Integrating Language Production and Comprehension

Language Prediction and Integration Seminar
Universität des Saarlandes
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Elli Tourtouri

Outline

• Traditional approaches in psycholinguistics
  • Independence of production & comprehension
  • Evidence challenging this independence
• Interweaving in action & action perception
  • Forward modeling in action
  • Forward modeling in action perception & evidence
  • Joint action
• Integration of production & comprehension
  • Forward modeling in language production & evidence
  • Forward modeling in language comprehension & evidence
• Dialogue
• Conclusions
• Questions
- Production & comprehension:
  - independent processes
  - distinct anatomical pathways
- Shared representations (cf. lexicon)
- Comprehension system assists production (external & internal self-monitoring)
Traditional model of communication
Traditional model of communication

- **Vertical split**
  - Discrete stages: A produces & B comprehends / B produces & A comprehends
  - Temporal separation between the two processes ("parallel monologues")

- **Horizontal split**
  - Processes underlying production & comprehension are separated within individuals
Evidence challenging the traditional split

Evidence challenging vertical split

- Contributions often overlap
- Addressee’s feedback can affect speaker’s contribution

- Interlocutors simultaneously produce their own & understand each other’s contributions; joint activity
Evidence challenging the traditional split

Evidence challenging horizontal split

- Faster picture-naming with phonologically related distractors
- Tongue & lips muscle activation when listening to speech, but not nonspeech
- Activation of production-related areas during comprehension at different levels (from phonology to narrative speech)

→ Production & comprehension processes are interwoven
→ Neural pathways underlying these processes cannot be separated
• Language comprehension uses the production system
• When & why?
  • Comprehension: incremental
  • Prediction → listeners get the time to
    • keep up with input
    • compensate for noise/ambiguity/etc.
• How?
  • Same system that is used for production (*)
  • Draw from motor perception accounts
Motor perception

- Traditionally, action & action perception have been studied separately; thought to involve separate representations & processes
- Evidence for effects of perception on action & vice versa
- Lately, link between action & perception
  - For facilitating overt imitation
  - For postdictive use
  - For predicting what they are about to do or perceive (time advantage)
Pickering & Garrod

• Language production: action
• Language comprehension: action perception
  ▶ If action & perception are interwoven, production & comprehension should also be interwoven

• Comprehension processes are accessed at different stages in production & production processes are accessed at different stages in comprehension

• Extensive use of prediction for both processes
action & action perception
Forward model
- motor-control theory
- internal model that mimics physical systems outside the brain
- generates simulations of these systems in real time
- rapid
- central role: perceptual **prediction** (allow for corrective movements)

Inverse model
- internal model that generates appropriate motor commands based on desired consequences
Model of the action system
Forward modeling in action perception

- Action perception
  - Association route: Draw on past perceptual experience (of objects or other people)
  - Simulation route: Draw on own action experience
    - covert imitation + “context” (body differences)
A model of action perception
Evidence for covert imitation in prediction

Relevant motor-related areas can be activated before a perceived event occurs (Haueisen & Knösche, 2001)

Mirror neurons in monkeys are activated by perceptual predictions, but also by perceived actions (Umiltá et al., 2001)

People are better at predicting a movement trajectory when watching a video of themselves vs. others (Knoblich & Flach, 2001)
A model of joint action

\[ u_B(t+1) \rightarrow \text{B's forward action model} \rightarrow \hat{a}_B(t+1), \hat{a}_B(t+1) \]

\[ u_A(t) \rightarrow \text{B's action implementer} \rightarrow a_A(t) \rightarrow \text{A's covert imitation} \rightarrow \text{A's forward action model} \]
Evidence for covert imitation in joint action

People overtly imitate each other
• intentionally or not
• close temporal coordination

People continue each other’s behavior by overtly imitating the predicted behavior
• response inhibition when predicted that the partner is about to act (Sebanz et al., 2006)

Complementary behavior
• e.g. ballroom dancing
unifying language production and comprehension
Application of the action framework to language processing

Language processing is structured (levels of linguistic representation)

- previous framework + structure
- speakers & listeners predict the content of levels of representation
A model of production

Production command $i(t)$

Production implementer

Utterance $p[\text{sem}, \text{syn}, \text{phon}](t)$

Comprehension implementer

Utterance percept $c[\text{sem}, \text{syn}, \text{phon}](t)$

Predicted utterance percept $\hat{c}[\text{sem}, \text{syn}, \text{phon}](t)$

Forward comprehension model

Predicted utterance $\hat{p}[\text{sem}, \text{syn}, \text{phon}](t)$

Efference copy
Why not use forward model in production itself?

- Predictions generated by the forward model are “impoverished” representations ≠ implemented production representations
  - $p^{\text{[phon]}}(t)$: /k/, /a/, /l/, /t/ + order, not articulatory program
  - $p^{\text{[syn]}}(t)$: N, not number

- Predicted representations are not necessarily computed sequentially
Why not use forward model in production itself?

The forward model represents time

\[
\text{The boy went outside to fly...} \quad / \delta \text{e/} \quad [+100 \text{ ms}]
\]

(kite) \ [+300 \text{ ms}]

The forward model does not intervene between the predicted representations (≠ production system)

e.g. can predict /k/ without having made any syntactic prediction
Evidence from speech production

MEG studies

- Reduced M100 when people spoke & listened to their speech unaltered vs. pitch-shifted (Heinks-Maldonado et al., 2006)
  
  - distorted condition: $c^[phon](t) \neq c[phon](t)$

- Same MEG response when people produced vs. imagined producing a syllable (Tian & Poeppel, 2010)
  
  - phonological information available even without use of production implementer (= forward model)

fMRI study

- Participants read aloud words receiving distorted auditory feedback on some of the trials (F1 shifted upwards or downwards). Within 100 ms, shifted speech in the opposite direction. (Tourville et al., 2008)
  
  - Predictive monitoring (correction followed feedback would be too slow)
A model of comprehension

Person B

B's utterance
\( p_{[\text{sem}, \text{syn}, \text{phon}]}_B(t) \)

Comprehension implementer

Utterance percept
\( c_{[\text{sem}, \text{syn}, \text{phon}]}_B(t) \)

Inverse model + context

Covert imitation

Derived production command
\( i_B(t) \)

Derived production command
\( i_B(t+1) \)

Overt Responses

Efference copy

Forward production model

Predicted utterance
\( p_{[\text{sem}, \text{syn}, \text{phon}]}_B(t+1) \)

Person A

Forward comprehension model

Predicted utterance percept
\( \hat{c}_{[\text{sem}, \text{syn}, \text{phon}]}_B(t+1) \)

Monitor

B's utterance
\( p_{[\text{sem}, \text{syn}, \text{phon}]}_B(t+1) \)
Evidence for prediction in comprehension

Prediction at different linguistic levels

- Phonology

The day was breezy so the boy went outside to fly...

...an airplane

...a kite

(Delong et al., 2005)

Prediction of the word & its phonological form
Prediction at different linguistic levels

• Syntax

• Disruption when encountering adjective mismatching in gender with upcoming, predictable noun

(Van Berkum et al., 2005)
Evidence for prediction in comprehension

Prediction at different linguistic levels

- Semantics

*The boy will eat the...*

*The boy will move the...* 

- More looks to edible objects than inedible objects when hearing *eat* vs. *move*

- Prediction of semantics (edible things) or of word (*cake*)?
Evidence for prediction in comprehension

Prediction at different linguistic levels

• Semantics
  Dikker & Pylkkänen (2011)
  • Pictures followed by noun phrase matching/mismatching with item (e.g. apple) or semantic field (e.g. collection of food)
  • M100 in visual cortex associated with matching the item but not the field
  ‣ Predictions for the form of the specific word
Evidence for covert imitation

- Integrated neural circuits
  - Same areas are active when listening to and producing /p/ and /t/ (Pulvermüller & Fadiga, 2010)
  - Activation of tongue & lip muscles when listening to speech vs. nonspeech (Fadiga et al., 2002)
  - Listening to incongruent but not congruent phoneme distracters leaves articulatory traces on the simultaneous production of phonemes (e.g. listening to /t/ vs. /g/ when producing /k/; Yuen et al., 2010)

- Evidence for rapid and automatic overt imitation & overt completion
Evidence that covert imitation facilitates comprehension

Covert imitation generates predictions that facilitate comprehension.

fMRI study: While adapting to time-compressed speech there is increased activation in an area related to articulation planning (Adank & Devlin, 2010).

rTMS study: Temporarily disrupting articulator representations (e.g. lip representations) during speech perceptions impaired categorical perception of relevant speech sounds (e.g. /ba/~/da/), but not others (e.g. /ka/~/ga/) (Möttönen & Watkins, 2009).

TMS study: stimulating parts of the brain controlling lip & tongue movements speeded up & increased accuracy of responses to lip- & tongue-articulated phonemes (D’Ausilio et al., 2009).
Evidence that covert imitation facilitates comprehension

Covert imitation generates predictions that facilitate comprehension

fMRI study: Aligned neural activation for speakers and listeners during narration at different lags. Better comprehension when listeners’ activity preceded that of the speaker (Stephens et al., 2010)

Covert imitation leads to prediction, which in turn facilitates comprehension

Imitation & prediction occur at many levels of linguistic representation
Interactive language

\[ i_B(t+1) \rightarrow B's \text{ forward production model} \rightarrow \hat{p}_{sem, syn, phon}^B(t+1) \rightarrow \hat{p}_{sem, syn, phon}^B(t+1) \]

\[ i_B(t) \rightarrow B's \text{ production implementer} \rightarrow p_{sem, syn, phon}^B(t) \rightarrow A's \text{ covert imitation} \rightarrow A's \text{ forward production model} \]
A: ...and then we looked along one deck, we were high up, and down below there were rows of, rows of lifeboats in case, you see,

B: -there was an accident

A: -of an accident
Interactive language

Authors’ account can explain

• how interlocutors can be so well coordinated
• existence & speed of completions, overt imitation & complementary responses
• why interlocutors can use the content of utterances to predict when they end (de Ruiter et al., 2006)
• alignment of interlocutors at different linguistic levels
Conclusions

• Production & comprehension are tightly interwoven

• Prediction holds a central role in production, comprehension & dialogue

• Speakers use forward models to predict aspects of their upcoming utterances

• Listeners covertly imitate speakers & then use forward models to predict what speakers are likely to say

• Explains rapidity of production & comprehension, & fluency of dialogue
Questions?
Thank you