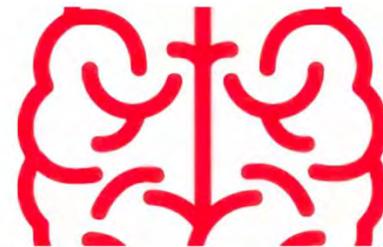


ROLE OF THE HIPPOCAMPUS IN WAKE- AND SLEEP-RELATED MOTOR MEMORY CONSOLIDATION

GENEVIÈVE ALBOUY

Sleep and Motor Memory Lab

Department of Health and Kinesiology, College of Health, University of Utah, USA



SLEEP AND MOTOR MEMORY LAB

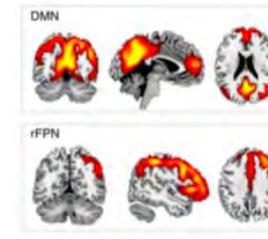
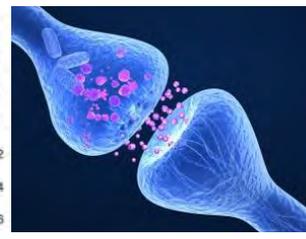
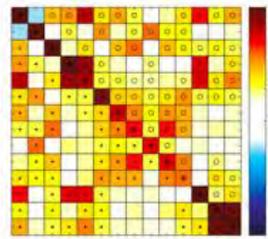
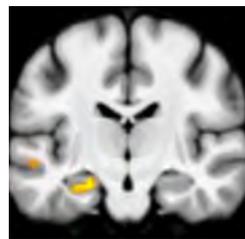


KU Leuven, Belgium



University of Utah, USA

MULTIMODAL NEUROIMAGING APPROACH



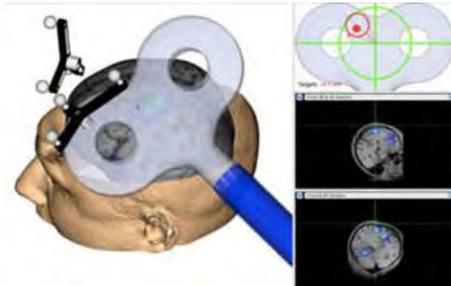
NEURAL PROCESSES SUPPORTING MOTOR MEMORY CONSOLIDATION

NEUROMODULATION

MODULATING THESE NEURAL SIGNATURES TO OPTIMIZE MOTOR MEMORY CONSOLIDATION



NINA DOLFEN



NIBS



MAREIKE GANN XIAOXI PAN

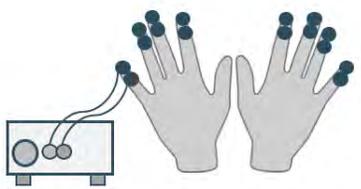


CONNECTIVITY

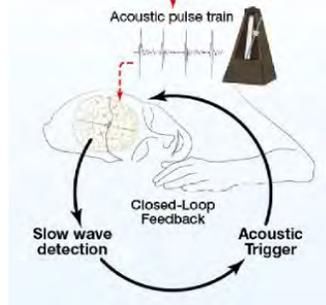


SIMON TITONE

SENSORY STIM



MENNO VELDMAN



TMR DURING SLEEP



JUDITH NICOLAS AINSLEY TEMUDO



SERENA REVERBERI

MOTOR SCHEMA



MORAN GILAT

PARKINSON



OWEN BENZLEY

EXERCISE



CHALLENGING TRADITIONAL MODELS OF MEMORY

1. **MEMORY SYSTEMS ARE LESS SEGREGATED THAN INITIALLY THOUGHT**
2. **MEMORY CONSOLIDATION IS FASTER THAN INITIALLY THOUGHT**

SIGNIFICANCE

OPEN IMPORTANT NEW AVENUES FOR NEUROMODULATION

1. **TARGETING BRAIN REGIONS INITIALLY OVERLOOKED**
2. **TARGETING TIME PERIODS INITIALLY IGNORED**

HIPPOCAMPUS AND MOTOR MEMORY



WHAT?

MEMORY IN HUMANS

Squire and Zola, 1996
Reber and Squire, 1994

DECLARATIVE MEMORY

EVENTS

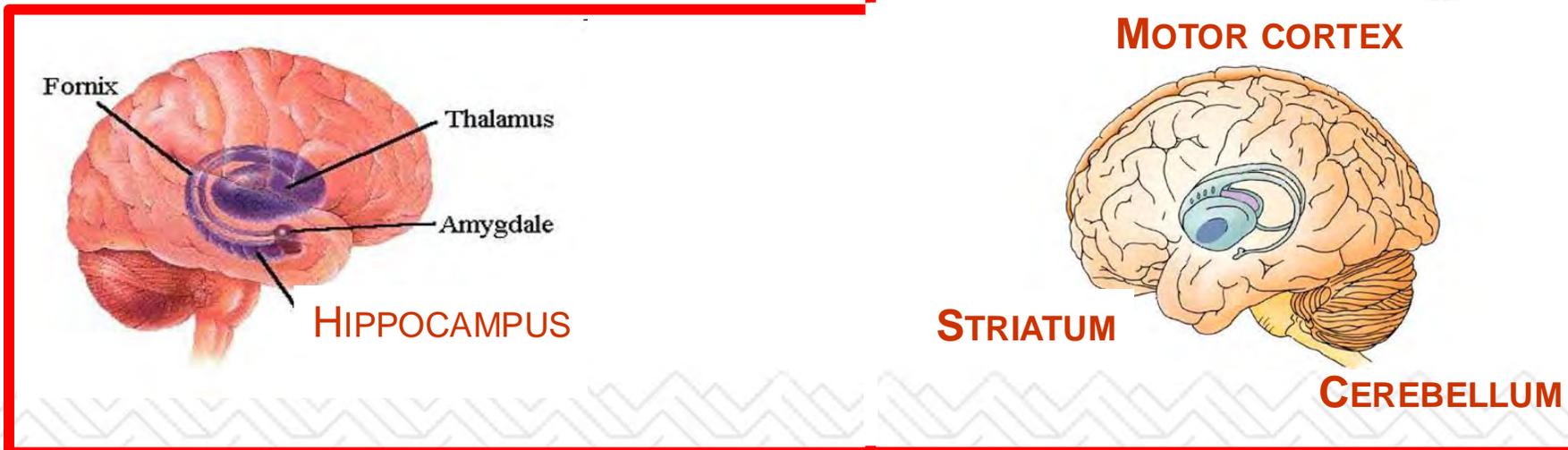
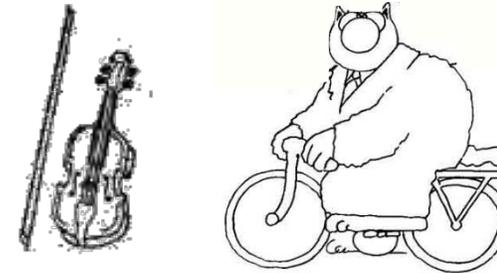


FACTS



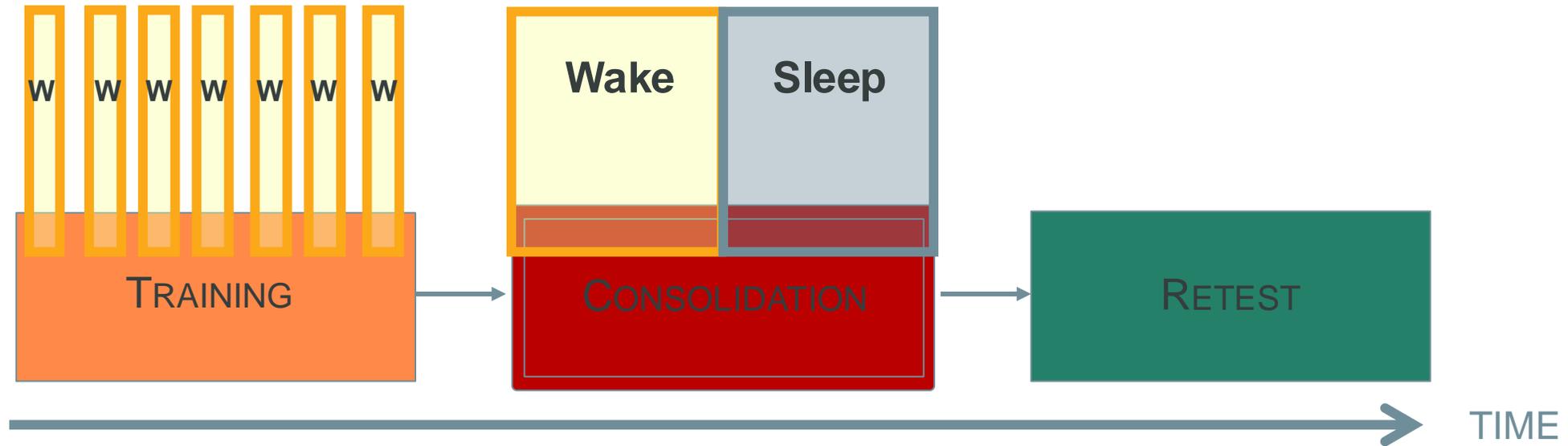
PROCEDURAL MEMORY

MOTOR SKILLS



MOTOR MEMORY CONSOLIDATION

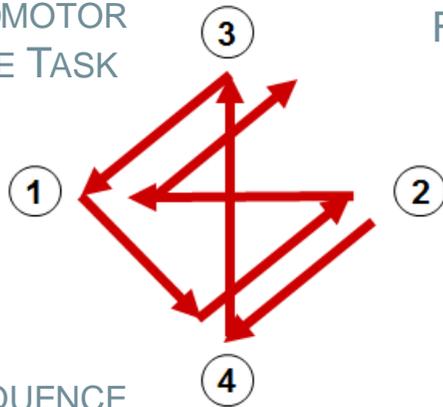
McGaugh, 2000
Robertson, 2004
Bonstrup et al., 2019



MOTOR SEQUENCE LEARNING

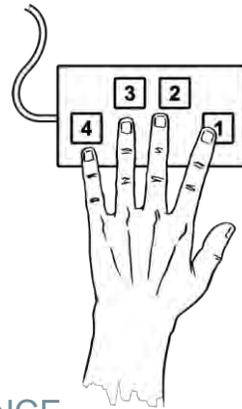


SERIAL OCULOMOTOR REACTION TIME TASK



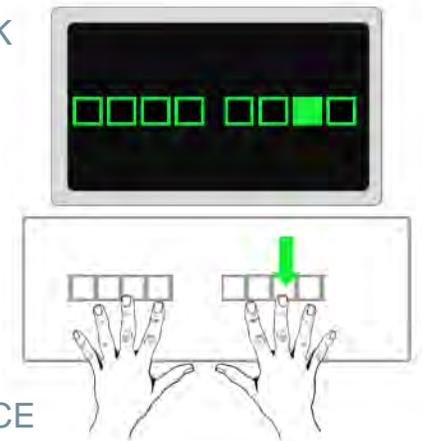
LEARNED SEQUENCE
[2 4 3 1 4 2 1 3]

FINGER TAPPING TASK



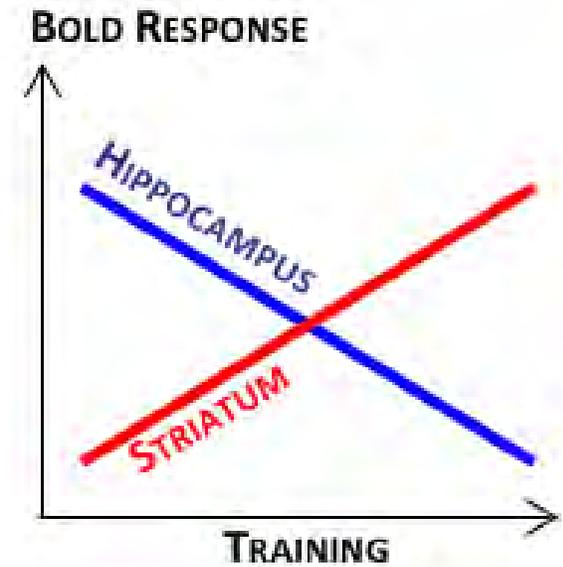
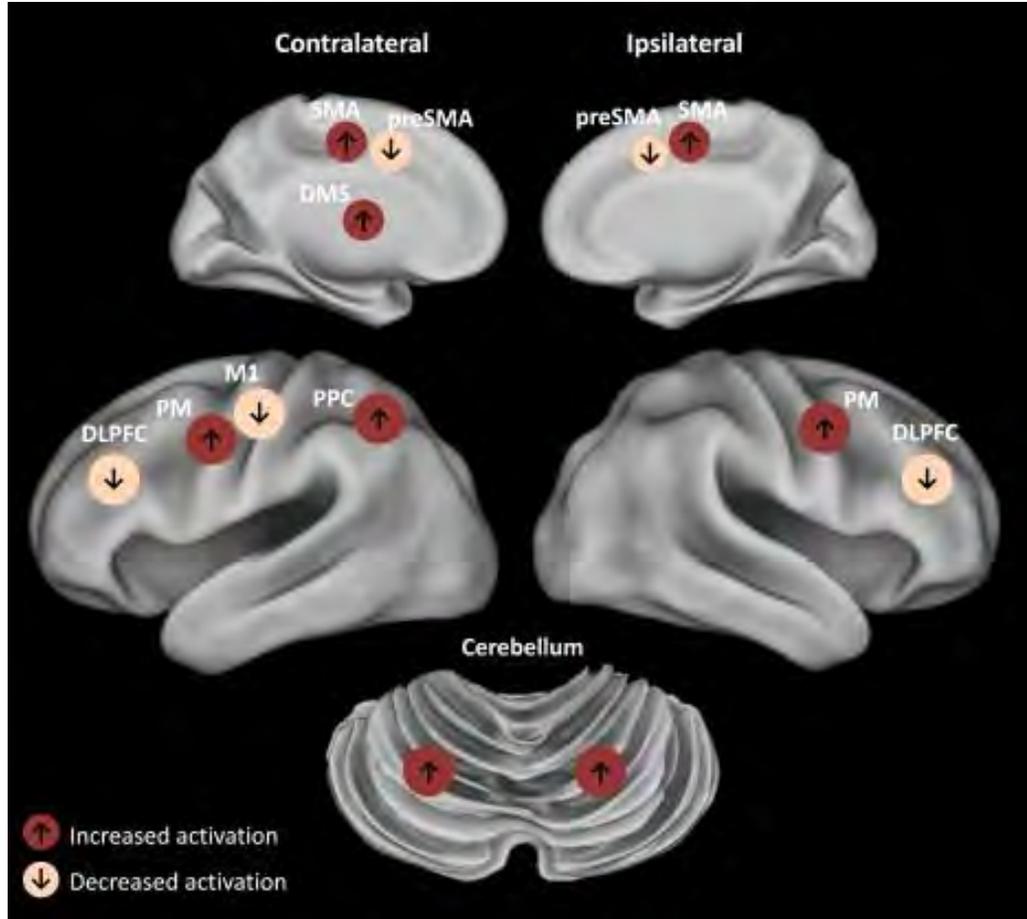
LEARNED SEQUENCE
[4 1 3 2 4]

SERIAL REACTION TIME TASK



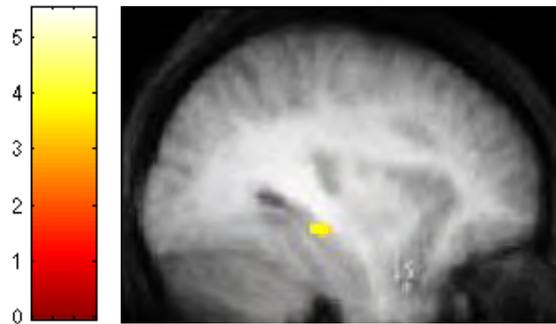
LEARNED SEQUENCE
[4 7 3 8 6 2 5 1]

NEURAL CORRELATES OF MOTOR SEQUENCE LEARNING



HIPPOCAMPUS AND MOTOR LEARNING

IMPLICIT AND EXPLICIT MOTOR SEQUENCE LEARNING



Schendan et al., 2003
Albouy et al., 2008
Fernandez-Seara et al., 2009
Rieckmann et al., 2010
Gheysen et al., 2010
Lewis et al., 2011
Rose et al., 2011
Albouy et al., 2012
Fogel et al., 2014
Cousins et al., 2016
King et al., 2017

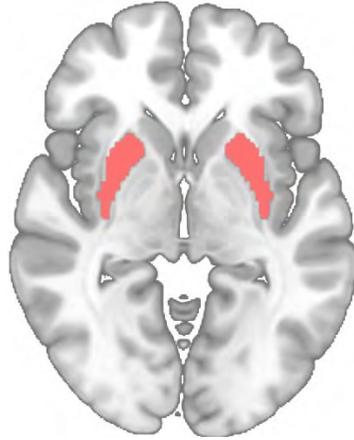
Pinsard et al., 2019
Jacobacci et al., 2020
Dolfen et al., 2021a,b
Veldman et al., 2021
Buch et al., 2021
King et al., 2022
Gann et al., 2022
Dolfen et al., 2023
Albouy et al., 2015
Kornysheva et al., 2024
Dolfen et al., 2024
Temudo et al., 2025

See Albouy et al., 2013 *Hippocampus* for a review

1. THE HIPPOCAMPUS IS RECRUITED DURING MOTOR SEQUENCE LEARNING

BUT IS THIS RELATED TO ANY MOTOR MEMORY PROCESSING?

HIPPOCAMPUS AND MOTOR MEMORY CONSOLIDATION



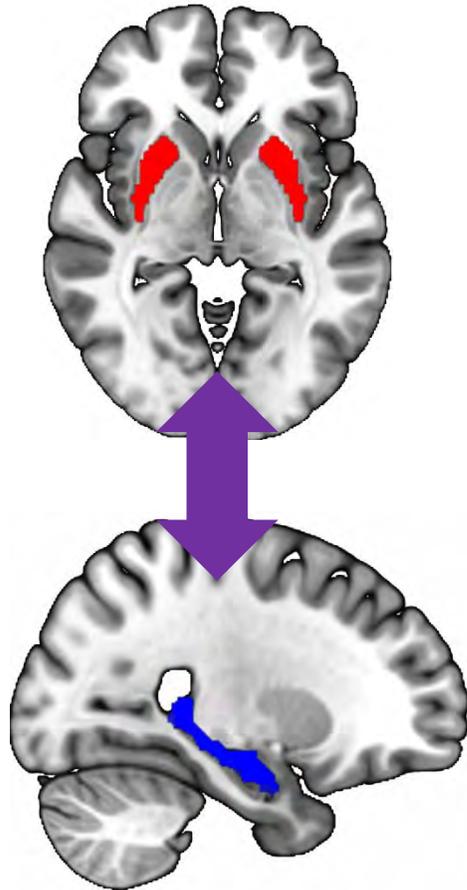
Albouy et al., 2008 *Neuron*



HIPPOCAMPAL ACTIVITY DURING INITIAL MOTOR SEQUENCE LEARNING MAY TRIGGER SUBSEQUENT OVERNIGHT MEMORY CONSOLIDATION

Offline Gain in Performance

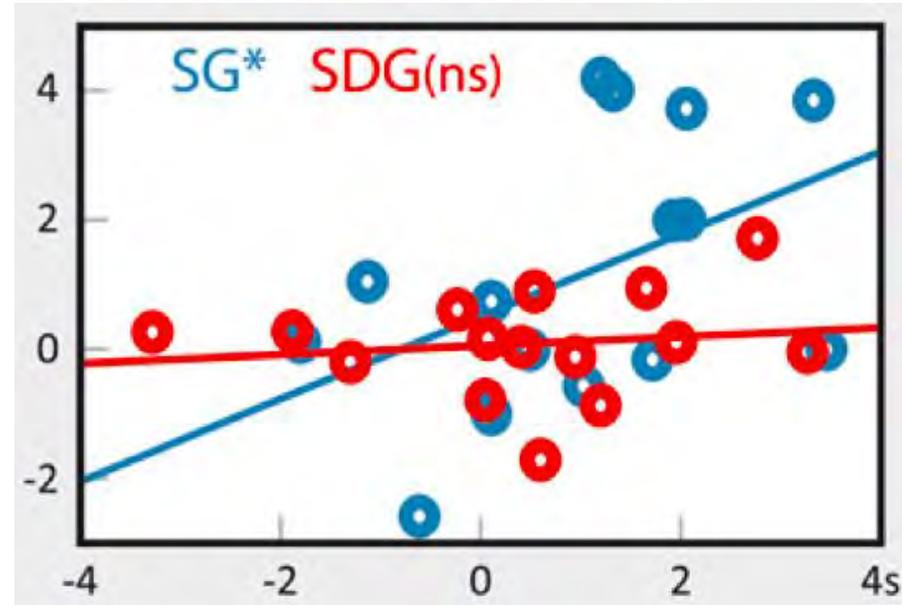
HIPPOCAMPUS AND MOTOR MEMORY CONSOLIDATION



Strength of the competitive interaction
between HC and Cn modulated by
performance inconsistency (a.u.)

Sleep Group SG

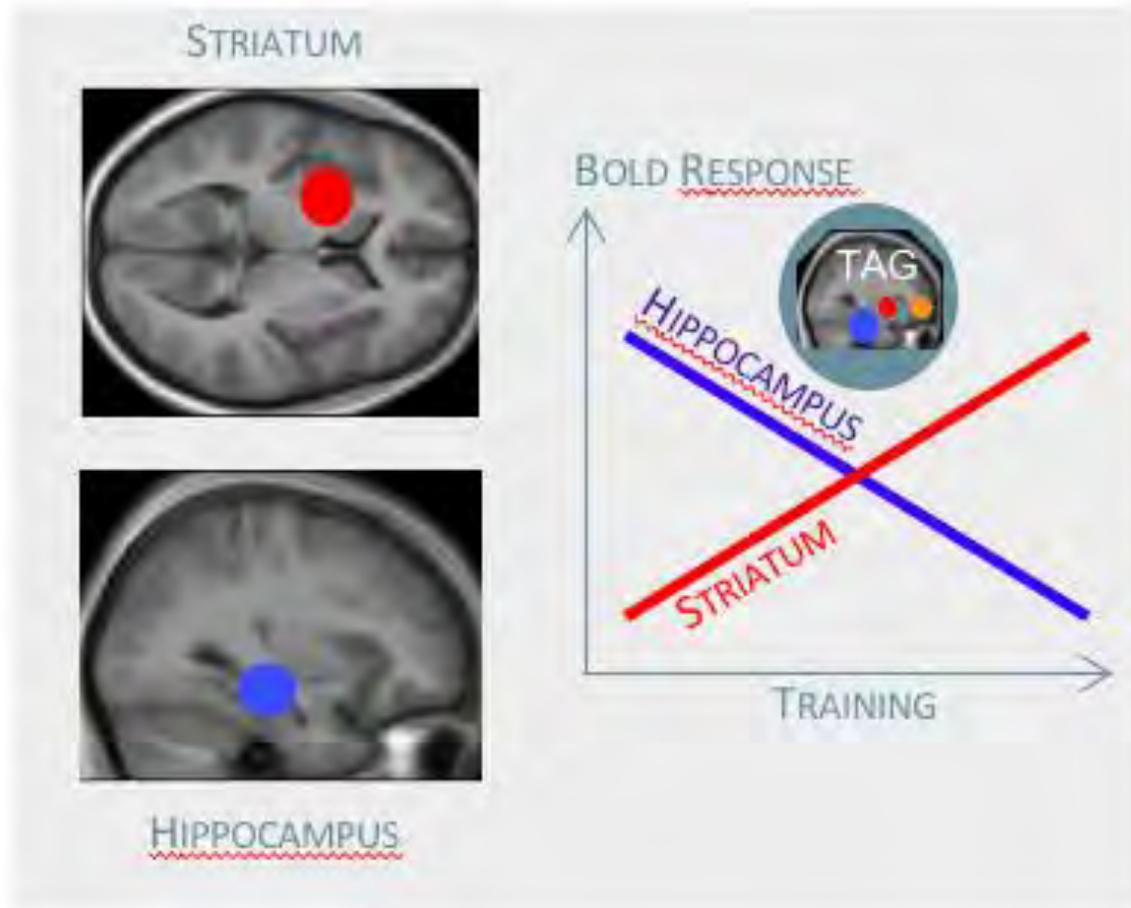
Sleep Deprived Group SDG



Sleep-dependent gain in performance (s)

Albouy et al., 2012 *Neuroimage*
Albouy et al., 2013 *PLoSone*

HIPPOCAMPUS AND MOTOR MEMORY



SLEEP-RELATED CONSOLIDATION
= ENHANCEMENT IN PERFORMANCE

Albouy et al., 2013 *Hippocampus*

HIPPOCAMPUS AND MOTOR MEMORY

Hippocampus



RESEARCH ARTICLE

The hippocampus is necessary for the consolidation of a task that does not require the hippocampus for initial learning

[Anna C. Schapiro](#) ✉, [Allison G. Reid](#), [Alexandra Morgan](#), [Dara S. Manoach](#), [Mieke Verfaellie](#), [Robert Stickgold](#)

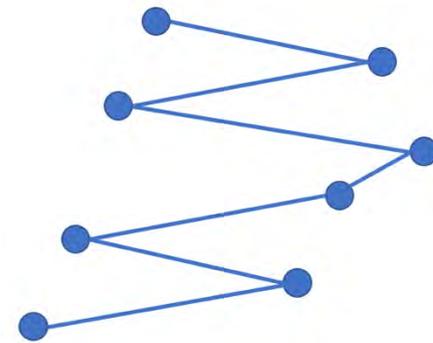
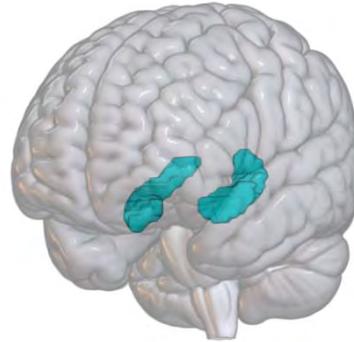
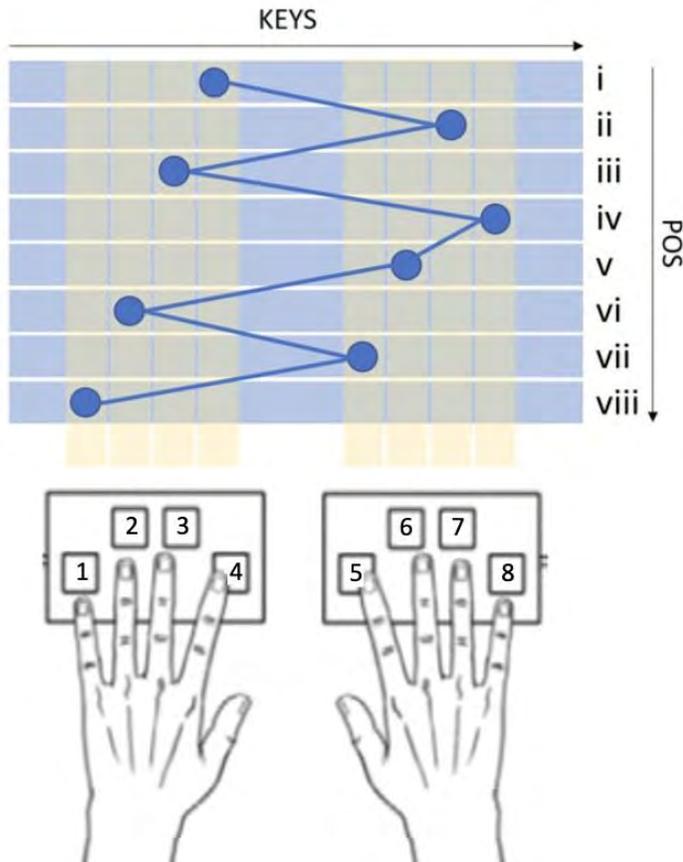
First published: 03 June 2019 | <https://doi.org/10.1002/hipo.23101> | [VIEW METRICS](#)

Funding information Clinical Science Research and Development Service, Department of Veterans Affairs; National Institutes of Health, Grant/Award Numbers: F32-NS093901, K24-MH099421, R01-MH092638, R01-MH48832, R01-MH67720

1. THE HIPPOCAMPUS IS RECRUITED DURING MOTOR SEQUENCE LEARNING
2. THE HIPPOCAMPUS IS INVOLVED IN MOTOR MEMORY CONSOLIDATION

BUT WHAT IS THE ROLE OF THESE HIPPOCAMPAL RESPONSES?

WHAT IS THE FUNCTIONAL ROLE OF THESE HIPPOCAMPAL RESPONSES?

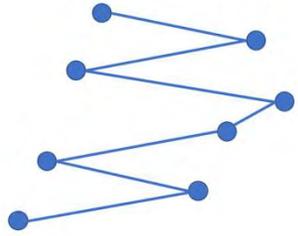


Time and space in the hippocampus

Marc W. Howard and Howard Eichenbaum

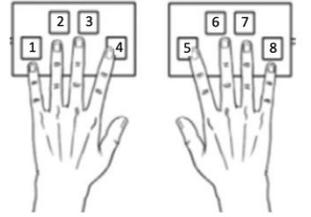
Center for Memory and Brain and Department of Psychological and Brain Sciences, Boston University

SPACE IN THE “MOTOR HIPPOCAMPUS”

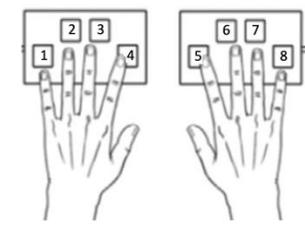
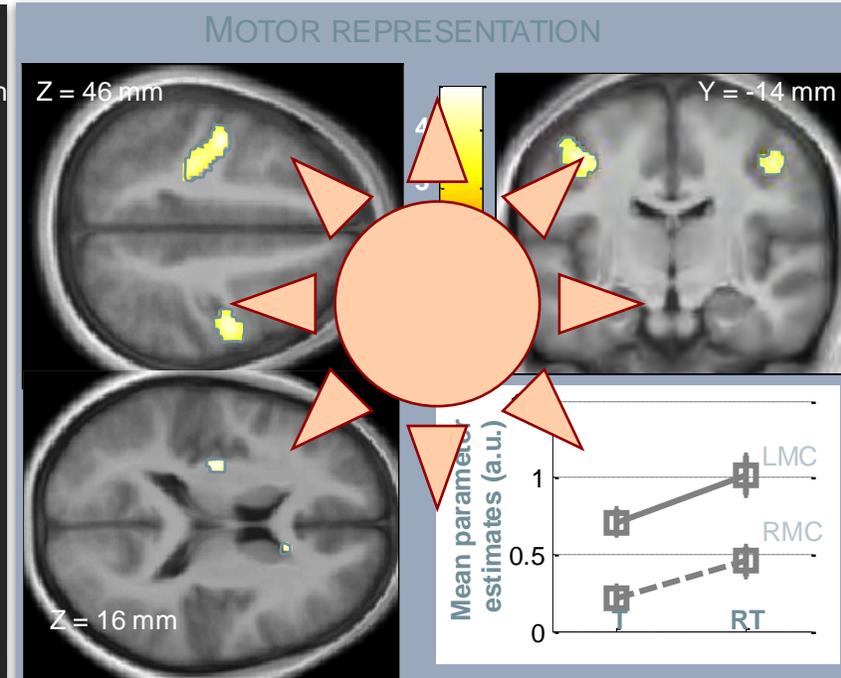
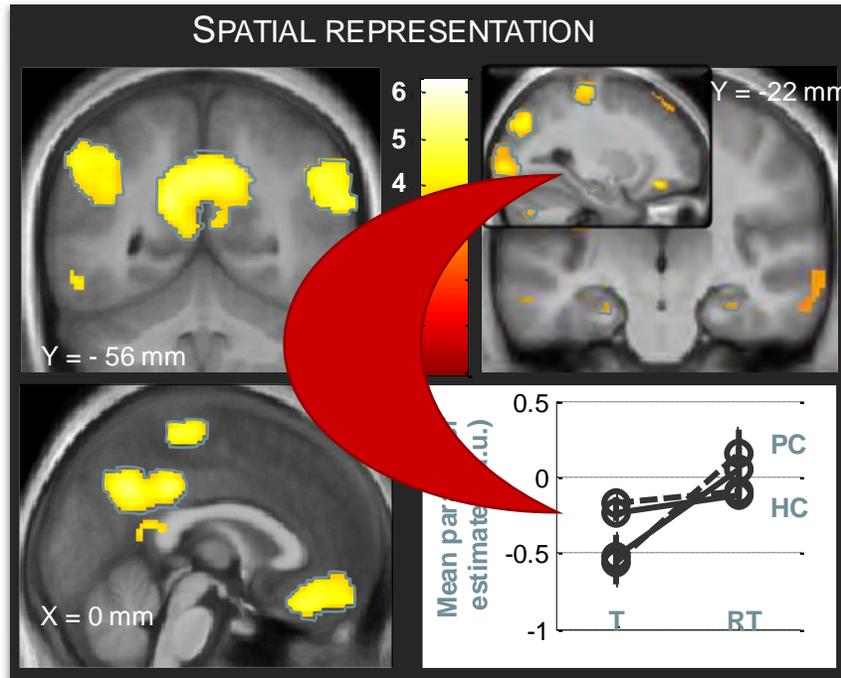
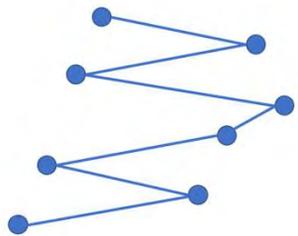


SPATIAL REPRESENTATION

MOTOR REPRESENTATION



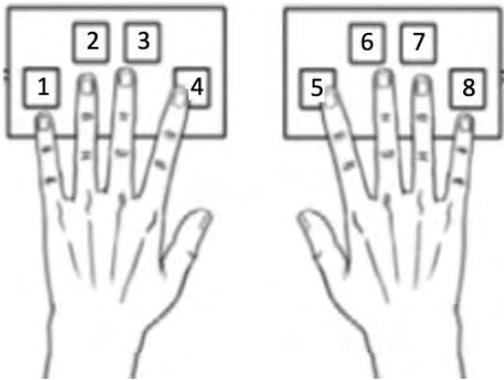
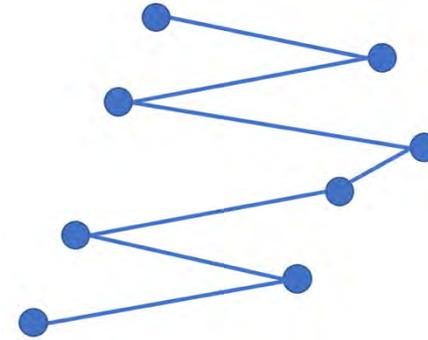
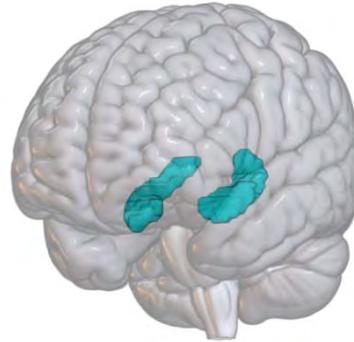
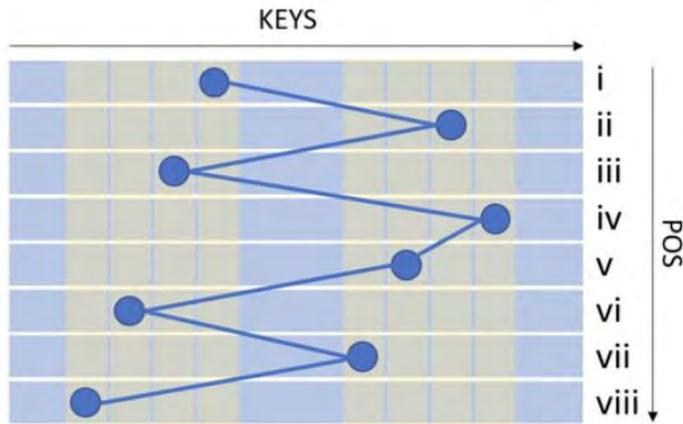
DISSOCIATION OF CONSOLIDATION PROCESSES



MEMORY TRACE SUPPORTED BY
HIPPOCAMPO-CORTICAL NETWORKS
THE CONSOLIDATION OF WHICH
DEPENDS ON SLEEP

MEMORY TRACE SUPPORTED BY
STRIATO-MOTOR NETWORKS
THE CONSOLIDATION OF WHICH
DEPENDS ON TIME

WHAT IS THE FUNCTIONAL ROLE OF THESE HIPPOCAMPAL RESPONSES?



Time and space in the hippocampus

Marc W. Howard and Howard Eichenbaum

Center for Memory and Brain and Department of Psychological and Brain Sciences, Boston University

TIME IN THE “MOTOR HIPPOCAMPUS”

1–16 • The Journal of Neuroscience, September 11, 2024 • 44(37):e0584242024



Nina Dolfen

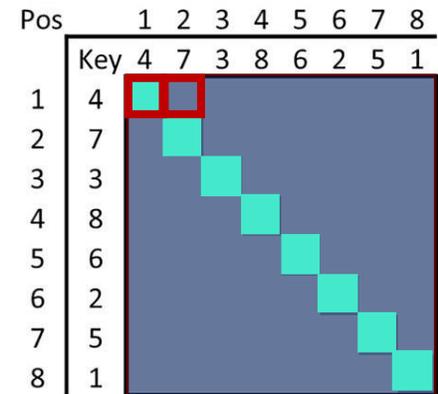
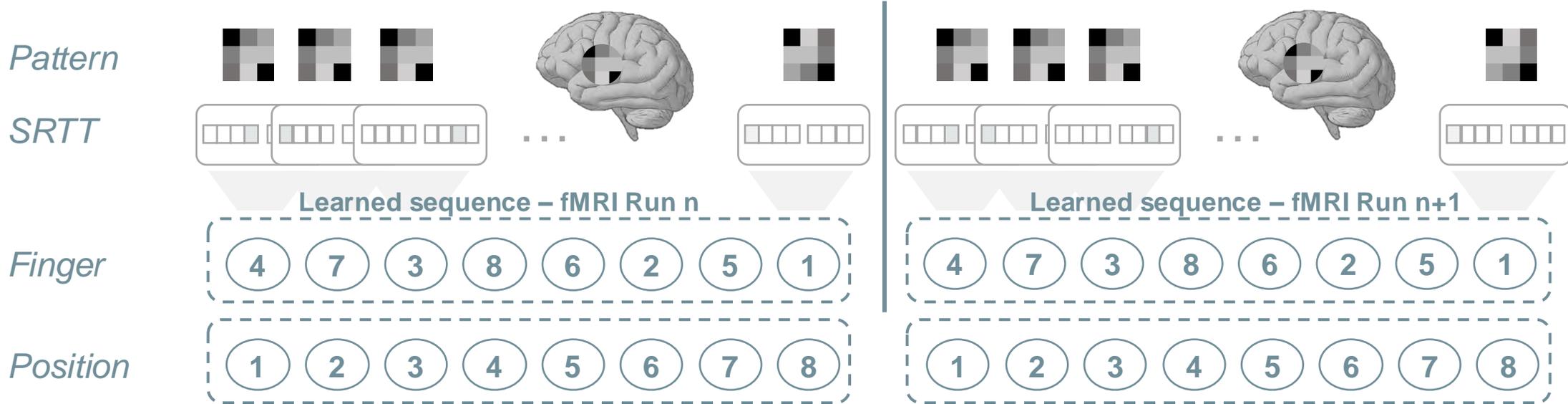
Behavioral/Cognitive

The Hippocampus Represents Information about Movements in Their Temporal Position in a Learned Motor Sequence

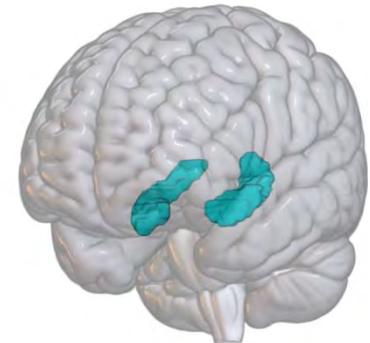
 Nina Dolfen,^{1,2,3}  Serena Reverberi,^{1,2}  Hans Op de Beeck,^{2,4}  Bradley R. King,⁵ and  Genevieve Albouy^{1,2,5}

¹Department of Movement Sciences, KU Leuven, 3001 Leuven, Flemish Brabant, Belgium, ²KU Leuven Brain Institute (LBI), 3000 Leuven, Flemish Brabant, Belgium, ³Department of Psychology, Columbia University, New York City, New York 10027, ⁴Department of Brain and Cognition, KU Leuven, 3000 Leuven, Flemish Brabant, Belgium, and ⁵Department of Health and Kinesiology, College of Health, University of Utah, Salt Lake City, Utah 84112

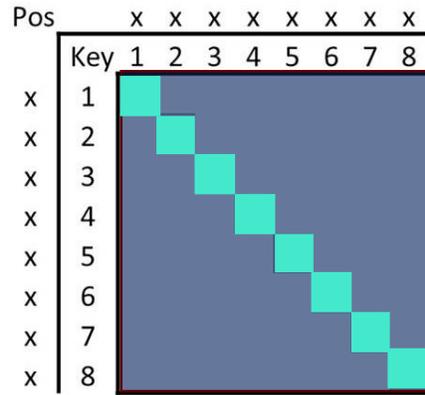
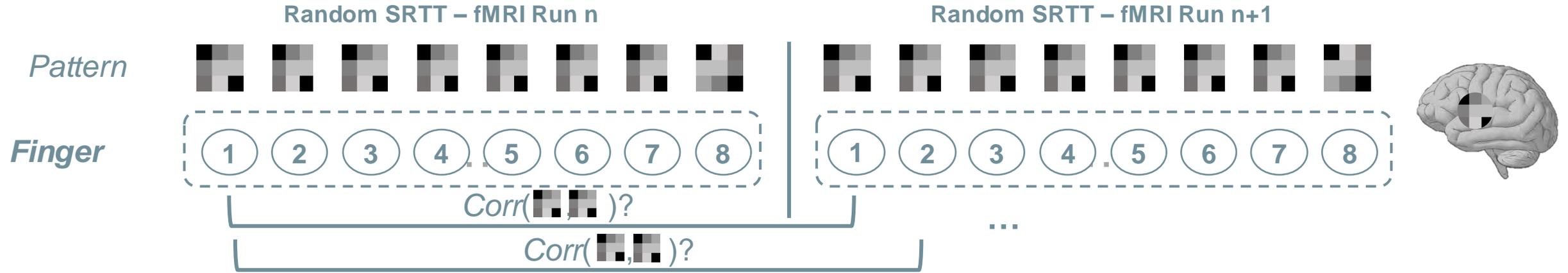
Hippocampal Activation Pattern Similarity across Sequence Repetitions



Sequence (SEQ)
Matrix

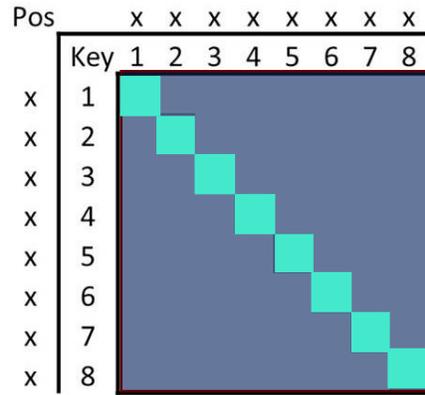
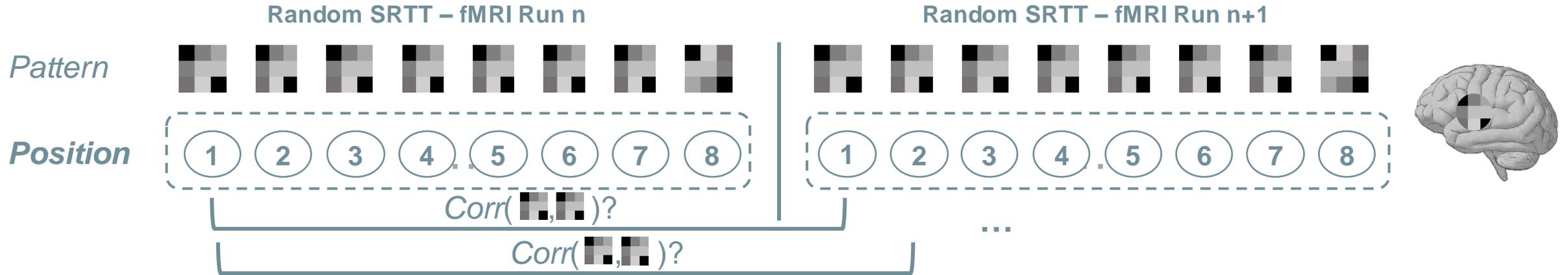


Finger coding in random movement patterns

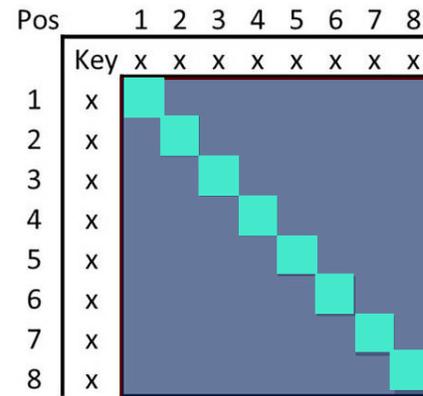


Random Key (RK) Matrix

Position coding in random movement patterns



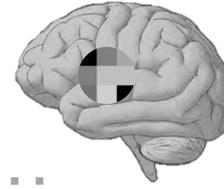
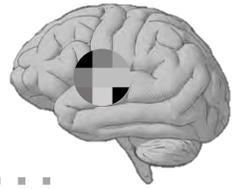
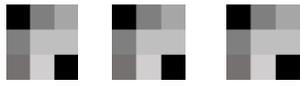
Random Key (RK) Matrix



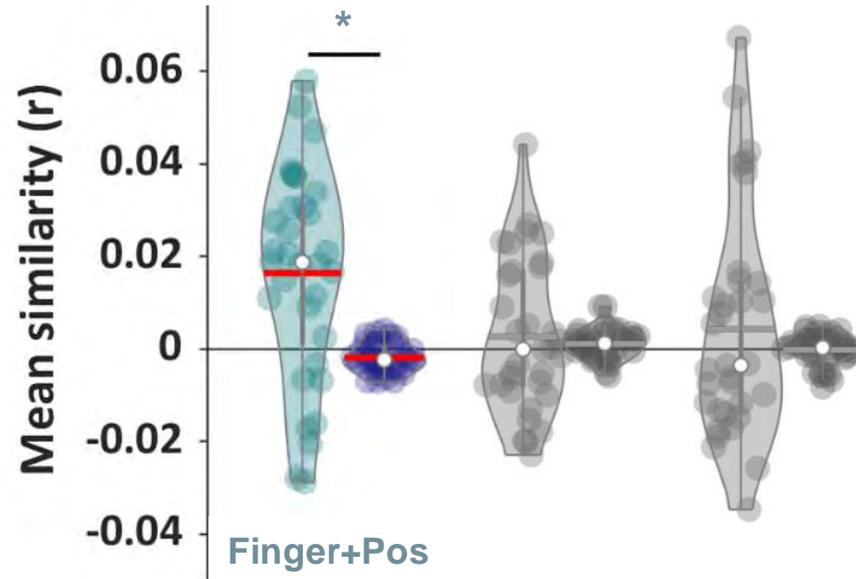
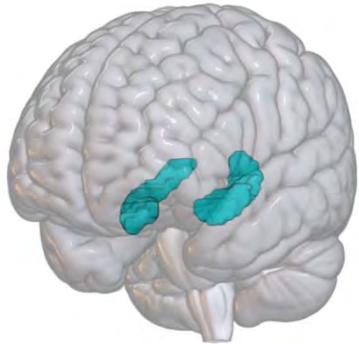
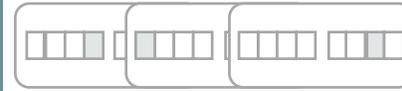
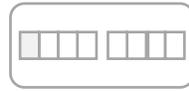
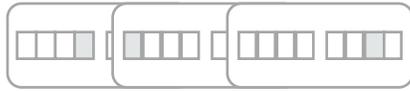
Random Position (RP) Matrix

Hippocampal Activation Pattern Similarity across Sequence Repetitions

Pattern

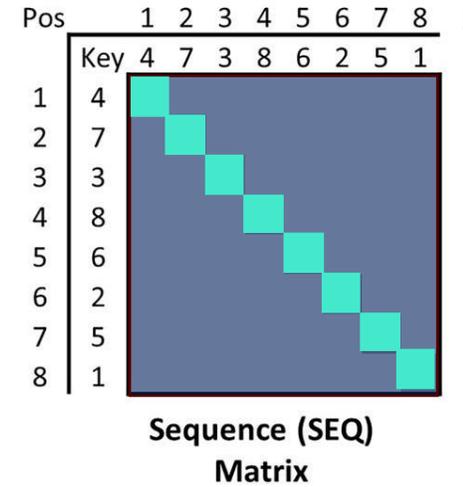


Movement



Same
Different

* $p_{FDR} < .001$

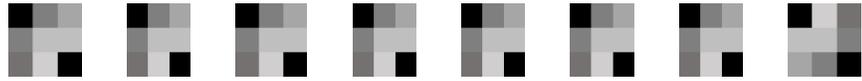


Finger coding in random movement patterns

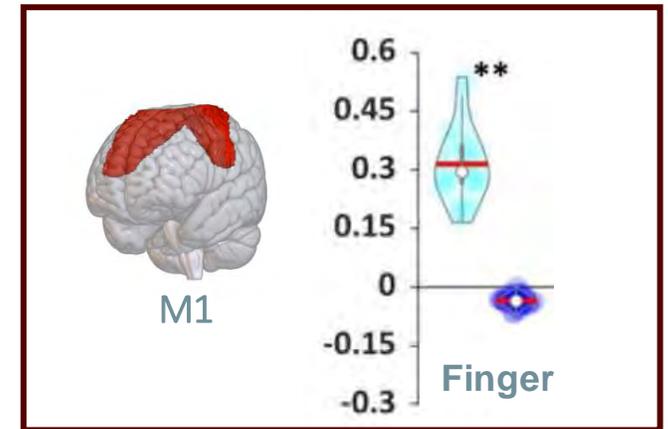
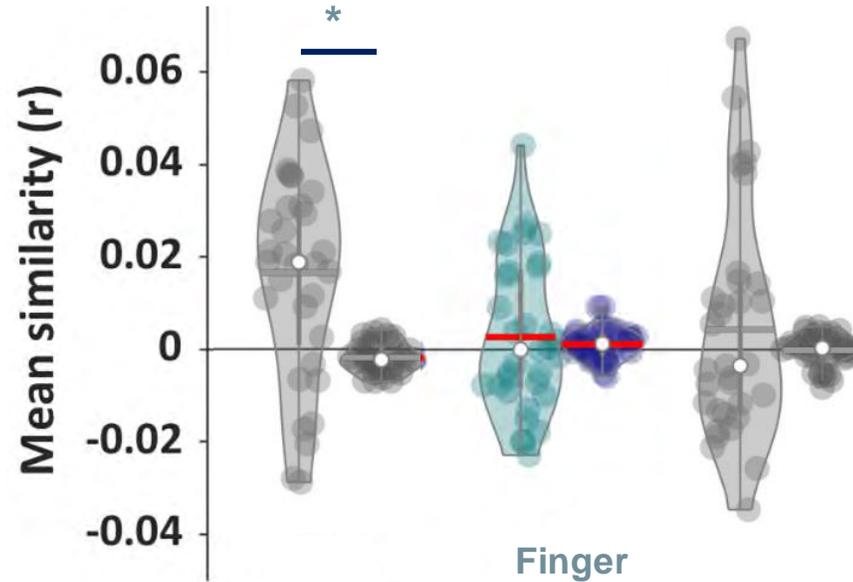
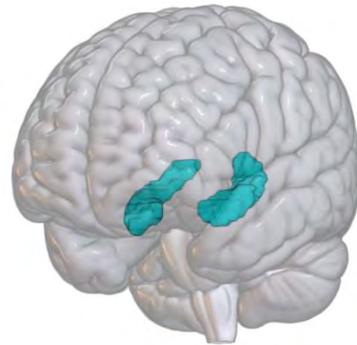
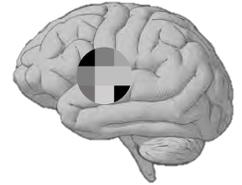
Random SRTT – fMRI Run n

Random SRTT – fMRI Run n+1

Pattern



Movement

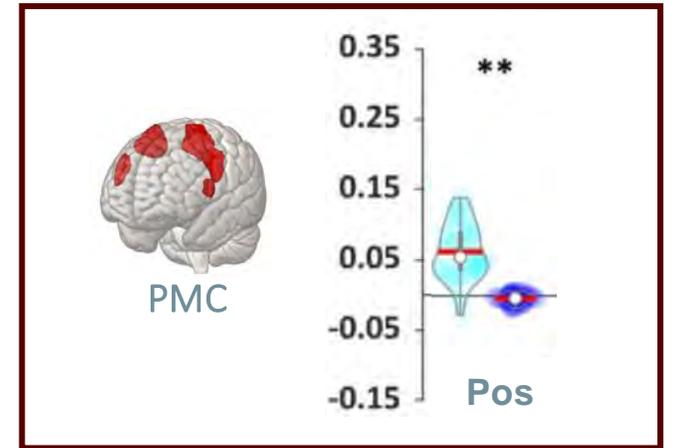
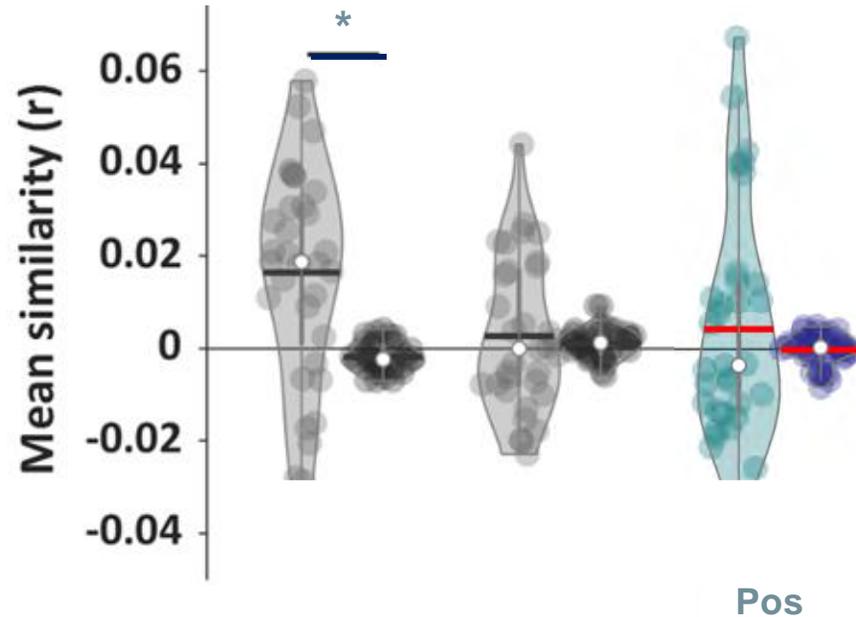
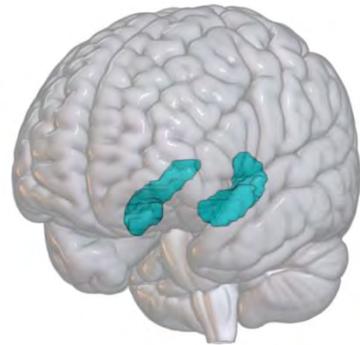
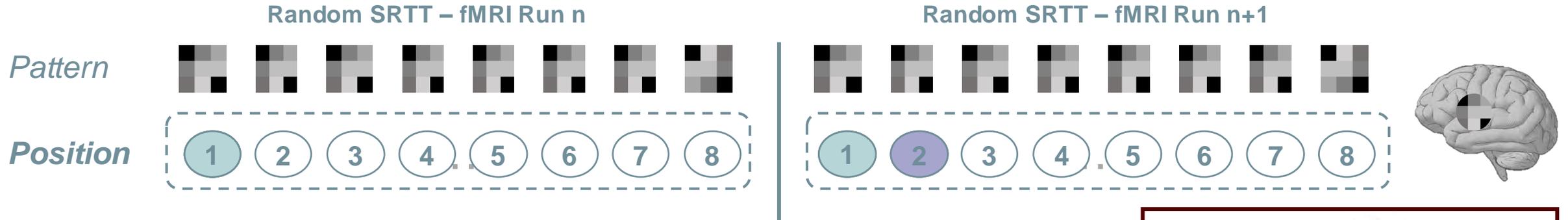


Same
Different

* $p_{FDR} < .001$

No evidence of finger coding in the hippocampus during random task practice

Position coding in random movement patterns



Same

Different

* $p_{FDR} < .001$

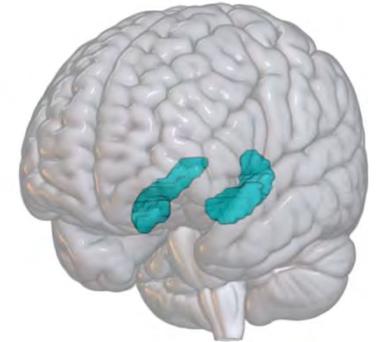
No evidence of position coding in the hippocampus during random task practice

Behavioral/Cognitive

The Hippocampus Preorders Movements for Skilled Action Sequences

Rhys Yewbrey^{1,2} and  Katja Kornysheva^{1,2}

¹Centre for Human Brain Health, School of Psychology, University of Birmingham, Birmingham B15 2TT, United Kingdom and ²Bangor Imaging Unit, Bangor University, Bangor LL57 2AS, United Kingdom



Hippocampal patterns carry information about finger-position binding above and beyond finger and position coding

1. THE HIPPOCAMPUS IS RECRUITED DURING MOTOR SEQUENCE LEARNING
2. THE HIPPOCAMPUS IS INVOLVED IN MOTOR MEMORY CONSOLIDATION
3. **THE HIPPOCAMPUS ENCODES SPATIO-TEMPORAL REPRESENTATIONS OF MOTOR SEQUENCES**

BUT IS THERE A “MOTOR” HIPPOCAMPUS?

HIPPOCAMPAL FUNCTION SHARED ACROSS MEMORY DOMAINS?



Ainsley Temudo



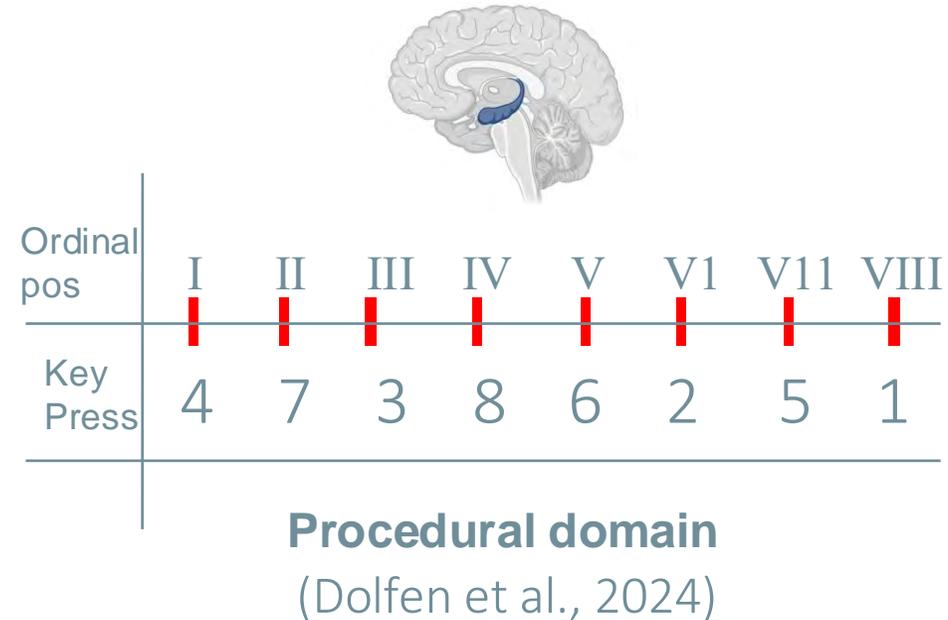
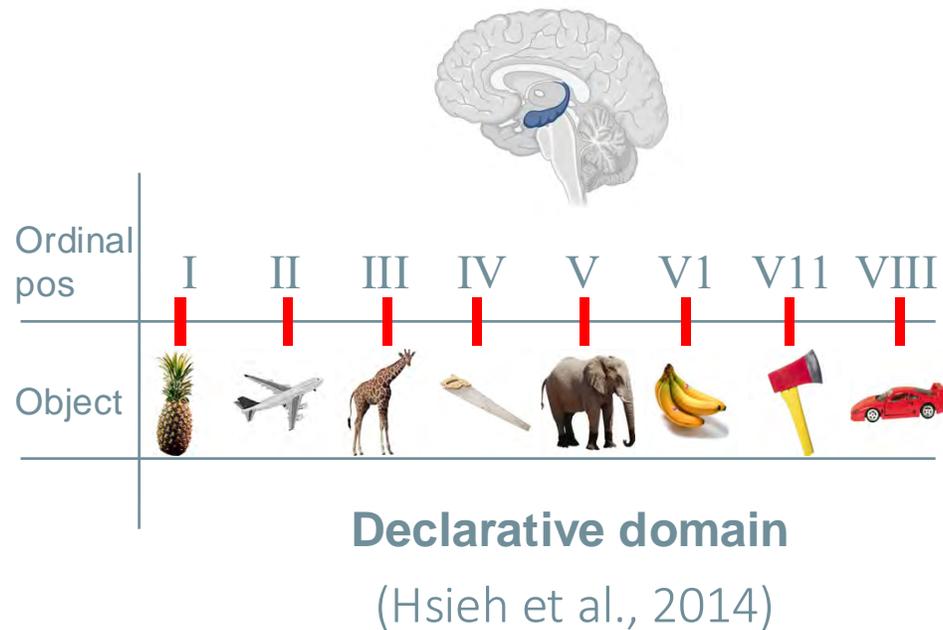
RESEARCH ARTICLE

The human medial temporal lobe represents memory items in their ordinal position in both declarative and motor memory domains

Ainsley Temudo¹, Nina Dolfen^{2,3}, Bradley R. King¹, Genevieve Albouy^{1*}

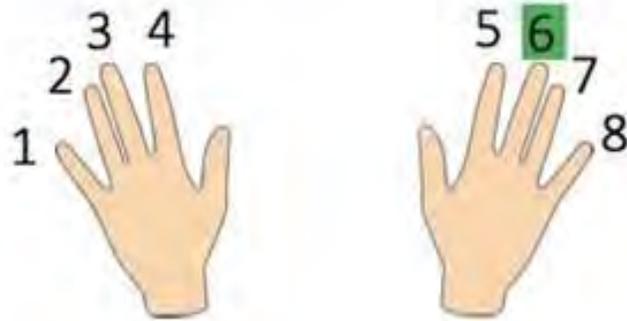
1 Department of Health and Kinesiology, College of Health, University of Utah, Salt Lake City, Utah, United States of America, **2** Department of Psychology, Columbia University, New York, New York, United States of America, **3** Department of Experimental Psychology, Ghent University, Ghent, Belgium

HIPPOCAMPAL FUNCTION SHARED ACROSS MEMORY DOMAINS?



Hippocampal function in encoding the order of items in a sequence may be shared across memory domains

Function shared across memory domains?



Object sequence



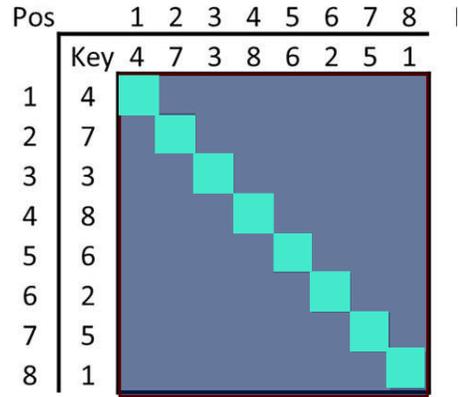
Motor sequence



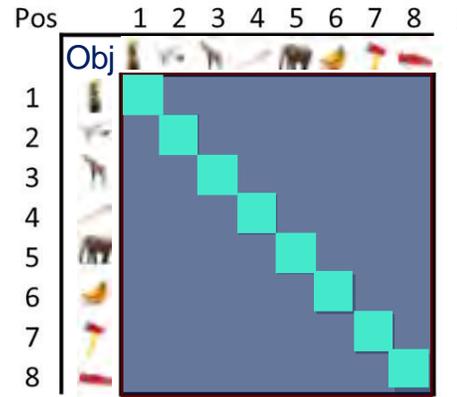
Random condition



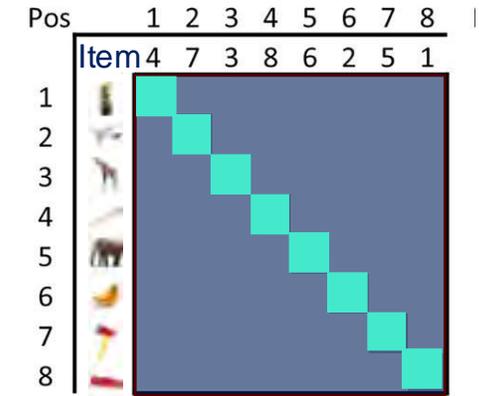
Function shared across memory domains?



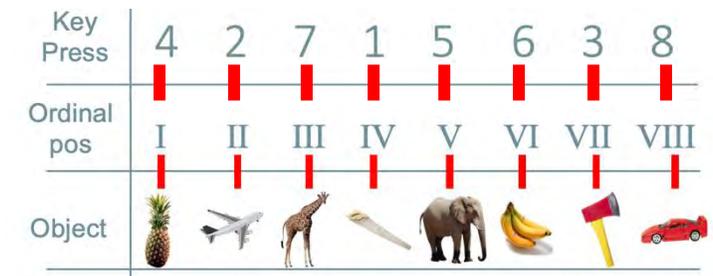
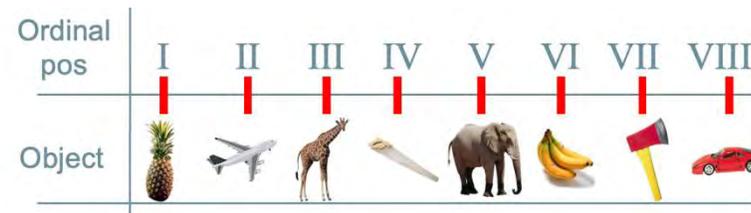
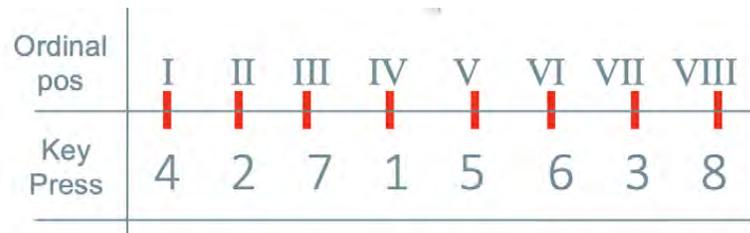
Motor sequence



Object sequence



Motor/Object sequence



Motor memory domain

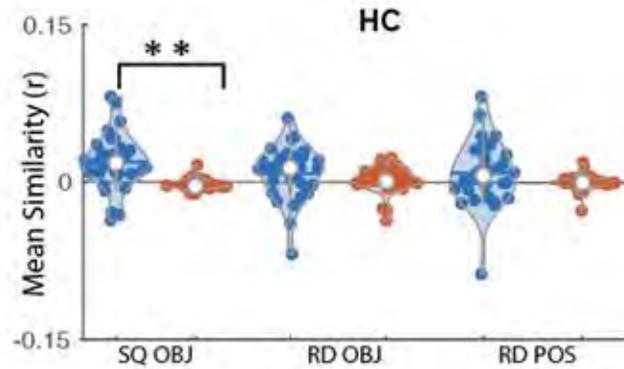
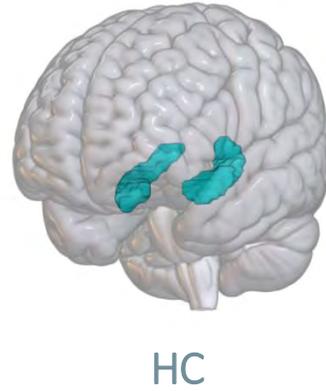
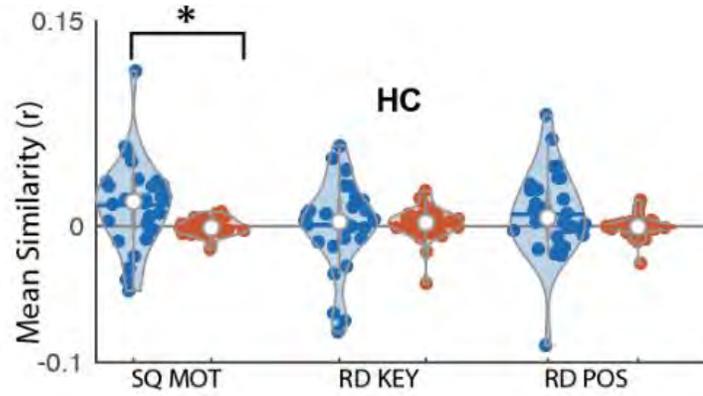
Ordinal pos	I	II	III	IV	V	VI	VII	VIII
Key Press	4	2	7	1	5	6	3	8

Declarative memory domain

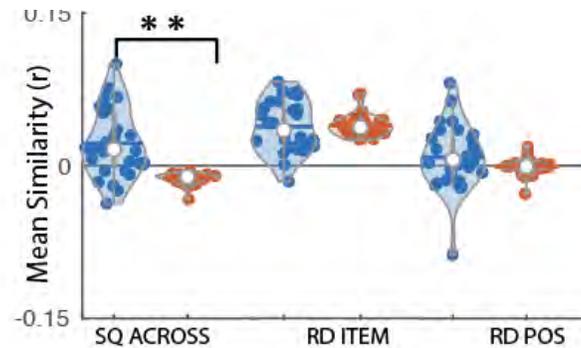
Ordinal pos	I	II	III	IV	V	VI	VII	VIII
Object								

Across memory domains

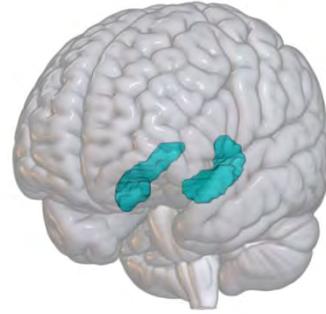
Key Press	4	2	7	1	5	6	3	8
Ordinal pos	I	II	III	IV	V	VI	VII	VIII
Object								



Temudo et al., 2025 PLoS Biol



Hippocampus contributes to the development of memory-domain general item-position maps that might provide a content-free cognitive framework for sequential behaviors across memory domains



HC

Temudo et al., 2025 PLoS Biol

Space and time: The hippocampus as a sequence generator

György Buzsáki^{1,2,3,4} and **David Tingley**¹

¹Neuroscience Institute, 435 East 30th St., Langone Medical Center, New York University, New York, NY 10016, USA

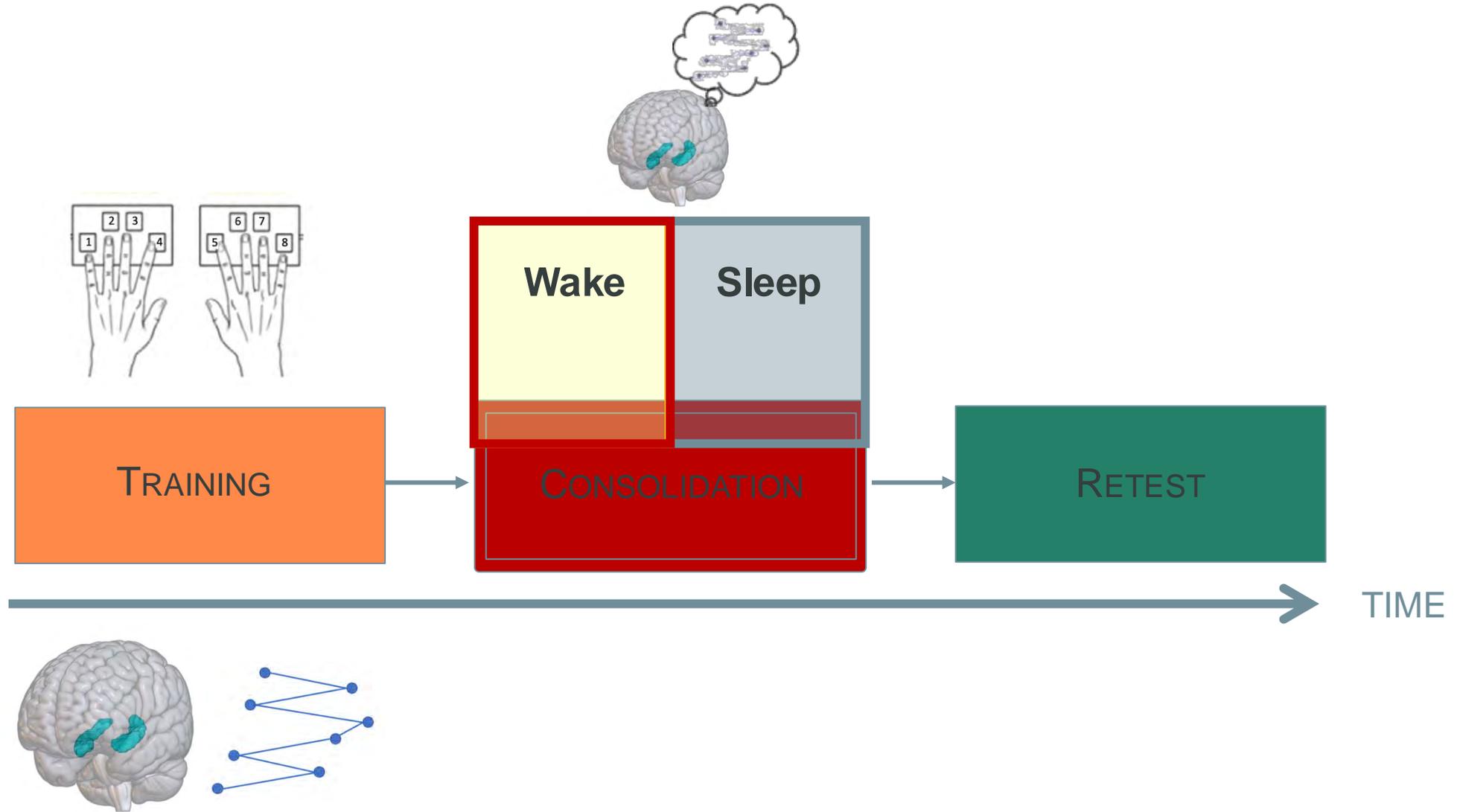
²Department of Neurology, Langone Medical Center, New York University, New York, NY 10016, USA

³Center for Neural Science, New York University, New York, NY 10003, USA

1. THE HIPPOCAMPUS IS RECRUITED DURING MOTOR SEQUENCE LEARNING
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HOW DOES THIS RELATE TO MEMORY CONSOLIDATION?

MOTOR MEMORY CONSOLIDATION



Article

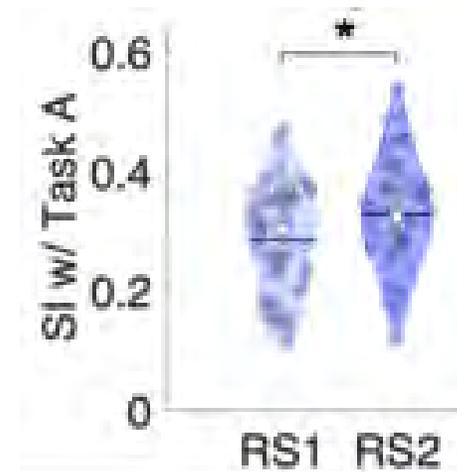
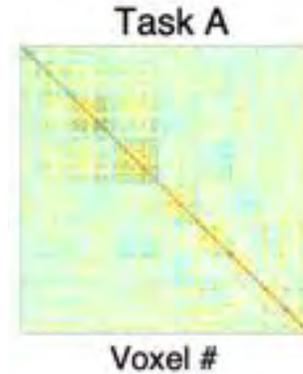
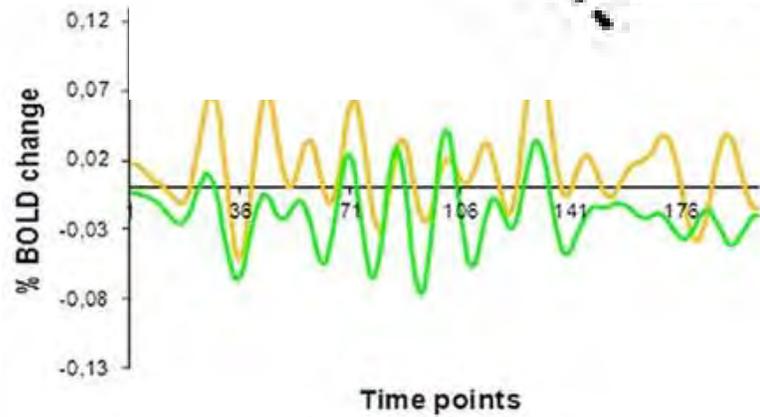
Persistence of hippocampal and striatal multivoxel patterns during awake rest after motor sequence learning

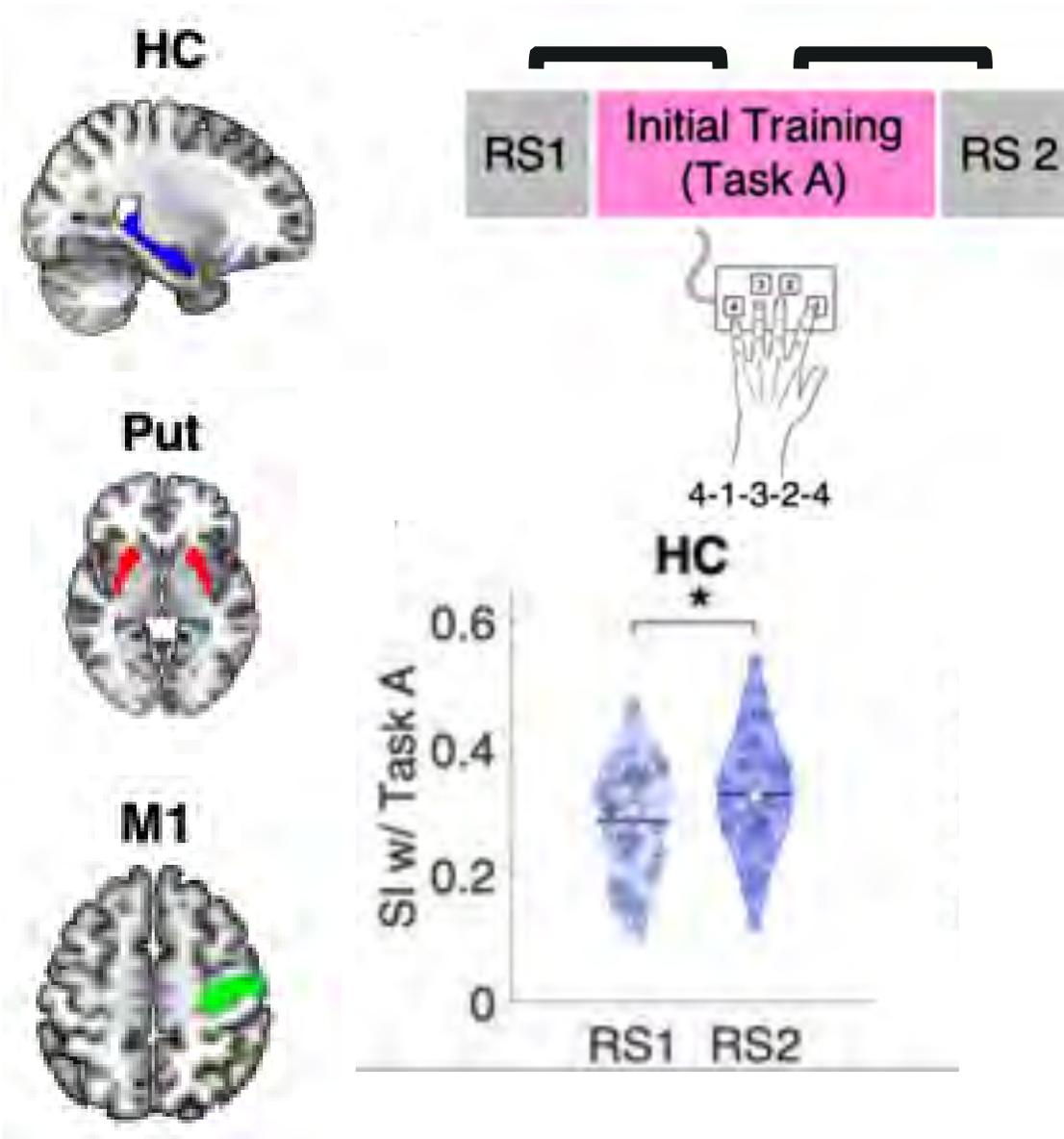
Bradley R. King,¹ Mareike A. Gann,² Dante Mantini,² Julien Doyon,³ and Geneviève Albouy^{1,2,4,*}



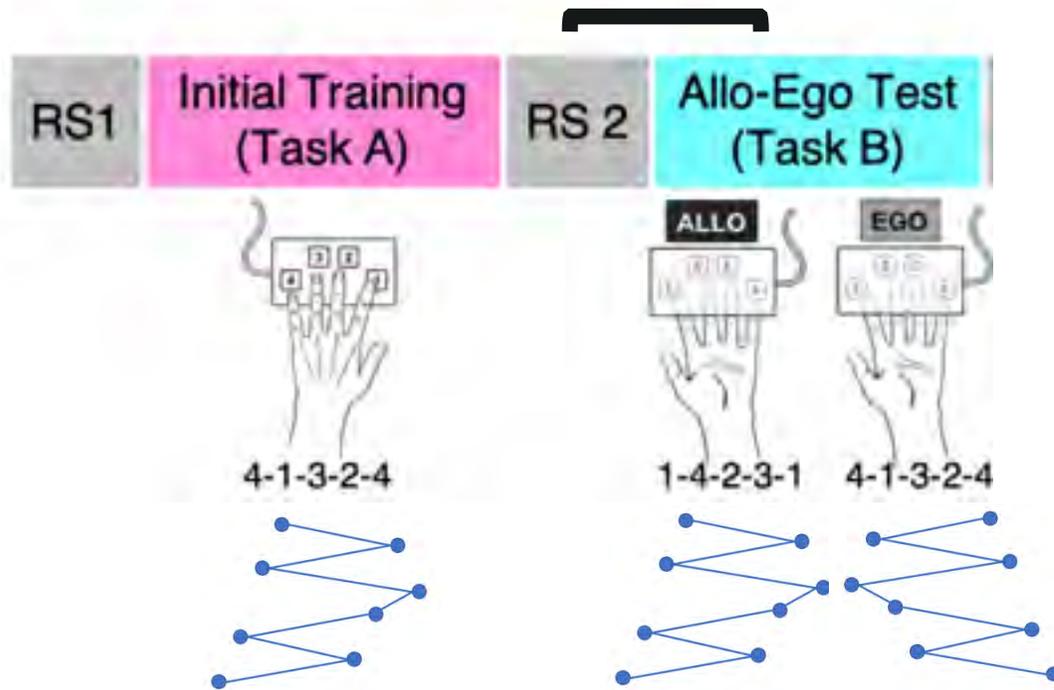
Brad King

MULTIVOXEL CORRELATION STRUCTURE ANALYSES

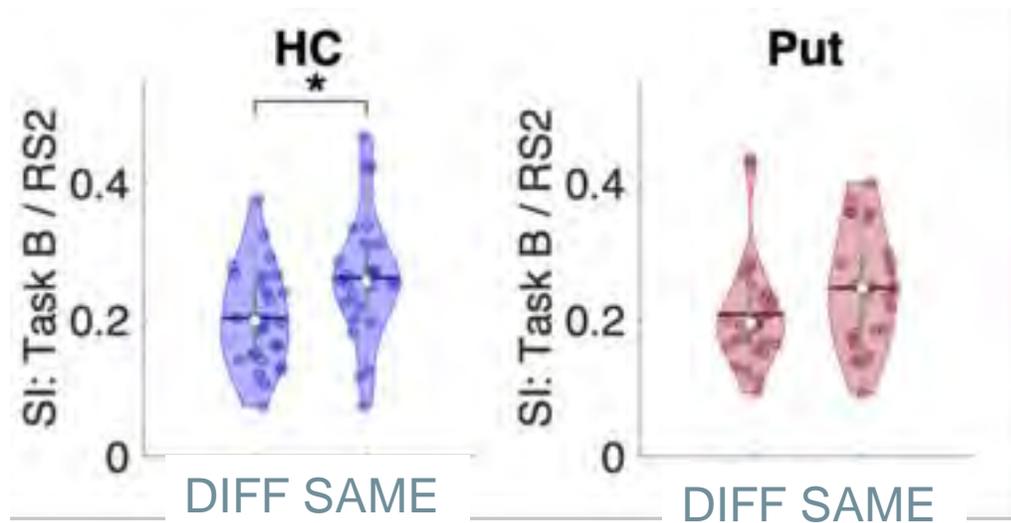




Q: Persistence of MSL-related patterns into subsequent wakeful rest?



Albouy et al., 2015; *Neuroimage*

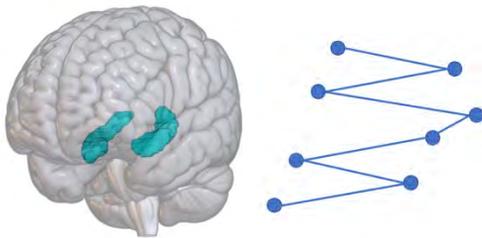
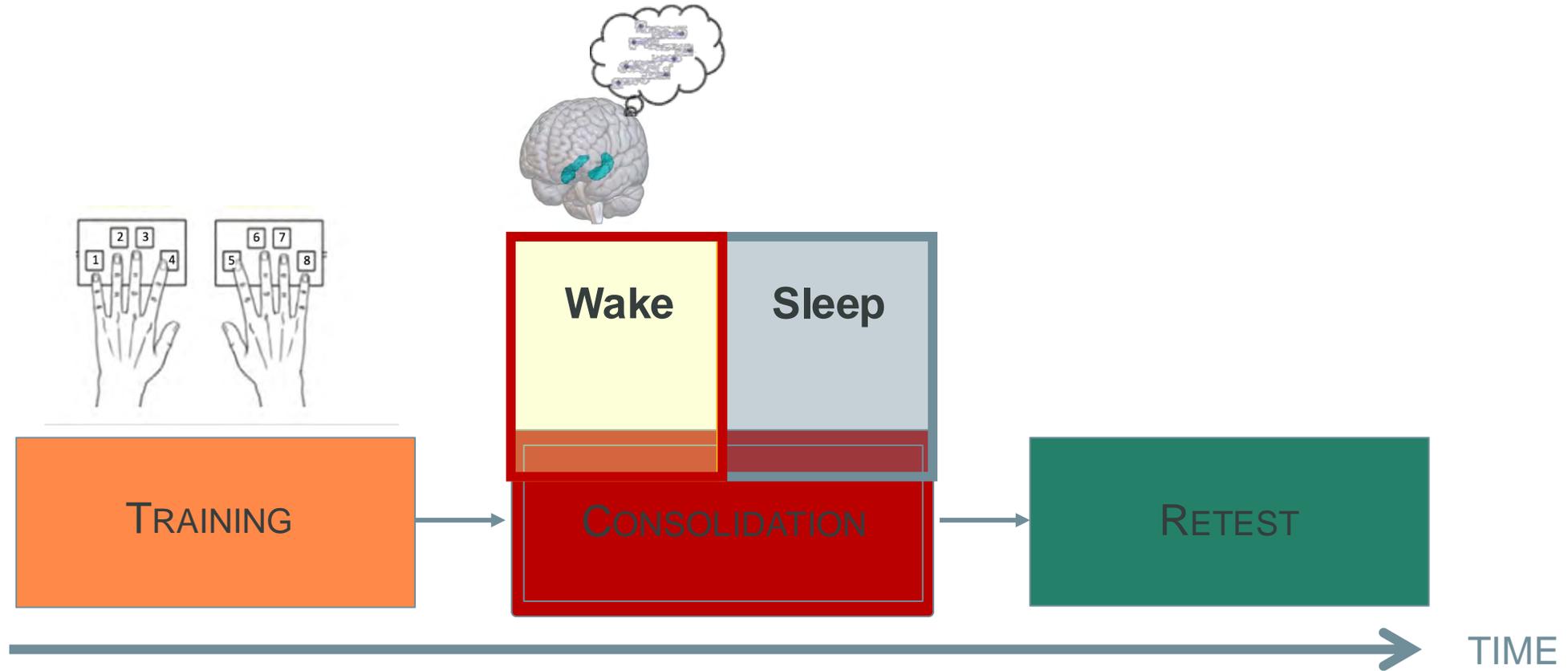


Q: Does pattern persistence reflect the reactivation of the learned spatio-temporal pattern?

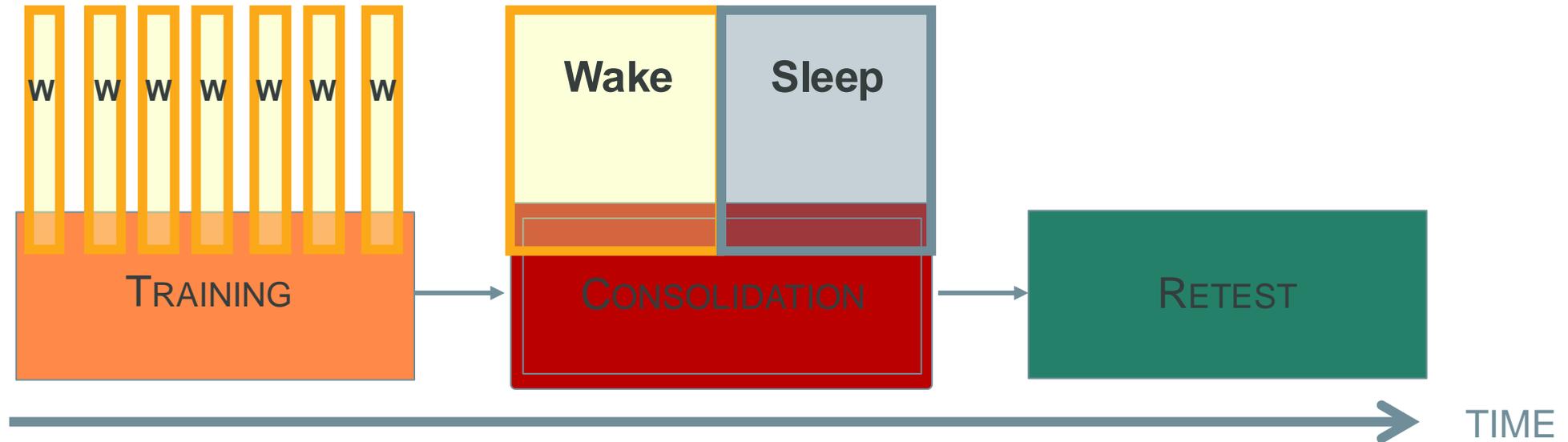
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5. **HIPPOCAMPAL REPRESENTATIONS OF THESE SPATIO-TEMPORAL PATTERNS PERSIST DURING SUBSEQUENT WAKEFUL REST**

WHAT IS THE TIMESCALE OF THESE “REACTIVATIONS”?

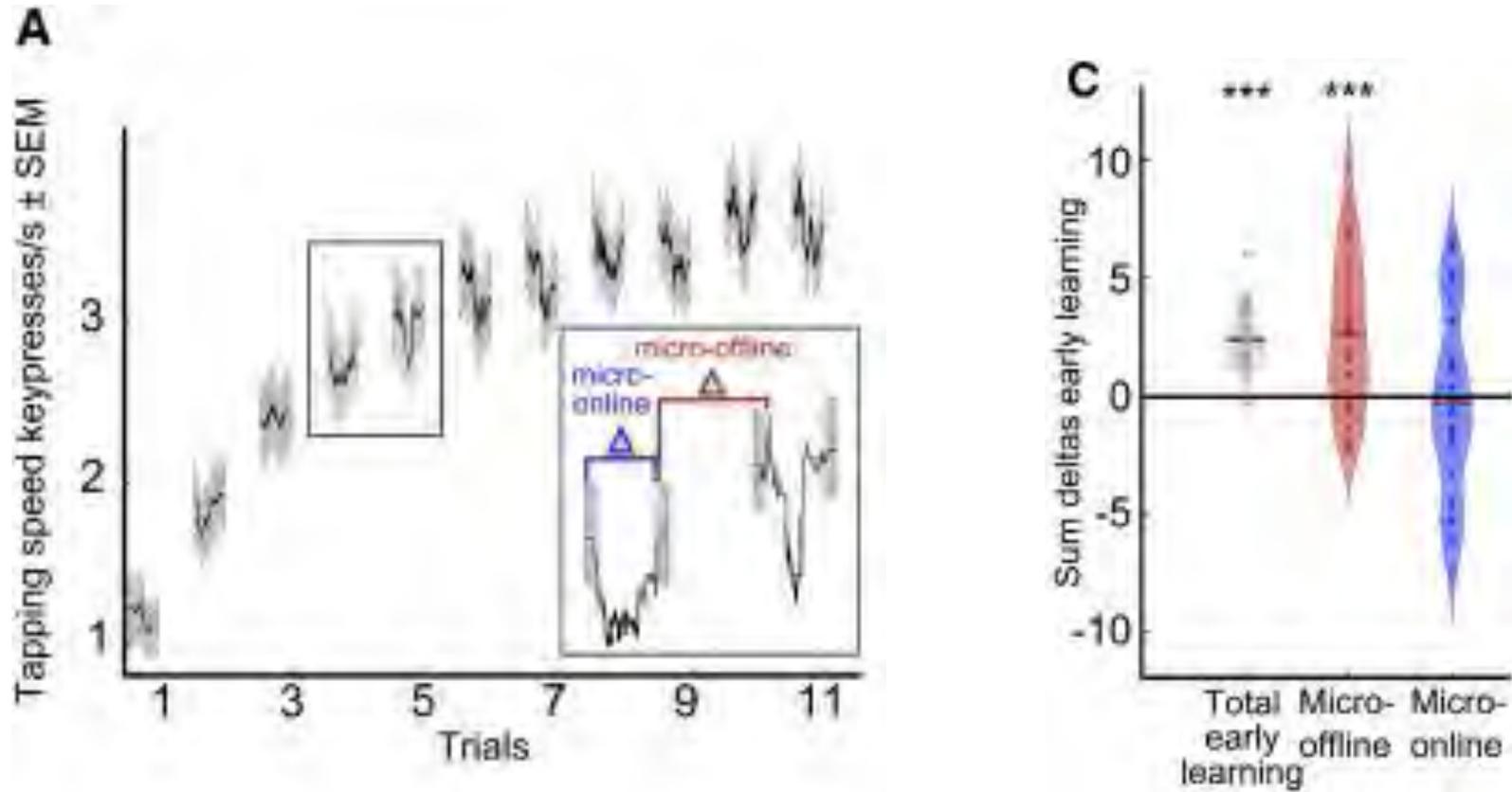
MOTOR MEMORY CONSOLIDATION



ARE SIMILAR PATTERNS OBSERVED DURING FAST CONSOLIDATION?



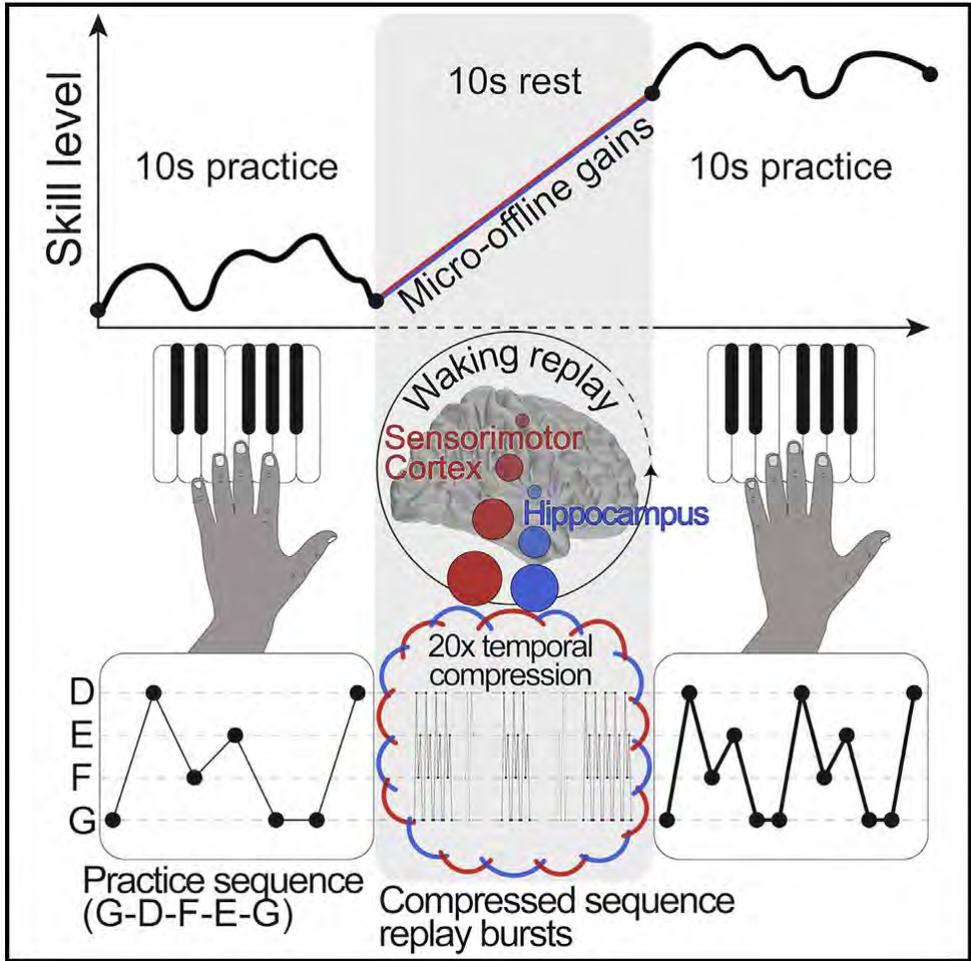
FAST CONSOLIDATION AT THE MICRO TIMESCALE



Bonstrup et al., 2019; *Curr Biol*

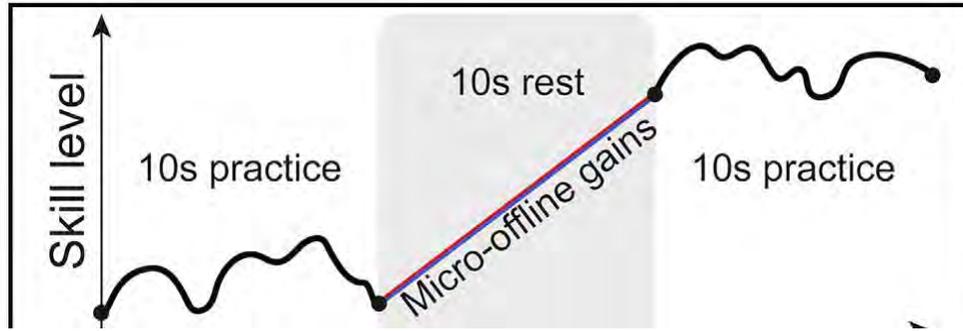
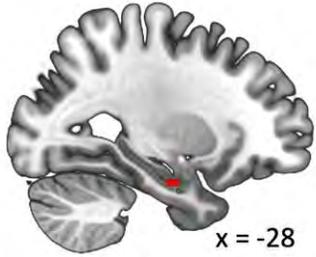
Buch et al., 2021; *Cell Rep*

FAST CONSOLIDATION AT THE MICRO TIMESCALE



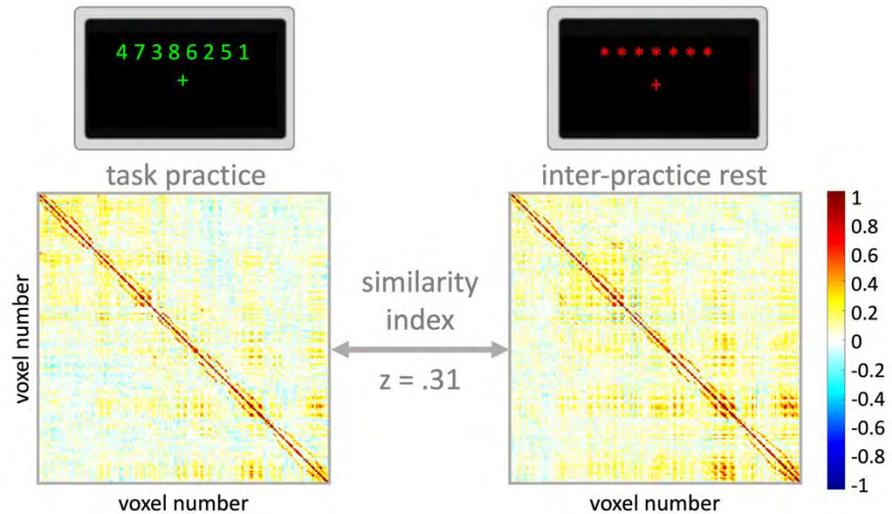
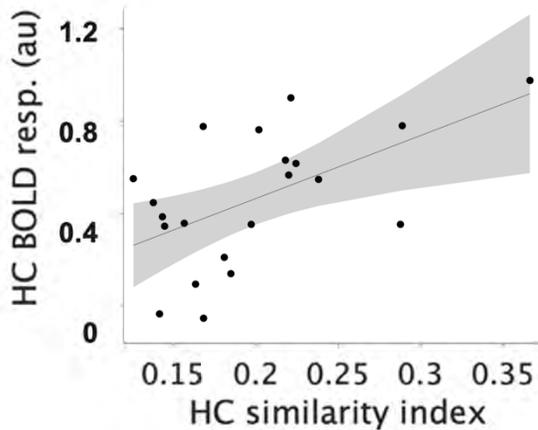
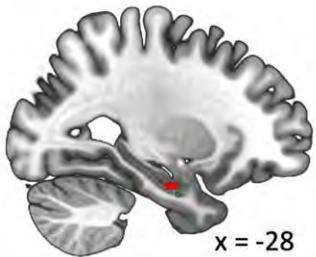
Buch et al., 2021; *Cell Rep*

FAST CONSOLIDATION AT THE MICRO TIMESCALE

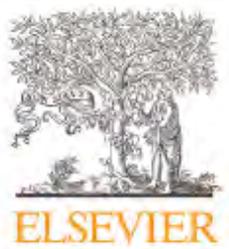


Jacobacci et al., 2022

Gann et al., 2023; Brain Stim



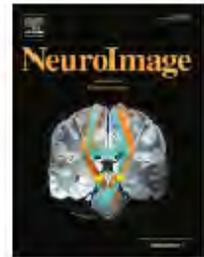
TMS TARGETING HIPPOCAMPAL NETWORKS



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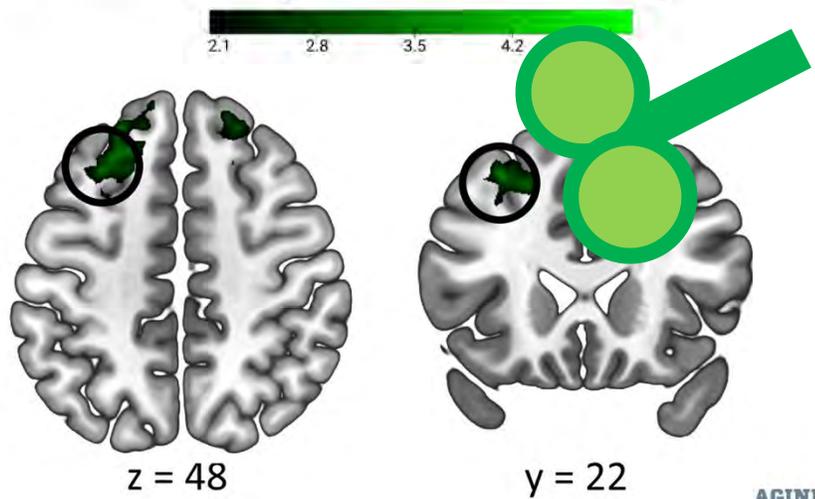
journal homepage: www.elsevier.com/locate/neuroimage



Mareike Gann

Hippocampal and striatal responses during motor learning are modulated by prefrontal cortex stimulation

Mareike A. Gann^{a,b}, Bradley R. King^{a,b}, Nina Dolfen^{a,b}, Menno P. Veldman^{a,b}, Kimberly L. Chan^c, Nicolaas A.J. Puts^{d,e,f}, Richard A.E. Edden^{d,e}, Marco Davare^g, Stephan P. Swinnen^{a,b}, Dante Mantini^{a,h}, Edwin M. Robertsonⁱ, Geneviève Albouy^{a,b,*}



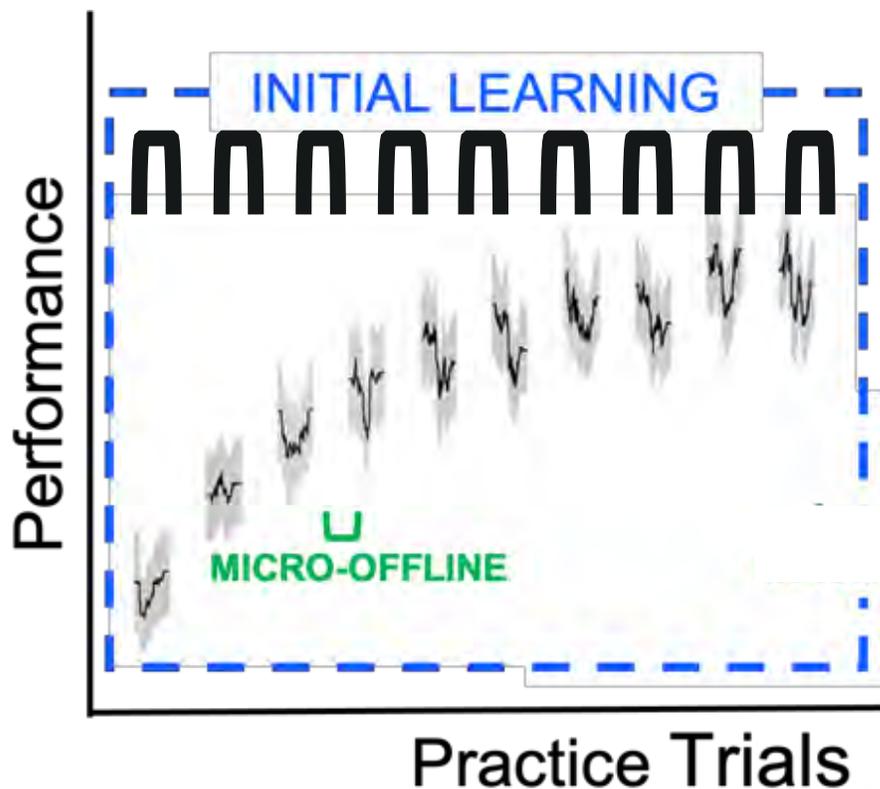


TMS

cTBS / iTBS

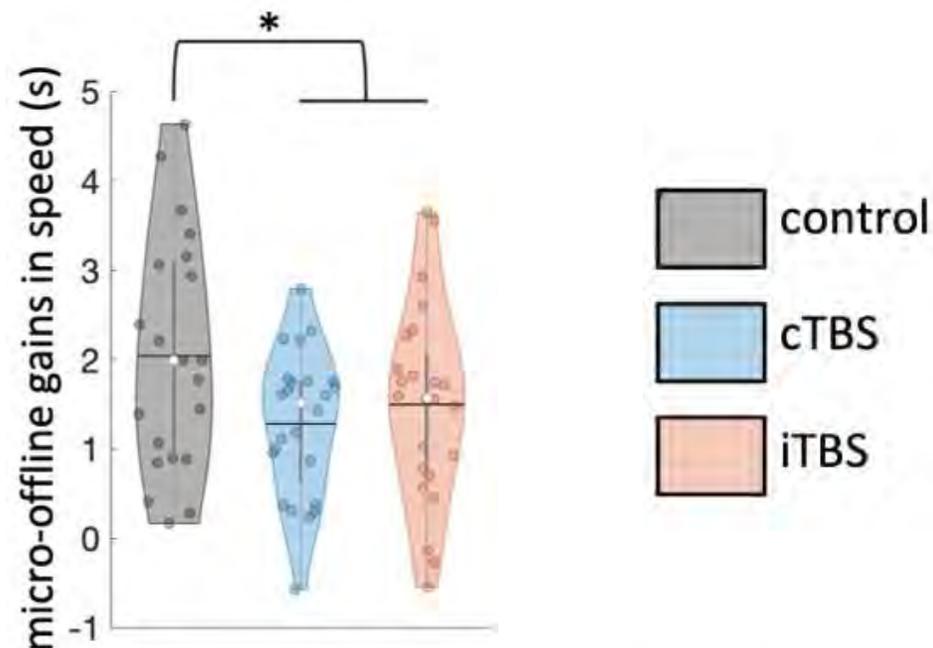


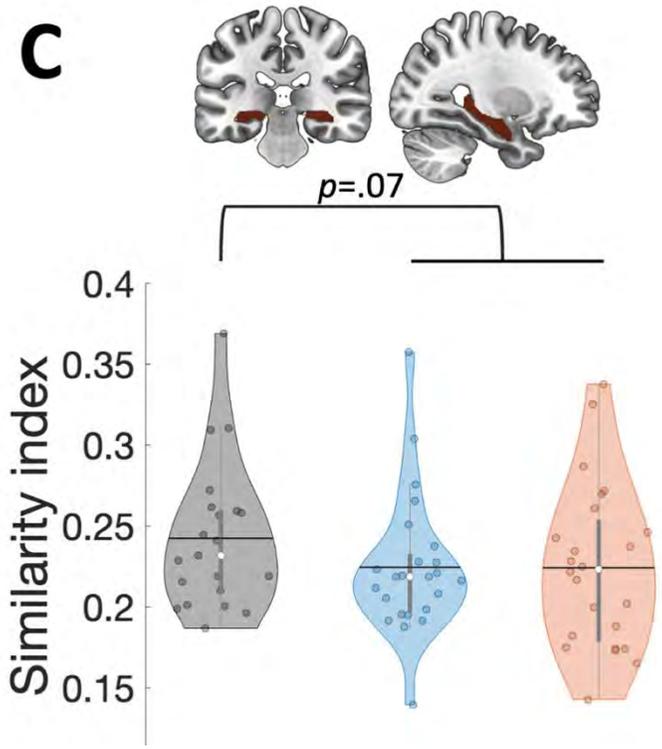
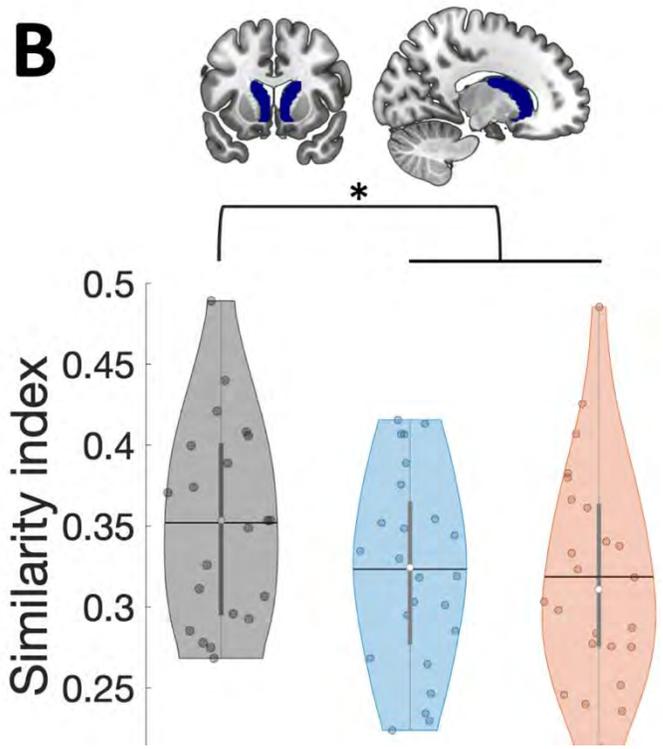
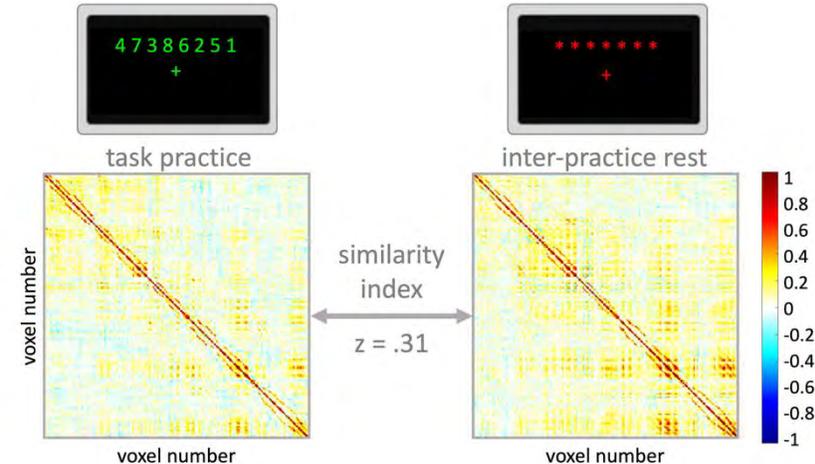
MSL



Prefrontal stimulation as a tool to disrupt hippocampal and striatal reactivations underlying fast motor memory consolidation

Mareike A. Gann^{a,b}, Nina Dolfen^{a,b}, Bradley R. King^c, Edwin M. Robertson^d, Geneviève Albouy^{a,b,c,*}

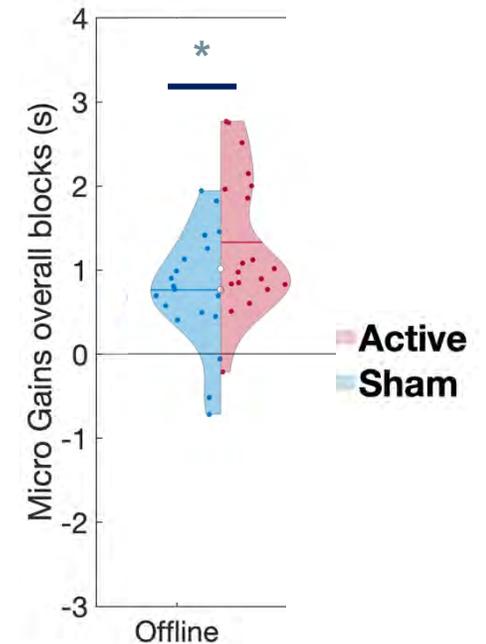
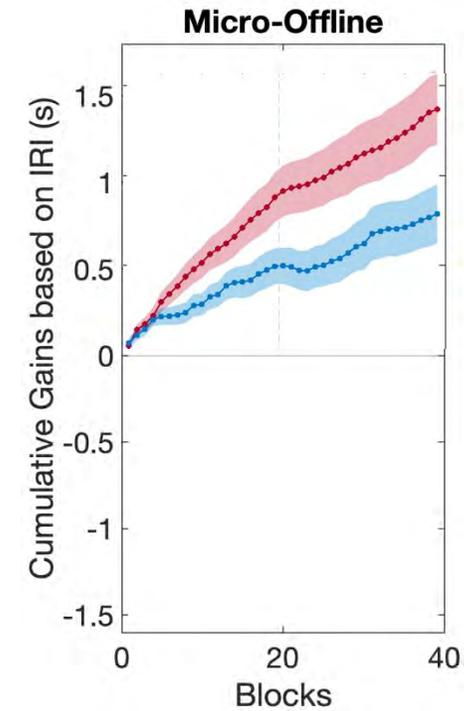
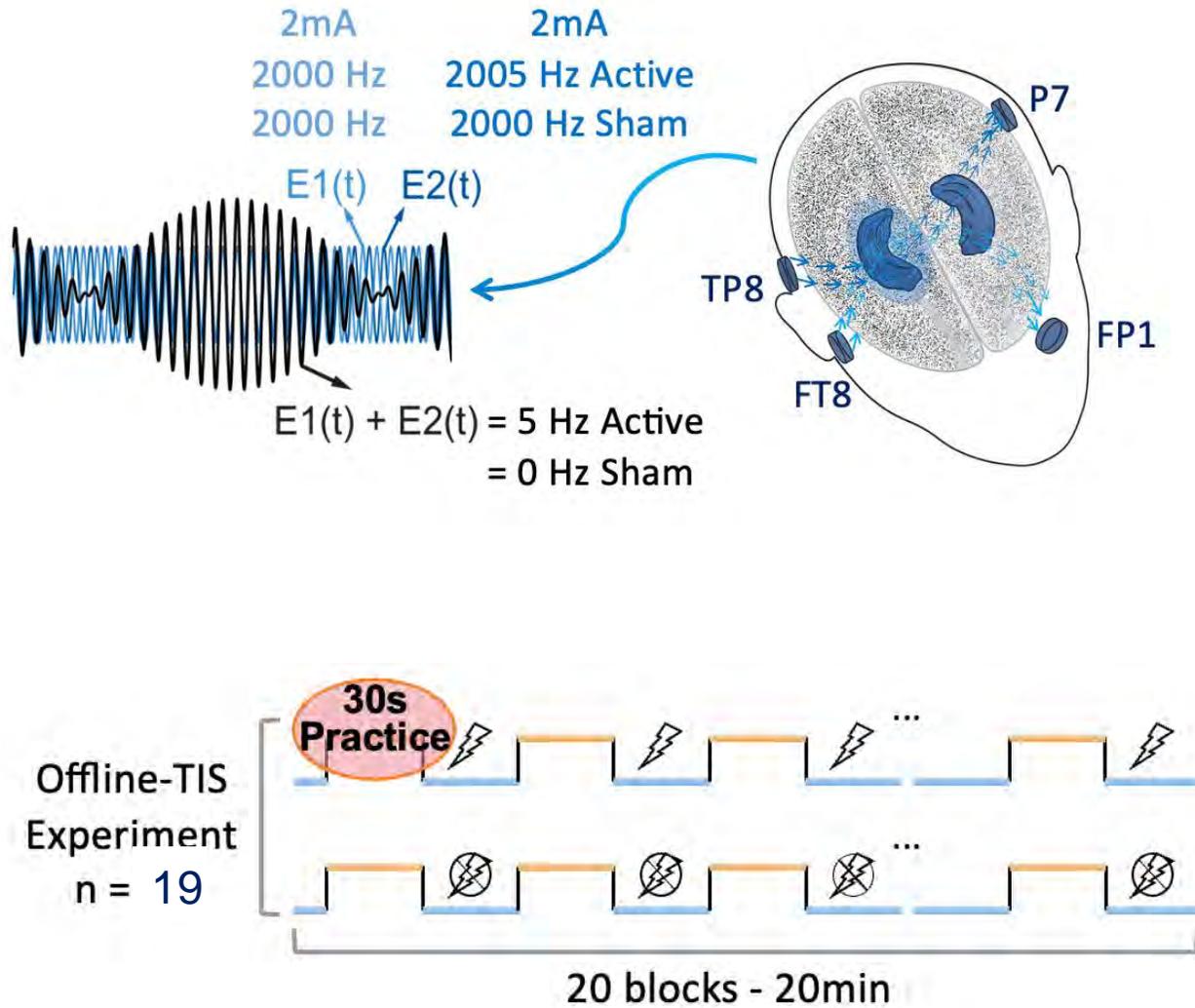




TEMPORAL INTERFERENCE STIMULATION

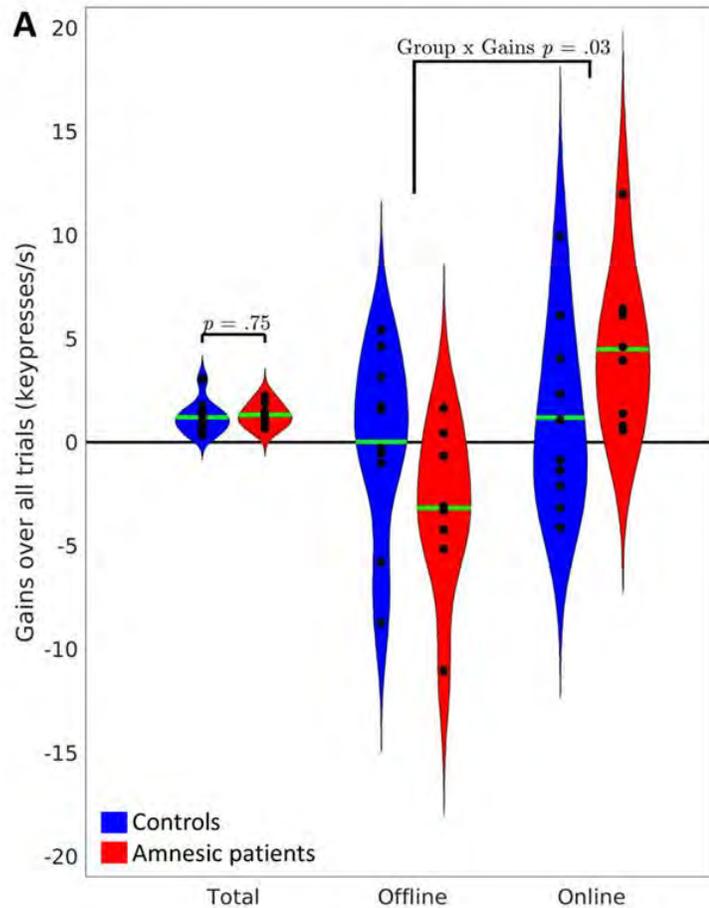


Xiaoxi Pan



MICRO-OFFLINE CONSOLIDATION IN PATIENTS

Amnesic patients



Parkinson's patients

1-7 • The Journal of Neuroscience, August 27, 2005 • 45(35):e2193242025

Behavioral/Cognitive

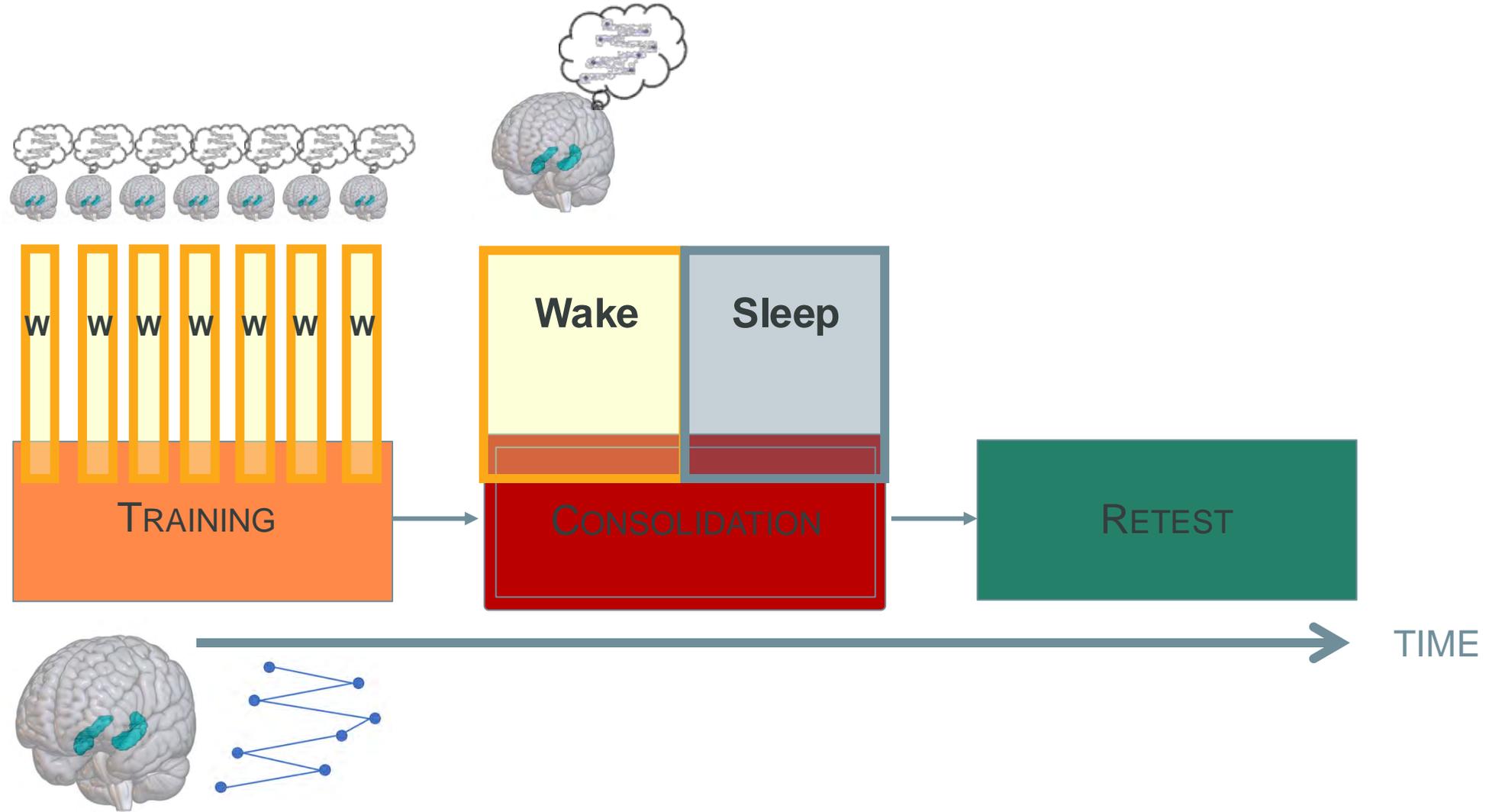
Impaired Online and Enhanced Offline Motor Sequence Learning in Individuals with Parkinson's Disease

Anke Van Roy,¹ Xiaojuan Dan,^{2,3} Letizia Micca,⁴ Moran Gilat,⁴ Piu Chan,^{2,3,5,6} Julien Doyon,⁷ Genevieve Albouy,^{1,8,9} and Bradley R. King¹

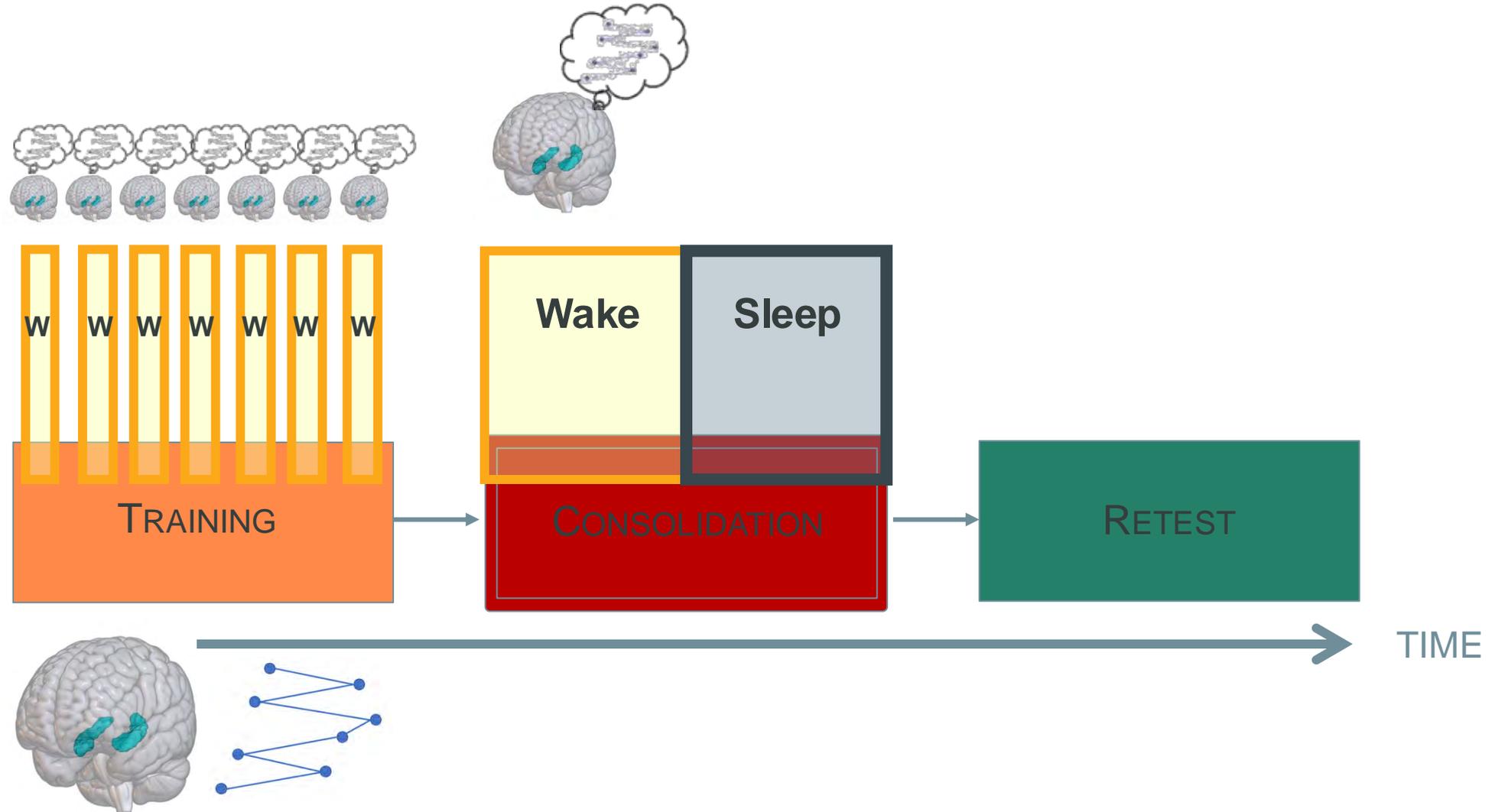
Van Roy et al., 2024 J Neuro

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6. **CAUSAL EVIDENCE FOR A ROLE OF THE HIPPOCAMPUS IN MOTOR MEMORY CONSOLIDATION AT THE MICRO TIMESCALE**

MOTOR MEMORY CONSOLIDATION



MOTOR MEMORY CONSOLIDATION



Somatosensory targeted memory reactivation enhances motor performance via hippocampal-mediated plasticity

Menno P. Veldman ^{1,2}, Nina Dolfen ^{1,2}, Mareike A. Gann^{1,2}, Anke Van Roy³, Ronald Peeters^{4,5}, Bradley R. King ³, Geneviève Albouy ^{1,2,3,*}



Menno Veldman



RESEARCH ARTICLE



Sigma oscillations protect or reinstate motor memory depending on their temporal coordination with slow waves

Judith Nicolas^{1,2*}, Bradley R King³, David Levesque⁴, Latifa Lazzouni¹, Emily Coffey⁶, Stephan Swinnen^{1,2}, Julien Doyon⁵, Julie Carrier^{4,7}, Genevieve Albouy^{1,2,3*}

Nicolas et al., 2022; *Elife*

Nicolas et al., 2025; *Nature Com*



Judith Nicolas

nature communications

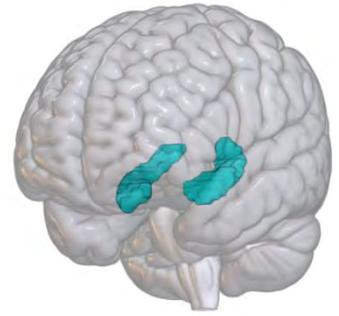


Article

<https://doi.org/10.1038/s41467-025-57602-2>

Unraveling the neurophysiological correlates of phase-specific enhancement of motor memory consolidation via slow-wave closed-loop targeted memory reactivation





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6. CAUSAL EVIDENCE FOR A ROLE OF THE HIPPOCAMPUS IN MOTOR MEMORY CONSOLIDATION AT THE MICRO TIMESCALE

DECLARATIVE MEMORY



EVENTS



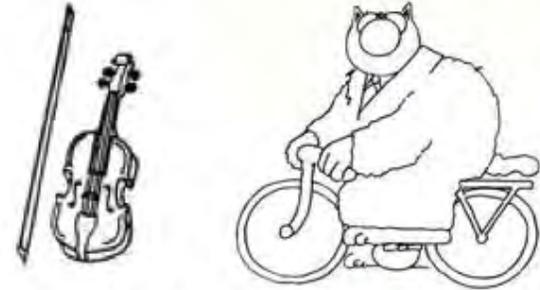
FACTS



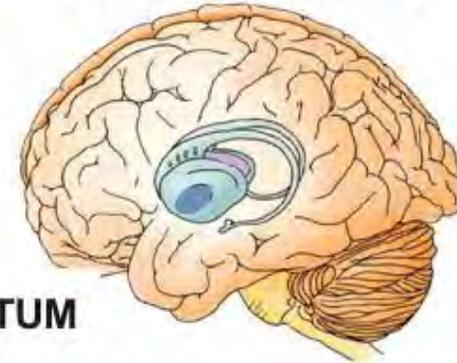
PROCEDURAL MEMORY



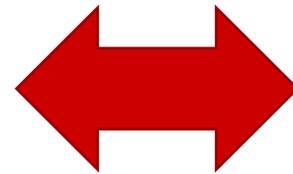
MOTOR SKILLS



MOTOR CORTEX



HIPPOCAMPUS



STRIATUM

CEREBELLUM



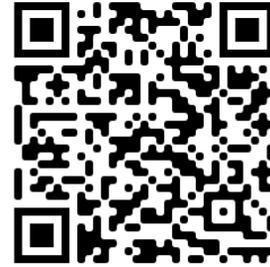
ACKNOWLEDGEMENTS



HEALTH
UNIVERSITY OF UTAH



Thank you!



[Lab Website](#)



genevieve.albouy@health.utah.edu

