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Vanderbilt SLP Journal Club: The Role of Hippocampal Memory in Language Use and Language Disorders

Melissa C. Duff, PhD, CCC-SLP

Moderated by:
Amy Hansen, MA, CCC-SLP, Managing Editor, SpeechPathology.com

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The Role of Hippocampal Memory in Language Use and Language Disorders

Melissa C. Duff
Communication and Memory Laboratory
Vanderbilt University

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Learning Objectives

- Describe the hallmark processing features of the hippocampus and how those are recruited to support language processing.
- Describe 2-3 methods for studying the contribution of the hippocampus to language processing.
- Explain how new evidence on the role of hippocampus in language relates to complex cognitive-communication disorders.

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Fundamental Properties of Language

- Language is a system of arbitrary relations
  - relationship between phonological form of a word and its meaning is largely arbitrary.
- Language processing is incremental
  - spoken language unfolds over time (~150–200 words/minute) making many words and phrases ambiguous.
- Language use is flexible and creative
  - speakers rhetorically or poetically select particular details to represent for a specific listener on a particular occasion.
- Language use is multi-modal
  - multiple, rich sources of information from visual world, gaze, gesture, are integrated with language.

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Long standing attempts to link memory to language

- Working memory and/or executive control processes
  - prefrontal cortex and/or perisylvian areas
  - meets demands of incremental language processing
- Semantic memory system
  - distributed cortical networks
  - supports access to diverse lexical and real-world knowledge
- Declarative/Procedural Hypothesis
  - Declarative memory (MTL/hippocampus) support lexicon via arbitrary binding; Procedural memory (basal ganglia) supports grammar via statistical rule based learning

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  - Declarative memory (**MTL/hippocampus**) support **lexicon** via arbitrary binding; Procedural memory (basal ganglia) supports grammar via statistical rule based learning

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Traditional view of hippocampal declarative memory

- Contributes exclusively to long-term memory
  - STM memory thought to be intact in amnesia
- Amnesia as selective deficit in memory
  - H.M. was free of aphasia; language comprehension and production undisturbed (although see MacKay et al., 1998)
- Semantic memory eventually hippocampal independent
  - neocortical consolidation processes
  - H.M.'s remote semantic knowledge considered intact

(Milner, Corkin & Teuber, 1968; Lackner, 1974; Ogden & Corkin, 1991; although see MacKay et al., 1998)

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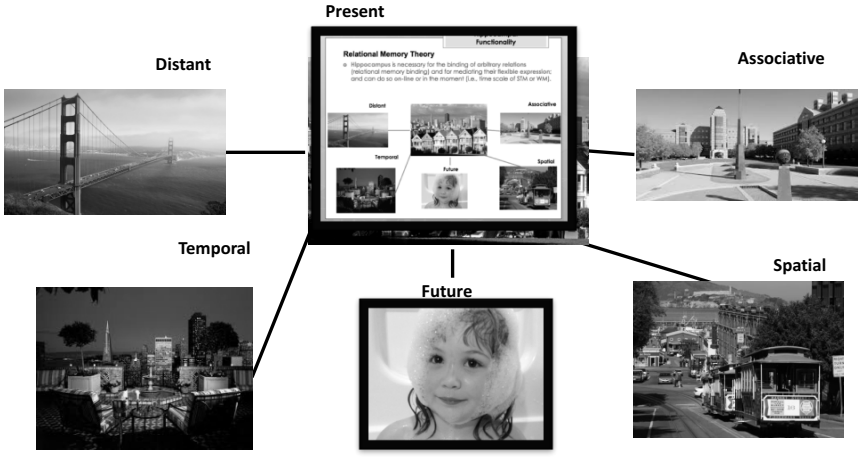
- **Hippocampus** is necessary for the binding of **arbitrary relations** (relational memory binding) and for mediating their **flexible expression**; and can do so **on-line** or in the moment (i.e., time scale of STM or WM).



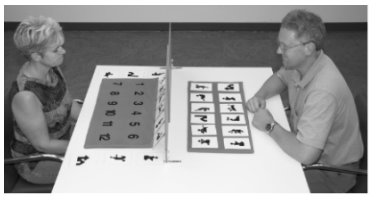
(e.g., Cohen & Eichenbaum, 1993; Eichenbaum & Cohen, 2001; Hannula et al., 2006; Hassibis et al., 2007) 13

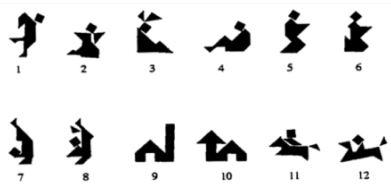
Hippocampal declarative memory contributions to language use and processing

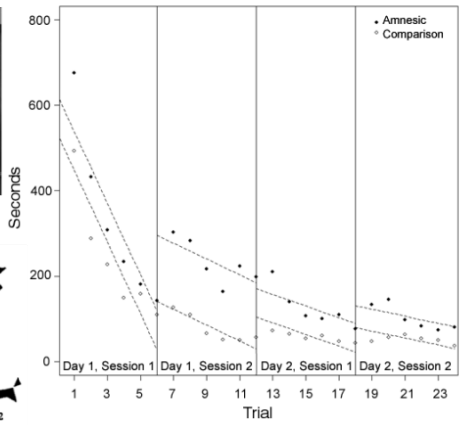
- many aspects of language use and processing place high demands on and receive contributions from the hippocampal declarative memory system
  - Patients with hippocampal amnesia
  - Discourse analysis, neuropsychoglogical and eyetracking methods
  - Deficits in a variety of linguistic and discourse functions

(Duff & Brown-Schmidt, 2012; *Front Hum Neurosci*) 14

- Intact rate of learning for the acquisition and successful use of referential labels in hippocampal amnesia in a collaborative referencing paradigm







(Duff, Hengst, Tranel, & Cohen, 2006; *Nature Neuroscience*) 15

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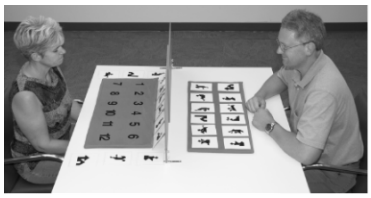

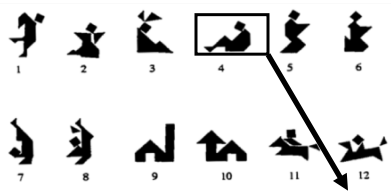

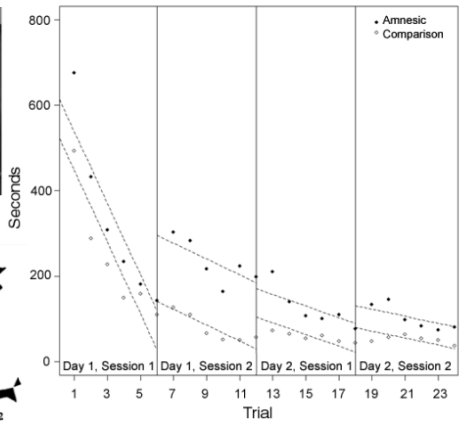

(Duff, Hengst, Tranel, & Cohen, 2006; *Nature Neuroscience*) 16

- **Hippocampal contributions to language**
  - Behavioral and Eye-tracking Studies
    - flexible and creative processing of language
    - incremental language processing
    - multi-modal language use
  - Direct Hippocampal recordings
    - Incremental processing of semantic context

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Hippocampal amnesia disrupts the flexible and creative use of language

- Definite reference
- Creative use of language

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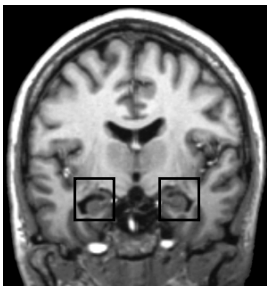
Hippocampal amnesia disrupts the flexible and creative use of language

- Definite reference
- Creative use of language

- 4 patients with hippocampal amnesia
  - 3 = anoxic/hypoxic episode; 1 = CHI
  - 2 males, 1 females
  - M age = 47.7 yrs; M education = 16 yrs
  - M WMS-III GMI = 59.16; M WAIS-III FSIQ= 101.5
- 4 healthy comparison participants
- 8 familiar communication partners
  - spouses, siblings, friends, parents
- Task completed across 24 trials
  - 6 trials per session, 2 sessions per day across 2 days



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Hippocampal amnesia disrupts the flexible and creative use of language

- Definite reference
  - *the* windmill vs *a* windmill
  - signals to listener that speaker believes referent is uniquely identifiable in the joint representation of the local context or shared communicative history

(Duff, Gupta, Hengst, Tranel, & Cohen, 2011; *Psychological Science*)

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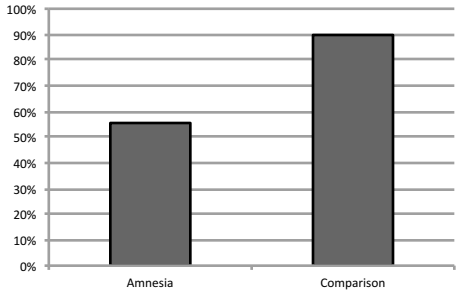
Hippocampal amnesia disrupts the flexible and creative use of language

- Definite reference
  - *the* windmill vs *a* windmill
  - signals to listener that speaker believes referent is uniquely identifiable in the joint representation of the local context or shared communicative history
  - Amnesia = 56%
  - Comparison = 90%



(Duff, Gupta, Hengst, Tranel, & Cohen, 2011; *Psychological Science*)

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Card #	Amnesia Participant	Comparison Participant
6	Praying	**a kneeling per-, uh, attached kneeler**
8	The tall dude	Viking ship
4	Gary	the recliner
7	reading a book	the reader
1	Kicking	the kicker
3	**a windmill**	the Indian
2	**an angle**	the mess
11	**a dog**	the horse
12	**a camel**	the camel
10	The pine tree and barn	the arrow
9	The barn and silo	the chimney
5	bending the knee	the detached

(Duff, Gupta, Hengst, Tranel, & Cohen, 2011; *Psychological Science*)

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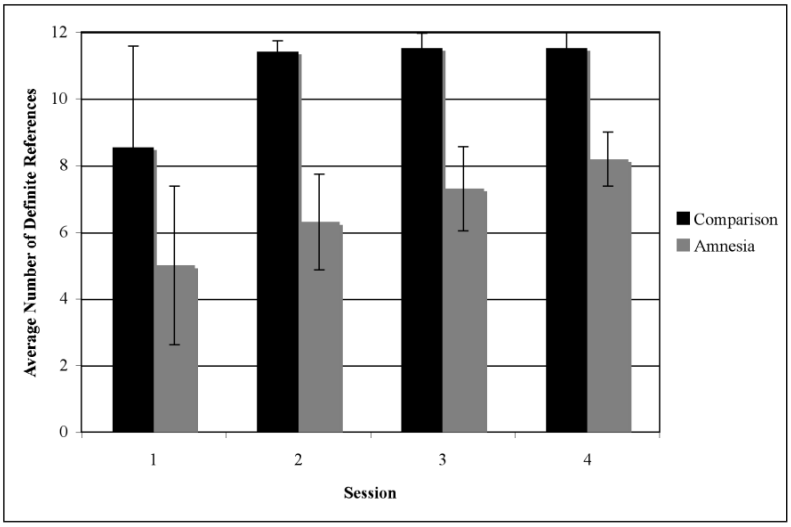

(Duff, Gupta, Hengst, Tranel, & Cohen, 2011; *Psychological Science*)

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Session #	Trial #	Referential expression
3	1	the barn
	2	Barn
	3	barn with a roof
	4	**a barn with a top**
	5	**a barn with a roof on the silo**
	6	**a barn with a silo**
4	1	the roof on the barn
	2	the barn with a roof
	3	**a barn with a top**
	4	barn with a top
	5	barn with a roof
	6	**a barn with a roof on the silo**

(Duff, Gupta, Hengst, Tranel, & Cohen, 2011; *Psychological Science*)

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Hippocampal amnesia disrupts the flexible and creative use of language

- Definite reference
  - amnesic patients had described the tangrams multiple times and were using concise labels, even after 24 trials the patients were still using indefinite reference (e.g., a windmill)
  - declarative memory plays a role in flexibly tailoring utterances for specific communication partners to reflect joint knowledge
  - role of declarative memory in language beyond word learning by linking a deficit in declarative memory to disruptions in referential processes (e.g., marking noun phrases as definite or indefinite)

(Duff, Gupta, Hengst, Tranel, & Cohen, 2011; *Psychological Science*)

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Hippocampal amnesia disrupts the flexible and creative use of language

- Definite reference
- Creative use of language

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Hippocampal amnesia disrupts the flexible and creative use of language

- Creative use of language
  - Creativity requires rapid combination and recombination of existing mental representations to create novel ideas and ways of thinking (Bristol & Viskontas, 2006).

(Duff, Hengst, Tranel, & Cohen, 2009; *Aphasiology*) 27

Hippocampal amnesia disrupts the flexible and creative use of language

- Creative use of language
  - Creativity requires rapid combination and recombination of existing mental representations to create novel ideas and ways of thinking (Bristol & Viskontas, 2006).

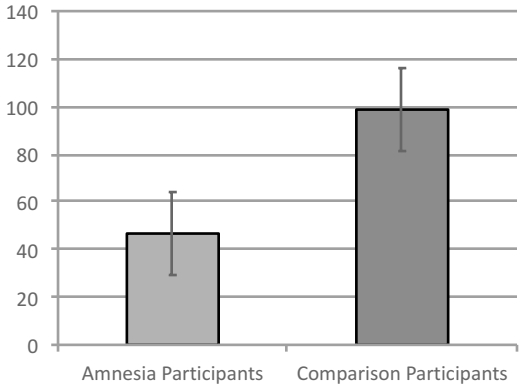
- Linguistic creativity as Verbal Play:

  Telling funny stories or jokes, playing with sounds and meanings of words, making puns, overt teasing of other or self-deprecating humor, use of marked or playful voices or registers, singing or song-like intonations, and use of sound effects (Crystal, 1998; Sherzer, 2002, Tannen, 1989)

- Coded for:
  - Functions- - referencing, teasing, narrative, other
  - Consensus coding

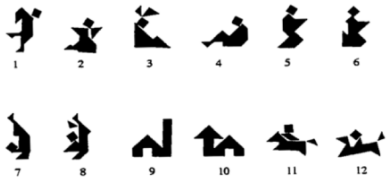
(Duff, Hengst, Tranel, & Cohen, 2009; *Aphasiology*) 28

Hippocampal amnesia disrupts the flexible and creative use of language



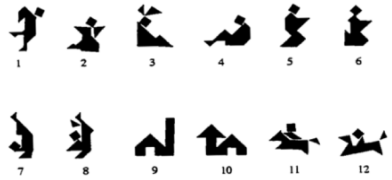
t (6) = 2.920, p =.027

(Duff, Hengst, Tranel, & Cohen, 2009; *Aphasiology*) 29



Amnesic	Comparison
Mountain with box sliding down	Messed up mountain
Siesta man	Lazy person
Barn with the arrow	Barn with the arrow
Dog with the tail up	Dog with a fin

(Duff, Hengst, Tranel, & Cohen, 2009; *Aphasiology*) 30



Amnesic	Comparison
Mountain with box sliding down	Messed up mountain
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Playing with the labels

Krammer holding a box of Seinfeld cereal
The bird ⟹ *Tippy Hedren*
Squirrelly Viking Ship
Indian stock exchange
The horsie of coursie
Hey, professor! I have the answer
Help I can't get up
The Urniator

(Duff, Hengst, Tranel, & Cohen, 2009; *Aphasiology*)

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Hippocampal amnesia disrupts the flexible and creative use of language

- Creative use of language
  - *Hippocampal declarative memory, in its role in the* creation, updating, and juxtaposition of mental representations and in their flexible and novel use, contributes to the creative use of language
  - Declarative memory plays a role in flexible use of knowledge, even previously acquired, remote knowledge
  - *Deficits in the creative use of language fits with other work*
    - *lack of creativity in other aspects of language use (Duff et al., 2007)*
    - *deficits in imagination in amnesia (Hassibis et al., 2007)*
    - *creative thinking more broadly in amnesia (Duff et al., 2009; Sheldon et al., 2013)*

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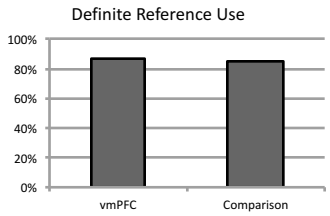
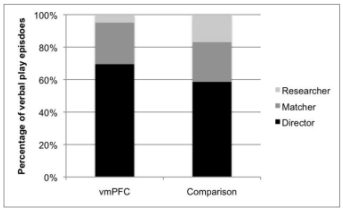
vmPFC damage <u>does not</u> disrupts the flexible and creative use of language





(Gupta, Tranel, & Duff, 2012; *Neuropsychologia; also see Kurczek & Duff, 2012; Brain & Language*) 33

- **Hippocampal contributions to language**
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Hippocampal amnesia disrupts on-line referential processing

To understand and use reference requires the ability to maintain a representation of the unfolding discourse history and the ability to integrate information about referential form with rich representations of context.

Work demonstrating hippocampal involvement over very short delays and no delays at all (e.g., Barense et al., 2007; Hannula et al., 2006; Hannula & Ranganath, 2008) suggests hippocampal damage would lead to deficits in online processing, even over very short discourse histories.

(Kurczek, Brown-Schmidt, & Duff, 2013; *Journal of Experimental Psychology: General*)

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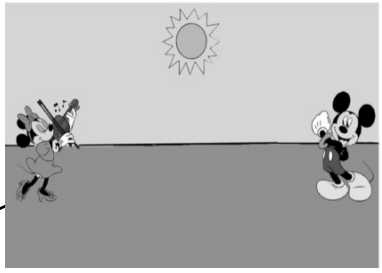
Minnie is playing the violin for Mickey as the sun is shining overhead. **She/ he** is wearing a yellow (green) bracelet and it looks like the song is being played well.

Different-Gender: Identifying referent (only) requires integrating pronoun & character gender



(Kurczek, Brown-Schmidt, & Duff, 2013; *Journal of Experimental Psychology: General*)

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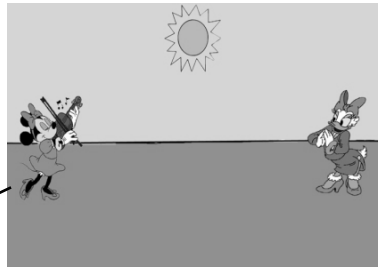
Minnie is playing the violin for Daisy as the sun is shining overhead. ***She*** is wearing a *yellow (green)* bracelet and it looks like the song is being played well.

Same-Gender: Identifying referent requires maintaining discourse representation



(Kurczek, Brown-Schmidt, & Duff, 2013; *Journal of Experimental Psychology: General*)

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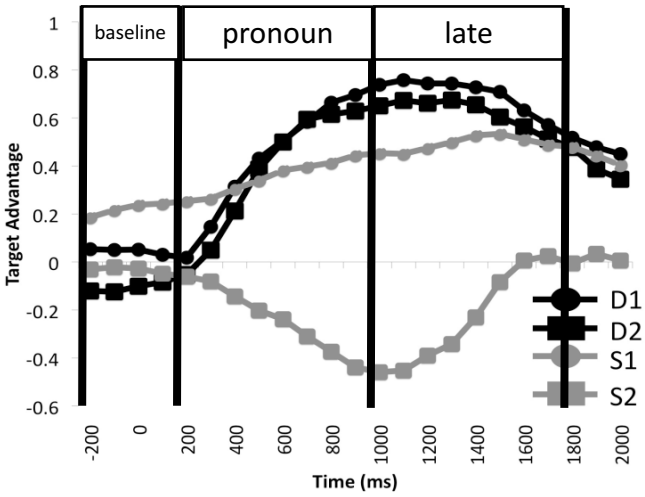
Results: Undergrads



ANALYSIS
- mixed models
- maximal ran effects
- 3 time regions
- DV: empirical logit of T/C fixations; calc. trial-by-trial basis

RESULTS: PRONOUN & LATE REGIONS
- Same-gender: 1st-mention preference
- Diff-gender: Mention is *ns*.

(Kurczek, Brown-Schmidt, & Duff, 2013; *Journal of Experimental Psychology: General*)

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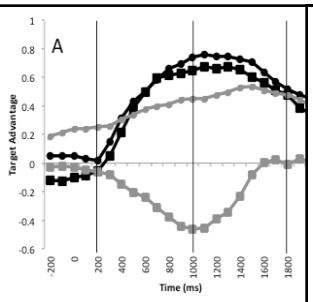
A. Healthy Undergrads
B. Healthy Comparison Participants
C. Amnesia Participants
D. BDC Participants



Amnesics were significantly impaired in their ability to use information about the relative salience of the two referents to disambiguate the pronoun

(Kurczek, Brown-Schmidt, & Duff, 2013; *Journal of Experimental Psychology: General*)

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Hippocampal amnesia disrupts the on-line processing of language

- *Patients with amnesia were impaired at disambiguating pronouns over a very short discourse history.*
- *Deficits here in on-line pronoun resolution fits with other work*
  - *in binding of and memory for temporal order of information* (Jenkins & Ranganath, 2010; Tubridy & Davachi, 2011)
  - maintenance of information outside language domain over short delays or no delays at all (Hannula & Ranganath, 2008; Warren et al., 2010)
  - *disruptions in other measures of online language processing in amnesia (Rubin, Brown-Schmidt, Duff et al 2011)*

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- **Hippocampal contributions to language**
  - Behavioral and Eye-tracking Studies
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Hippocampal amnesia disrupts gesture production

- We gesture when we talk.
- Co-speech gesture
  - **Temporally** – tend to be produced in rhythm with the accompanying speech
    - Gestures slightly precede concept (~300ms)
  - **Semantically** – communicate similar, analog forms of speech

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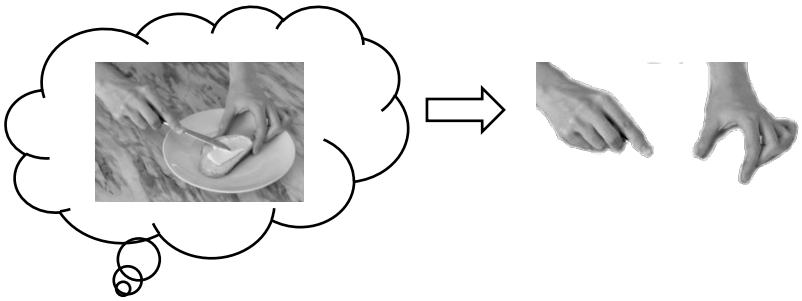
Hippocampal amnesia disrupts gesture production

Our gesture iconically reflects our thoughts.



McNeill; Kendon

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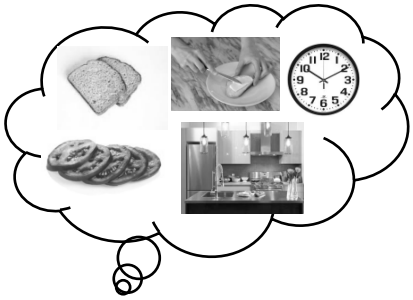
Hippocampal amnesia disrupts gesture production

The hippocampus is responsible for generating a rich, multi-faceted representation in the mind.



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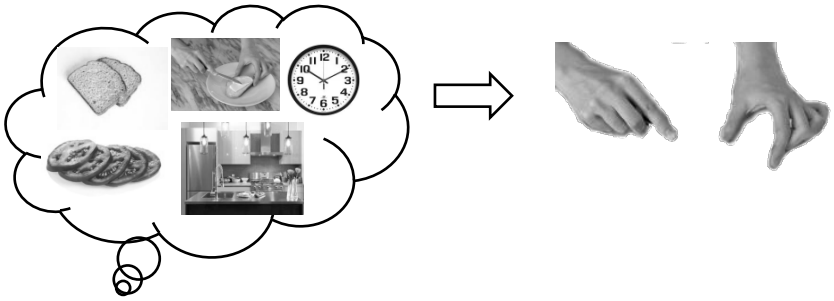
Hippocampal amnesia disrupts gesture production

Hippocampal-mediated representations may support gesture production.



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Hippocampal amnesia disrupts gesture production

(1) Their account of JFK's assassination
(2) Their most frightening experience
(3) How to make their favorite sandwich
(4) How to go shopping in a supermarket

Spoken language
Amount of speech produced (word count)

Gesture
Categorized as iconic, deictic, and beat
Gesture rate was calculated (gestures/word)

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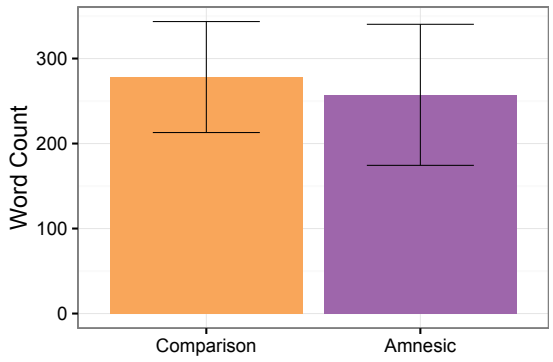
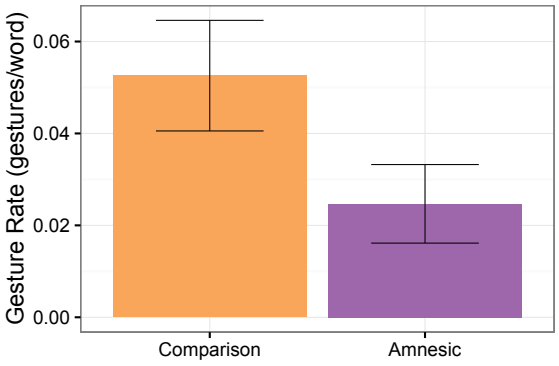
Patients with amnesia talked the same amount as comparison participants.



(Hilliard, Cook, & Duff, 2017; *Cortex*) 47

Patients with hippocampal amnesia gestured less than comparison participants.



(Hilliard, Cook, & Duff, 2017; *Cortex*) 48

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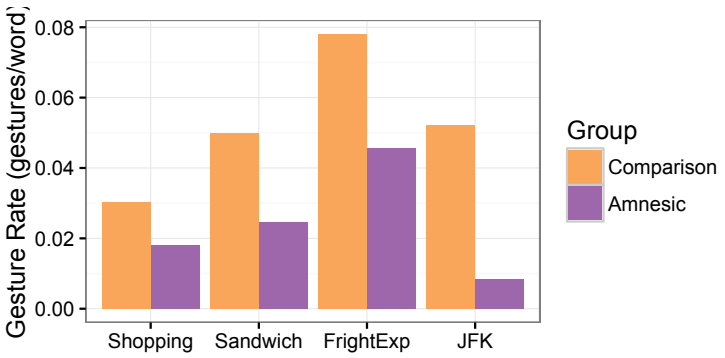

(Hilliard, Cook, & Duff, 2017; *Cortex*)

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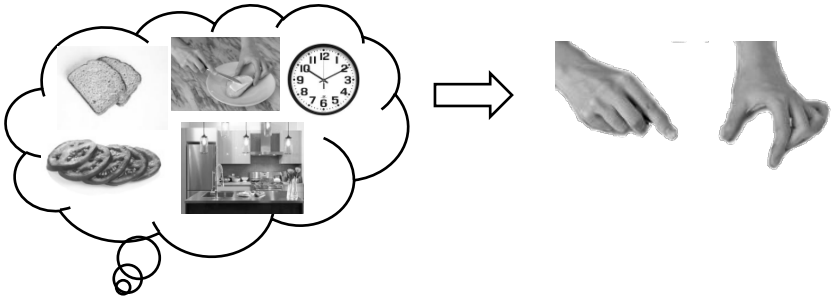
Hippocampal amnesia disrupts gesture production

Hippocampal-mediated representations support gesture production.



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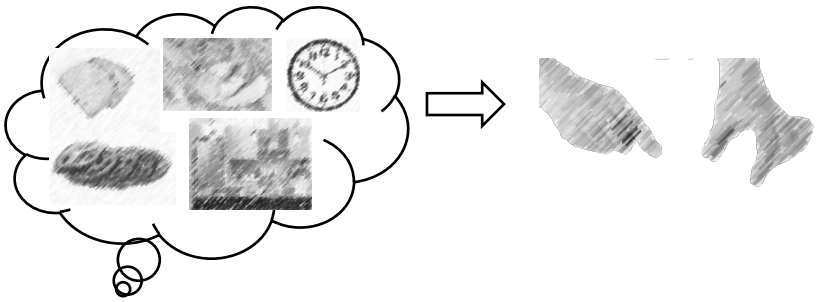
Hippocampal amnesia disrupts gesture production

An impoverished hippocampal representation leads to impoverished gesture production.



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    - multi-modal language use
  - Direct Hippocampal recordings
    - Incremental processing of semantic context

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PNAS

Direct brain recordings reveal hippocampal rhythm underpinnings of language processing

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Language is classically thought to be supported by perisylvian cortical regions. Here we provide intracranial evidence linking the hippocampal complex to linguistic processing. We used direct recordings from the hippocampal structures to investigate whether theta oscillations, pivotal in memory function, track the amount of contextual linguistic information provided in sentences. Twelve participants heard sentences that were either constrained ("She locked

language comprehension (13). The activation of a concept invariably results in the coactivation of other associated features or concepts (14, 15). Given the critical role of the medial temporal lobe in retrieving learned associations (16), we examined activity recorded directly from the hippocampal complex of participants performing a linguistic-context task.

Twelve patients implanted stereotactically with depth elec-

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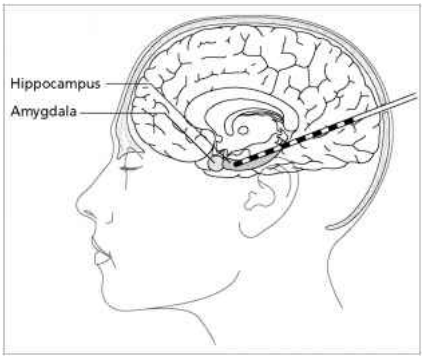

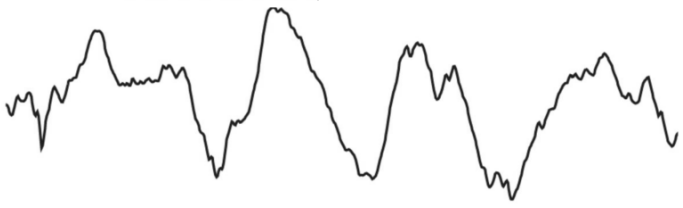

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- 12 patients implanted with depth electrodes.
- Patients heard sentences missing the final word
  - She locked the door with a [picture: key]
    - Linguistically constraining
  - She came in here with a [picture: key]
    - Linguistically unconstraining

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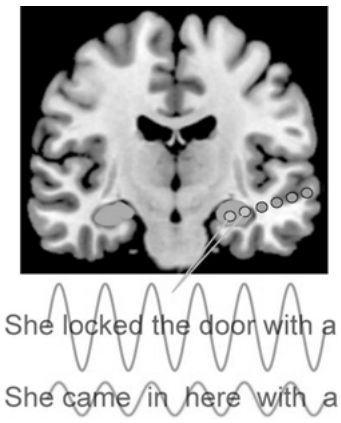
Two main findings:

1. Context increases theta power during sentence processing.
2. Theta power increase with strong semantic associations.

Implications:
First neurophysiological data for direct hippocampal contribution to language processing.

Suggests a shared neural network for memory and language.

Further evidence for hippocampus as part of the language network.



http://www.ru.nl/donders/@1051360/memory-language/

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Implications for other disorders

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- Discourse cohesion and coherence are impaired in individuals with TBI and AD (e.g., Coelho, 2002; Coelho, Liles, & Duffy, 1991; Davis & Coelho, 2004; Dijkstra, Bourgeois, Allen, & Burgio, 2004; Glosser & Deser, 1991; Liles, Coelho, Duffy, & Zalagens, 1989; Ripich, Carpenter, & Ziol, 2000; Van Leer & Turkstra, 1999; Youse & Coelho, 2005)
- Discourse cohesion
  - e.g., John and Mary just moved to a new house. ***They*** has been busy cleaning ***it***.
- Discourse coherence
  - overall interrelatedness of the discourse (local and global)
- Deficits attributed to frontal lobe dysfunction and interventions directed toward frontal lobe functions

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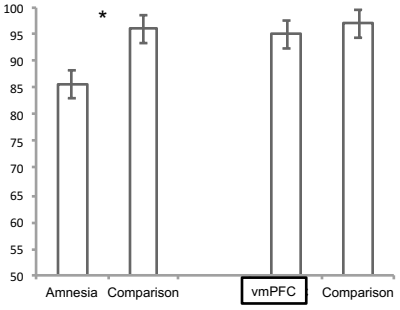
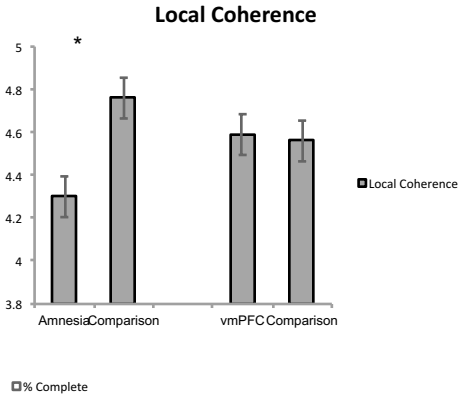
Amnesia - $t(46) = 2.25$, $p = 0.030$
vmPFC - $t(46) = 0.58$, $p = 0.570$





Amnesia - $t(46) = 2.52$, $p = 0.018$
vmPFC - $t(46) = 1.11$, $p = 0.270$

Kurczek & Duff, 2011, *Aphasiology*; Kurczek & Duff, 2012, *Brain and Language*)

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Discussion

- Growing body of work on the expanding reach of the hippocampus
  - Decision making, future thinking, empathy, creativity, perception, and language
- Linking deficits in language processing to the hippocampus demonstrates how promiscuously the hallmark processing features of the hippocampus are used in service of a variety of cognitive domains.
- Hippocampal declarative memory is well situated to meet many of the demands of language use and processing
  - arbitrary relations for word learning (e.g., Gabrieli et al., 1988; Warren & Duff, 2014; Klooster & Duff, in prep)
  - creative and flexible use of language (e.g., Duff et al., 2009; 2011)
  - on-line language processing (e.g., Rubin et al., 2012; Kurczek et al., 2013)
  - Integration of multi-modal information (e.g., Hilliard, Cook, & Duff, in prep)

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Discussion

- Documenting the contribution of hippocampal declarative memory to aspects of language expands the dynamic network of neural substrates and cognitive processes that support understanding and use of language
- Characterize the nature and time course of hippocampal declarative memory interactions with other cognitive/neural systems that support language use and processing
- Implications for underlying mechanism(s) of disruption in individuals with more complex communication impairment associated with diffuse neural and cognitive deficits (e.g., traumatic brain injury)

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