2 and 3)

Participants were trained with four 5-minute audiobook segments (different to BKB talker) with noise used in test sessions, and with vibration always on. During training, a sentence was played, the participant was asked to repeat it to the experimenter, and then the sentence text was displayed. The SNR was progressively reduced towards their SRT for different segments across the training sessions (see Figure 2).

Methods (continued…)

Tactile signal processing

1. The speech-in-noise signal is downsampled to 16 kHz (see Figure 3 for flow diagram)
2. The signal is filtered into 4 bands (100-1000 Hz, with equal ERB spacing)
3. The speech envelope is extracted from each band
4. The envelope from each band is used to modulate four carrier tones in the frequency range where touch is most sensitive (at 50, 110,170 and 230 Hz)
5. Each carrier is passed through an expander to exaggerate the speech envelope modulations and to reduce noise contribution (see Figure 4)

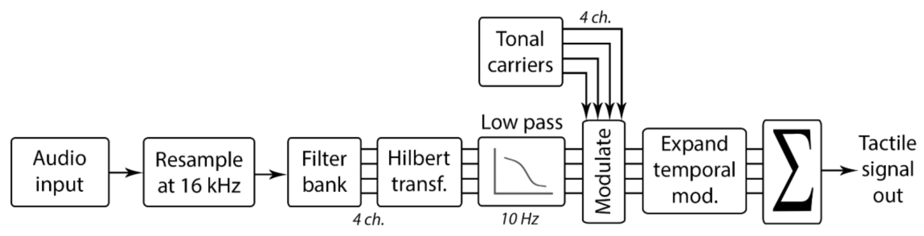

Figure 3: Schematic representation of the signal processing chain for the tactile signal generation.

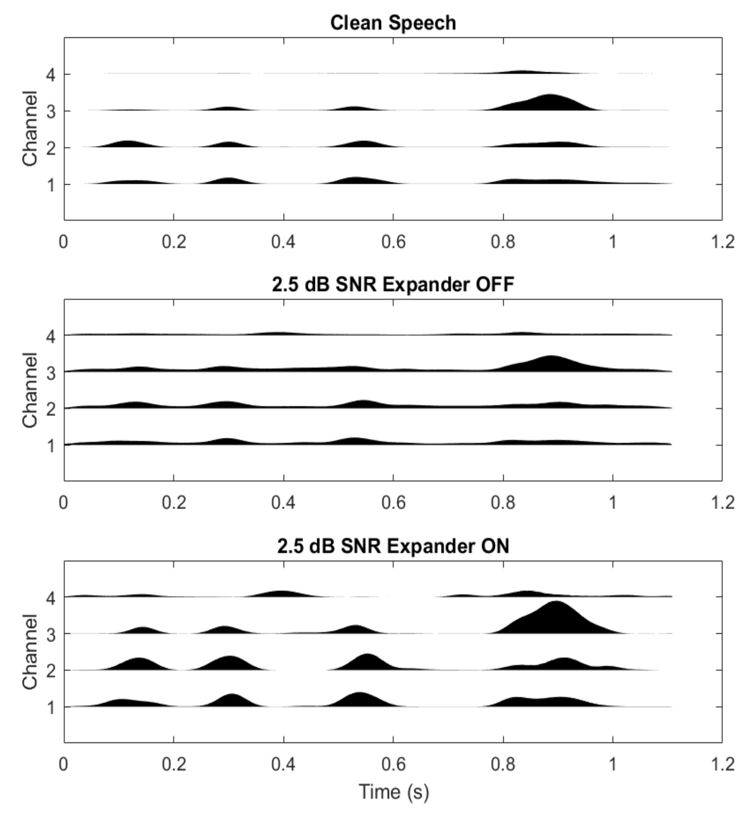

Figure 4: Illustration of the effect of the expander on the tactile signal amplitude for the sentence "He hit his head". Panel A and B show the tactile signal for clean speech and for speech-in-noise (at the lowest SNR used in the study). Panel C shows the same signal as panel B, but with the expander on.

Results

- A significant interaction effect, indicating that the effect of tactile stimulation in the post-training session was significantly larger than in the pre-training session (F(1,9) = 14.2, p = .004). Main effects of Condition and Session were non-significant.
- Paired t-tests (with a Bonferroni corrected alpha of .025), revealed a significant effect of Condition in the post-training session (t(9) = 3.4, p = .008), but not in the pretraining session (t(9) = .82, p = .43).
- Before training, in 7 out of 10 participants' performance 6 was worse with tactile stimulation, and individual results were highly variable. Some participants reported finding the vibration distracting before training.
- After training, all ten participants performance improved with tactile stimulation, with the smallest improvement being 0.5 %-points (improving from 67.8 % to 68.3 %; P8) and the largest improvement being 21.8 %-points (33.8 % to 55.6 %, P1). The mean improvement with tactile stimulation after training was 8.3 %-points (improving from 54.3 % to 62.5 %).

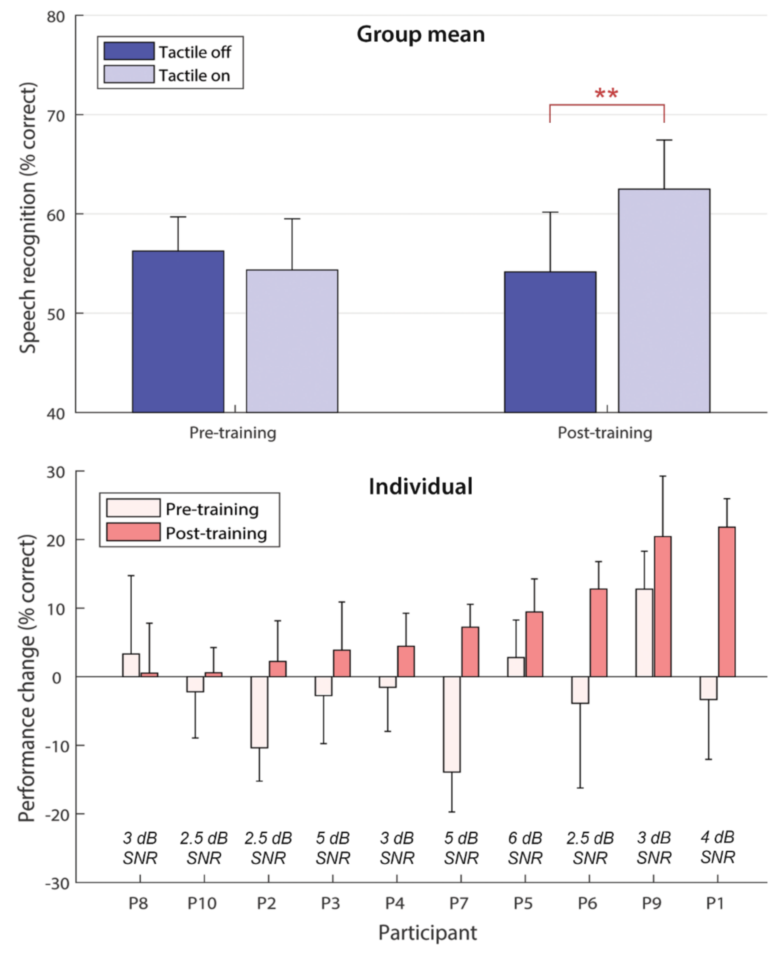

Figure 5: Results for 10 CI users. Participants' speech-in-noise performance was assessed before and after 2 days of training, totaling 20 mins exposure to speech-in-noise and tactile stimulation. Error bars show the standard error of the mean

Next steps

- Develop a portable device that would allow for remote training. An important realisation from the current work is the difficulty in recruiting CI participants (who often live many miles from the university) to attend multiple testing sessions. **See our prototype device and remote training system being demoed in the pod.**
- Assess viability of this approach for enhancement of lip-reading in CI users
- Assess the potential for using tactile stimulation to improve spatial hearing cues, and to increase music enjoyment in CI users.

References

Fletcher MD, Mills SR, Goehring T. (2018) Vibro-tactile enhancement of speech intelligibility in multi-talker noise for simulated cochlear implant listening. *Trends in Hearing*

Huang J, Sheffield C, Lin P, Zeng F (2017) Electro-Tactile Stimulation Enhances Cochlear Implant Speech Recognition in Noise. *Scientific Reports.*

Acknowledgements

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UNIVERSITY OF Southampton

Please visit the pod for a demonstration of electro-haptics

Contact: M.D.Fletcher@soton.ac.uk

British Cochlear Implant Group Meeting
Newcastle, 4-5th April 2019