Neural representations of restored acoustic rhythm in noise

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Introduction
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In dynamic soundscapes, extreme masking may incentive filling-in of sound signals lost
Introduction

• An important problem is posed by fluctuating, cluttered acoustic environments
  • rule rather than exception
  • what adaptive mechanisms meet this demand?
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  • rule rather than exception
  • what adaptive mechanisms meet this demand?

• Key to facilitate communication:
  • improve likelihood of invariant perceptual outcomes
    • despite simultaneous maskers
Research questions

• During filling-in:

(1) How does adjustment to dynamic percepts correspond to adjustment in dynamic neural representations?

(2) What functional mechanisms underlie this correspondence?
Part 1: Perceptual restoration of missing acoustic rhythm

Part 2: Reconstruction of missing speech sequences
Part 1: Perceptual restoration of missing acoustic rhythm

Part 2: Reconstruction of missing speech sequences
Research methodology

- 5 Hz rhythm with noise maskers (1.2 s each)
  - 1 hour total

Non-rhythmic

Rhythmic
Research methodology

- 5 Hz rhythm with noise maskers (1.2 s each)
  - 1 hour total

- Auditory cortex response by whole-head magnetoencephalography (MEG)
Research methodology

• Neural representations defined by periodicity: spectral analysis viable
Results

5 Hz evoked power

* $p < 0.01$
Results

5 Hz evoked power

Neuro-psychometric comparison

Non-rhythmic probes

Rhythmic probes

[dB] 40 30 20

Absent  Filling-in

Missed  Driven

Time from probe onset [s]

Neural discriminability [z]

Synchronized  Endogenous

$d'$ sensitivity

*p<0.01
Part 1 discussion

• 5 Hz power neurally restored in noise without 5 Hz rhythm stimulus
  • marker of restoration, from cortical activity

• Differential response related to percept & behavior

• Modulation rate probed relevant to human speech communication
Part 1: Perceptual restoration of missing acoustic rhythm

Part 2: Reconstruction of missing speech sequences
Research methodology
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'Twas the night before Christmas, when all through the house not a creature was stirring, not even a mouse. The stockings were hung by the chimney with care, in hopes that St. Nicholas soon would be there.

The children were nestled all snug in their beds, while visions of sugar plums danced in their heads. And Mama in her 'kerchief, and I in my cap, had just settled our brains for a long winter's nap.

When out on the lawn there arose such a clatter, I sprang from my bed to see what was the matter. Away to the window I flew like a flash, tore open the shutter, and threw up the sash.

The moon on the breast of the new-fallen snow gave the lustre of midday to objects below, when, what to my wondering eyes should appear, but a miniature sleigh and eight tiny reindeer.

With a little old driver, so lively and quick, I knew in a moment it must be St. Nick. More rapid than eagles, his coursers they came, and he whistled and shouted and called them by name.

"Now Dasher! Now Dancer! Now, Prancer and Vixen! On, Comet! On, Cupid! On, Donner and Blitzen! To the top of the porch! To the top of the wall! Now dash away! Dash away! Dash away all!"

As dry leaves that before the wild hurricane fly, when they meet with an obstacle, mount to the sky so up to the house-top the coursers they flew, with the sleigh full of toys, and St. Nicholas too.

And then, in a twinkling, I heard on the roof the prancing and pawing of each little hoof. As I drew in my head and was turning around, down the chimney St. Nicholas came with a bound.

He was dressed all in fur, from his head to his foot, and his clothes were all tarnished with ashes and soot. A bundle of toys he had flung on his back, and he looked like a peddler just opening his pack.

His eyes--how they twinkled! His dimples, how merry! His cheeks were like roses, his nose like a cherry! His droll little mouth was drawn up like a bow, and the beard on his chin was as white as the snow.

The stump of a pipe he held tight in his teeth, and the smoke it encircled his head like a wreath. He had a broad face and a little round belly, that shook when he laughed, like a bowl full of jelly.

He was chubby and plump, a right jolly old elf, and I laughed when I saw him, in spite of myself. A wink of his eye and a twist of his head soon gave me to know I had nothing to dread.

He spoke not a word, but went straight to his work, and filled all the stockings, then turned with a jerk. And laying his finger aside of his nose, and giving a nod, up the chimney he rose.

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MEG responses, speech delivered → data-driven source selection → Analyze gaps

Subject R2349

repeat

time

MEG responses
MEG responses, speech delivered → data-driven → source selection

Analyze gaps

Subject R2349

Speech envelope

clothes were all tarnished, with a she s
Analyze gaps

Subject R2349

MEG responses
speech delivered

Train decoder

Source selection

Speech envelope

Subject: MEG responses, speech delivered

Clothes were all tarnished, with a she shed, with a she s
Analyze gaps

Subject R2349

MEG responses, speech delivered

Source selection

data-driven

Speech envelope

MEG responses, speech gaps

train

decoder

Repeat

Subject R2349

Clothes were all tarnished with a she*

Reconstruct speech
Analyze gaps

Subject R2349

MEG responses, speech delivered → source selection

Repeat

time

Analyze gaps

Clothes were all tarnished, with a she's

Speech envelope

MEG responses, speech gaps → decoder

Train

Reconstruct speech
Analyze gaps

Subject R2349

MEG responses, speech delivered

source selection

MEG responses, speech delivered

Speech envelope

MEG responses, speech gaps

train S decoder

MEG responses, speech gaps

train S decoder

Reconstruct speech

clothes were all tarnished, with a slightest she...
MEG responses, speech delivered → source selection → data-driven → MEG responses

Analyze gaps

Subject R2349

Speech envelope

MEG responses, speech gaps → train S → decoder

Reconstruct speech

MEG responses, noise gaps → train N → decoder

Reconstruct speech
Analyze gaps

MEG responses, speech delivered
Source selection

Speech envelope

MEG responses, speech gaps

train S
Decoder

MEG responses, noise gaps

train N
Decoder

Reconstruct speech

Subject R2349

Clothes were all tarnished, with a she shed.
**Results**

Reproducible reconstruction of missing envelope

* Reproducible reconstruction of missing envelope
  - *p* < 0.01

**Repetition rate**

- Low
- Medium
- High
- Control

<table>
<thead>
<tr>
<th>Repetition rate</th>
<th>Reproducibility [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>10</td>
</tr>
<tr>
<td>Medium</td>
<td>20</td>
</tr>
<tr>
<td>High</td>
<td>30</td>
</tr>
<tr>
<td>Control</td>
<td>0</td>
</tr>
</tbody>
</table>

* *p* < 0.01
Part 2 discussion

• Auditory cortex activity partially reconstructs missing speech envelope
  • over ecologically-relevant timescales
  • disappears with little or no prior experience
Conclusions

• Temporal coding sustained during acoustic signal gaps consistent with perceptual restoration

• Sustained filling-in over steady or syllabic rhythm modulation components

• Adaptive modifications include
  • patterned cortical dynamics during restoration
  • decoding of missed speech tokens
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K.I.T. 金沢工業大学
Kanazawa Institute of Technology
Operating definitions (for volitional tasks)

• “To Recall”: the description is either a real memory or an object seen previously

• “To Recreate”: an imagined scene/object previously created is to be reconstructed

• “To Imagine”: a new fictitious scene/object is to be imagined for the first time

from Hassabis et al., 2007