Spelling interface using intracortical signals in a completely locked-in patient enabled via auditory neurofeedback training

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Setup

- Complete Locked-in Syndrome due to late stage ALS (and likely frontotemporal dementia or other factors - not discussed by authors).
- 2 x 64-channel electrode arrays implanted
  - One in primary motor cortex
  - One in supplementary motor area

Overall Typing Procedure

Baseline recording.
Hand-adjust parameters. 20 trials practice, >80% to proceed to spelling

1. Imagined movement, motor cortex activity
2. Raw electrode data (subset of channels)
3. "Neural Signal Processor" (analog-to-digital + bandpass 250-7500 Hz)
4. Compute **Spike rate metric (SRM)** for each channel
5. Add SRM across channels, linear decode to audio tone (128-480 Hz)
6. Play audio tone (gives feedback to subject). (Tone updated every 250 ms)

Subject moves tone lower for "No", higher for "Yes"

See supplementary videos - https://www.nature.com/articles/s41467-022-28859-8#Sec14

Spike Rate Metric

- Every day - 10 minute rest recording to estimate baseline activity. After visual inspection, manually (??) set baseline activity level.
- Spike detection - "threshold crossing" - >4.5 RMS value
- "Spike rate metric" (SRM): Count threshold crossings in 50 ms bins. SRM = average binned count over past 1 second

Spike Rate Metric to Audio Tone

Neurofeedback communication. The patient was provided auditory feedback of neural activity levels by mapping the SRM for one or more channels to the frequency of an auditory feedback tone, as shown in Fig. 1. Single channel spike rates were normalized according to the spike rate distribution of each channel. Selected channels' normalized SRMs were then summed and linearly mapped to the range of 120–480 Hz, determining the frequency of the feedback tone produced by an audio speaker. Feedback tones were updated every 250 ms. The firing rate r_i of each selected channel was constrained to the range $[a_i, b_i]$, normalized to the interval [0,1], and optionally inverted, and the resulting rates were averaged:

$$r(t) = \frac{1}{n}\sum_{i}^{n}\frac{1-c_i}{2} + c_i\frac{\max(\min(r_i(t), b_i), a_i)}{b_i - a_i} \quad (1)$$

where $r(t)$ is the overall normalized firing rate, and the c_i are 1 or -1. The normalized rate was then linearly mapped to a frequency between 120 and 480 Hz for auditory feedback. Feedback tones were pure sine waves lasting 250 ms each. Initially, channels were selected randomly for feedback. Then the parameters a_i, b_i, c_i as well as the channels used for control were chosen and iteratively optimized each day in the neurofeedback training paradigms.

Information Transfer Rate

To evaluate the performance of the speller, the information transfer rate[36] (ITR) B during speller sessions that were rated as intelligible was calculated as:

$$B = \log_2 N + P \log_2 P + (1 - P) \log_2 \frac{1 - P}{N - 1} \quad (2)$$

where N is the number of possible speller selections (30 including space, delete, question mark and end program), and P is the probability that a correct letter was selected. Multiplication with selected symbols and division by session duration yields bits per minute.

Discussion

- Very low speed communication.
  - Total: 5747 "intelligible" characters over 5338 min (1.08 char / min)
  - Estimated ITR: 5.2 bit / min
- Some vague biological handwaving to explain failure of multi-channel decoding

Phrases from Subject

ers mal moechte ich mich niels und seine birbaumer bedanken
kop?f immerlqz gerad
kein shirt aber socken
mama kopfmassage
erstmal kopfteil viel viel hoeh ab jetzt imm
an alle muessen mir viel oefter gel augengel
alle sollen meine haende direkten auf baubch
zum glotze und wenn besuchen da ist das kopfteil immer gaaanz rauf
wili ch tool balbum mal laut hoerenzn
und jetwzt ein bier
turn on word recognition
is it easy back once confirmation
tell alessandro i need to save edit and delete whole phrases and all of that into the list where <SON>
why cant you leave the system on. ifind that good
jungs es funktioniert gerade so muehelos
mixer fuer suppen mit fleisch
gulaschsuppe und dann erbsensuppe
wegen essen da wird ich erst mal des curry mit kartoffeln haben und dann bologna und dann gefuellte und dann kartoffeln suppe
<SON> ich liebe meinen coolen <SON>
<SON> willst du mit mir bald disneys robin hood anschauen
alles von den dino ryders und brax autobahnund alle aufziehautos
(son’s name) moechtest du mit mir disneys die hexe und der zauberer anschauen auf amazon
mein groesster wunsch ist eine neue bett und das ich morgen mitkommen darf zum grillen

Media Coverage

https://www.loudersound.com/news/completely-paralysed-man-communicates-for-the-first-time-in-months-asks-to-listen-to-tool

Scandal!

- Alleged misconduct by Niels Birbaumer and Ujwal Chaudhary in 2013-2014.
  - https://www.nature.com/articles/d41586-019-02862-4
  - Retraction of 2 articles:
    - https://pubmed.ncbi.nlm.nih.gov/28141803/
    - https://pubmed.ncbi.nlm.nih.gov/30958815/
- Dissent and support of the authors: http://www.communication4als.com/
- Writing by the whistleblower: https://journals.plos.org/plosbiology/article?id=10.1371/journal.pbio.2004750