Isolating neural signatures of conscious speech perception with a “no-report” sine-wave speech paradigm

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Isolating content-specific NCCs

Goals of research program

Develop paradigms to enable neural contrasts between:
  • perceived vs. not-perceived
  • task-relevant vs. task-irrelevant

Test theories that make conflicting predictions:
  • local recurrence vs. global ignition
  • first-order vs. higher-order

Address basic outstanding questions:
  • where are NCCs roughly located (anterior vs. posterior)?
  • when do NCCs roughly emerge (early vs. late)?
Testing domain-general theories of perceptual awareness with auditory brain responses

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Awareness Manipulations

- masking
- threshold detection
- change blind/deafness
- inattentinal blind/deafness
- attentional blink
- bistable perception
Sine-Wave Speech (SWS)

SWS: Previous SWS experiments (EEG, fMRI, ECoG)
- Liebenthal et al. (2001) JASA
- Liebenthal et al. (2005) Cerebral Cortex
- Dehaene-Lambertz et al. (2005) NeuroImage
- Möttönen et al. (2006) NeuroImage
- Khoshkhoo et al. (2018) Brain and Language

original speech:

task-irrelevant → task-relevant

OR

task-relevant → task-relevant


http://www.lifesci.sussex.ac.uk/home/Chris_Darwin/SWS/
“No report” inattentional blindness paradigm

**Phase 1**
- **Stimuli:**
  - Task: red dots
  - Not-perceived vs. perceived

**Phase 2**
- **Stimuli:**
  - Task: red dots
  - Not-perceived vs. perceived

**Phase 3**
- **Stimuli:**
  - Task: shapes
  - Task-irrelevant vs. task-relevant
“No report” sine-wave speech (SWS) paradigm

<table>
<thead>
<tr>
<th>Phases</th>
<th>Stimuli</th>
<th>Percepts</th>
<th>Tasks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1</td>
<td>noise</td>
<td>noise</td>
<td>tones</td>
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<tr>
<td></td>
<td>sws</td>
<td>noise</td>
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<tr>
<td>Phase 2</td>
<td>noise</td>
<td>sws</td>
<td>tones</td>
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<td></td>
<td>noise</td>
<td>sws</td>
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<tr>
<td>Phase 3</td>
<td>noise</td>
<td>sws</td>
<td>speech</td>
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<tr>
<td></td>
<td>noise</td>
<td>sws</td>
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</tr>
</tbody>
</table>

- not-perceived vs. perceived
- task-irrelevant vs. task-relevant
Stimuli

SWS:
- brain
- wave
- yard

Noise (flipped SWS):

Pure Tones:
- low
- med
- high
Procedure

Phase 1: One-back Task on Pure Tones

Speech Awareness Assessment

Phase 2: One-back Task on Pure Tones

SWS Training & Recognition Test

Phase 3: One-back Task on SWS

Speech Awareness Assessment

# of stimuli per phase:
SWS: 300 (100 per word)
noise: 300 (100 per noise)
tones: 300 (100 per tone)

# of one-backs per phase:
SWS: 30 (10 per word)
noise: 30 (10 per noise)
tones: 30 (10 per tone)

Example stim sequence
Speech awareness assessment (after phase 1 & 2)

1. In your own words, describe what the computer-generated noises sounded like.

2. Did you hear any of the following in the computer-generated sounds? For each of the categories in the table below, circle a number representing your experience.

1=very confident I did not hear it  
2=confident I did not hear it  
3=uncertain  
4=confident I did hear it  
5=very confident I did hear it

<table>
<thead>
<tr>
<th>Category</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distorted music</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Distorted words</td>
<td></td>
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<tr>
<td>Distorted environmental sounds</td>
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<td>Distorted animal sounds</td>
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</table>

5. If you marked a “4” or “5” for hearing the computer-generated noises as “distorted words”, please write down the words you heard.
SWS training & recognition test (btw phase 1 & 2)

9 Stimuli:  
- brain  
- language  
- world  
- chill  
- speech  
- yard  
- church  
- wave  
- zombie

1) Self-paced training
   • SWS → Original Speech → SWS
   • repeat until clearly hear SWS as speech

2) Speech recognition test
   • 9 SWS + 3 noise (flipped) versions of “brain”, “wave”, “yard”
   • 10 AFC task (9 words + 1 “no word” option)

**Accuracy** = 94% total; **99%** for “brain”, “wave”, “yard”
Behavioral results: speech awareness

Phase 1: Confidence Ratings

Confidence in Hearing Distorted Words
(1 = least : 5 = most)

- Red bars: Could Not Identify Any Words
- Black bars: Identified At Least One Word

Speech not-perceived
(N=12)

Speech perceived
(N=9)

Phase 2: Confidence Ratings

Confidence in Hearing Distorted Words
(1 = least : 5 = most)

- Red bars: Could Not Identify Any Words
- Black bars: Identified At Least One Word
SWS stimuli, speech not-perceived in phase 1 (N=12)

- Ph1: heard noise, task-irrel
- Ph2: heard speech, task-irrel
- Ph3: heard speech, task-rel
SWS stimuli, speech not-perceived in phase 1 (N=12)

EN

Ph1: heard noise, task-irrel
Ph2: heard speech, task-irrel
Ph3: heard speech, task-rel
SWS stimuli, speech not-perceived in phase 1 (N=12)

Difference [Phase 2 - Phase 1]
200-300ms

EN

Ph1: heard noise, task-irrel
Ph2: heard speech, task-irrel
Ph3: heard speech, task-rel
SWS stimuli, speech not-perceived in phase 1 (N=12)

Difference
[Phase 2 - Phase 1]

200-300ms

EN

Ph1: heard noise, task-irrel
Ph2: heard speech, task-irrel
Ph3: heard speech, task-rel
SWS stimuli, speech not-perceived in phase 1 (N=12)

Difference [Phase 2 - Phase 1]

200-300ms

400-650ms

Ph1: heard noise, task-irrel
Ph2: heard speech, task-irrel
Ph3: heard speech, task-rel
SWS stimuli, speech not-perceived in phase 1 (N=12)

Difference
[Phase 2 - Phase 1]

200-300ms

400-650ms

Ph1: heard noise, task-irrel
Ph2: heard speech, task-irrel
Ph3: heard speech, task-rel

LN

EN

LP
SWS stimuli, speech not-perceived in phase 1 (N=12)

**Difference [Phase 2 - Phase 1]**

200-300ms

-2μV

+2μV

**Difference [Phase 3 - Phase 2]**

400-650ms

-2μV

+2μV

Ph1: heard noise, task-irrel
Ph2: heard speech, task-irrel
Ph3: heard speech, task-rel

LN

EN

LP
SWS stimuli, speech not-perceived in phase 1 (N=12)

Ph1: heard noise, task-irrel
Ph2: heard speech, task-irrel
Ph3: heard speech, task-rel
Noise (flipped) stimuli, speech not-perceived in any phase (N=21)

Ph1: heard noise, task-irrel
Ph2: heard noise, task-irrel
Ph3: heard noise, task-rel
SWS stimuli, speech not-perceived in phase 1 (N=12)

Ph1: heard noise, task-irrel
Ph2: heard speech, task-irrel
Ph3: heard speech, task-rel
SWS stimuli, speech perceived in phase 1 (N=9)

Ph1: heard speech, task-irrel
Ph2: heard speech, task-irrel
Ph3: heard speech, task-rel

LN
LP
Results summary

Perceiving vs. Not-perceiving speech [phase 2 vs. 1]:
- early negativity (EN: 200-300ms)
- late positivity (LP: 400-650ms)

Task-relevant vs. Task-irrelevant speech [phase 3 vs. 2]:
- differences early & late in time, including...
- larger late positivity (300-650ms)
- unique sustained late negativity (400-800+ms)
Conclusions & Open Questions

• Perceptual differences much smaller than task differences

• Important to develop paradigms to enable perceived vs. not-perceived contrasts for *task-irrelevant* stimuli

• Which stages of processing do the EN and LP index?

  \[
  \begin{align*}
  \text{EN} &= \text{NCC} & \text{OR} & \text{EN} &= \text{preconscious} \\
  \text{LP} &= \text{post-perceptual} & & \text{LP} &= \text{NCC} \\
  \text{EN} &= \text{NCC} & \text{OR} & \text{EN} &= \text{detection} \\
  \text{LP} &= \text{NCC} & & \text{LP} &= \text{identification}
  \end{align*}
  \]
Thank you for your attention and awareness!

Collaborators:
- Andy Dykstra
- Enriqueta Canseco-Gonzalez
- James Glass
- Camille Hendry
- Steve Hillyard

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www.reed.edu/psychology/scalp
Source estimate of EN (200-300ms): left PFC
Inferior Frontal Gyrus - BA 10
Source estimate of LP (400-650ms): global [inferior frontal, superior temporal, inferior parietal, etc.]
Source estimate of LN (400-800ms): bilateral PFC
Middle Frontal Gyrus - BA 10

sustained LN

400-800ms
Pure tone stimuli, task-relevant in phase 1 & 2 (N=21)

Ph1: heard tones, task-rel
Ph2: heard tones, task-rel
Ph3: heard tones, task-irrel
Behavioral results

Subjects who did not perceive speech in phase 1
Subjects who perceived speech in phase 1