Cognitive Science & Technology

SAND2010-5361P

From Sensing to Enhancing Brain Processes

PI: Laura Matzen, 1434

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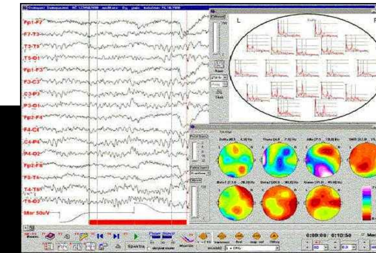
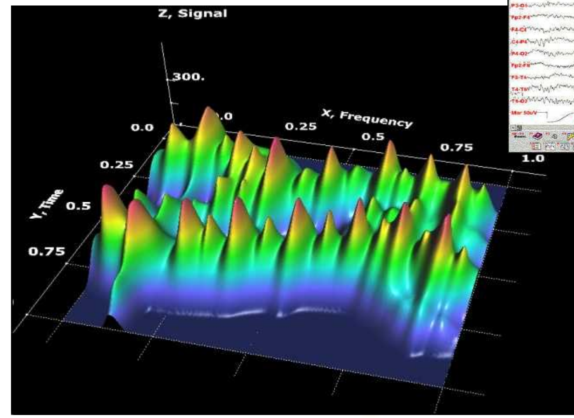
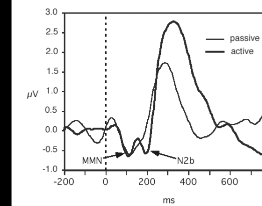
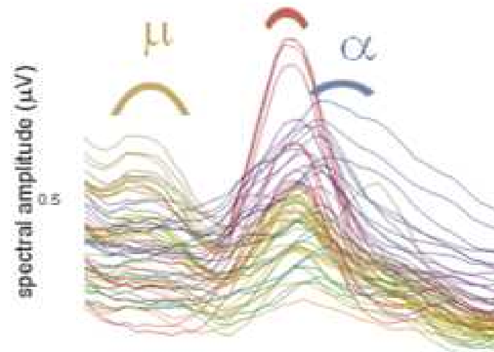
AAWC
Feedback
Eye Tracking

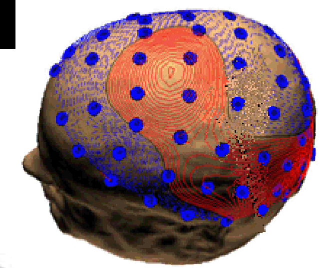
?

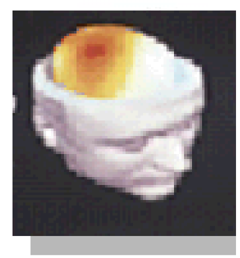


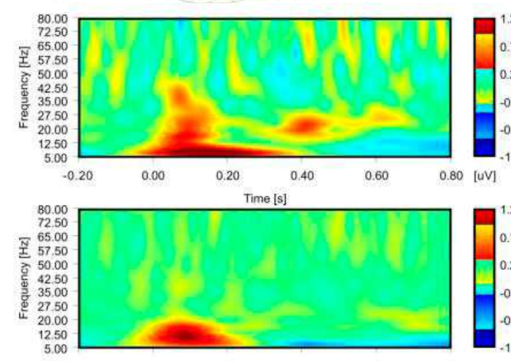

Z, Signal
300.
X, Frequency
Y, Time
0.0
0.25
0.5
0.75
1.0


passive
active
MMN
N2b
µV
ms
-200
0
200
400
600
800


µ
α
spectral amplitude (µV)
0.5

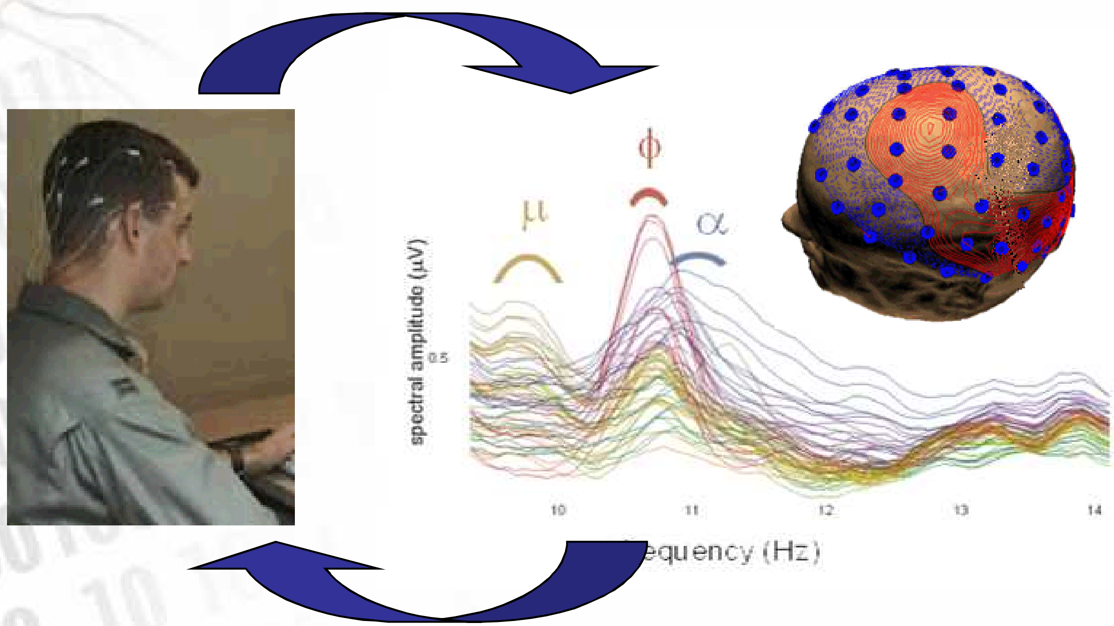




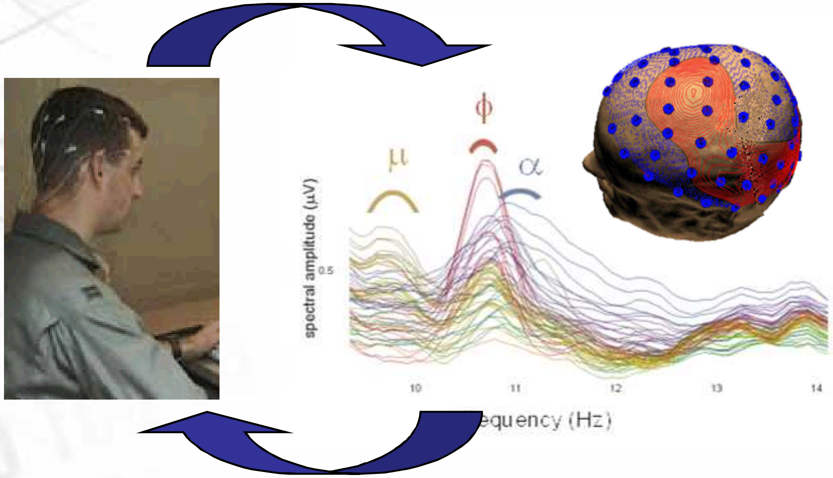

Frequency [Hz]
Time [s]
[uV]
1.20
0.72
0.24
-0.24
-0.72
-1.20

Project Goals

- Develop scientific basis for designing systems that apply recorded brain activity to improving human performance

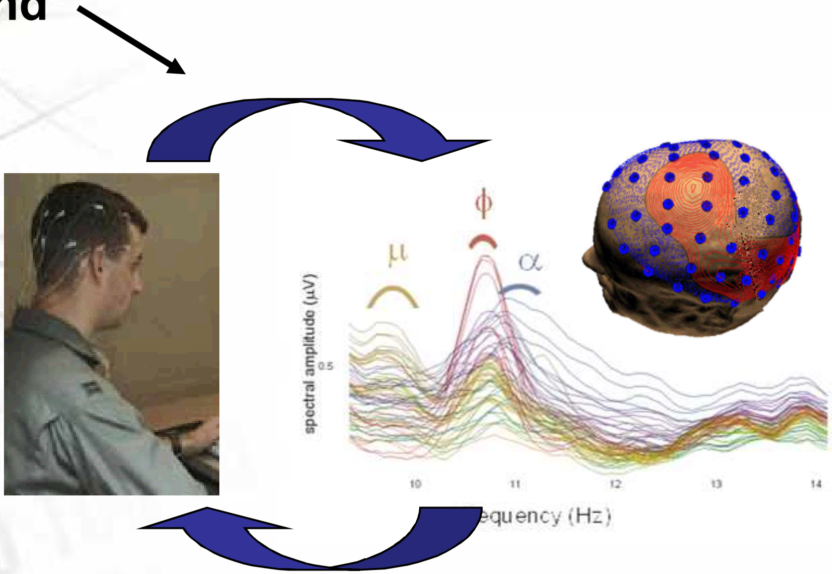


Scientific Goals



Scientific Goals

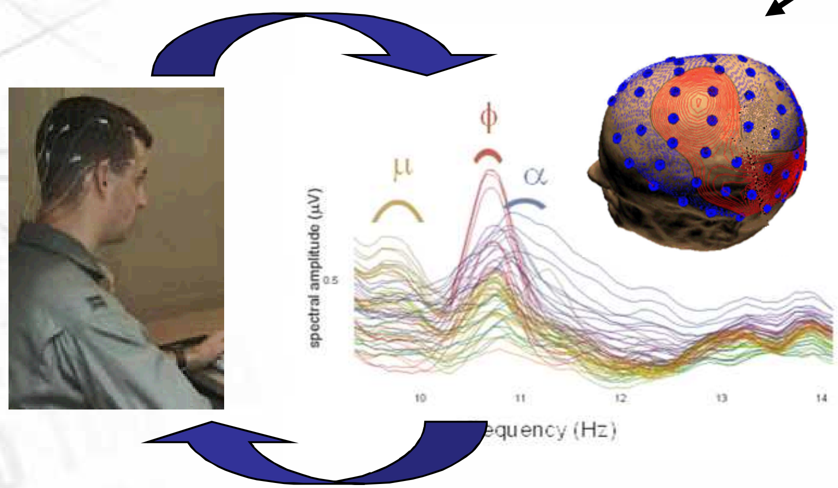
Test hypotheses about relationship between task performance and brain activity



Scientific Goals

Test hypotheses about relationship between task performance and brain activity

Use computational modeling to characterize brain activity associated with good and poor performance



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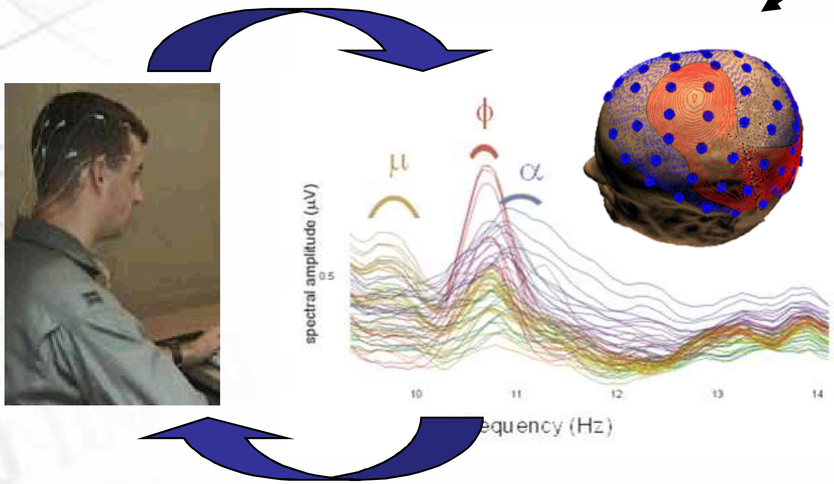

Test effectiveness of methods for optimizing neural performance

Scientific Goals

Test hypotheses about relationship between task performance and brain activity

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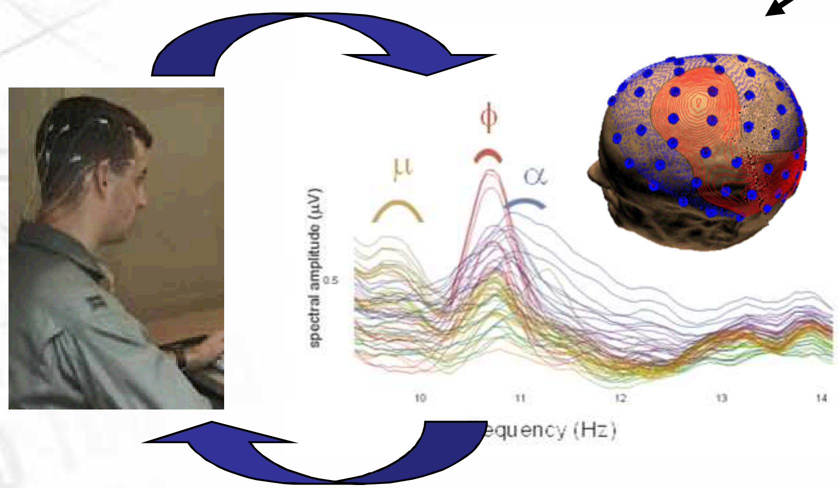
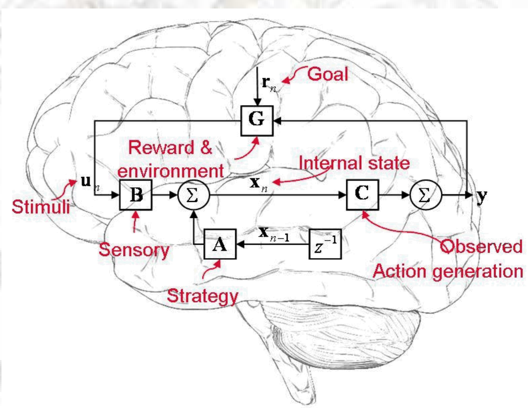


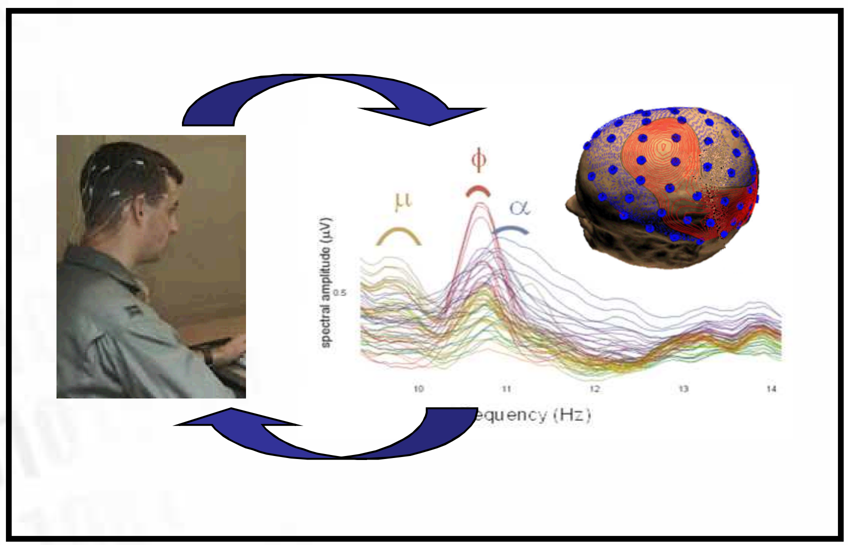
Test effects of optimizing neural performance on task performance

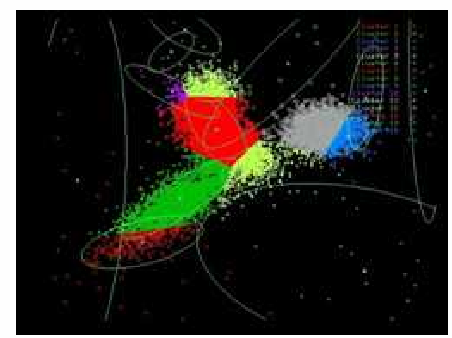
Test effectiveness of methods for optimizing neural performance

Technological Goals

- Create framework for engineering cutting-edge neurotechnologies
- Develop novel applications of computer modeling and machine learning techniques to processing and interpreting brain activity







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Programmatic Goals

Establish electrophysiology lab at Sandia

Develop relationships with Beckman Institute and Mind Research Network

The Mind Research Network
For Neurodiagnostic Discovery

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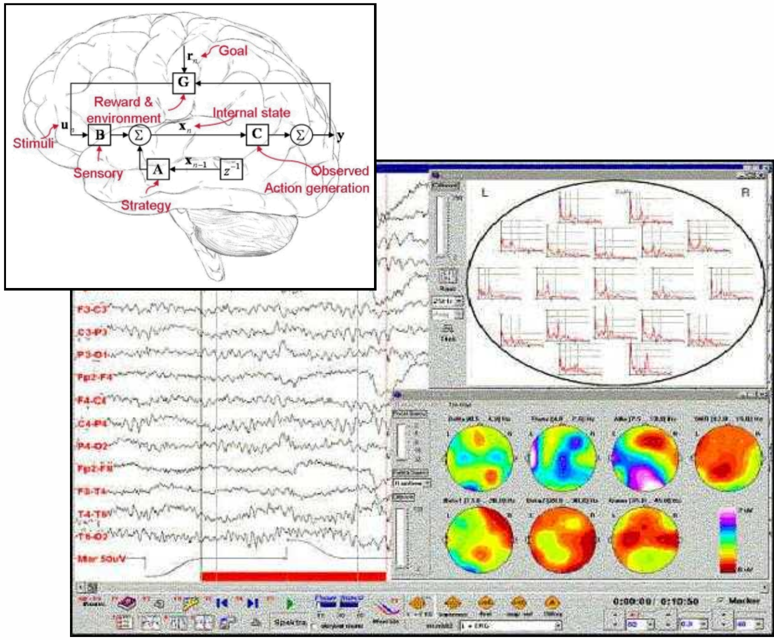
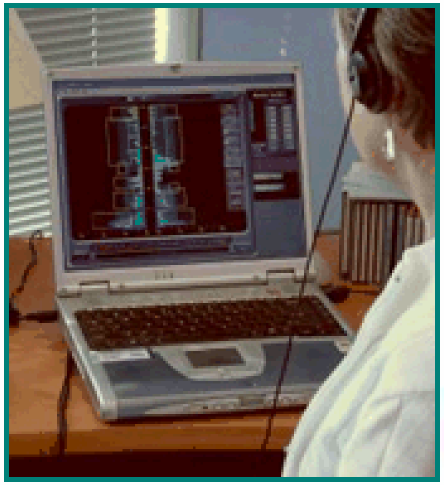
Experimental Hypotheses

1) We can characterize the causal relationship between neural activity and good/poor task performance



2) We can implement neural interventions to optimize task performance



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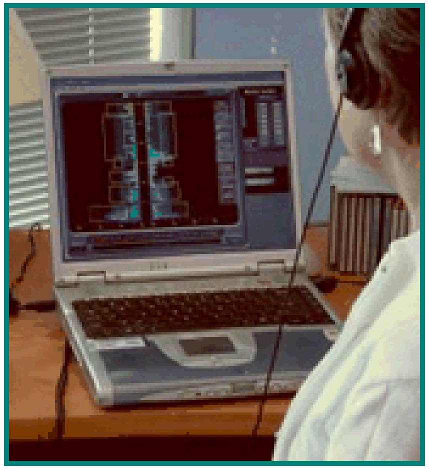
Intervention Techniques

Cognitive Training

Neurofeedback



Transcranial direct current stimulation (tDCS)

Techniques that could be used to close the loop between recording brain activity and enhancing performance

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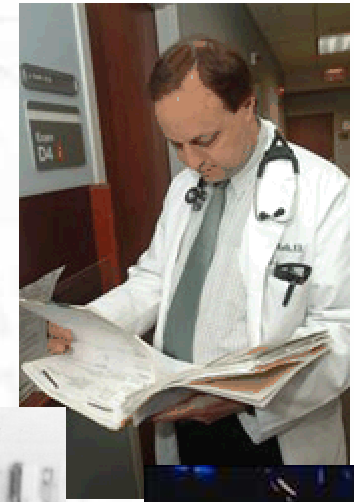
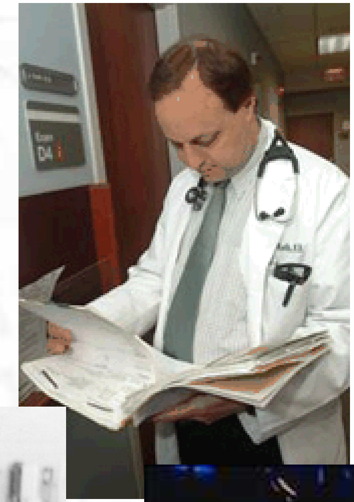
Improving Decision Making by Enhancing Memory



Improving Decision Making by Enhancing Memory

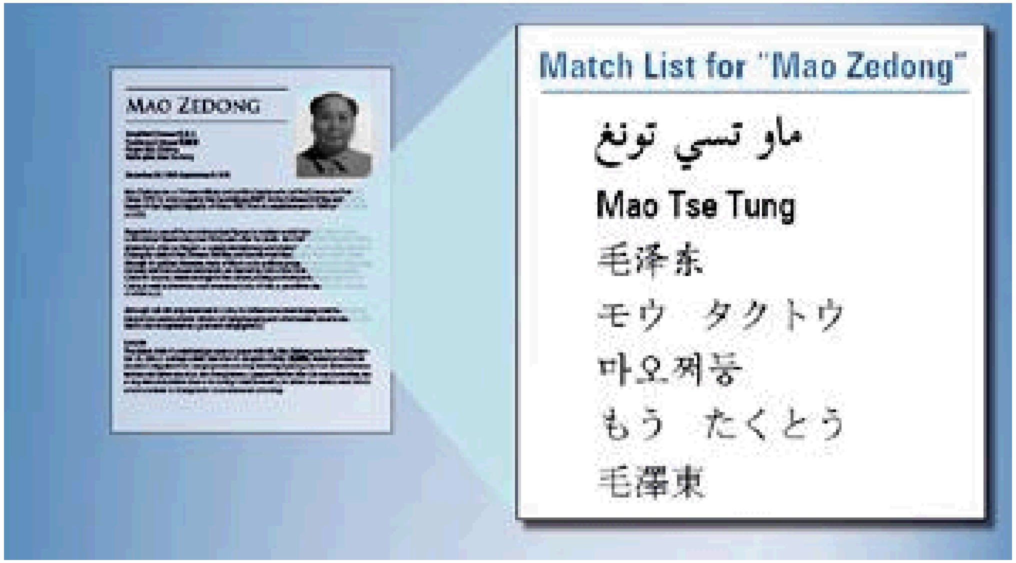
- Enhance memory for decision-relevant information
  1) Increase amount of information remembered
  2) Reduce memory errors



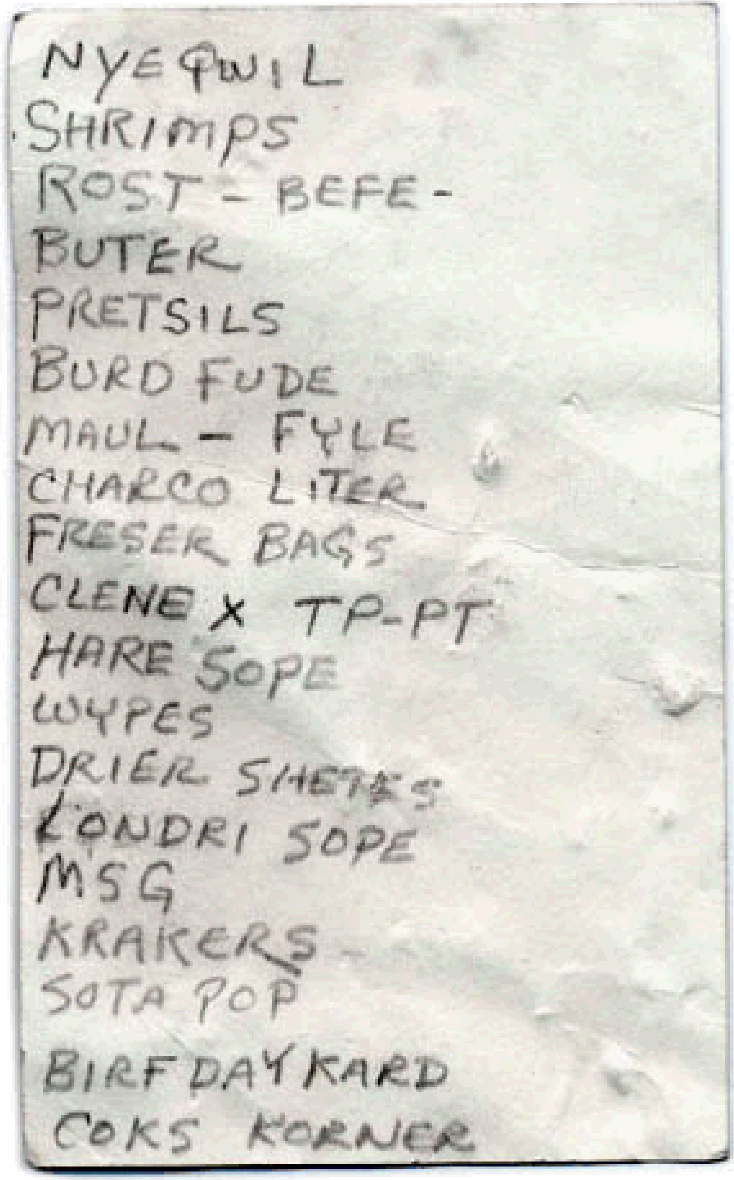

Improving Decision Making by Enhancing Memory

- Underlying meaning (gist) vs. surface form



  - Different relevance to different tasks
  - Processed differently in the brain

Examples of gist and surface form information



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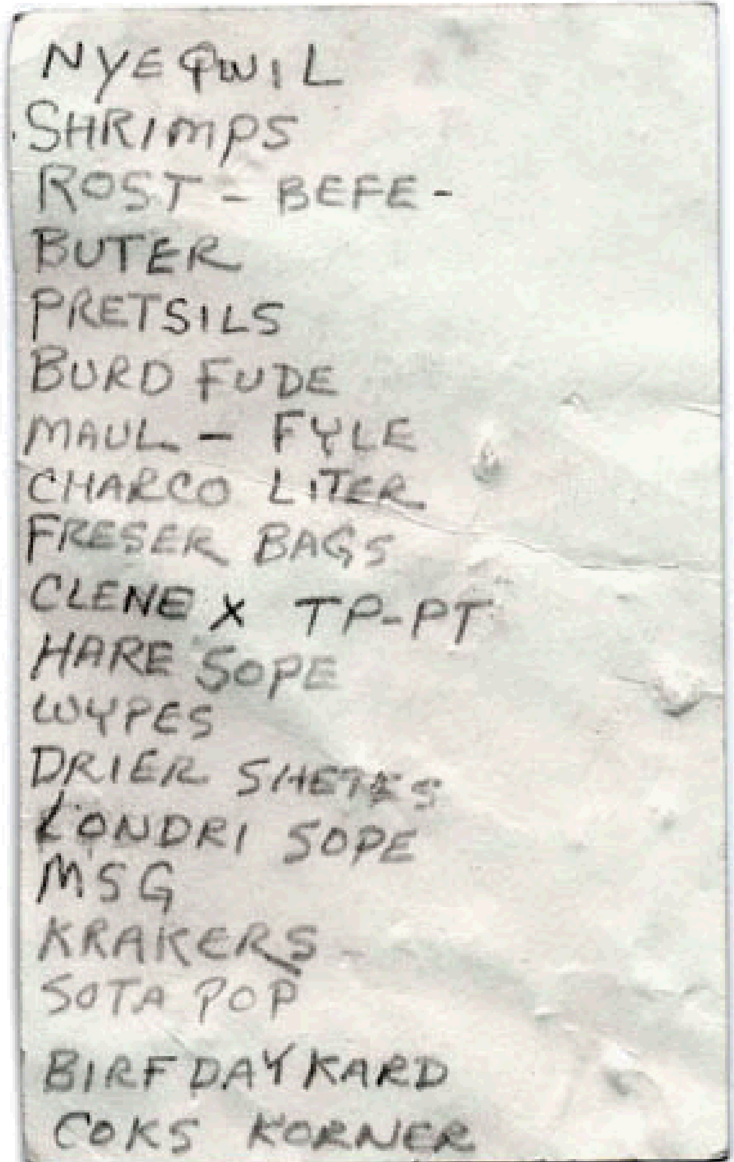
Examples of gist and surface form information

- Gist:
  - Grocery list
  - Bad spelling
- Surface forms
  - Exact items
  - Exact spellings



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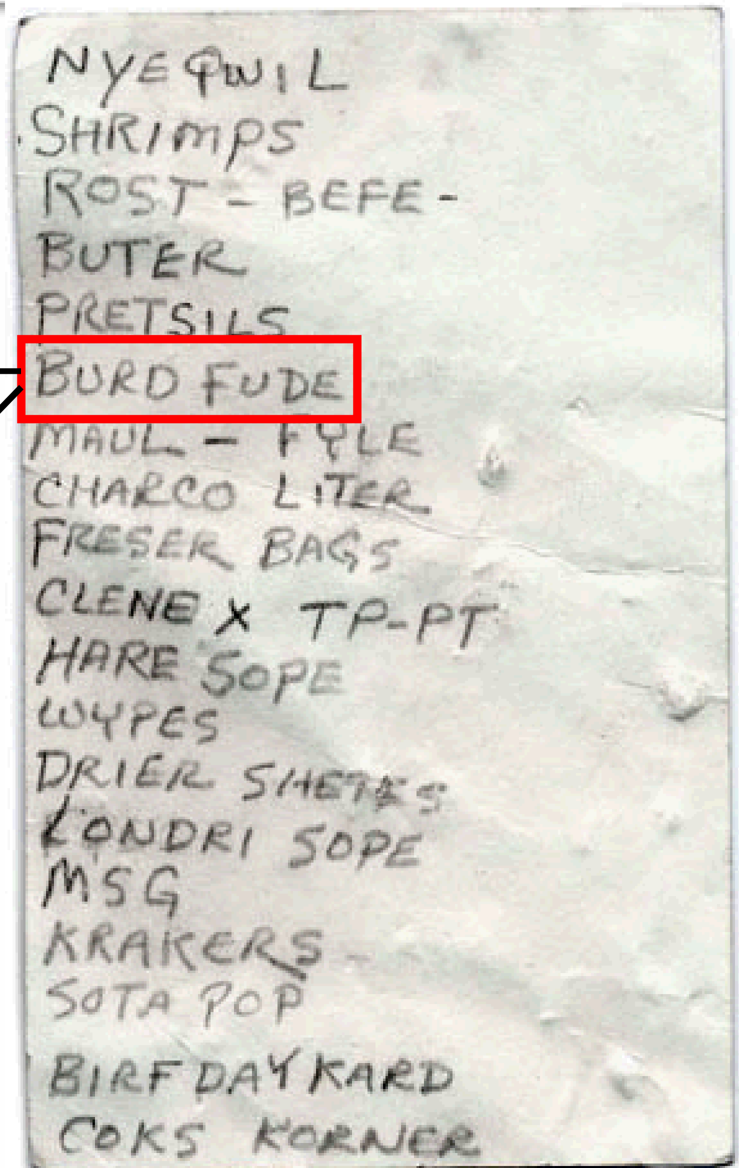
Examples of gist and surface form information

Gist

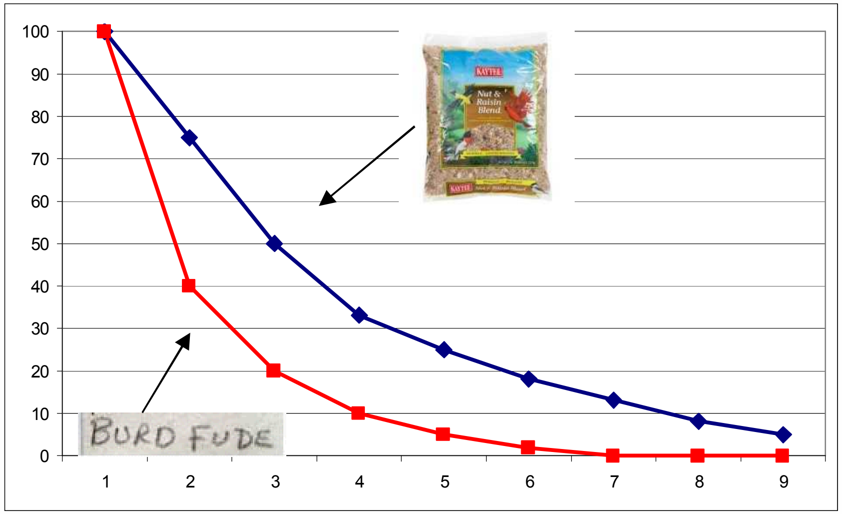
Surface form

BURD FUDE



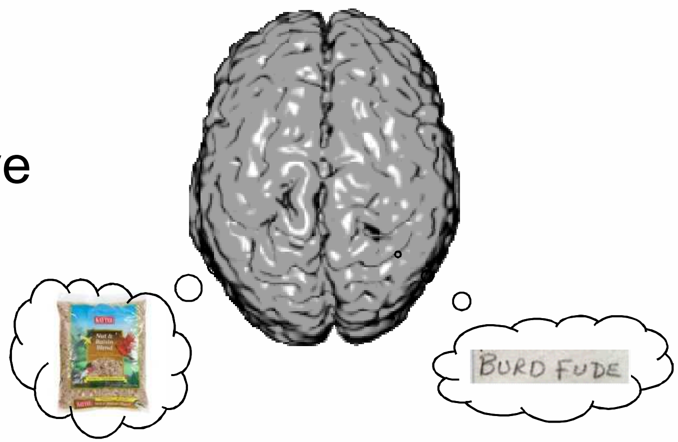
Gist and surface form are processed differently in the brain

- Gist and surface information are forgotten at different rates
  - Prone to different types of errors over time



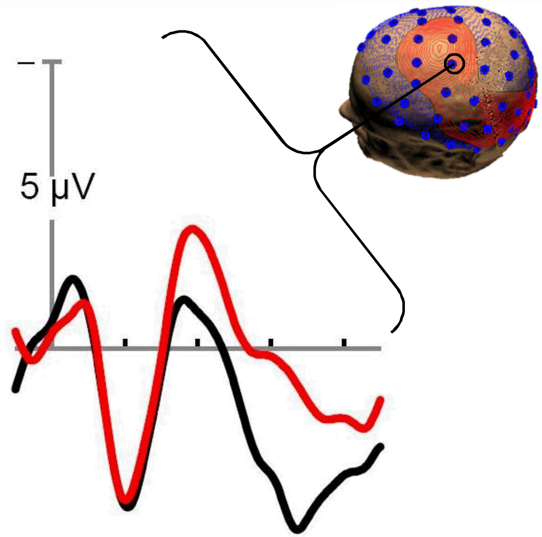
- Hemispheric processing differences
  - Leverage differences to improve memory/reduce errors

What did you study?



Why focus on this problem?

- Memory
  - Underlies decision making
  - Neural signals can potentially predict good and poor memory performance



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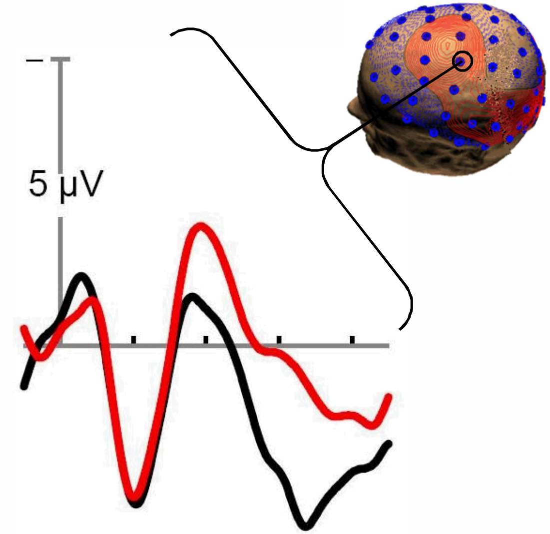
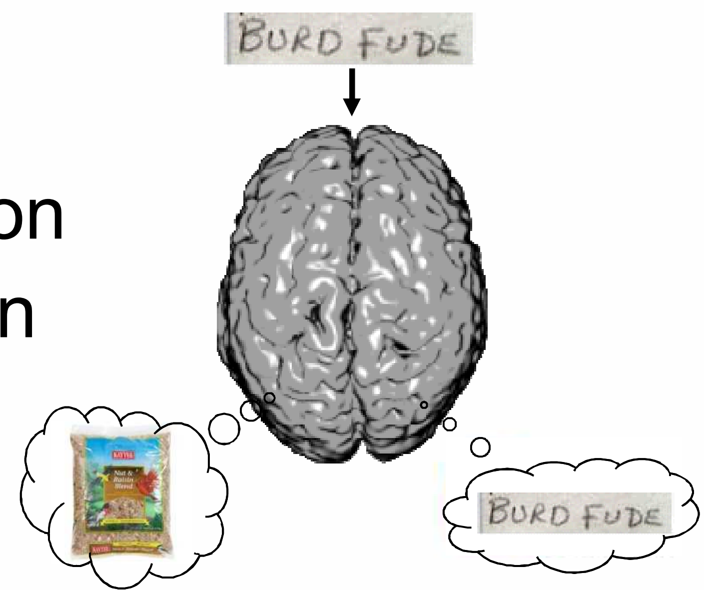


- Gist vs. surface form
  - Components of all information
  - Processed differently in brain



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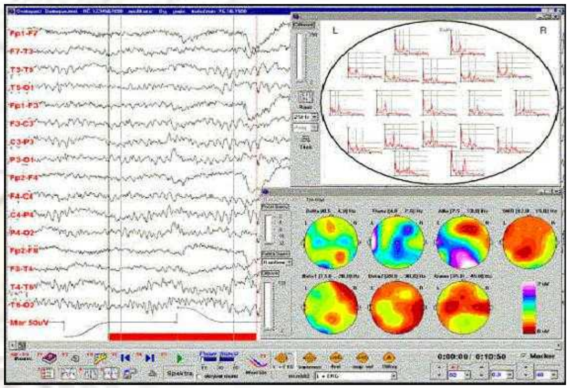
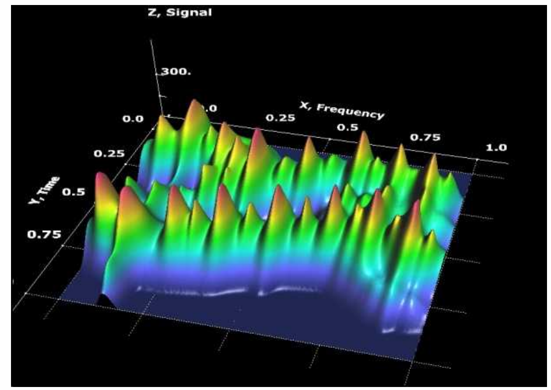
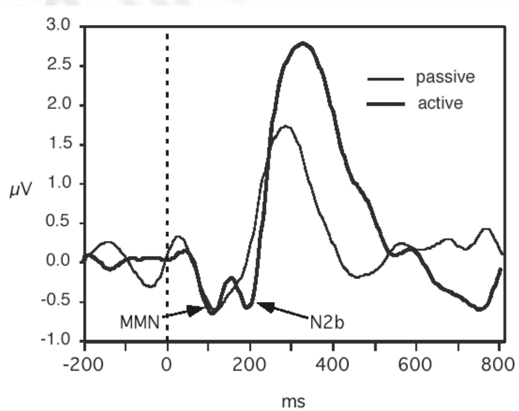
Methods – EEG and ERPs
Provide real-time info about brain activity

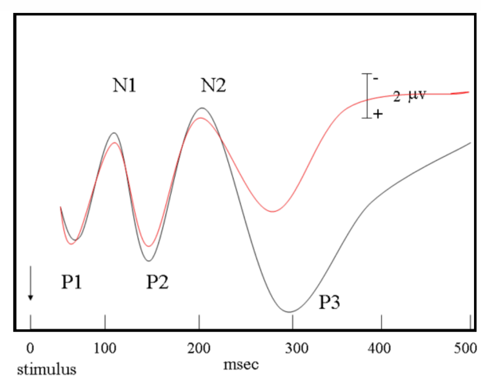
- Electroencephalography (EEG)





- Event-related potentials (ERPs)





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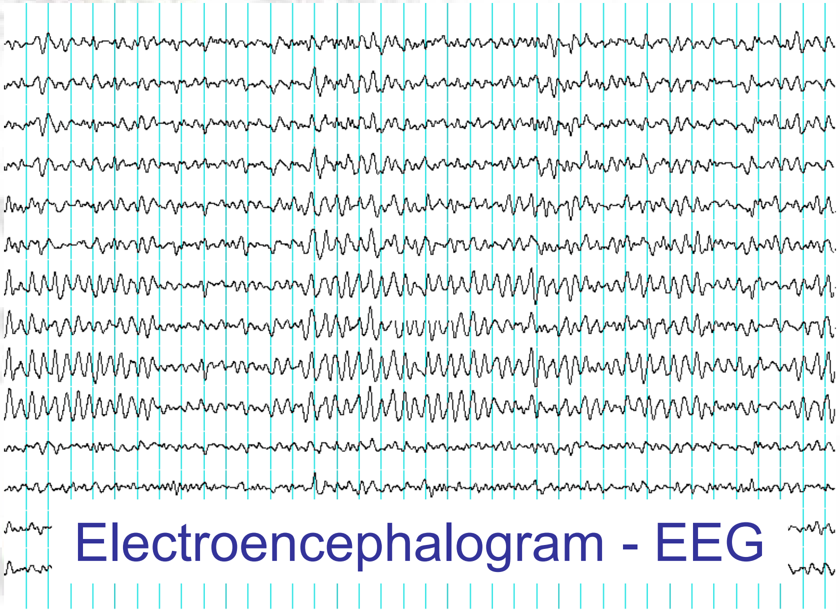
Background on EEG and ERPs



Electroencephalogram - EEG

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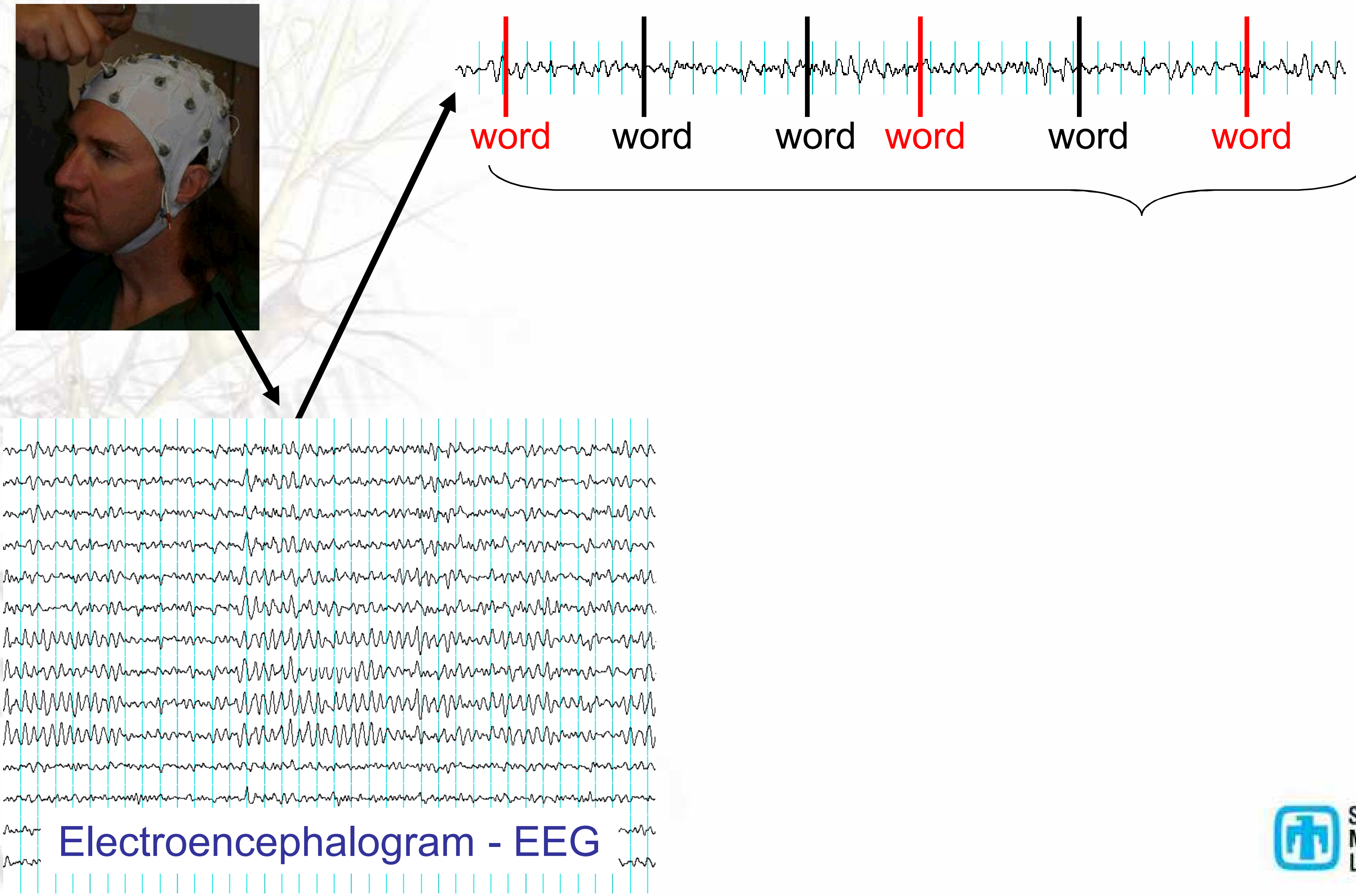
Background on EEG and ERPs



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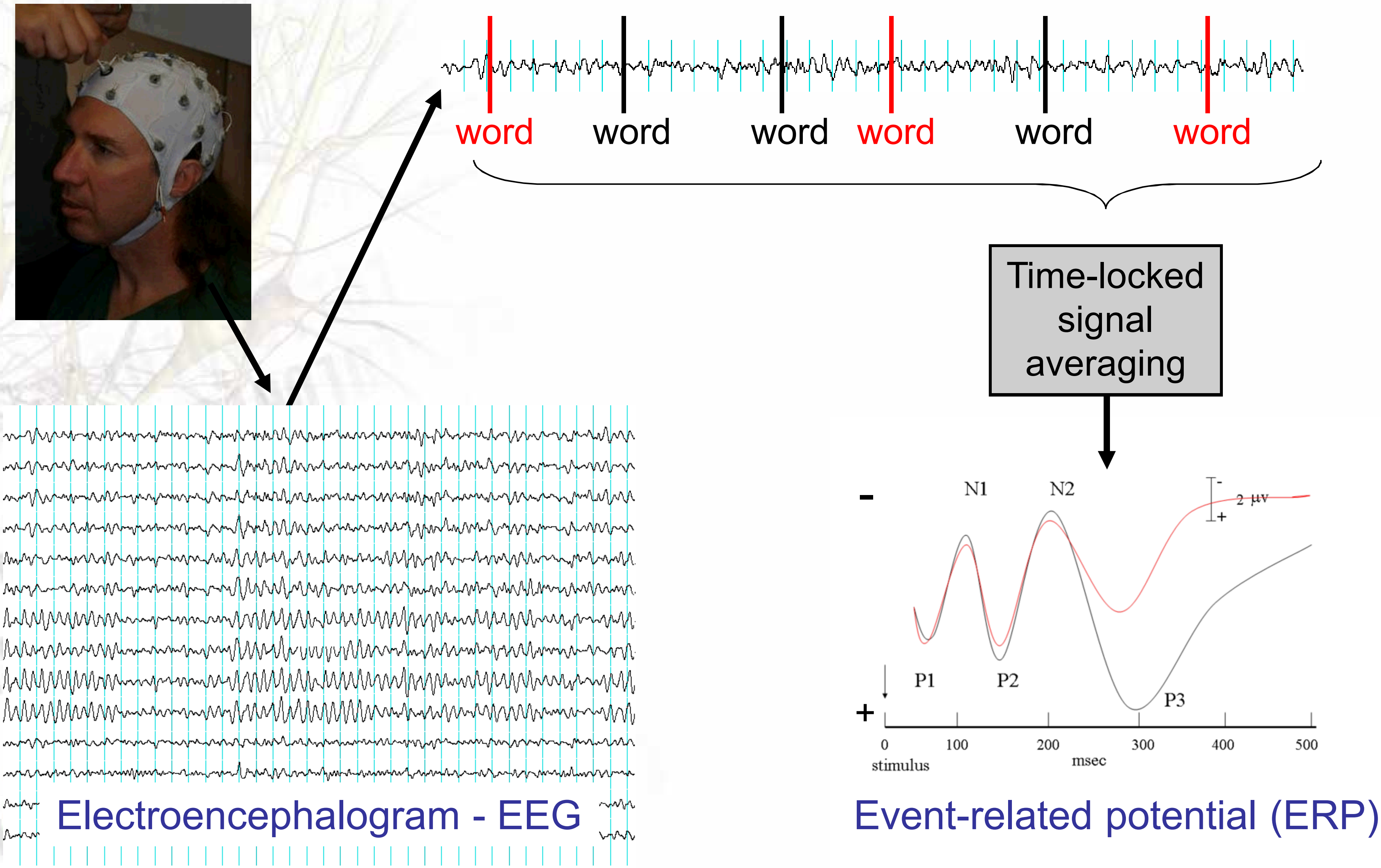
Background on EEG and ERPs



ERPs enable prediction of what will be remembered or forgotten

- Dm effect = difference related to subsequent memory

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- Words studied while EEG is recorded:

shrimp, roast beef, butter, pretzels, bird food…

ERPs enable prediction of what will be remembered or forgotten

- Dm effect = difference related to subsequent memory
- Later test: words **REMEMBERED** or **FORGOTTEN**

shrimp, roast beef, butter, pretzels, bird food…

ERPs enable prediction of what will be remembered or forgotten

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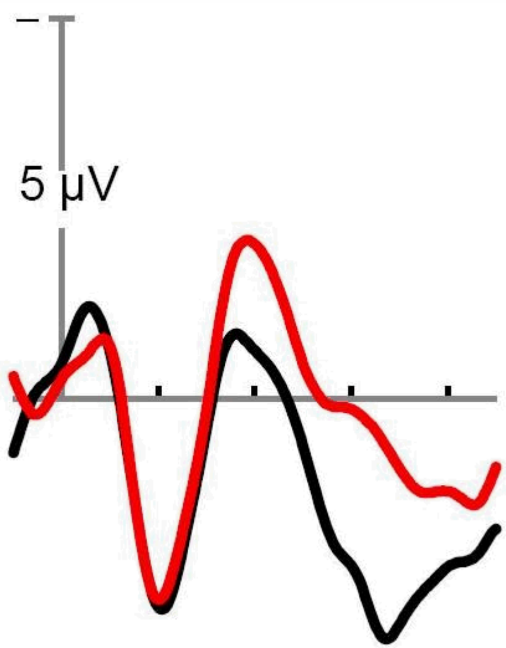
ERPs enable prediction of what will be remembered or forgotten

- Dm effect = difference related to subsequent memory
- Later test: words **REMEMBERED** or **FORGOTTEN**

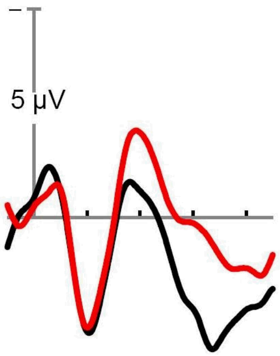
shrimp, roast beef, butter, pretzels, bird food…

Brain activity DURING STUDY:
Words that will be remembered later more positive than words that will be forgotten

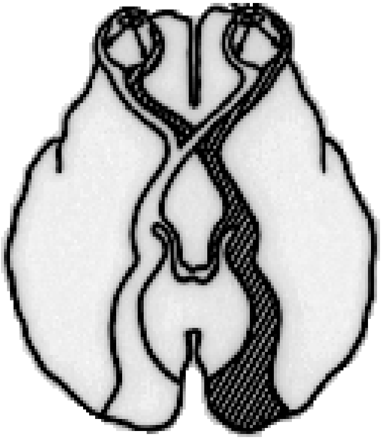


Existing technique for influencing memory in the brain

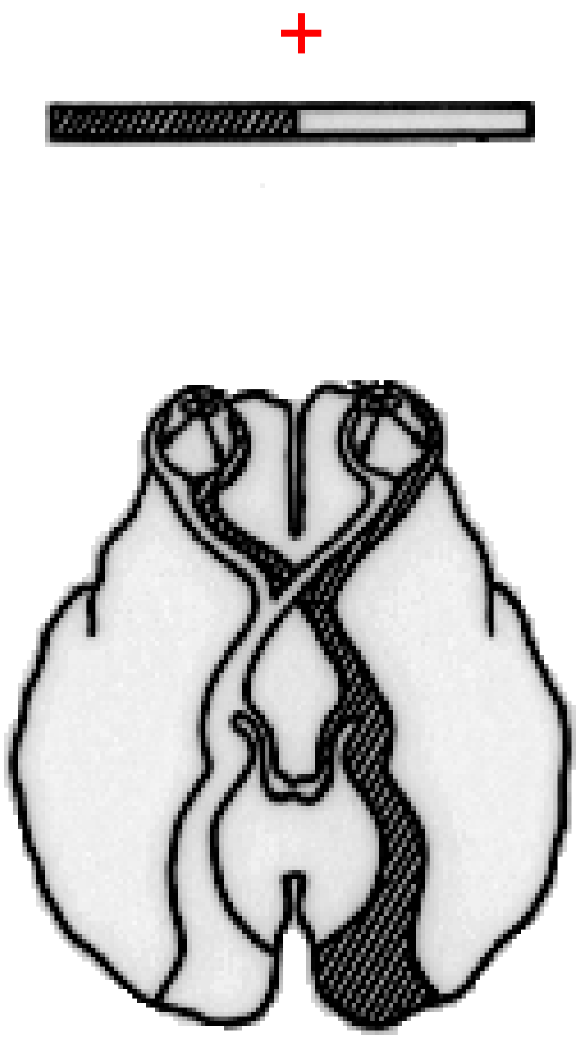
- Brain activity can predict memory performance



- Brain structure can bias memory performance
  - Hemispheric differences in memory
  - Visual half-field paradigm



Visual half-field paradigm



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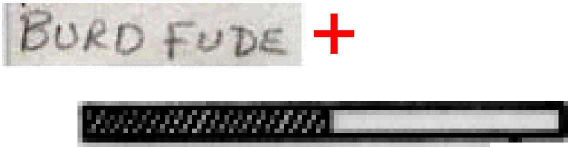

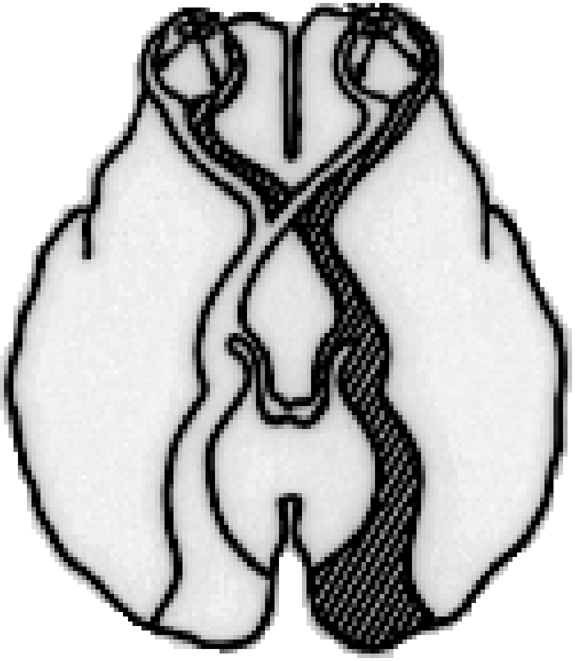

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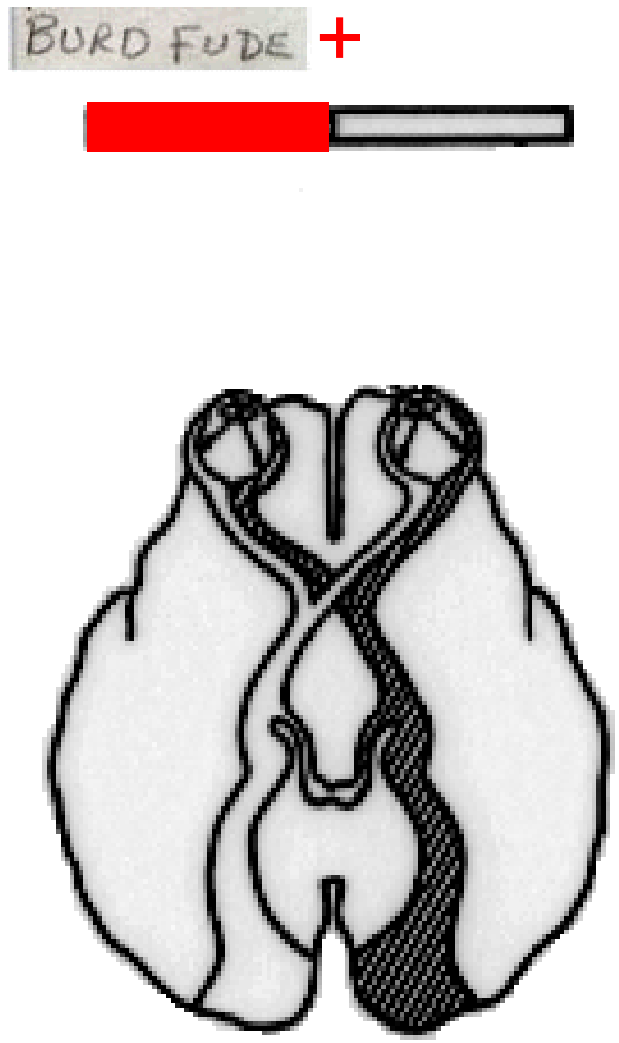

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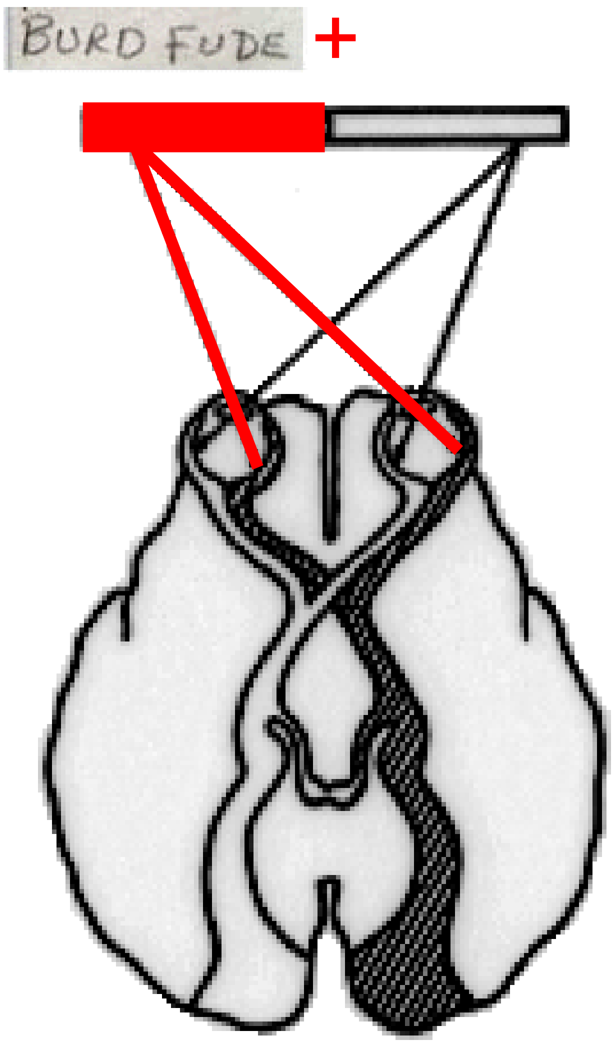

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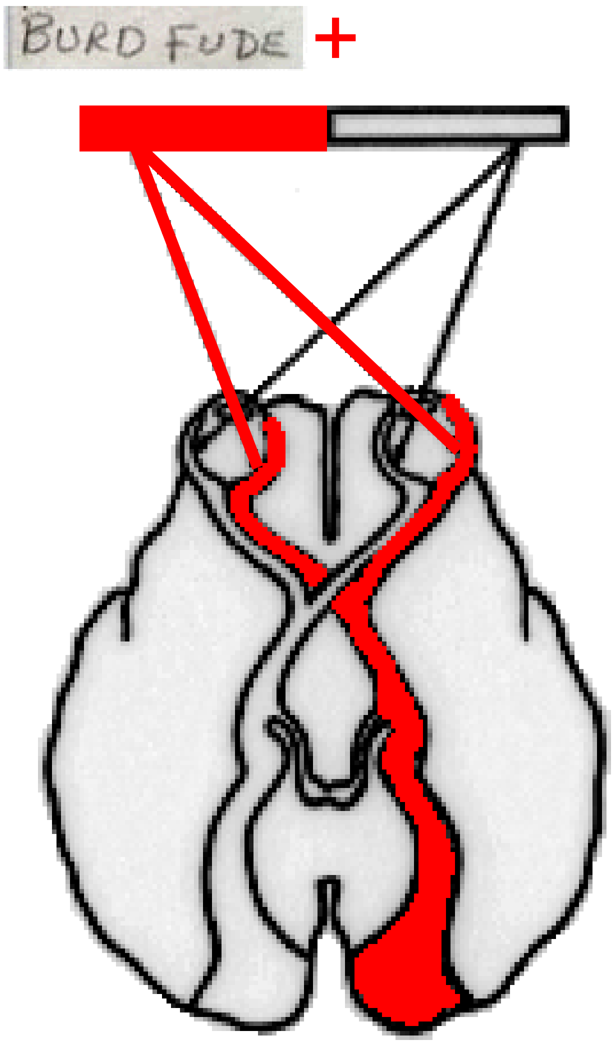

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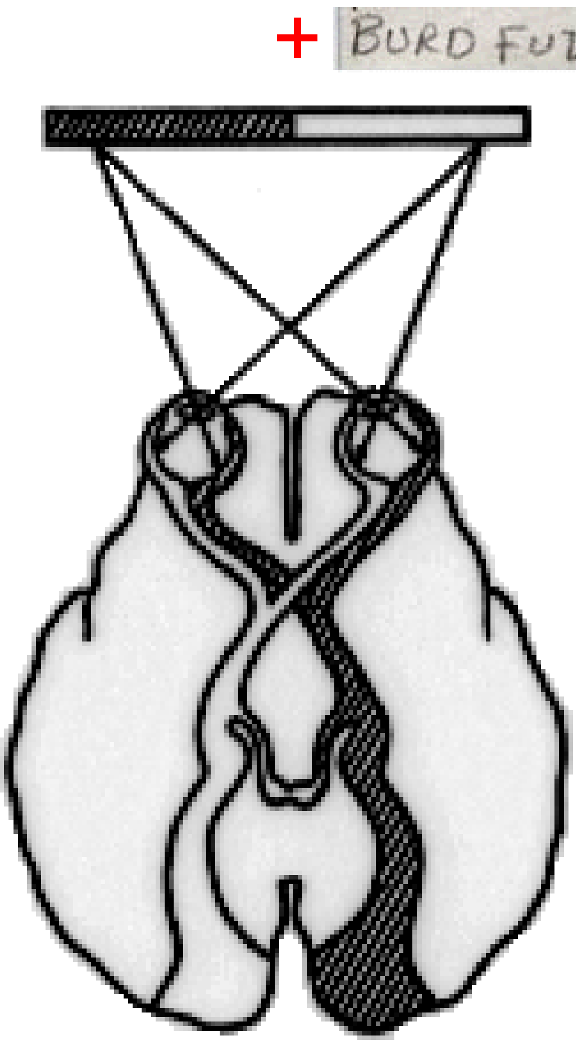
Visual half-field paradigm



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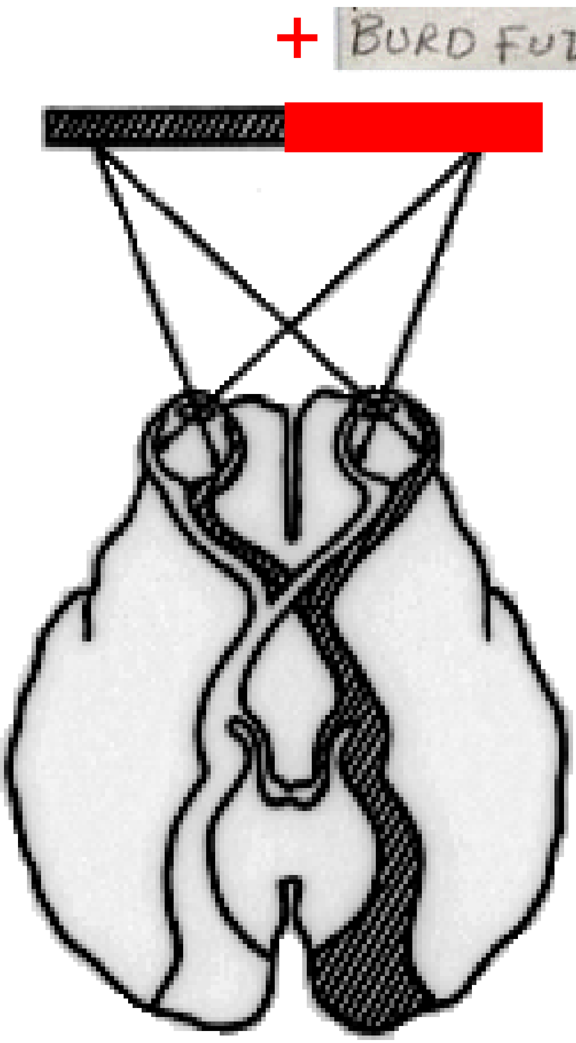

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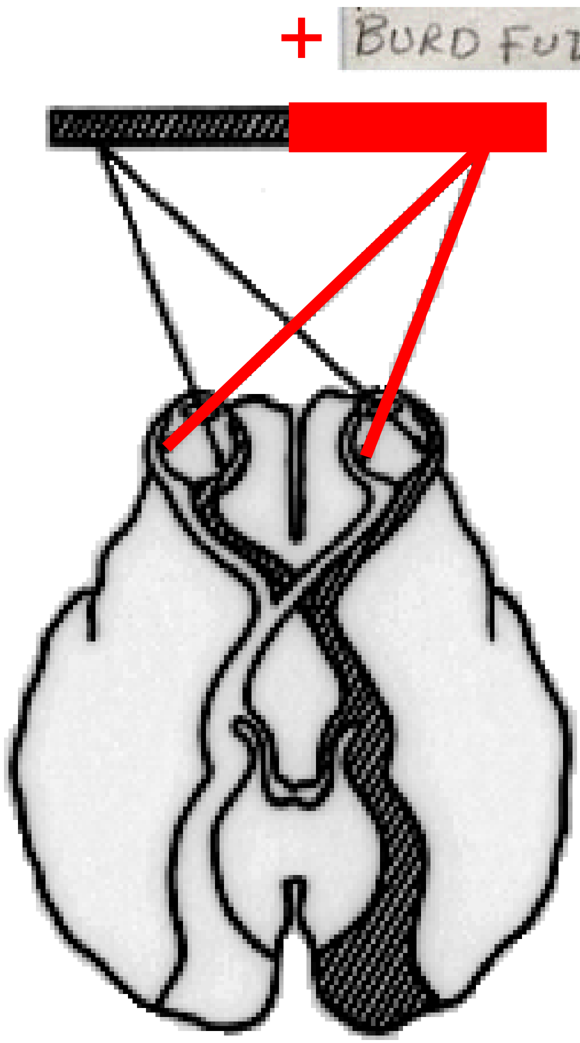

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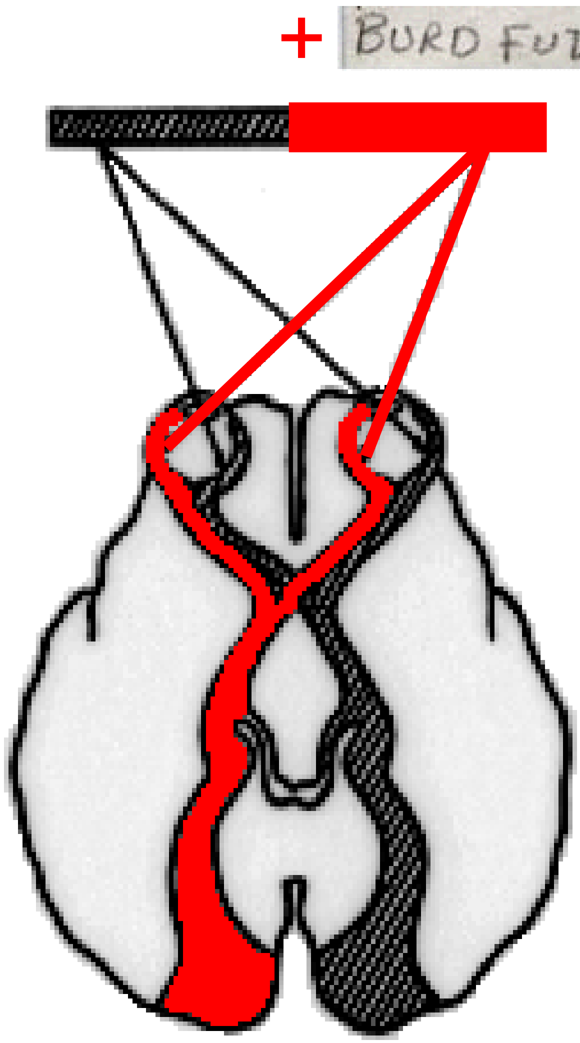
Visual half-field paradigm



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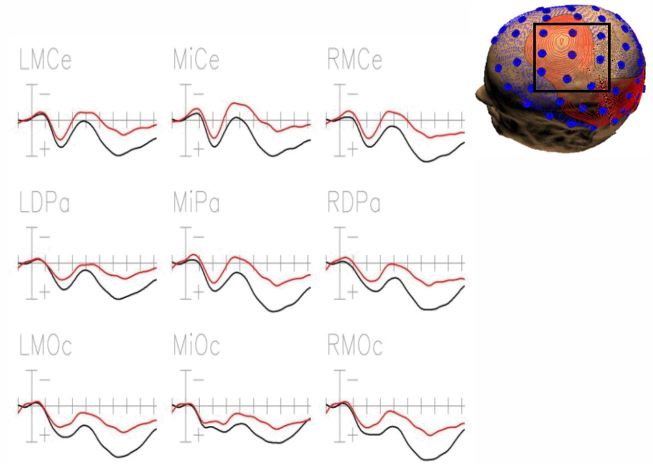
Characterization of Neural Activity

- Brain activity during study is predictive of future memory performance
  - Test ways of optimizing processing during study
    - → *Increase amount of information remembered*

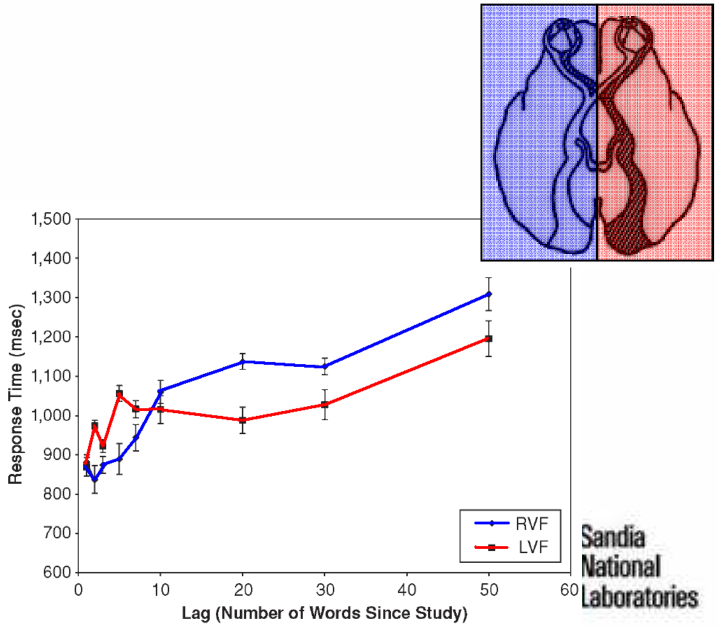
- Visual half-field presentation can influence memory, memory errors (but inefficient)
  - Test other methods for biasing processing to one hemisphere
    - → *Reduce number of memory errors*

Characterization of Neural Activity

- Characterize Dm effect for both gist and surface form information



- Map forgetting functions for gist and surface form information in left and right hemispheres



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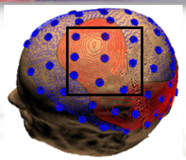
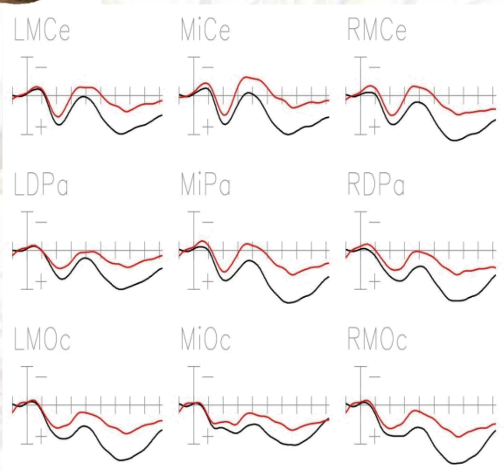
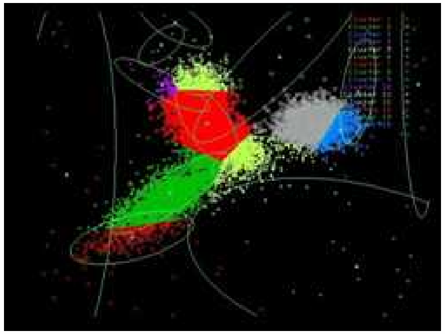
Characterization of Neural Activity

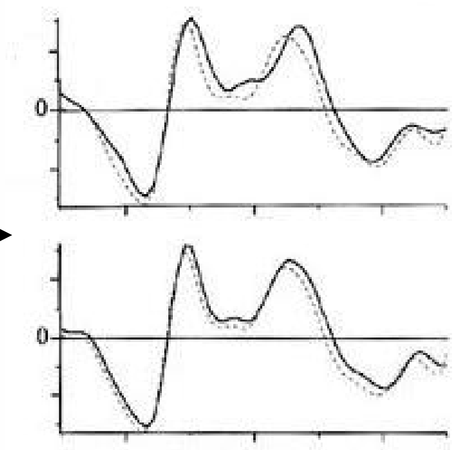




Recorded brain activity sorted by task performance



Use machine learning techniques to characterize good and poor neural performance



Use matched filtering to quantify neural performance

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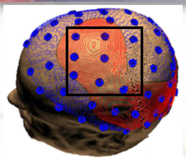
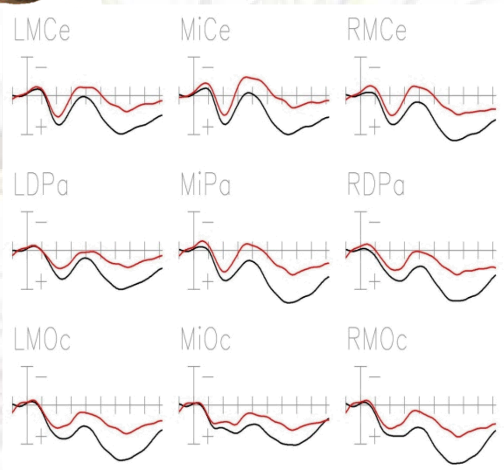
Characterization of Neural Activity





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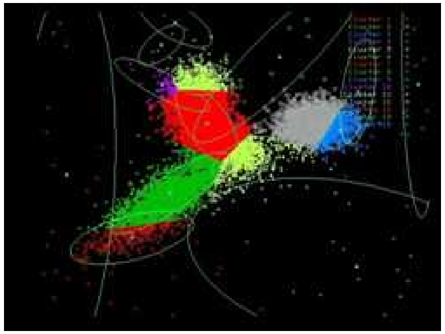

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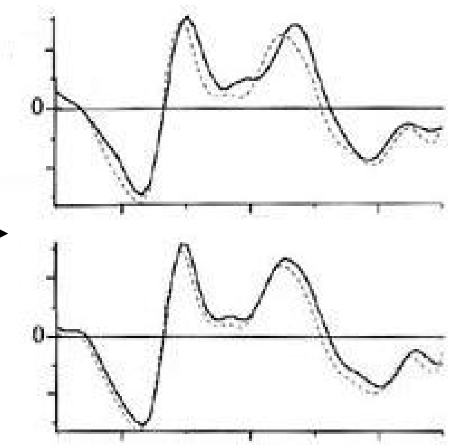


Use matched filtering to quantify neural performance

Use task performance and neural performance to assess intervention techniques

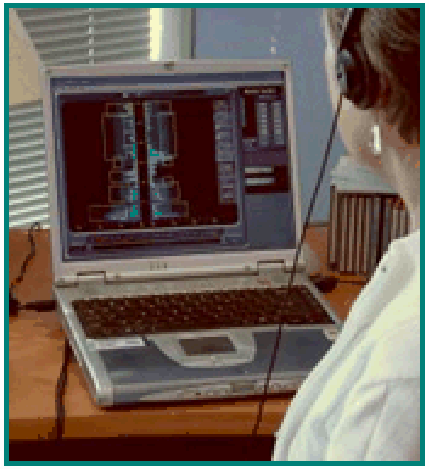
Intervention Techniques

Cognitive Training

Learn memory strategies

Test effects on Dm, hemi differences

Neurofeedback



Learn to enhance Dm positivity, bias processing to LH or RH

Test relationships between task performance and neural performance

Transcranial direct current stimulation (tDCS)

Enhance Dm positivity, bias processing to LH/RH

Test relationships between task performance and neural performance

Surety Analysis

- Use surety engineering framework developed for cognitive systems (Peercy et al., 2008)
- Assess surety and maturity of each component of system as research progresses
  - Outline:
    - Year 1 – Develop requirements and use cases
    - Year 2 – Fault analysis, develop controls, assess adequacy of controls
    - Year 3 – Iterations on process, final maturity analysis

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Project Plan

FY10 | FY11 | FY12

Characterization Studies

Computational Model

EEG lab operational at Sandia

Cognitive Training Studies

Neurofeedback Studies

tDCS Studies

Surety Analysis

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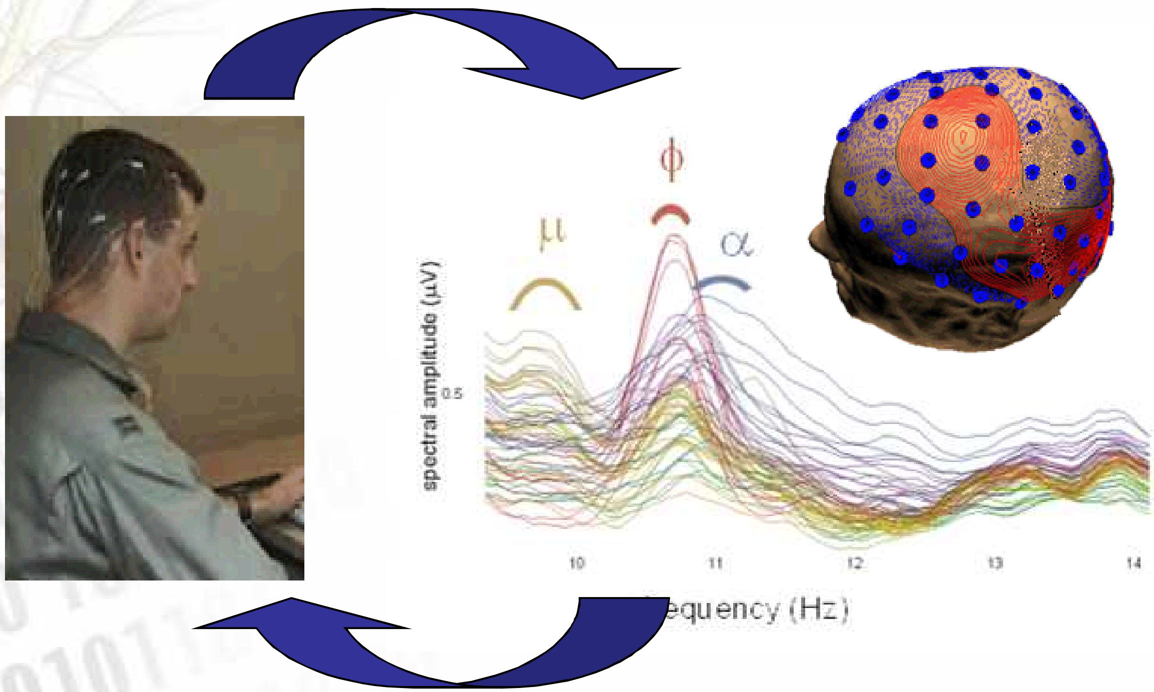
Summary



Characterization studies

↓

Modeling of brain activity

↓

Use model and brain data to design targeted interventions

↓

Assess effects of interventions on brain activity

↓

Assess effects of changes in brain activity on task performance

Characterization studies

↓

Modeling of brain activity

↓

Use model and brain data to design targeted interventions

↓

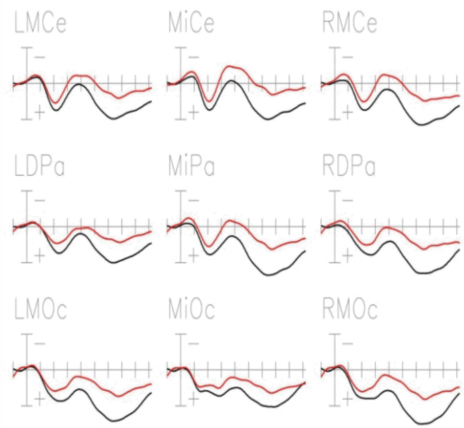
Assess effects of interventions on brain activity

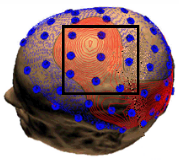
↓

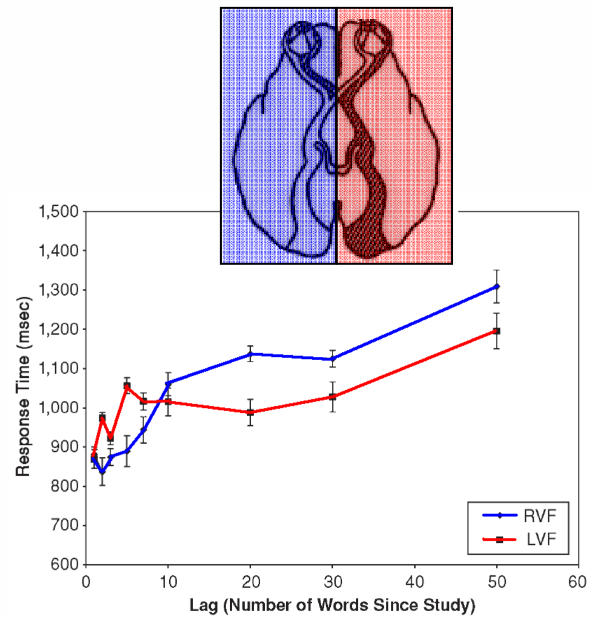
Assess effects of changes in brain activity on task performance

Characterize Dm effect for gist and surface form information

Map forgetting functions of gist and surface form info in LH and RH







Characterization studies

↓

Modeling of brain activity

↓

Use model and brain data to design targeted interventions

↓

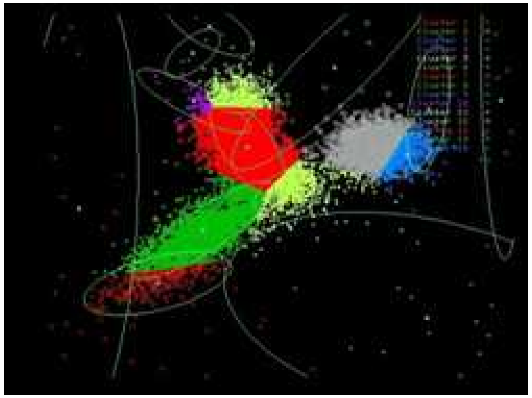
Assess effects of interventions on brain activity

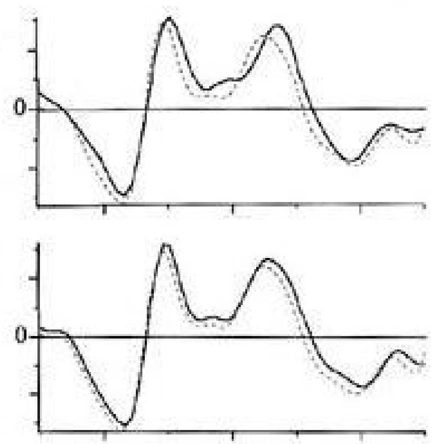
↓

Assess effects of changes in brain activity on task performance

Use machine learning techniques to characterize good and poor performance

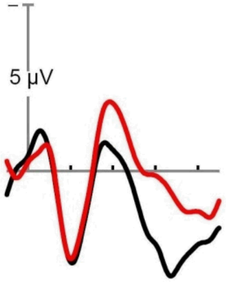
Develop templates for use in matched filtering

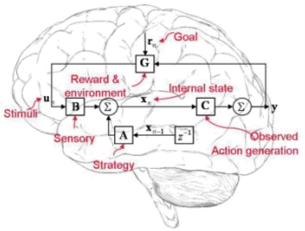


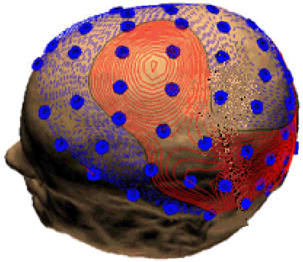


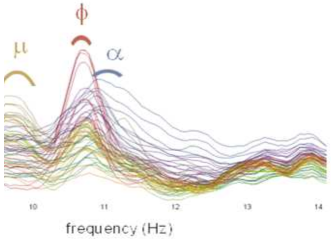
Summary: Memory and Decision Making

- Enhancing memory
  - Decision making tasks requiring memory for gist or surface form information
  - Characterize good and poor performance
  - Use interventions to optimize brain's processing of gist or surface form info









Summary

- Scientific contributions:
  - Novel, causal data about relationship between brain activity and task performance
    - Dm effect, hemispheric processing differences
  - Deeper understanding of processes fundamental to decision making
  - Assessment of effectiveness of different types of intervention techniques
    - Individual differences
  - Foundation for system that can detect suboptimal neural performance and design an individualized intervention to mitigate it

Research Plan

Characterization studies

↓

Modeling of brain activity

↓

Use model and brain data to design targeted interventions

↓

Assess effects of interventions on brain activity

↓

Assess effects of changes in brain activity on task performance

Year 1 (FY10):

• Set up EEG lab at Sandia

• Characterize brain activity (event-related potentials) associated with good and poor memory performance

• Model brain activity associated with good and poor memory

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Lab Setup

- Set up EEG lab at Sandia (899/2222)
  - 128-channel EEG system from Advanced Neuro Technologies

    Includes electrode caps and amplifier with active shielding, specialized software for stimulus presentation, recording, EEG and ERP signal analysis, and source modeling

  - 16-channel BrainVision portable EEG system

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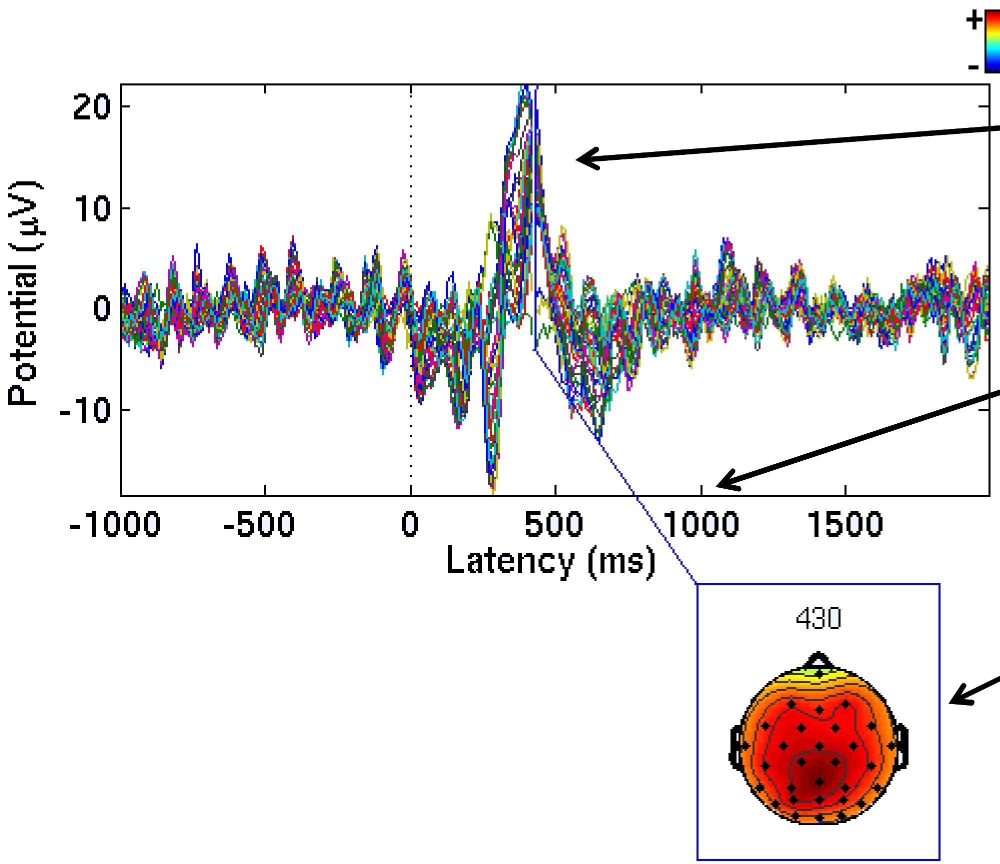
Characterization Studies

- Experiment 1:
  - Characterize brain activity for good memory performance
    - Data collection completed
- Experiment 2:
  - Characterize brain activity for memory errors
    - Data collection May-July at Univ. of Illinois
- Experiment 3:
  - Map time course of memory/memory errors in left and right hemispheres
    - Data collection June-August at Sandia

Properties of ERP Components



- Amplitude
- Latency
- Distribution

ERPs are named based on their latency and direction of the peak (ex: P300 = positive-going peak at 300 ms)

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ERPs of Interest

- Dm Effect
  - Difference related to subsequent memory
  - Items that will be remembered later have a more positive waveform than items that will be forgotten
  - Dm represents the modulation of several ERP components (P200, N400, LPC)

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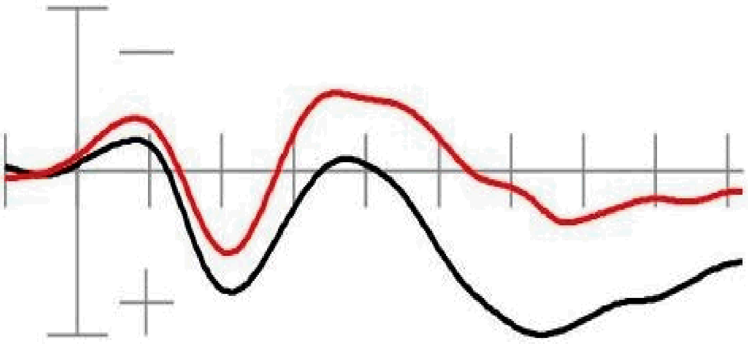
ERPs of Interest

- P200
  - High-level visual processing
    - May reflect comparisons of sensory inputs to information stored in memory
- N400
  - Semantic access, primarily language
    - Amplitude decreases when access is facilitated
- Late Positive Compo
  - Explicit recognition memory



Characterization Strategy

- Experimental characterization:
  - Elicit Dm under novel experimental conditions
  - Acquire new evidence about underlying neural processes
- Computational characterization:
  - Use modeling approaches to create templates of “optimal” neural performance
    - Explore individual differences
    - Improve signal-to-noise ratio, move toward greater predictability of later performance

Dm Characterization

- Typical Dm Effect:
  - Paradigm: Each item studied once, tested once
  - Broad positivity across P200, N400, and LPC time windows
- Our experimental strategy:
  - Varied study and test conditions
  - Characterize differences in Dm morphology
  - Relate morphology to behavioral memory performance across conditions

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Experimental Design

Increasing memory accuracy ↓

- Study conditions:
  - Words studied once
  - Words studied twice (at short and long intervals)
  - Words studied and then tested (at short and long intervals)
- Analysis:
  - Compare conditions with varying degrees of memory performance
  - Analyze ERPs at study (P200, N400, LPC), ERPs at test, Dm effects for studied words and reminding cues

→ What processes lead to Dm Effect?

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Experimental Design

Study List

- fight
- alarm
- cut
- nation
- cut
- nation
- storm
- assent
- fire
- noon
- fight
- alarm

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Experimental Design

Study List

fight
alarm
cut
nation
cut
nation
storm
assent
fire
noon
fight
alarm

Words studied once

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Experimental Design

Study List

- fight
- alarm
- cut
- nation
- cut
- nation
- storm
- assent
- fire
- noon
- fight
- alarm

Words studied twice, short lag (One intervening word)

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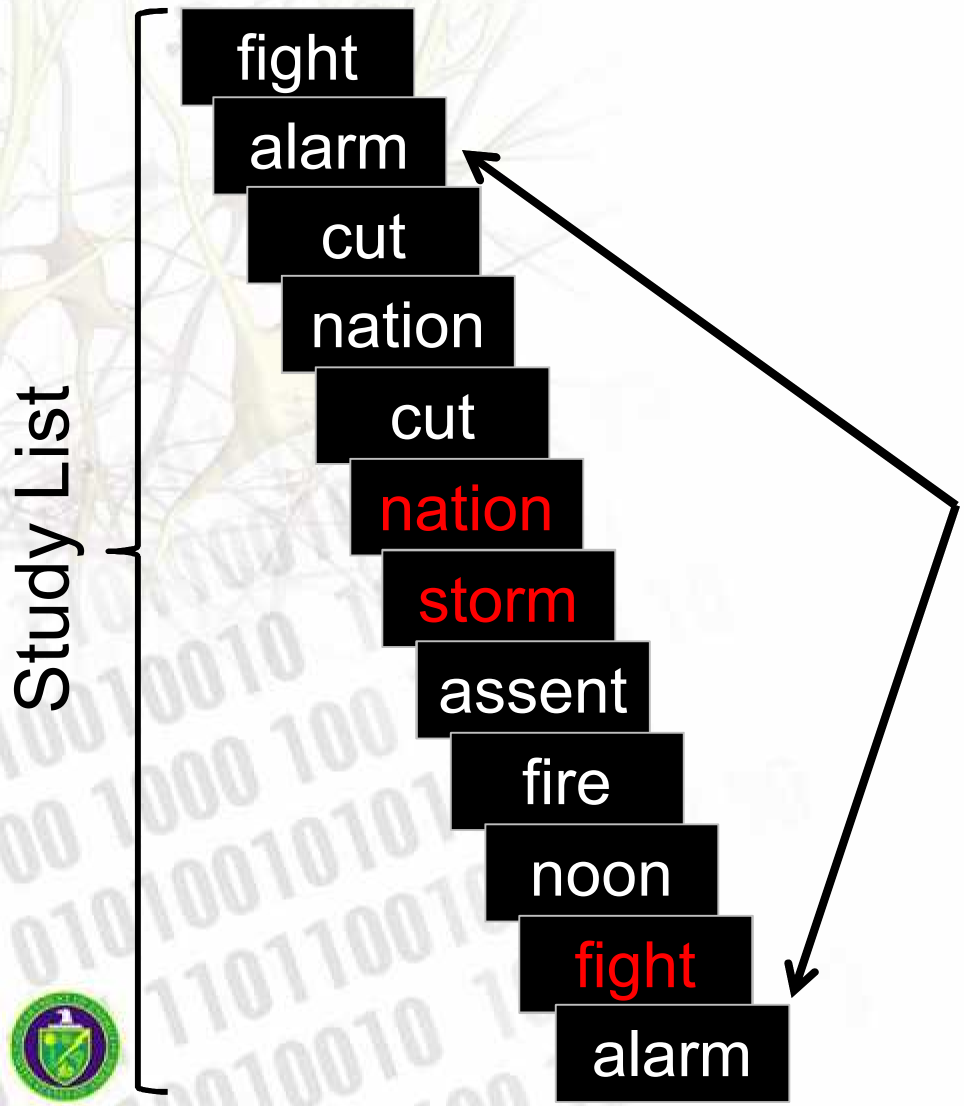
Experimental Design



Words studied twice, long lag (Nine intervening words)

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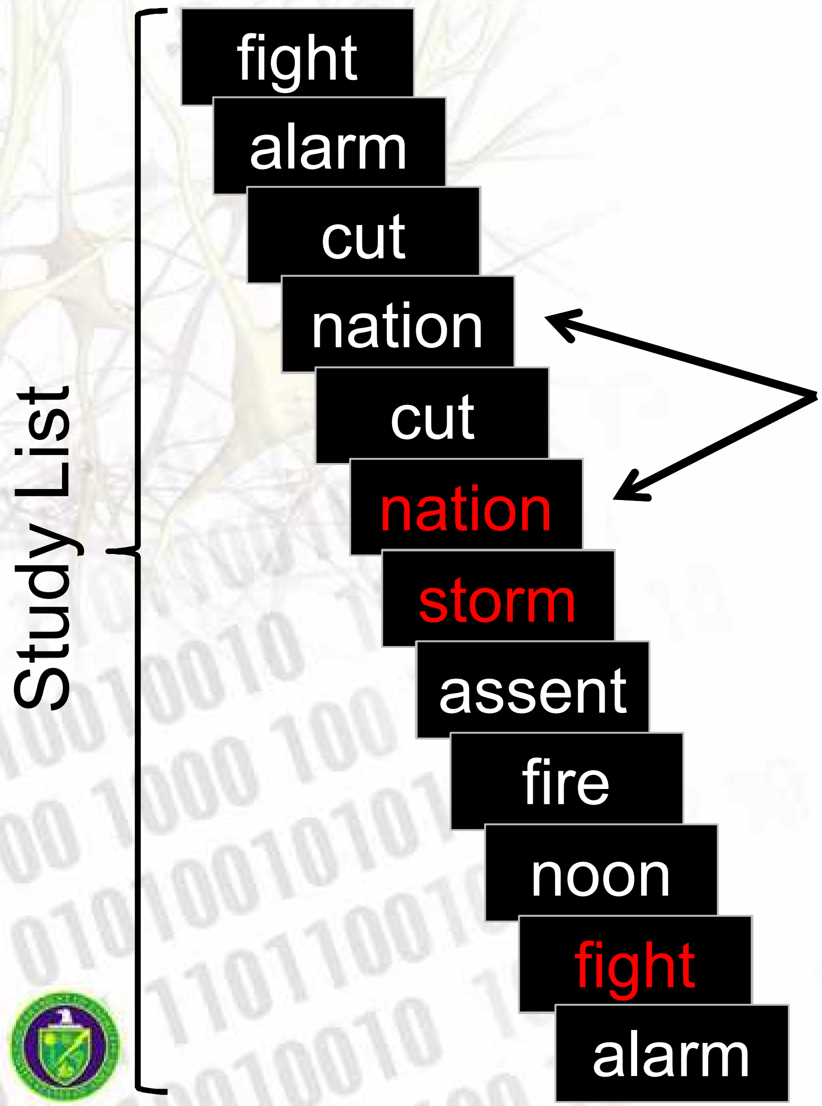
Experimental Design



Words studied and tested, short lag (One intervening word)

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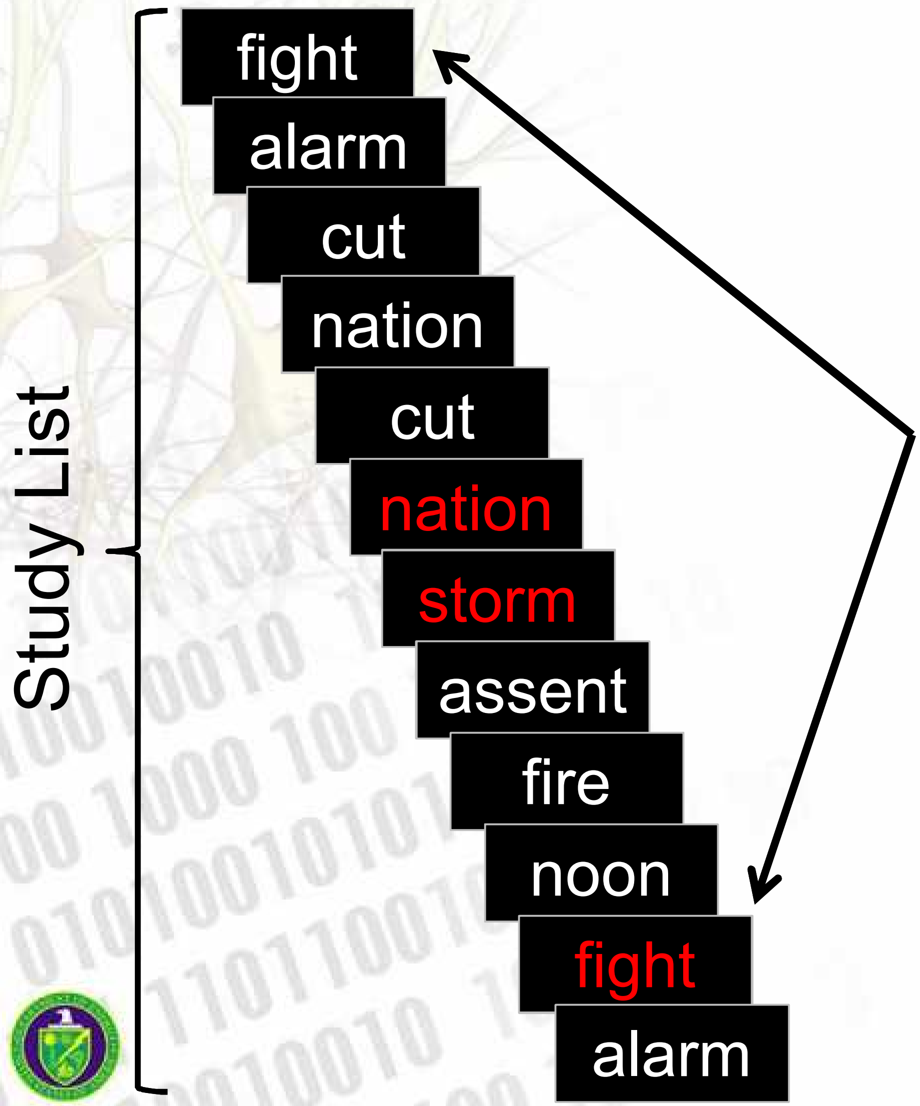
Experimental Design



Words studied and tested, long lag (Nine intervening words)

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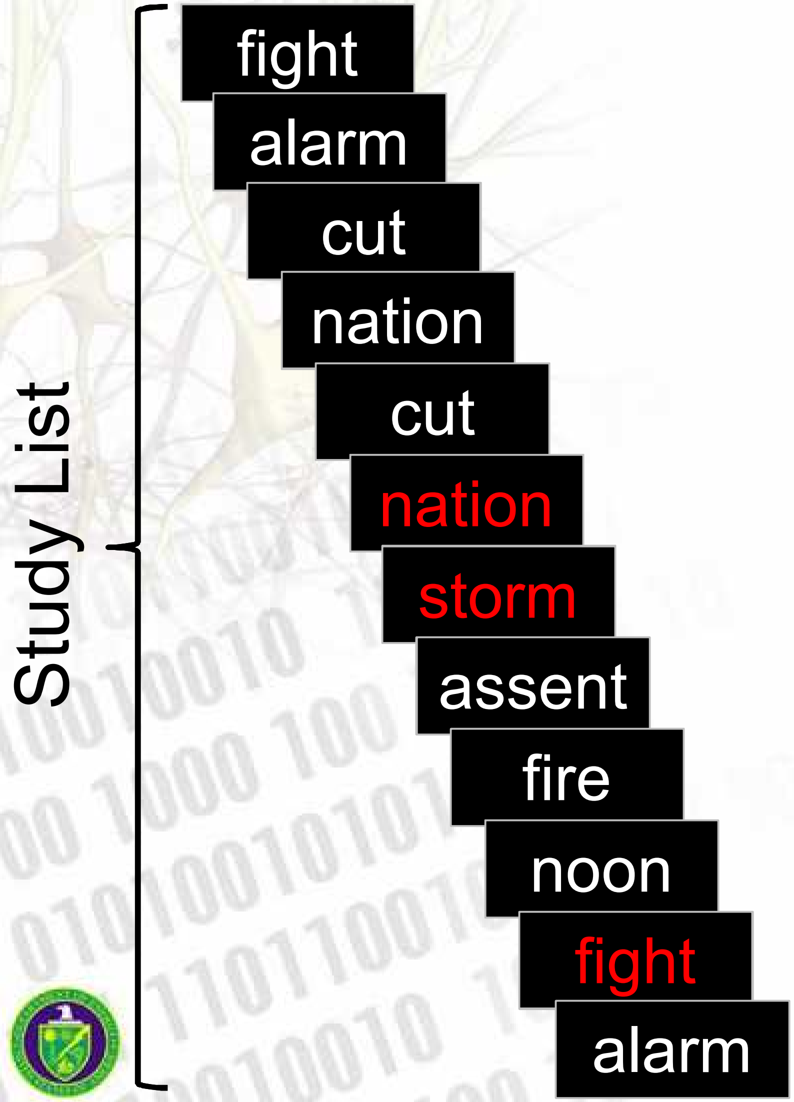
Experimental Design



Subsequent Test

- Items from all conditions tested (or retested), along with an equal number of new, unstudied items

Stimulus Presentation Parameters

- Four study blocks, each followed by a test block
- 80 words presented per study block
  - 20 studied once
  - 20 studied twice (half short, half long lag)
  - 20 tested during study block (half short, half long lag)
  - 20 paired with synonyms (half studied, half tested)
- 160 words per test block
  - 80 from study block
  - 80 new, unstudied items

Stimulus Presentation Parameters

- Cue indicating condition (study or test) presented for 1000 ms
- Word presented for 1000 ms
- Test words followed by response period (participants answer “yes” or “no” via button press)
- 500 ms interstimulus interval

#

fight

#

alarm

#

cut

#

nation

#

cut

#

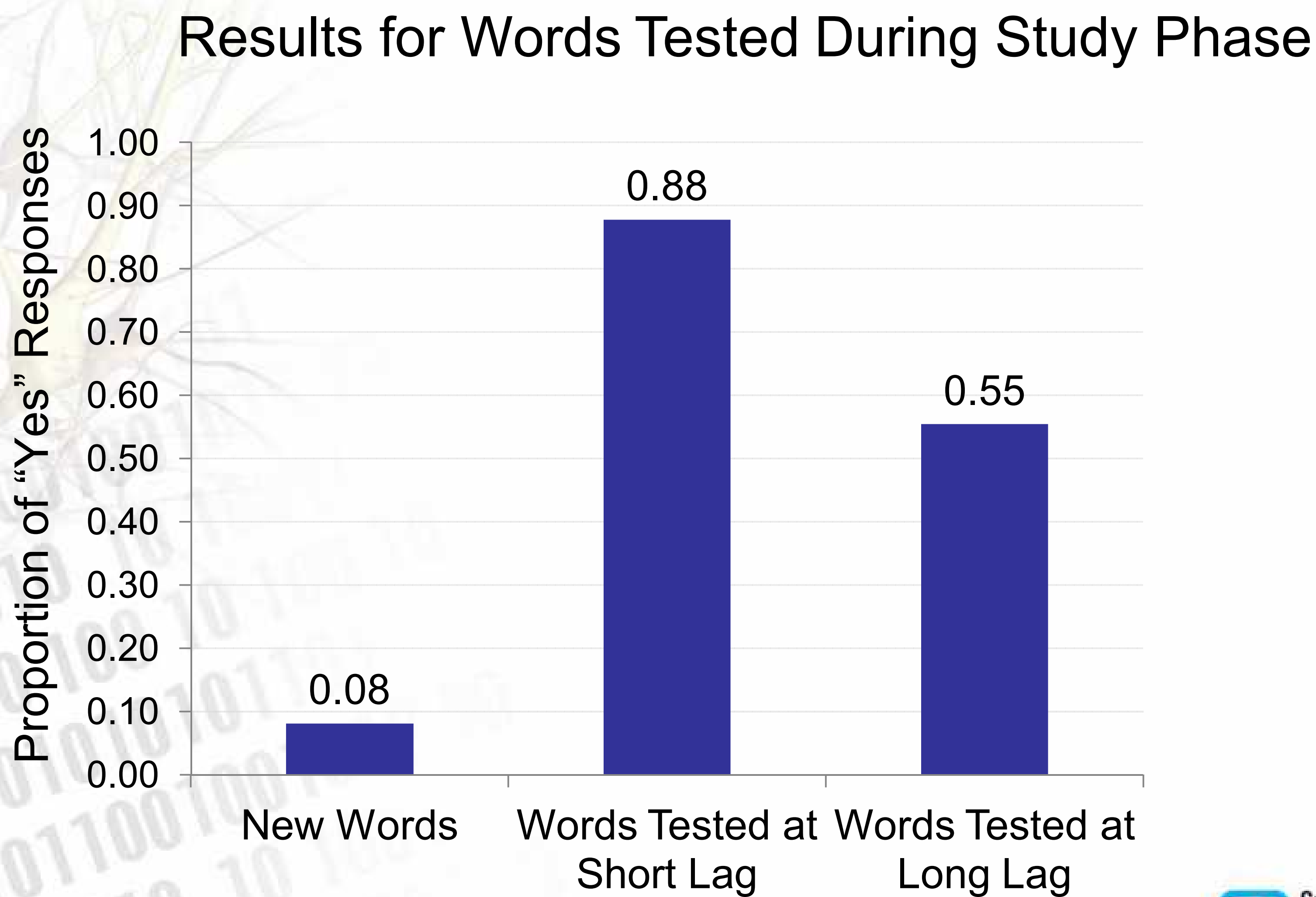
nation

?

Participants

- 24 Univ. of Illinois undergraduates
  - 12 male, 12 female
  - Average age 21
  - All right handed, monolingual English speakers, no history of neurological disorders

Behavioral Results



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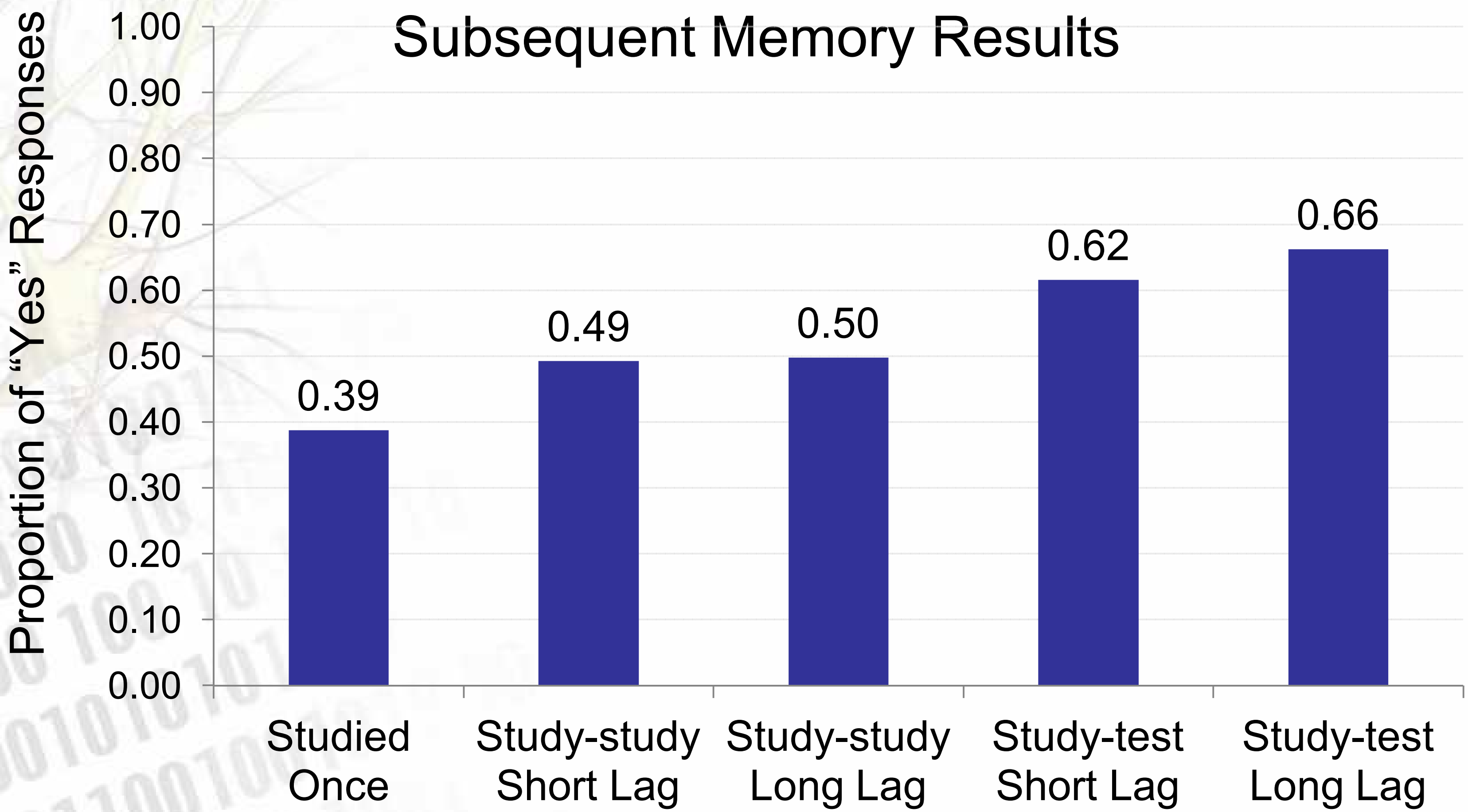
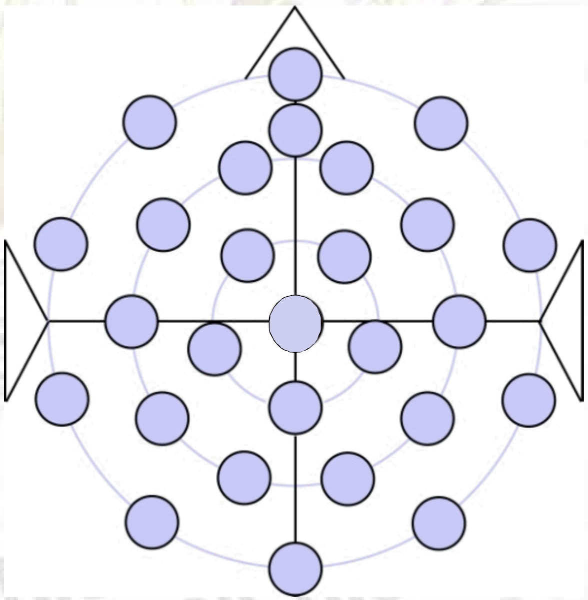
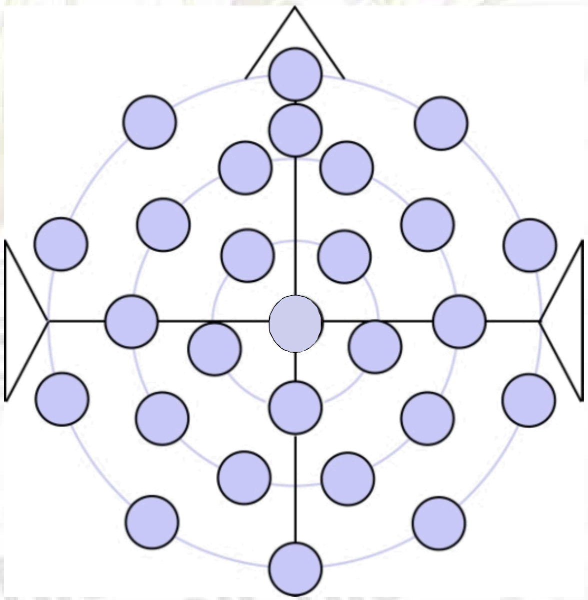
Behavioral Results

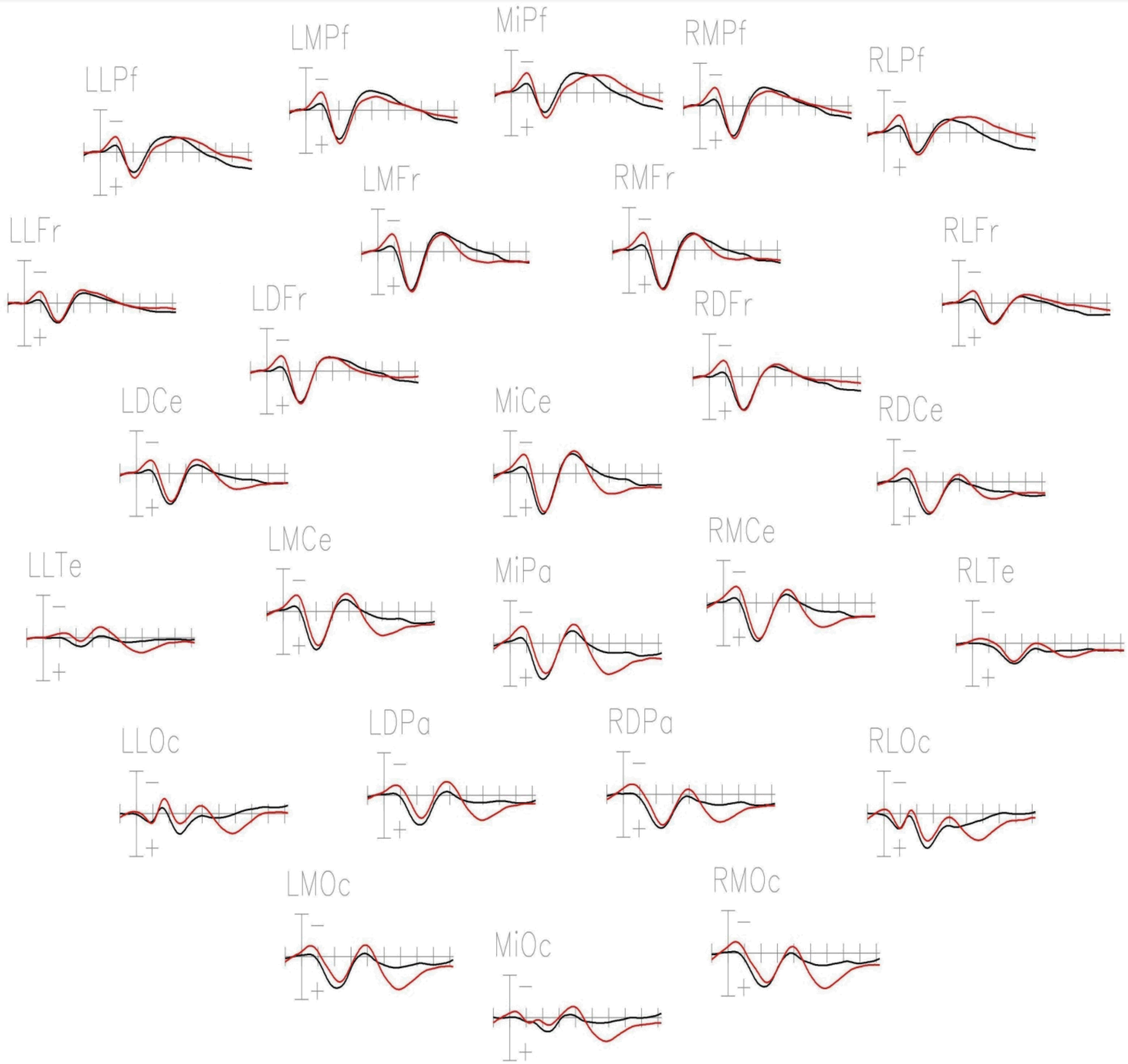


ERP Orientation



ERP Orientation





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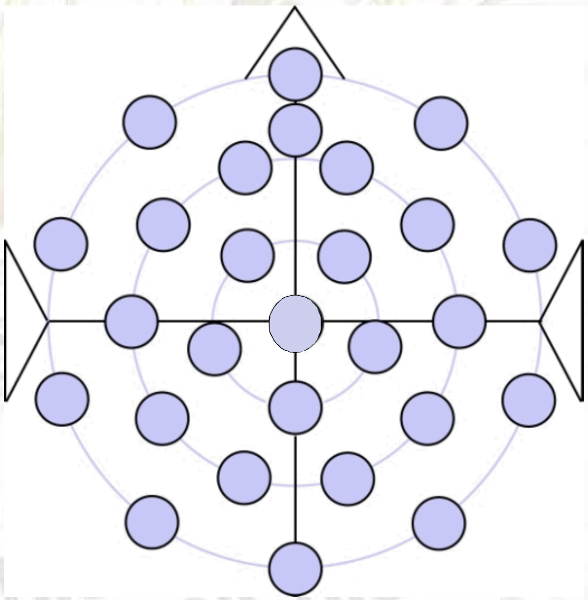
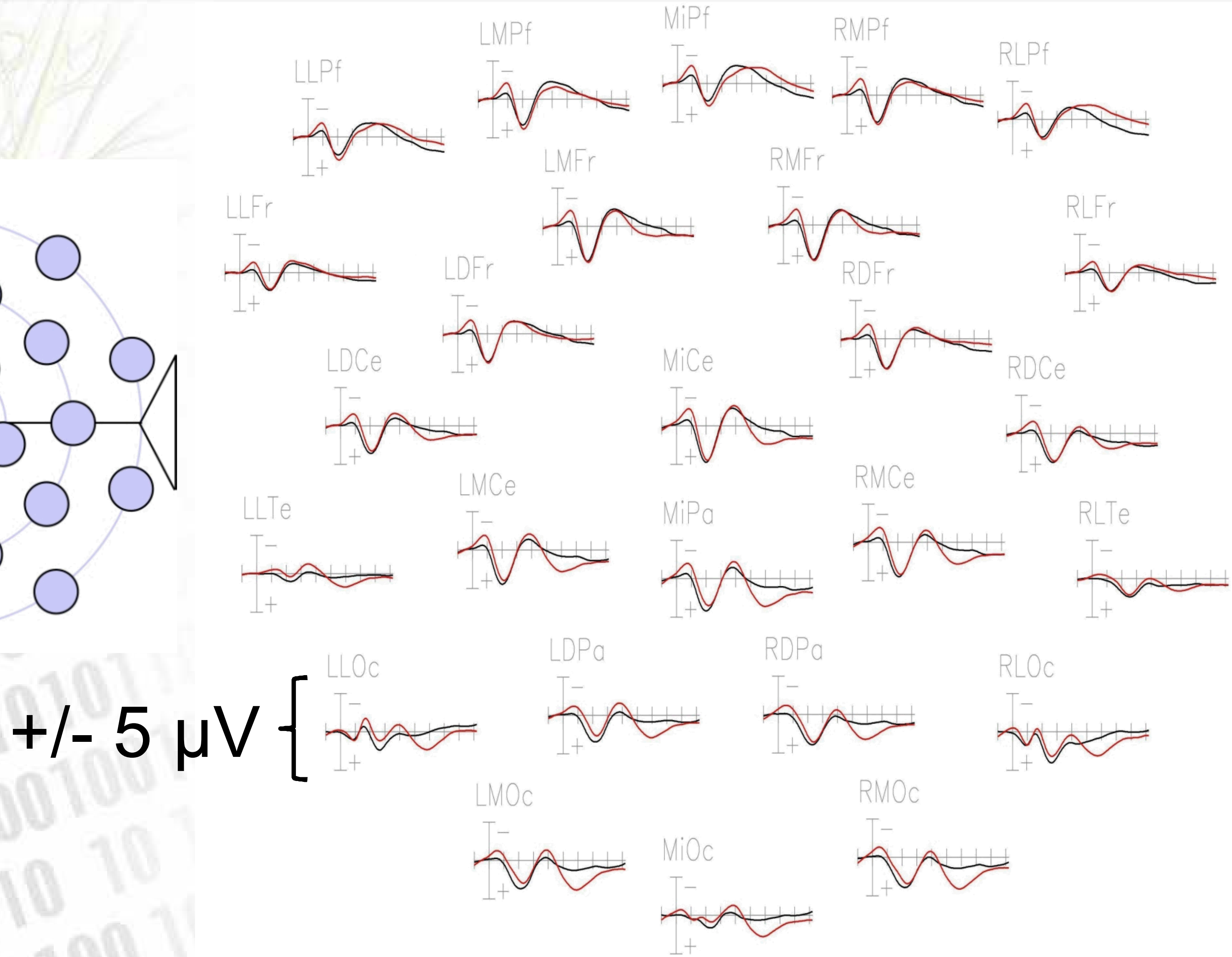
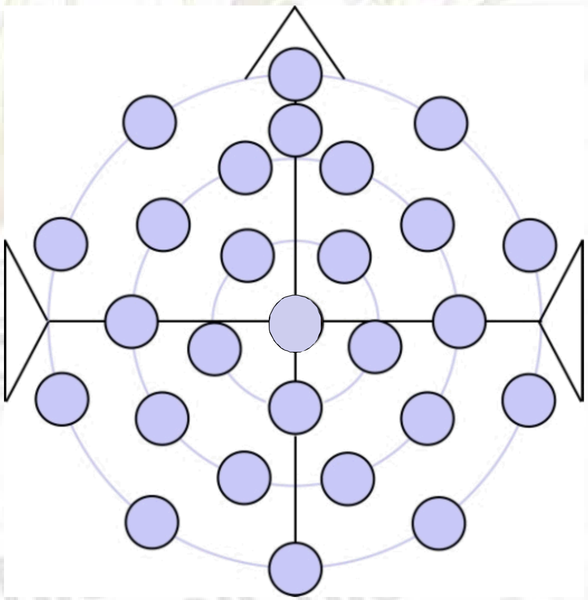
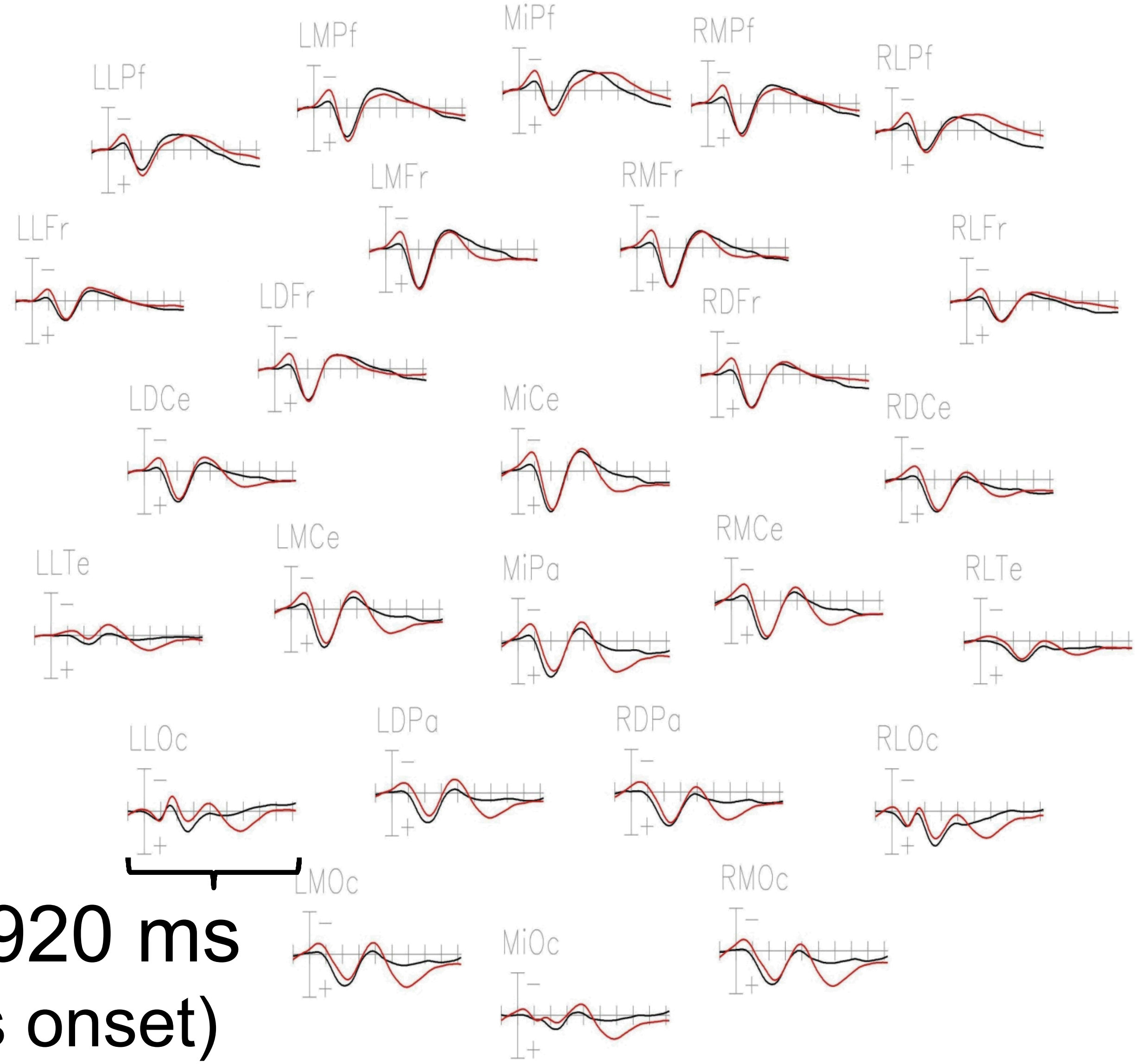




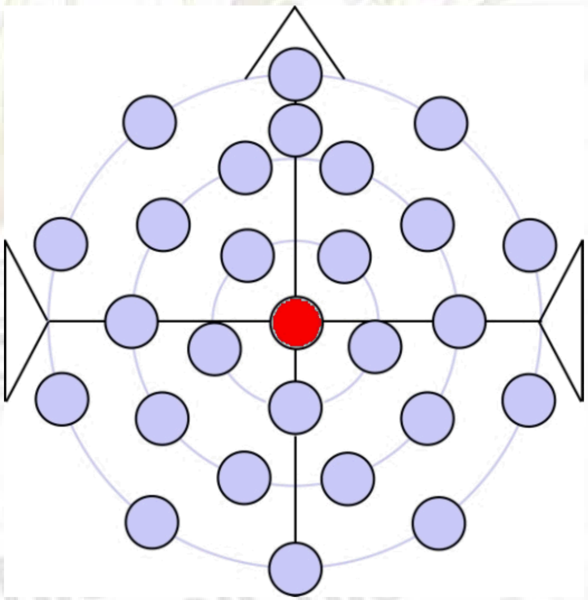
ERP Orientation

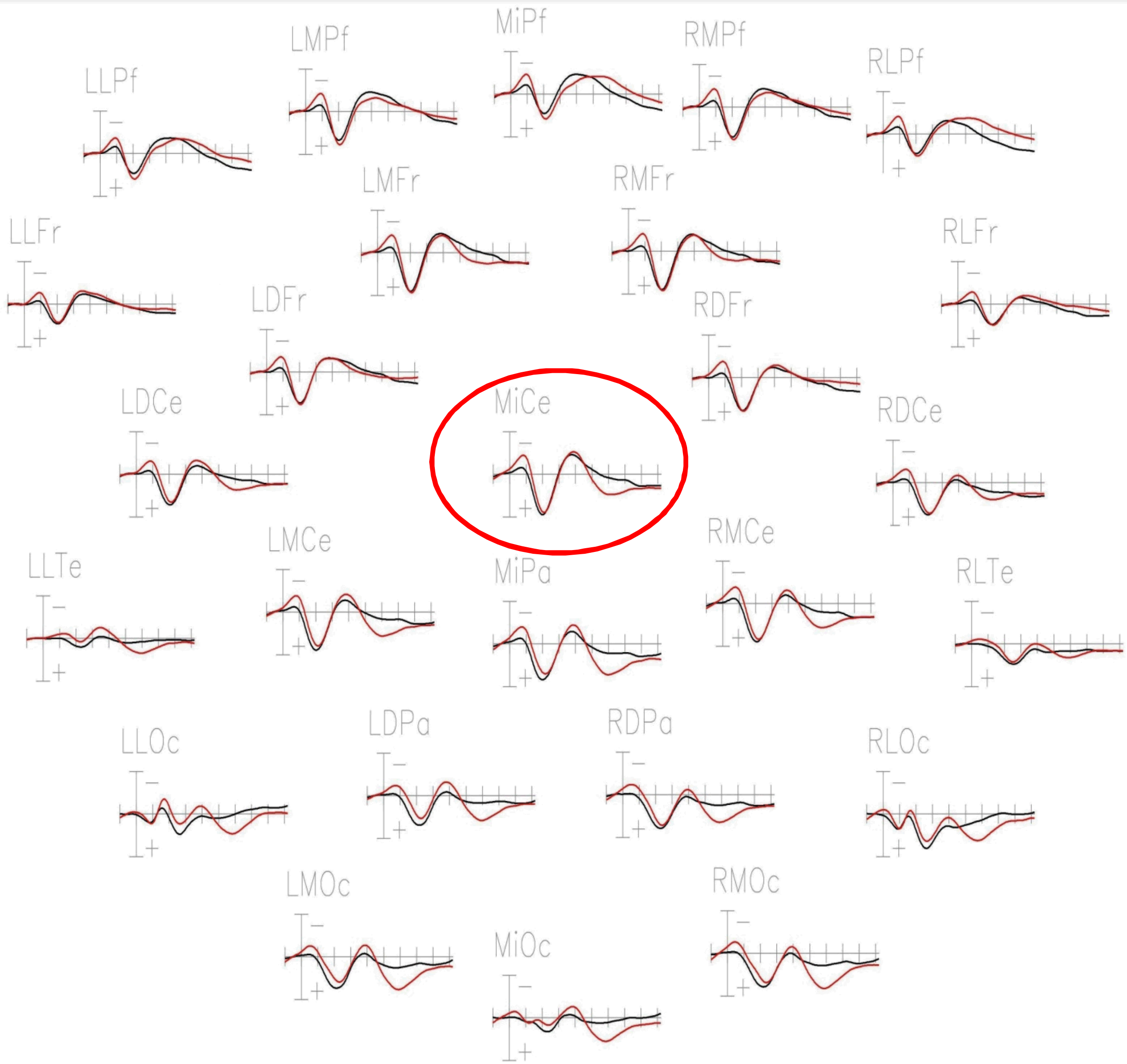




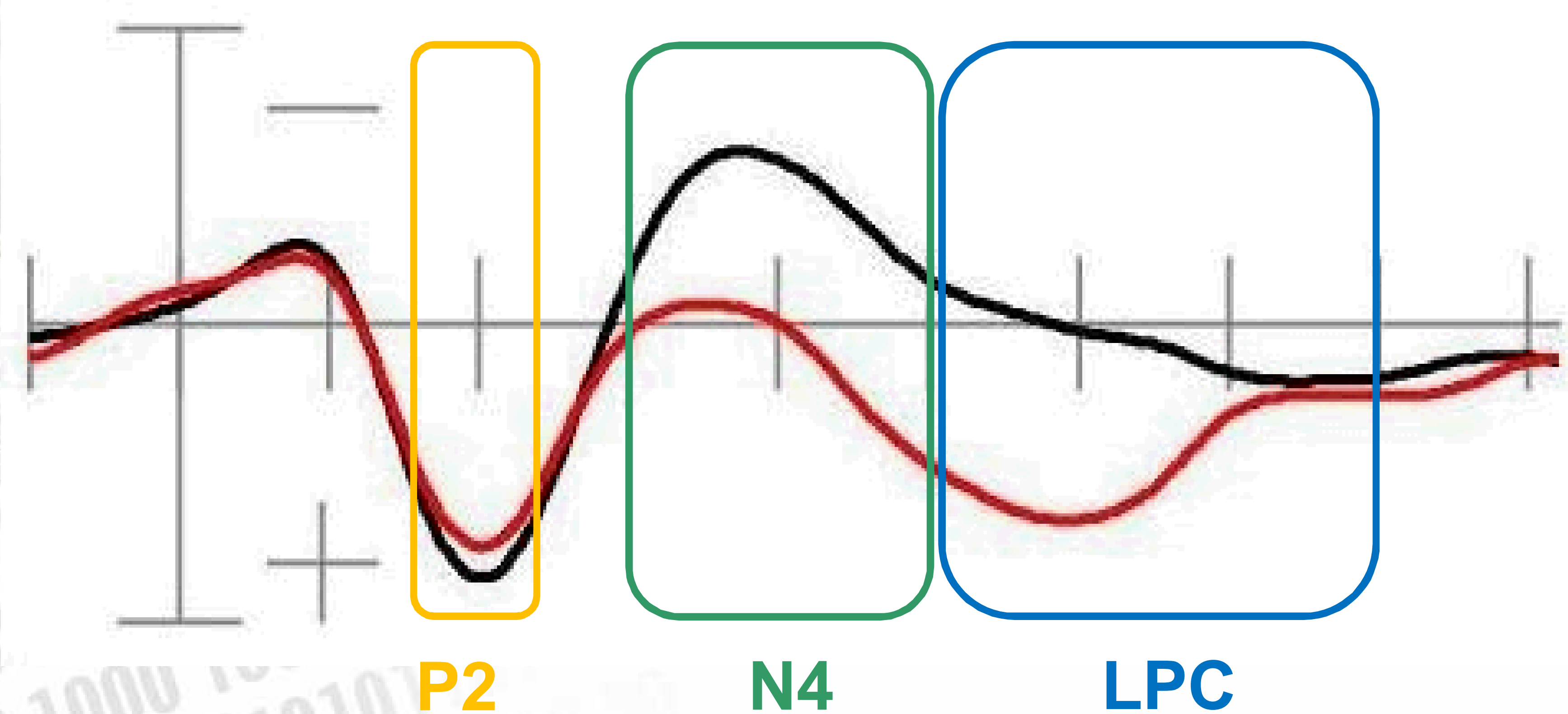
-100 ms to 920 ms
(0 = stimulus onset)

ERP Orientation





Critical Time Windows



Words Studied Twice, Short Lag

fight
alarm
cut
nation
cut
nation
storm
assent
fire
noon
fight
alarm

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Words Studied Twice, Short Lag

fight
alarm
cut =
nation
cut =
nation
storm
assent
fire
noon
fight
alarm

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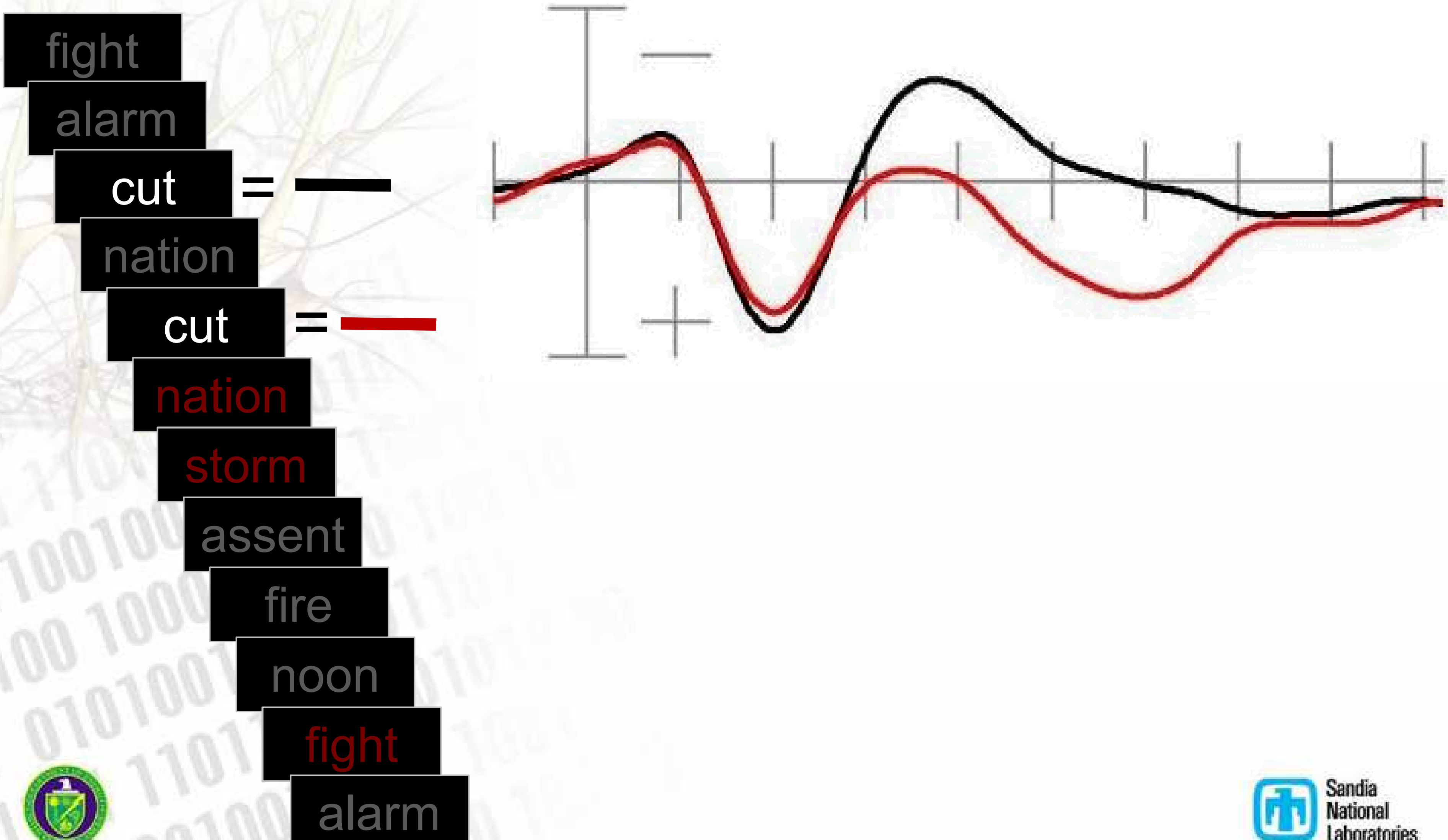
Words Studied Twice, Short Lag



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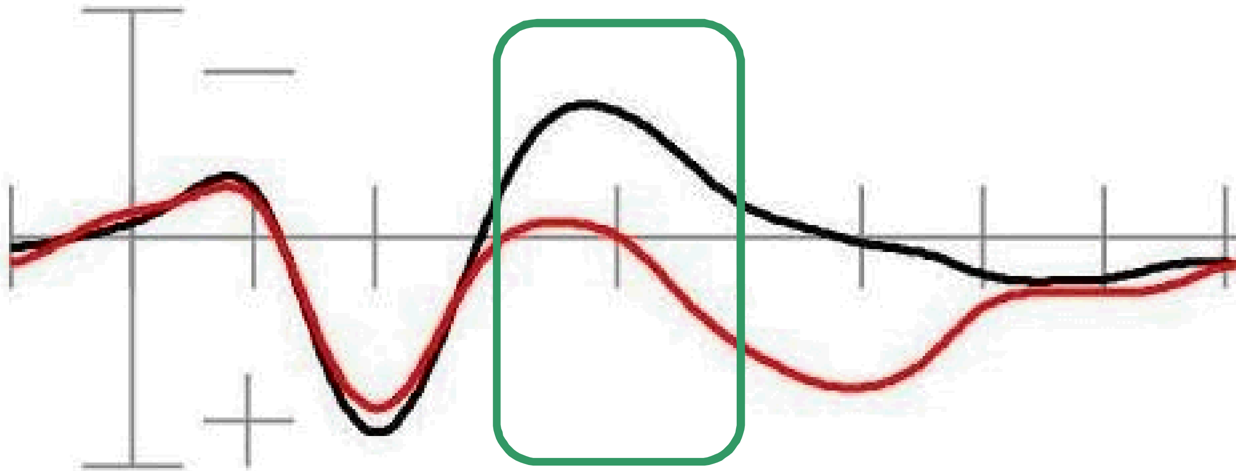
Words Studied Twice, Short Lag



<u>N4 smaller for repetition:</u>

- Semantic access facilitated
- Implicit memory

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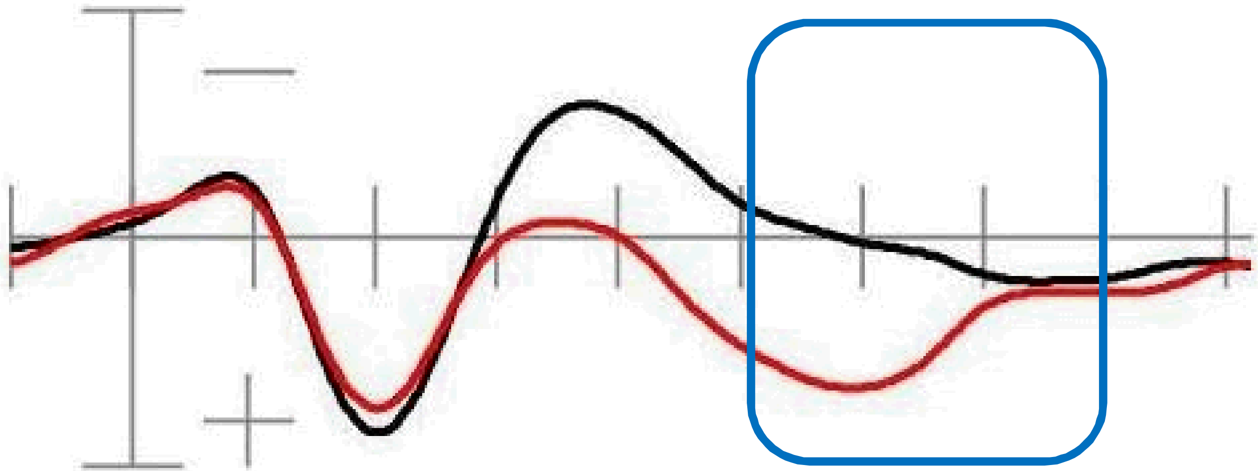
Words Studied Twice, Short Lag



LPC larger for repetition:

- Explicit memory
- Conscious recollection

Words Studied Twice, Long Lag

fight
alarm =
cut
nation
cut
nation
storm
assent
fire
noon
fight
alarm =

Words Studied Twice, Long Lag

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nation
cut
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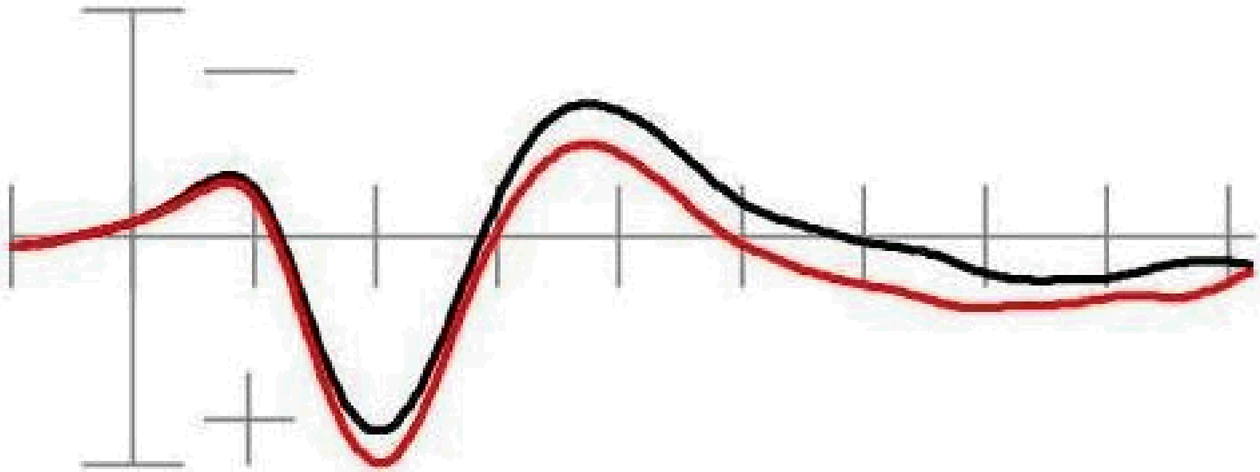
fight
alarm =



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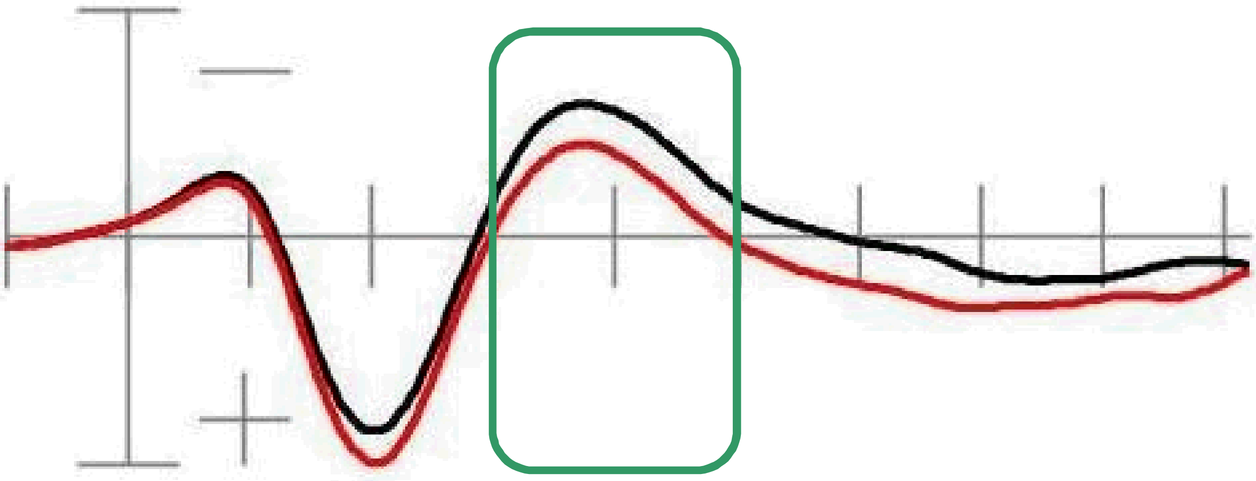

<u>N4 smaller for repetition:</u>

- Smaller difference than short lag

Words Studied Twice, Long Lag

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assent
fire
noon
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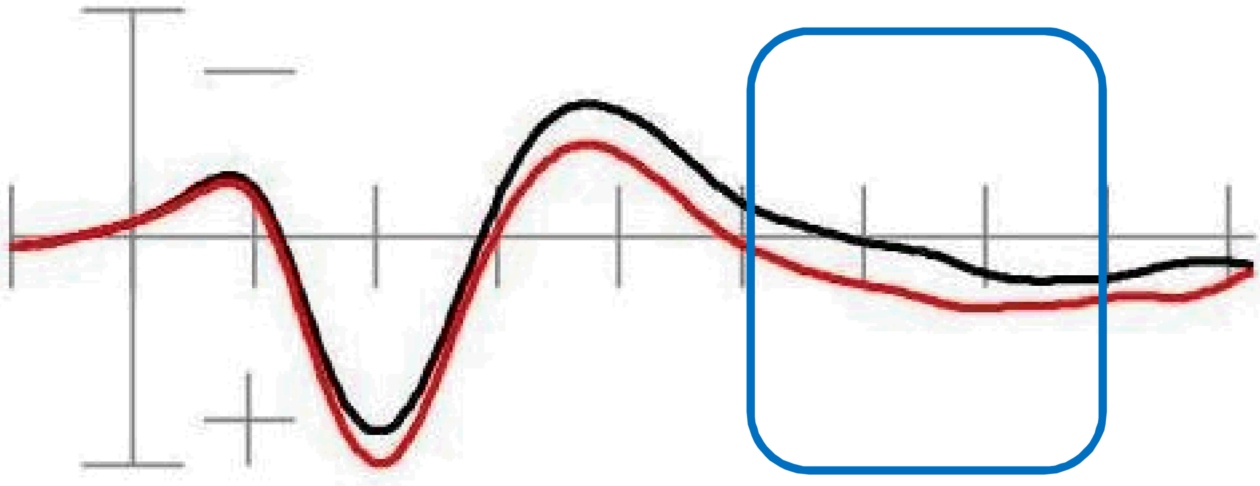
alarm =



LPC larger for repetition:

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Words Studied and Tested, Short Lag

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Words Studied and Tested, Short Lag

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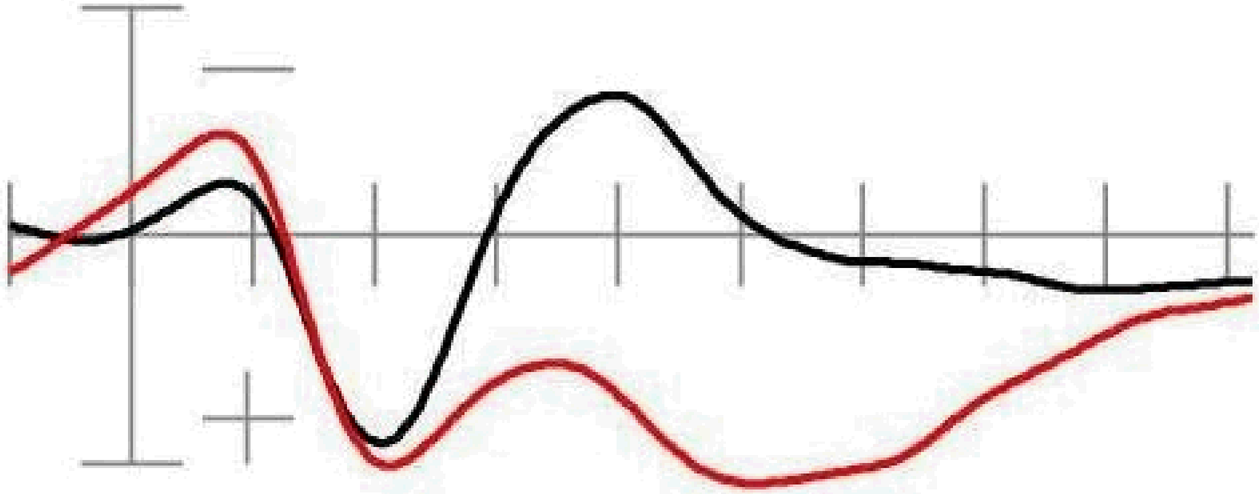

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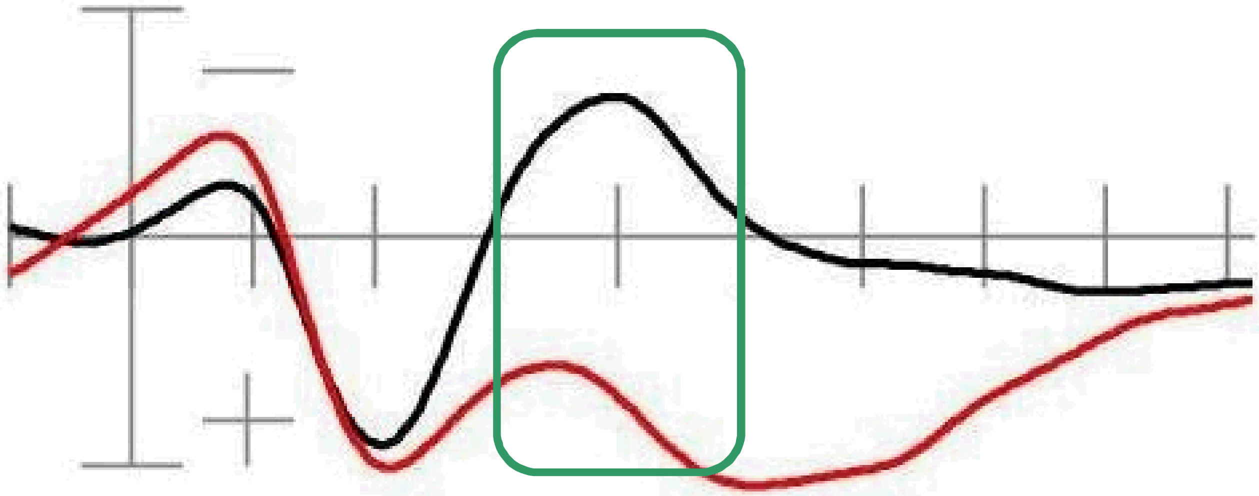

<u>N4 smaller for repetition:</u>

- Larger difference than twice-studied words

Words Studied and Tested, Short Lag

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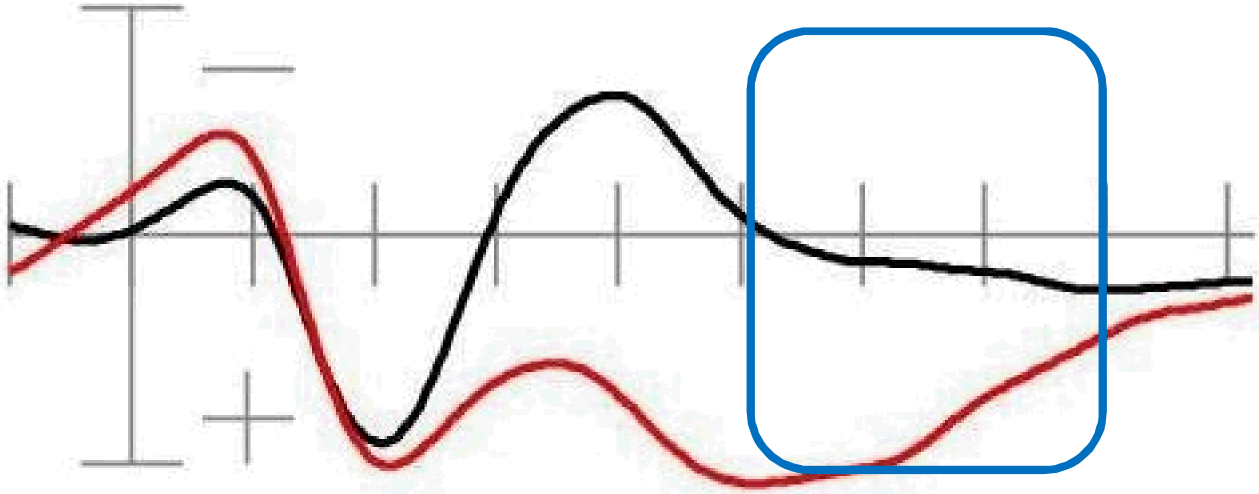

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Words Studied and Tested, Long Lag

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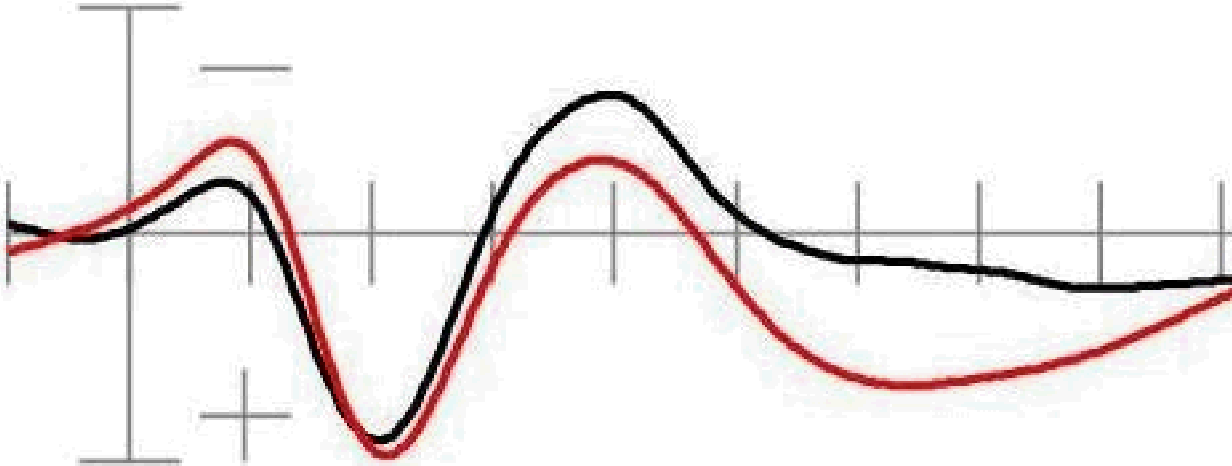

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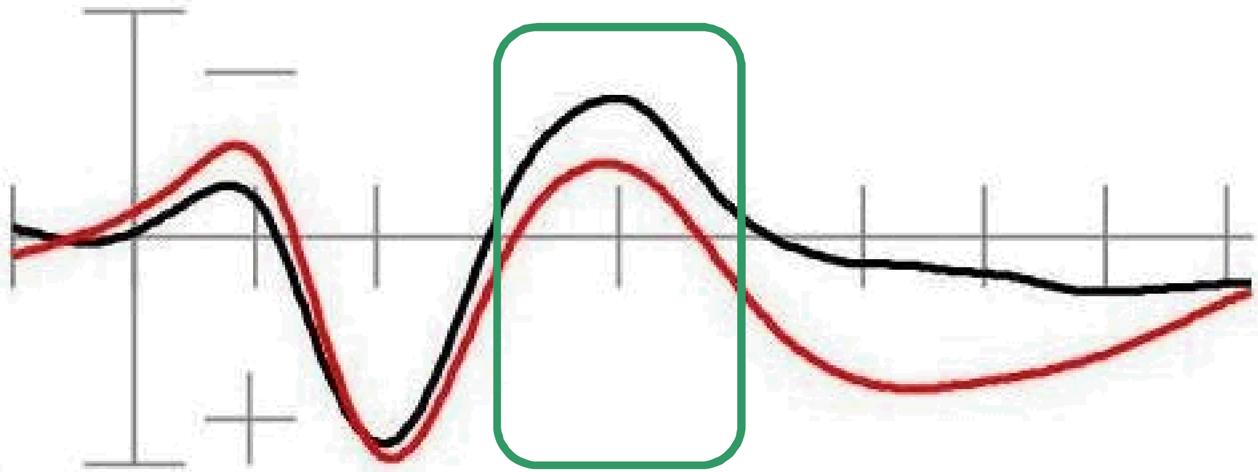
Words Studied and Tested, Long Lag



<u>N4 smaller for repetition:</u>

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Words Studied and Tested, Long Lag

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noon
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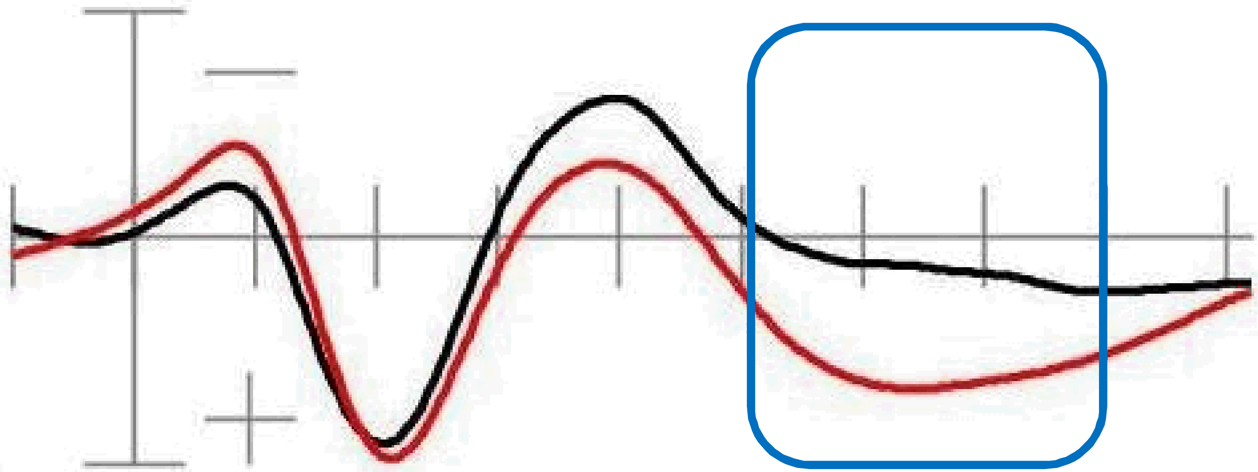

LPC larger for repetition:

- Smaller difference than short lag

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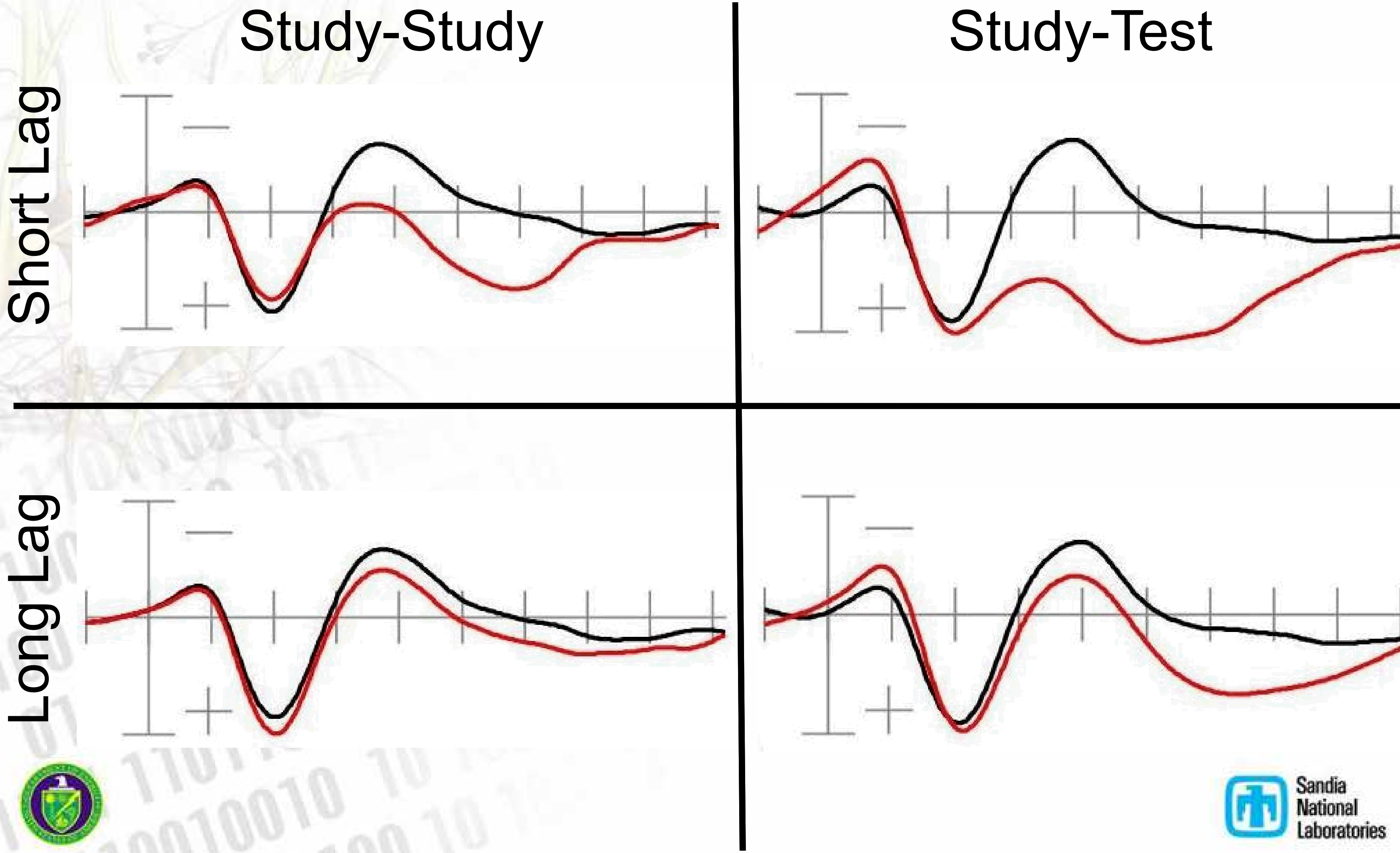
All Repetition Effects



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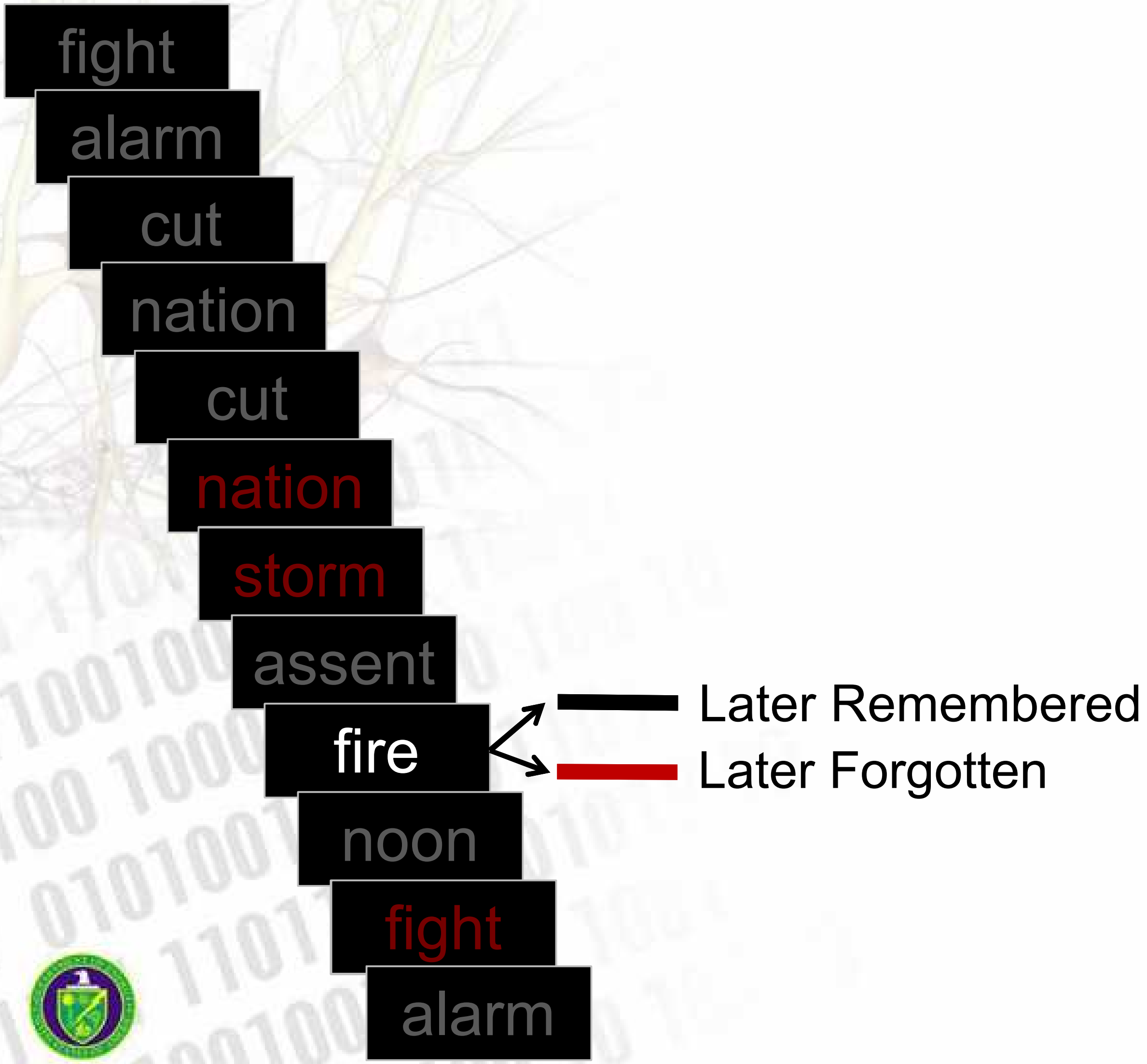
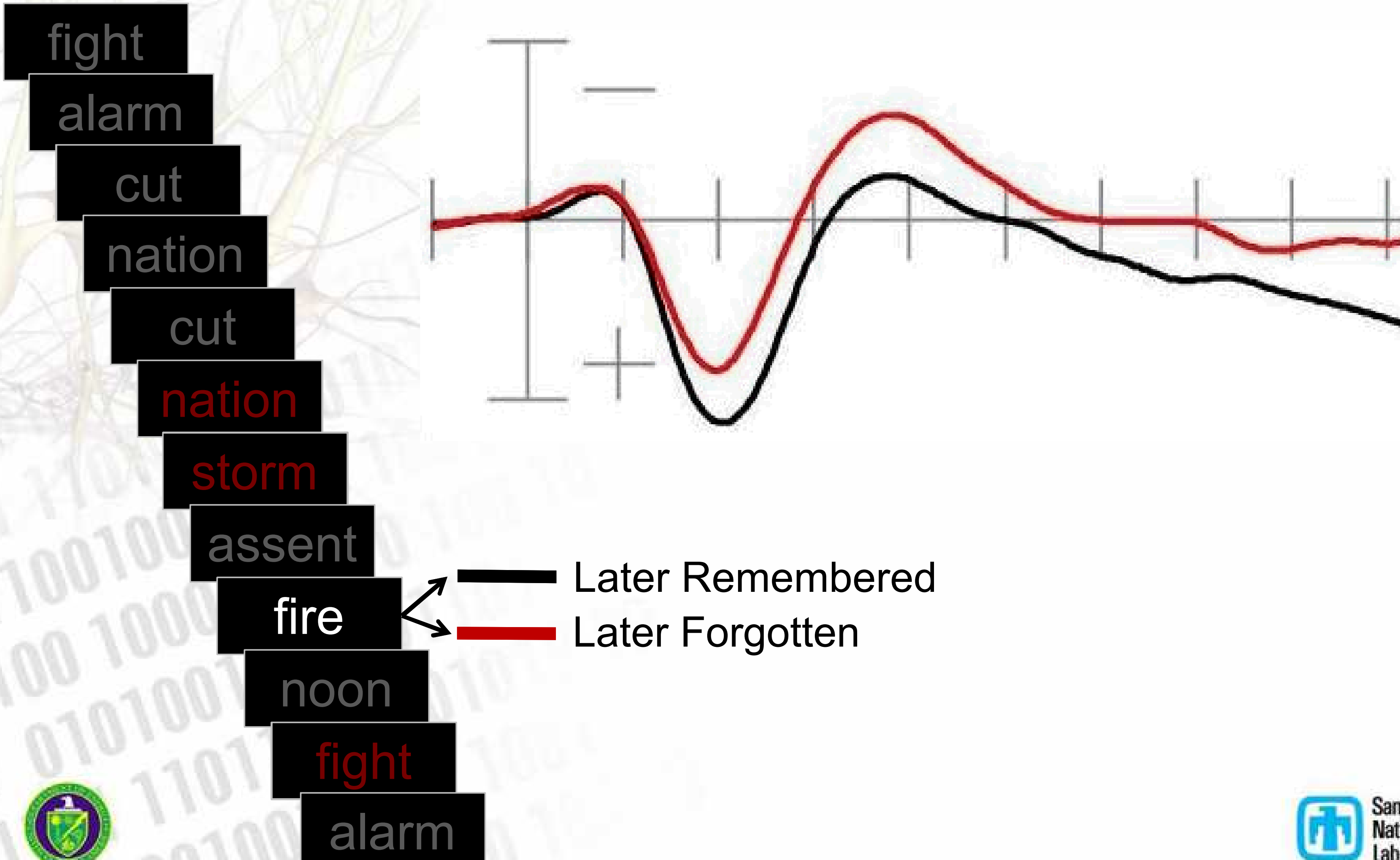
Dm Effect
Once-studied words



Dm Effect
Once-studied words



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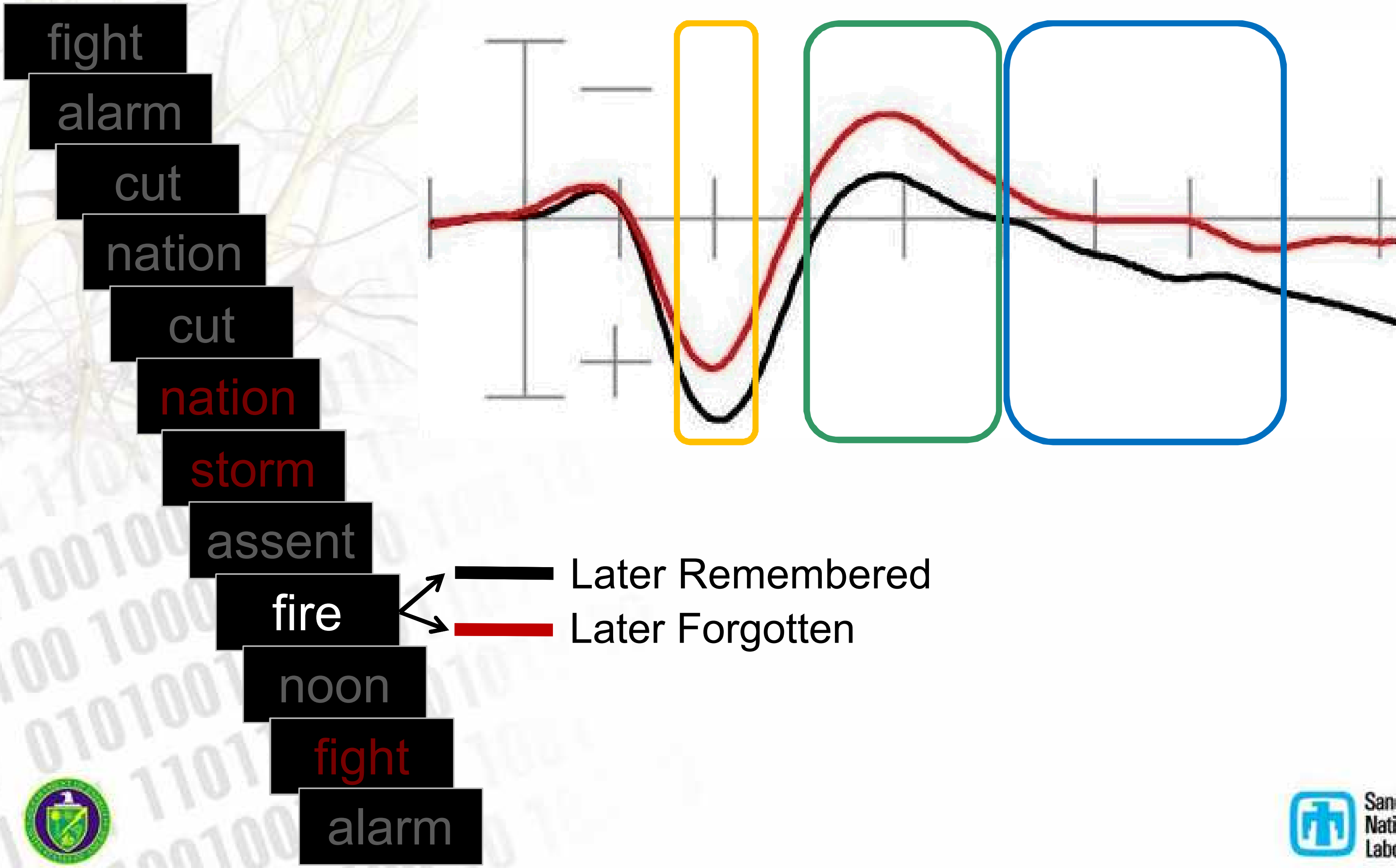
Dm Effect
Once-studied words



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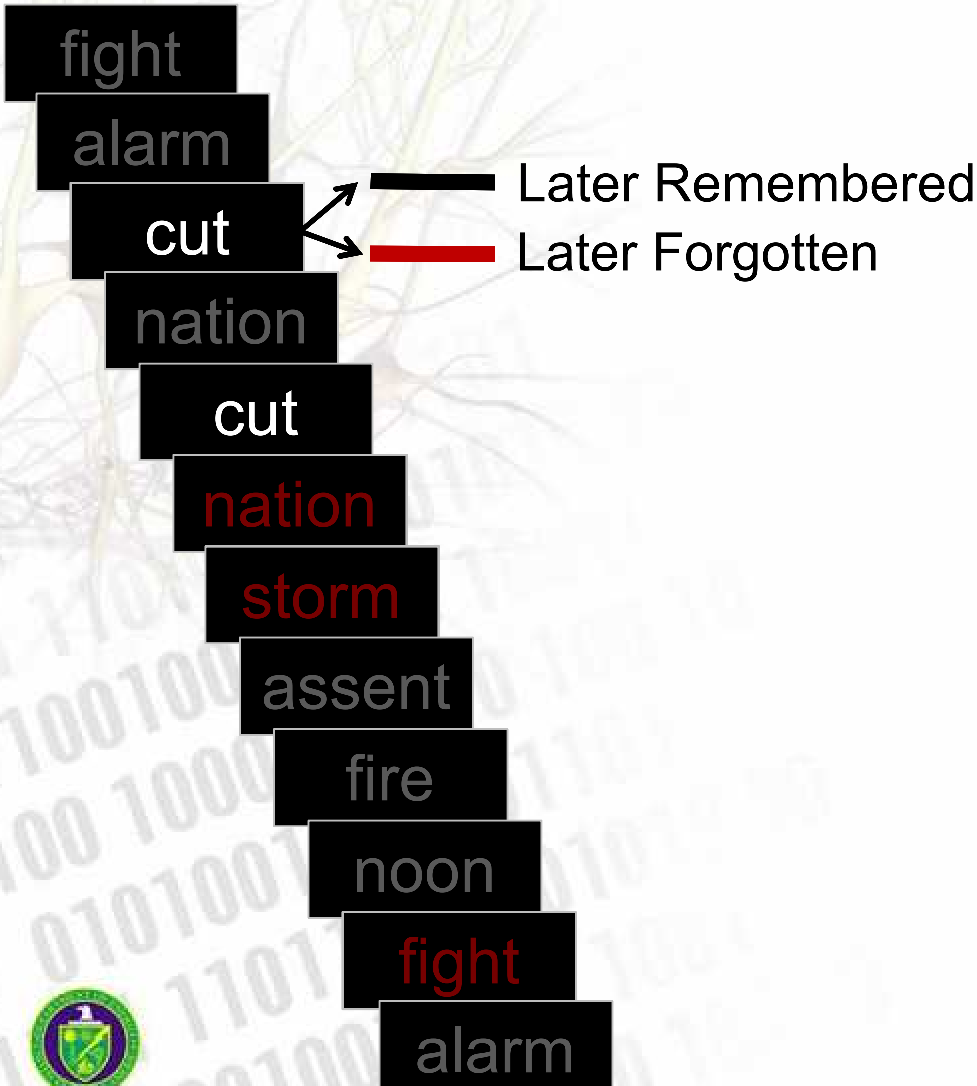
Dm Effect
Once-studied words



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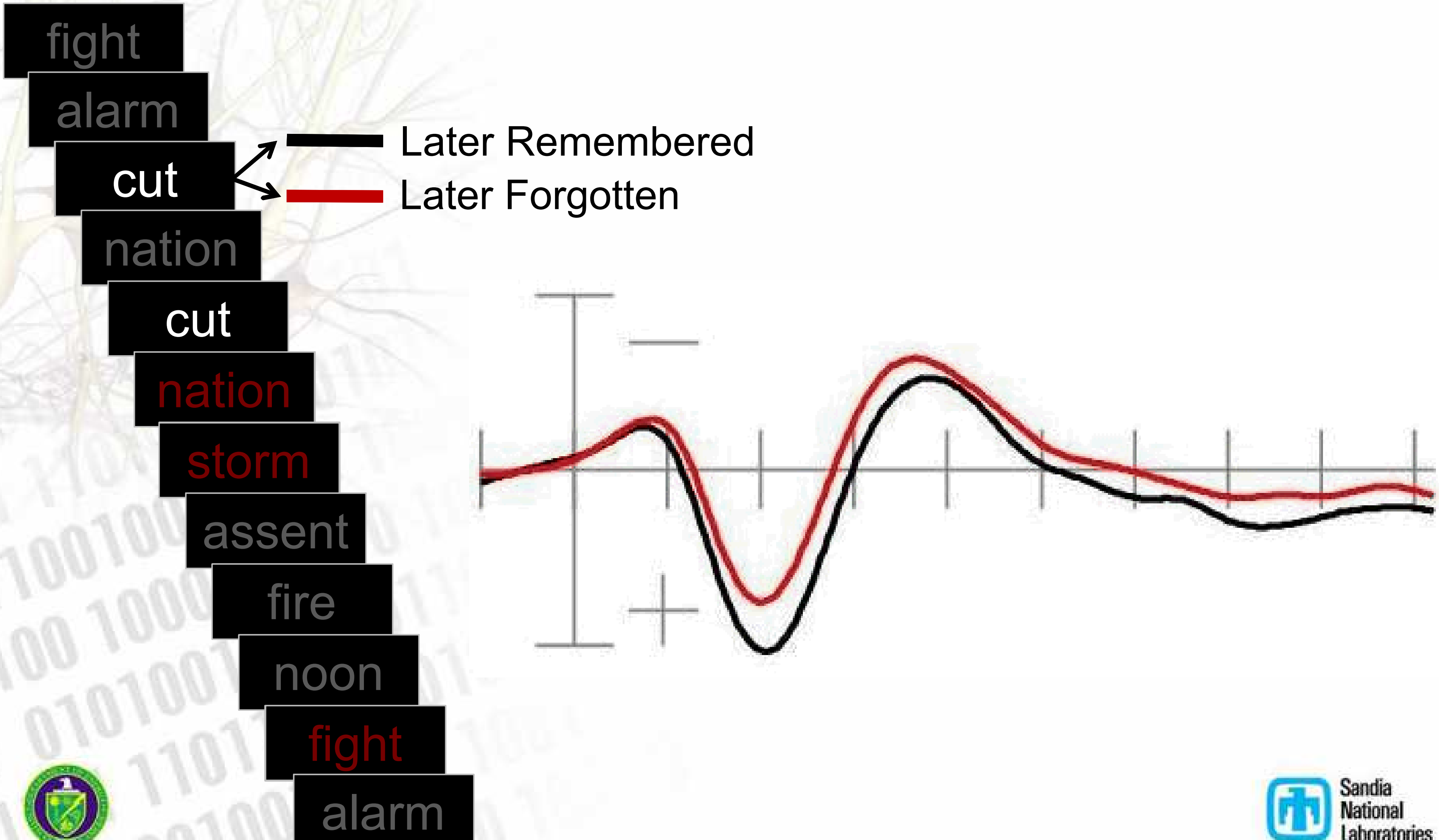
Dm Effect
Study-study words



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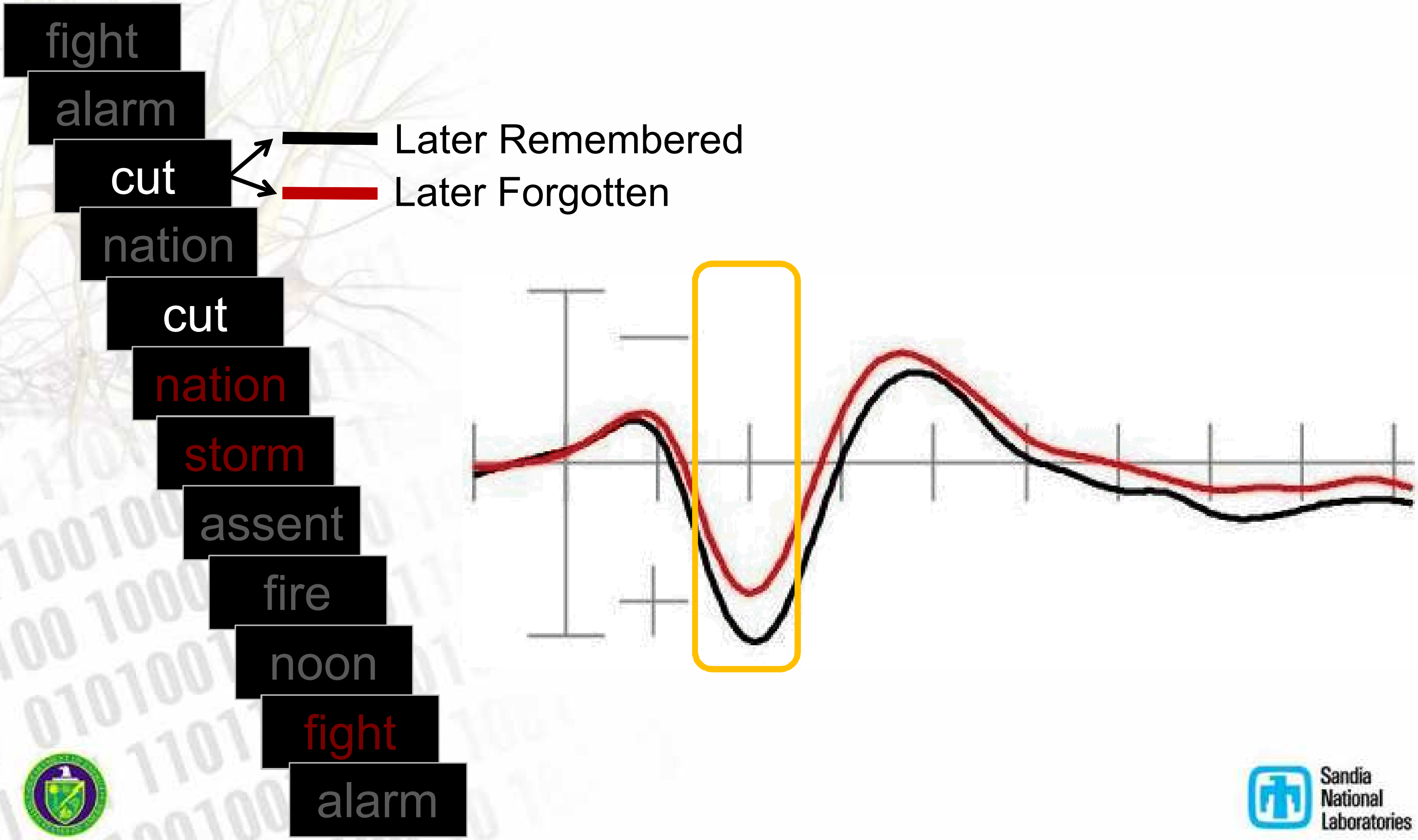
Dm Effect
Study-study words



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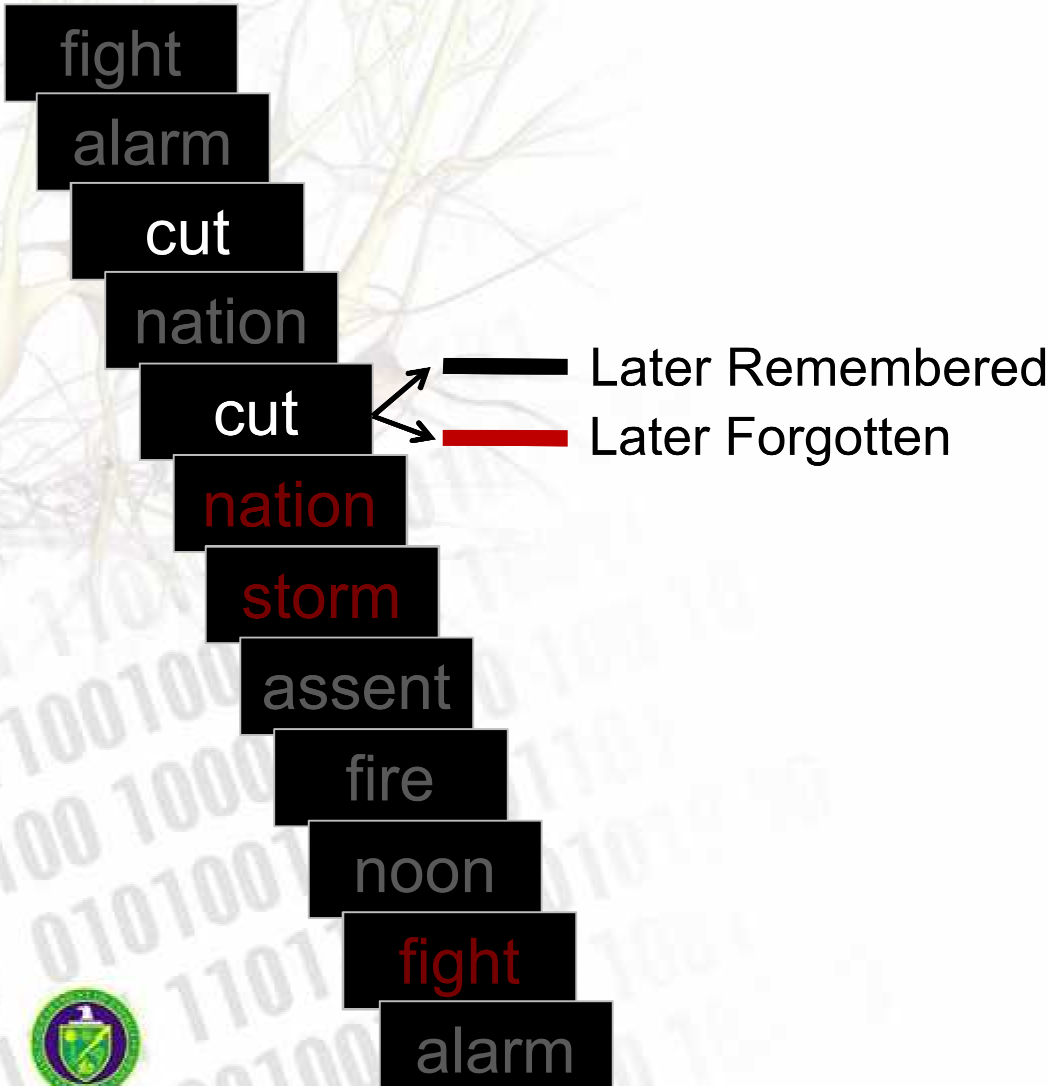
Cognitive Science & Technology

Dm-R Effect
Study-study words, short lag



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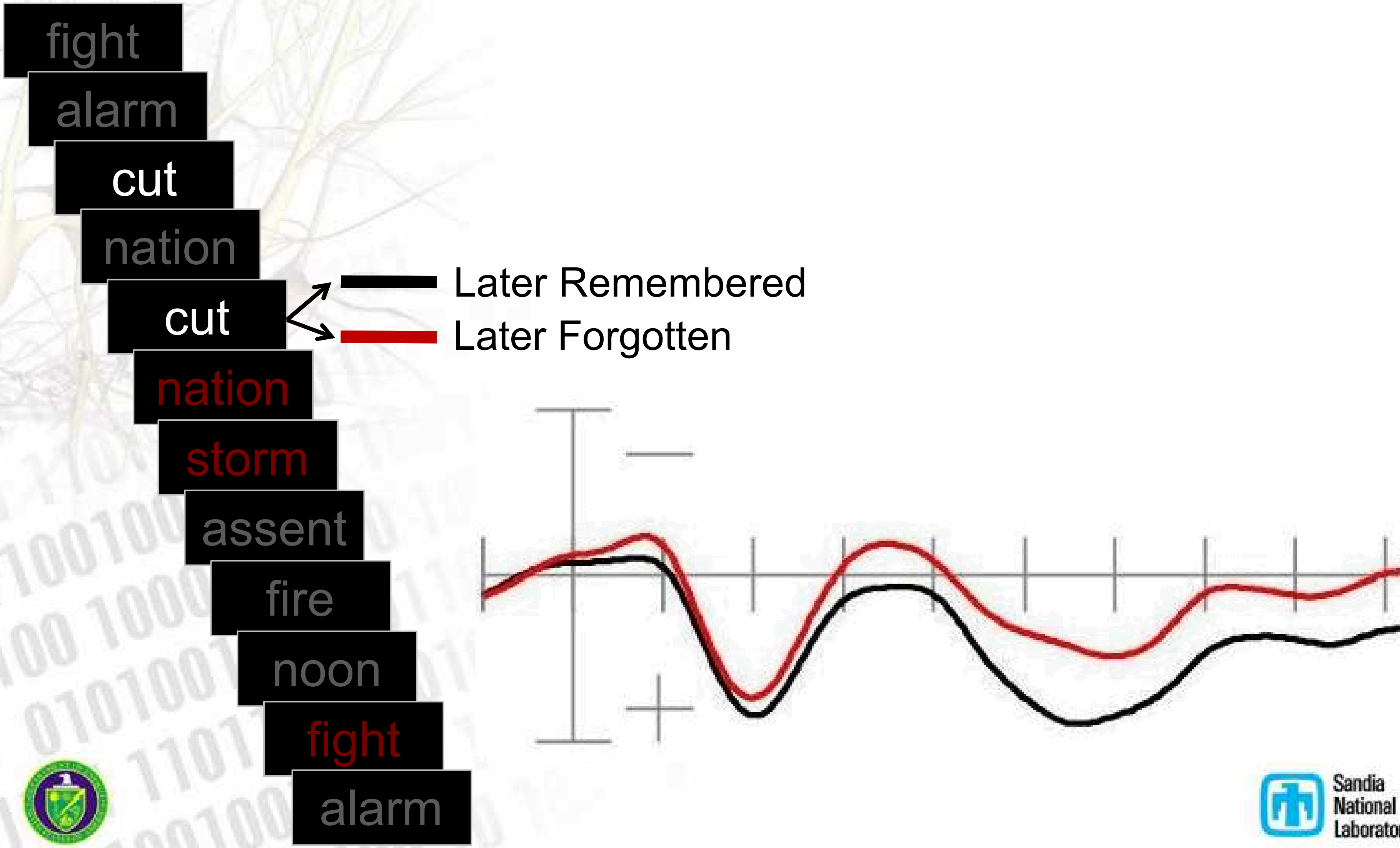

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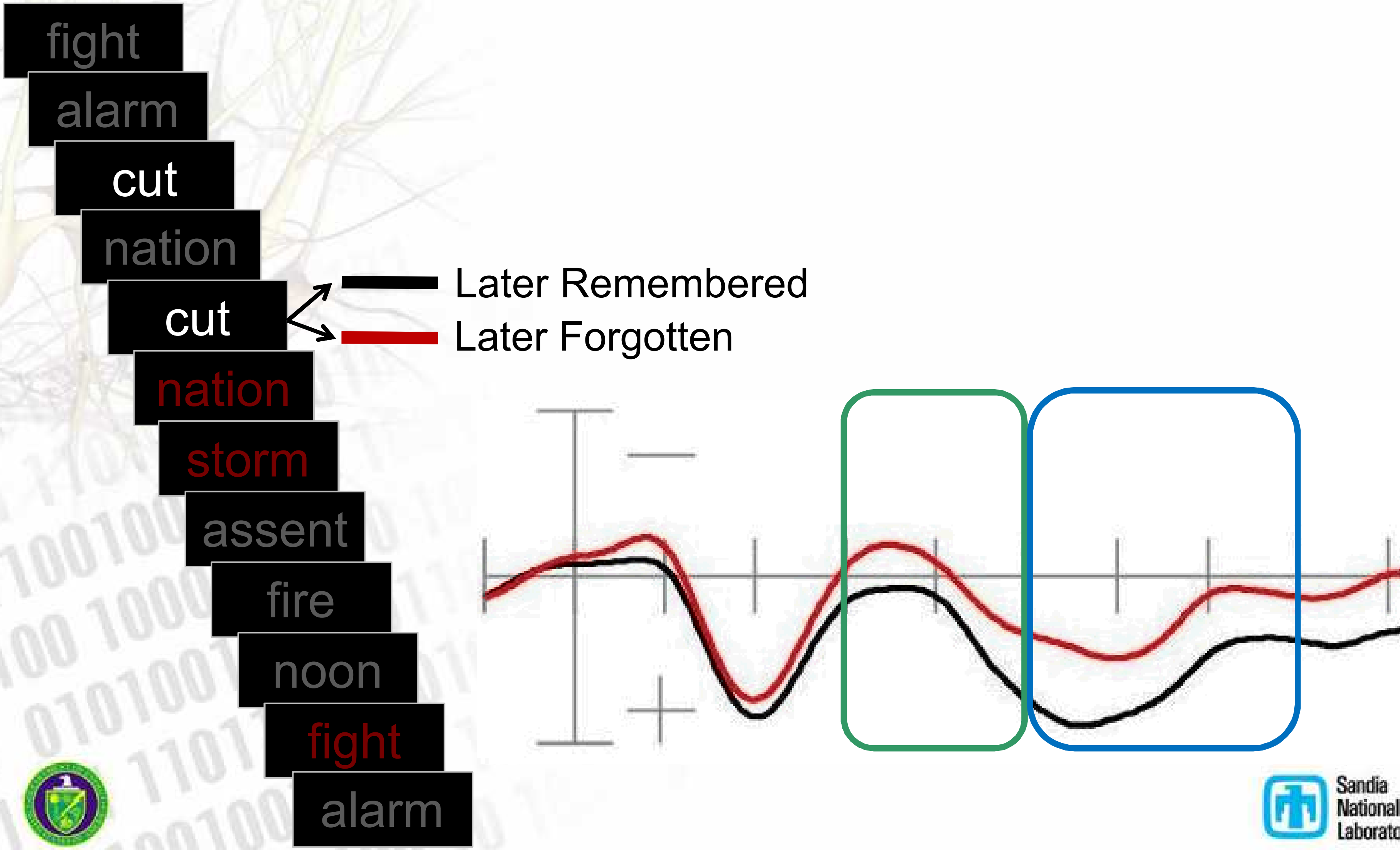

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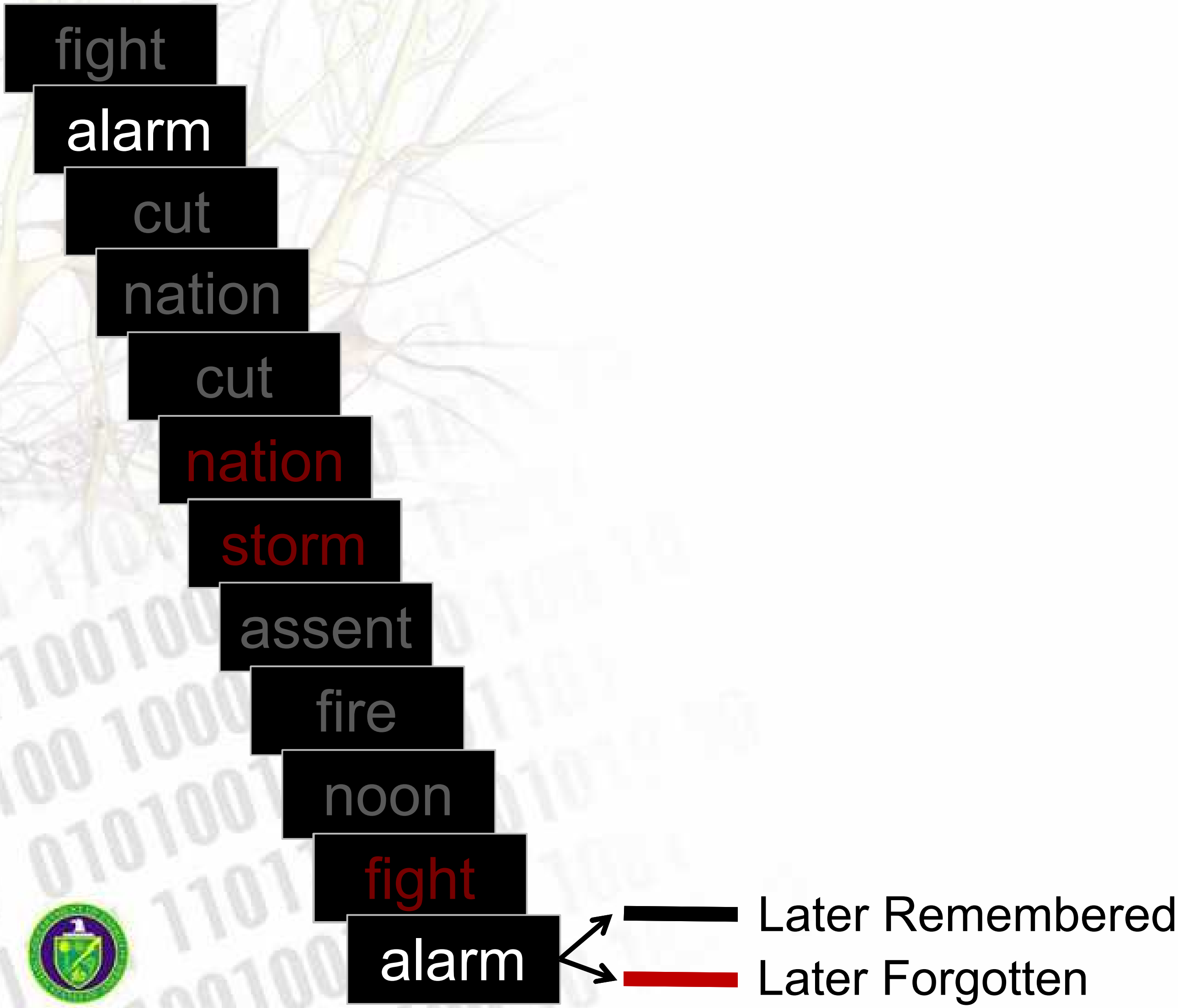

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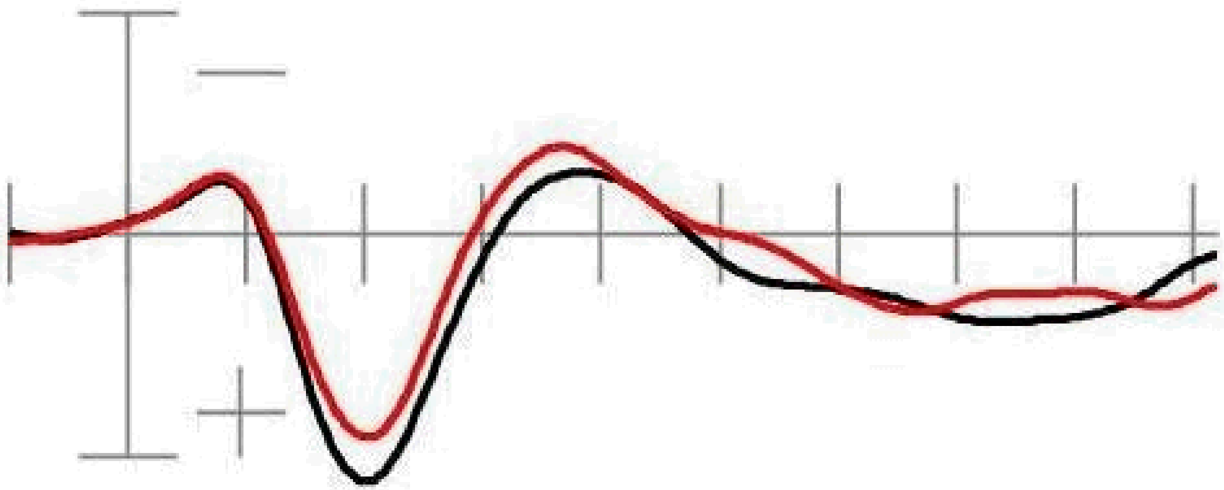
Dm-R Effect
Study-study words, long lag

fight
alarm
cut
nation
cut
nation
storm
assent
fire
noon
fight
alarm



Later Remembered
Later Forgotten

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Dm-R Effect
Study-study words, long lag

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Comparison of Study-Study Conditions

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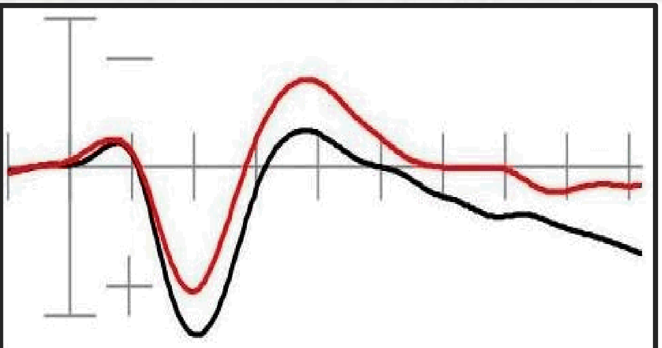
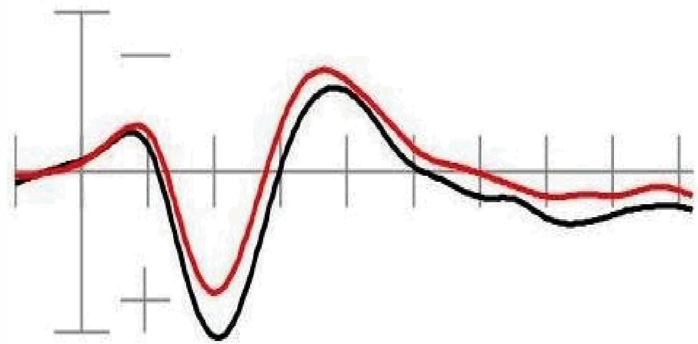
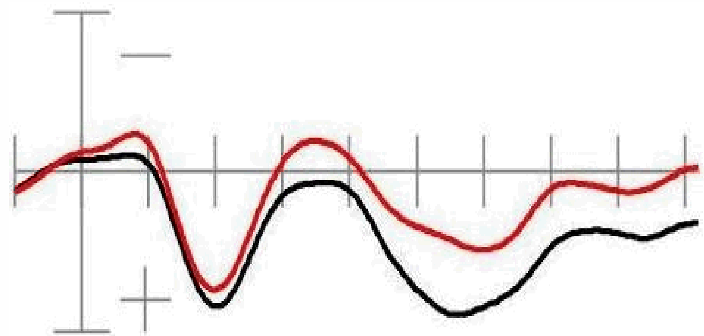


"Classic" Dm Effect
(Once-studied Words)

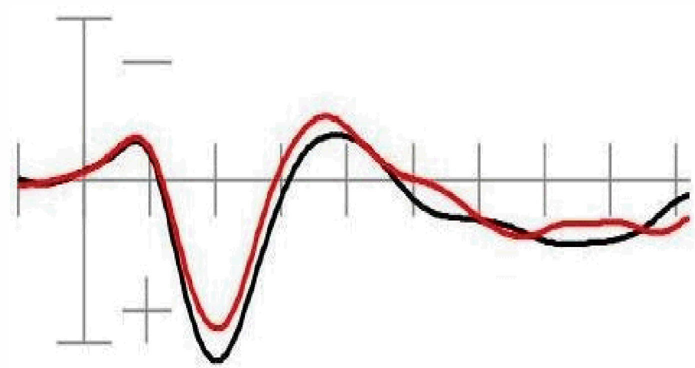
Twice-studied Words
First Presentation



Twice-studied Words
Second Presentation
Short Lag



Twice-studied Words
Second Presentation
Long Lag



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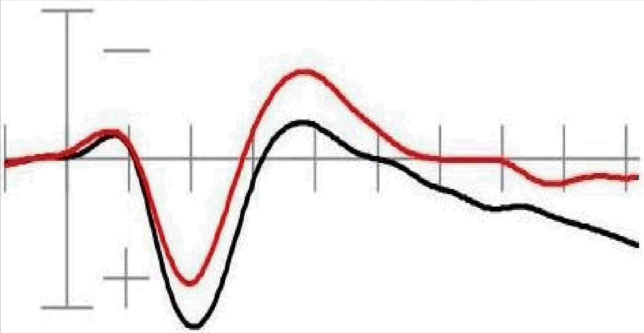
Comparison of Study-Study Conditions



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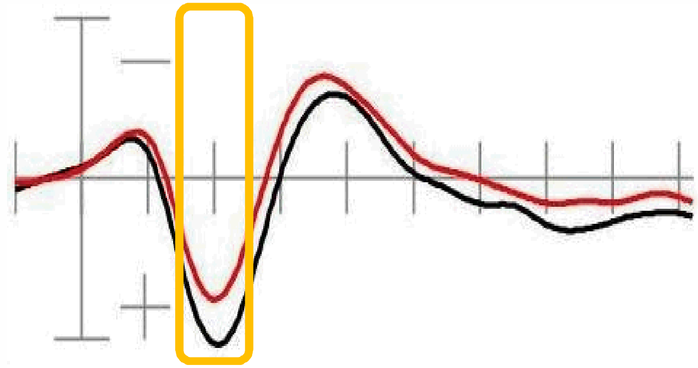
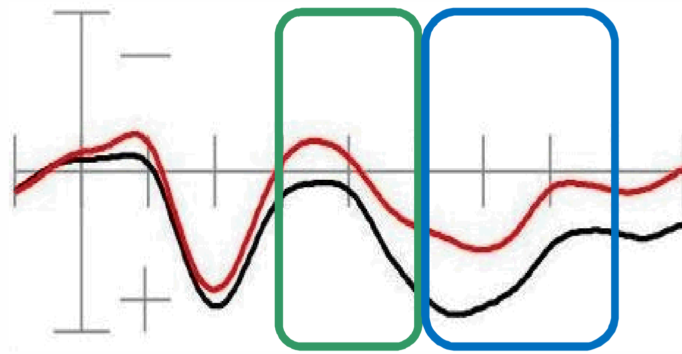


Twice-studied Words
Second Presentation
Short Lag



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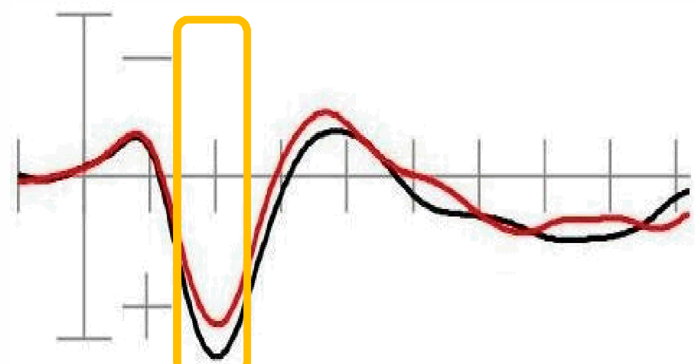

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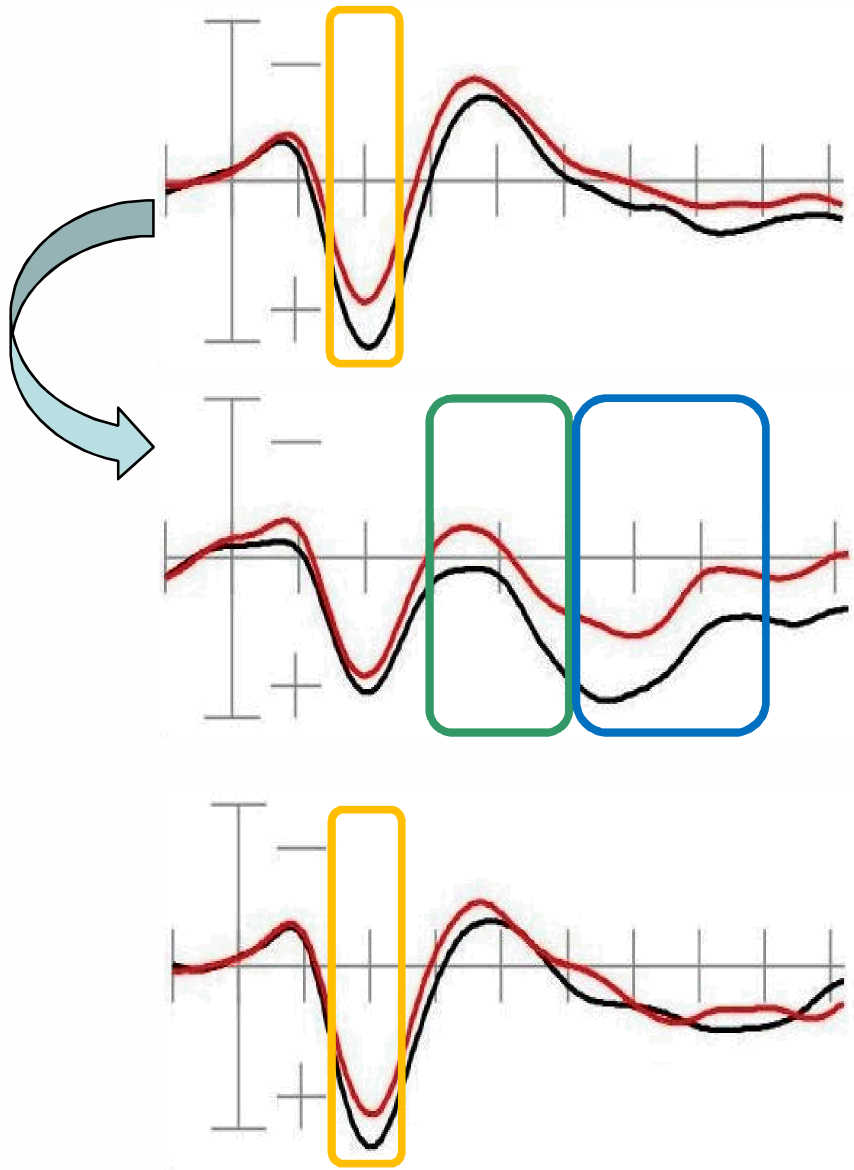
Comparison of Study-Study Conditions

Short lag repetitions:

- Interaction between two presentations

- Subsequent memory driven by second presentation



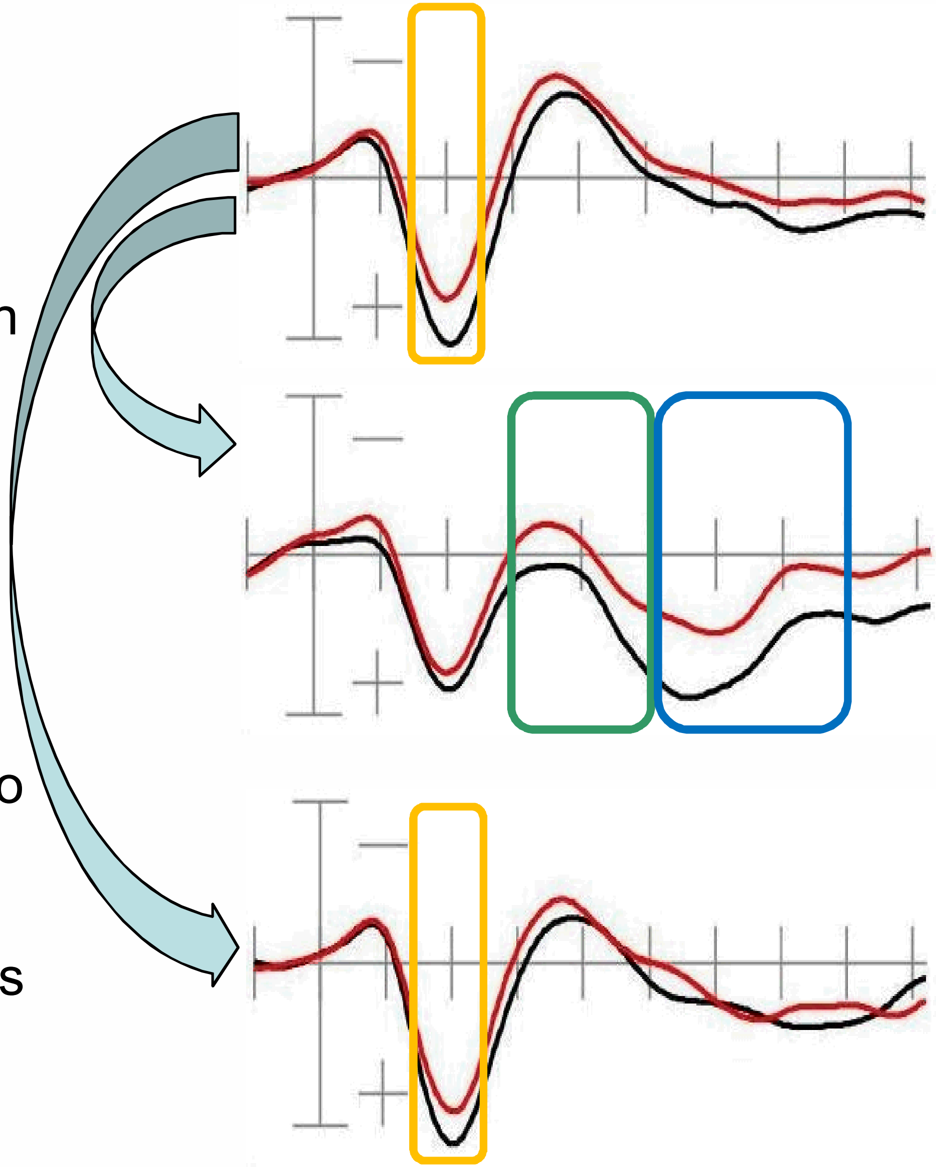
Comparison of Study-Study Conditions

Short lag repetitions:
- Interaction between two presentations

- Subsequent memory driven by second presentation

Long lag repetitions:
- No interaction between two presentations

- Two distinct memory traces



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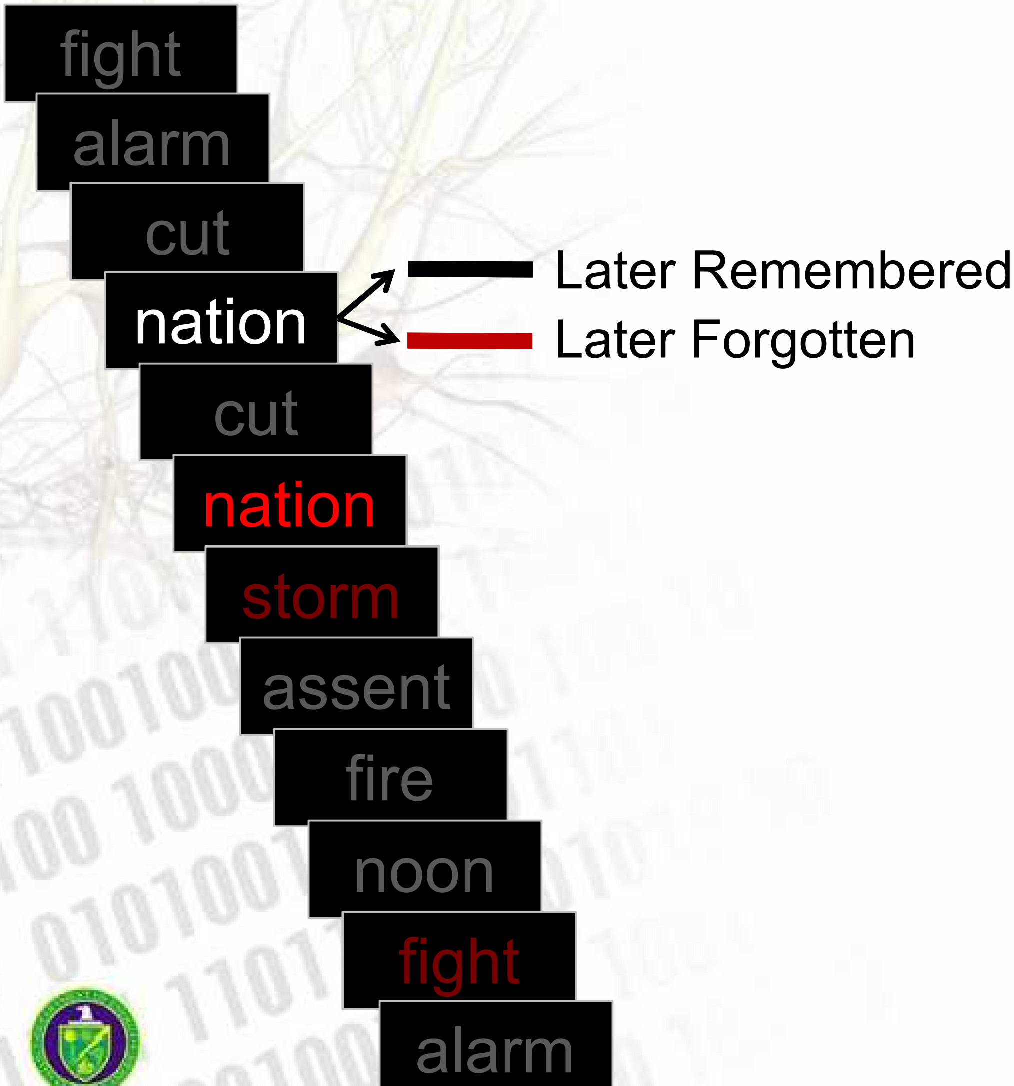
Dm Effect
Study-test words



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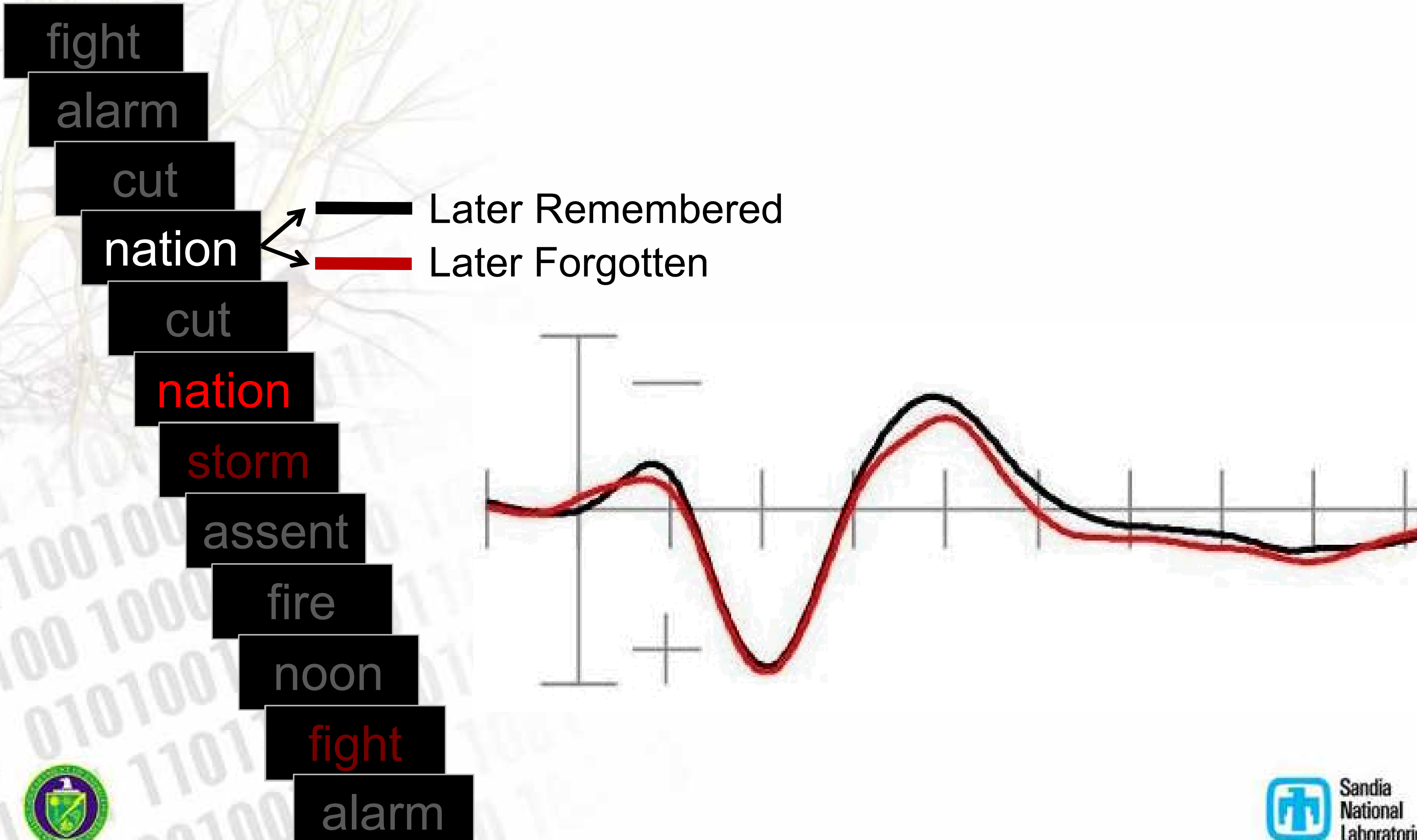
Dm Effect
Study-test words



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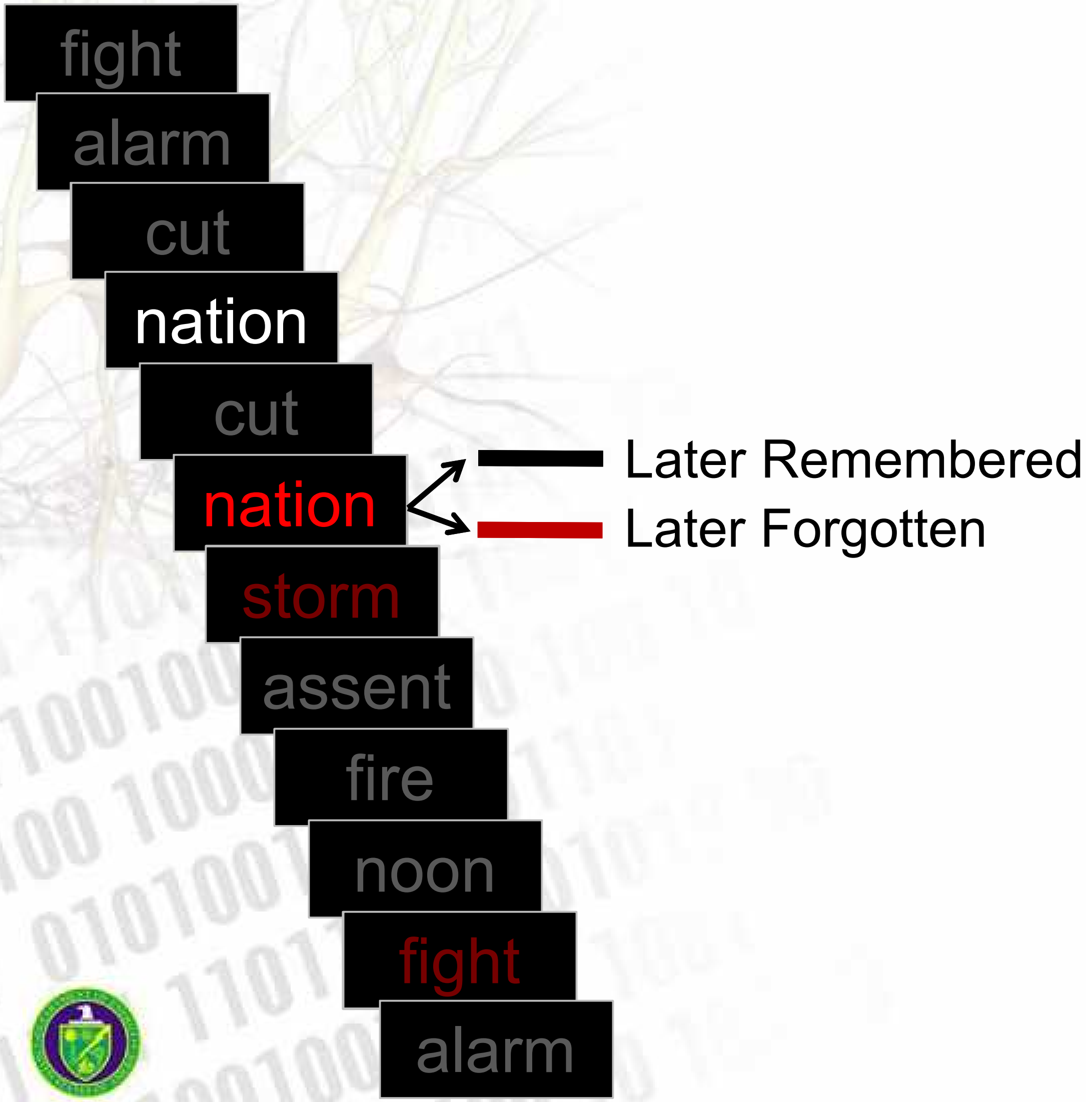
Dm-R Effect
Study-test words, short lag



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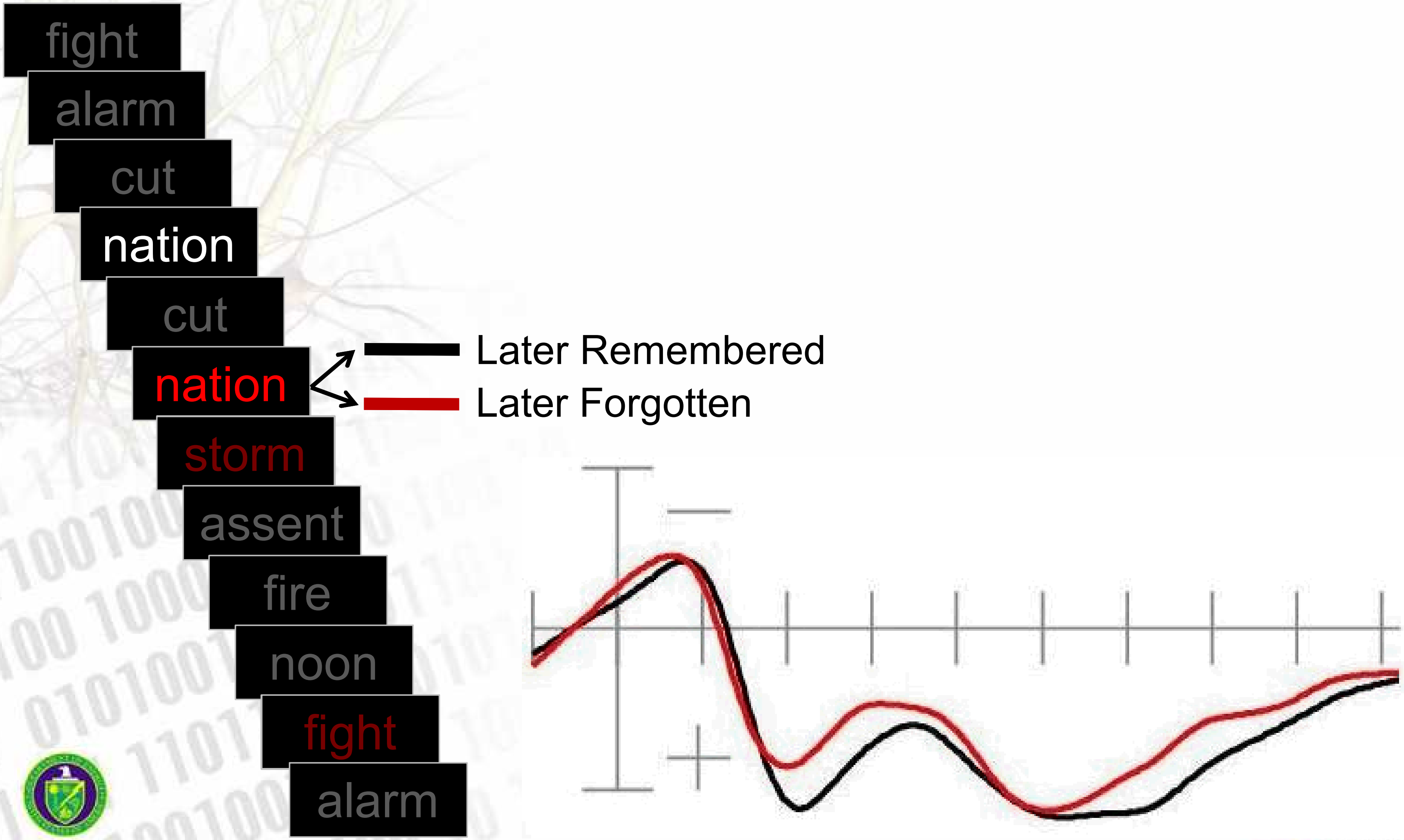

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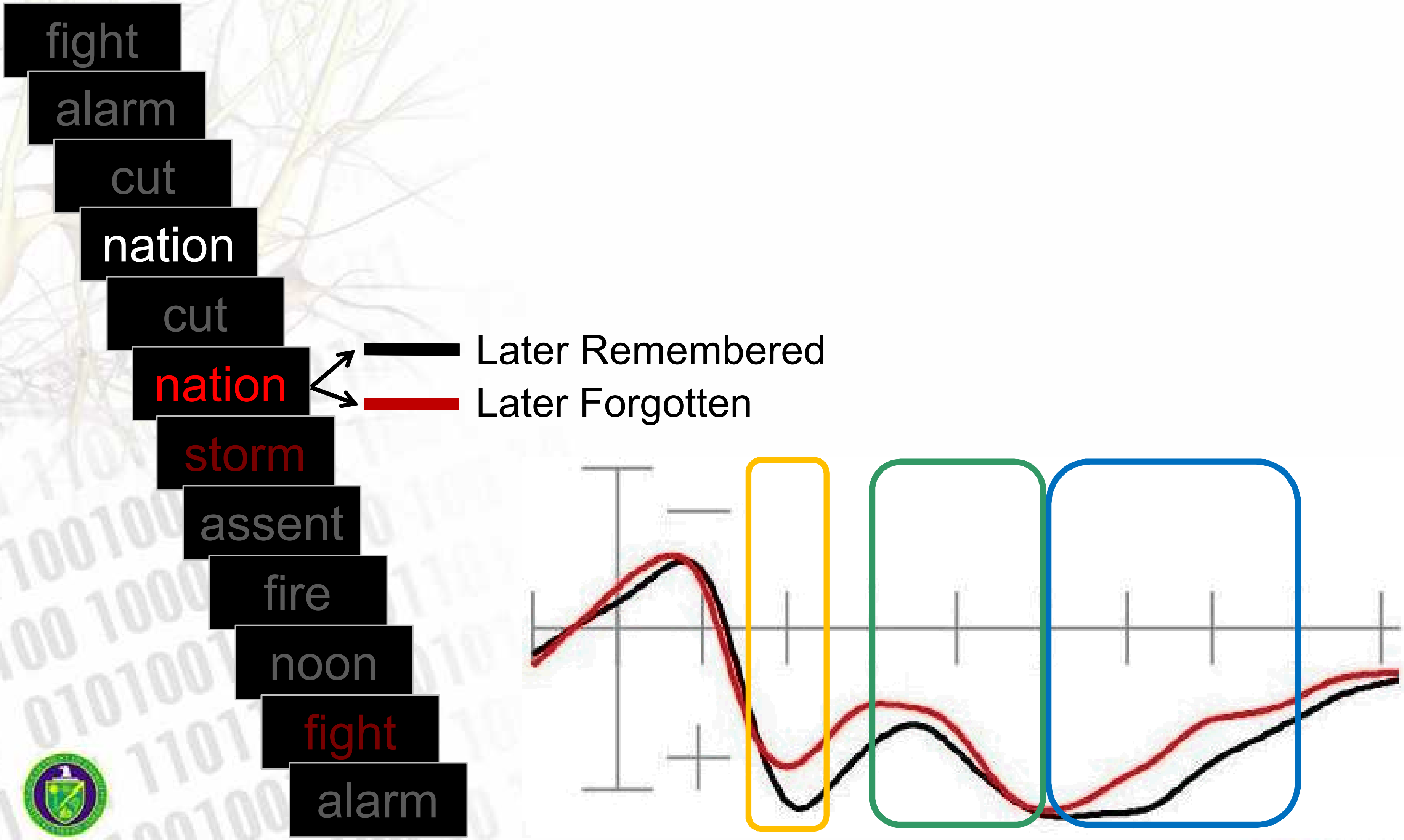

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Dm-R Effect
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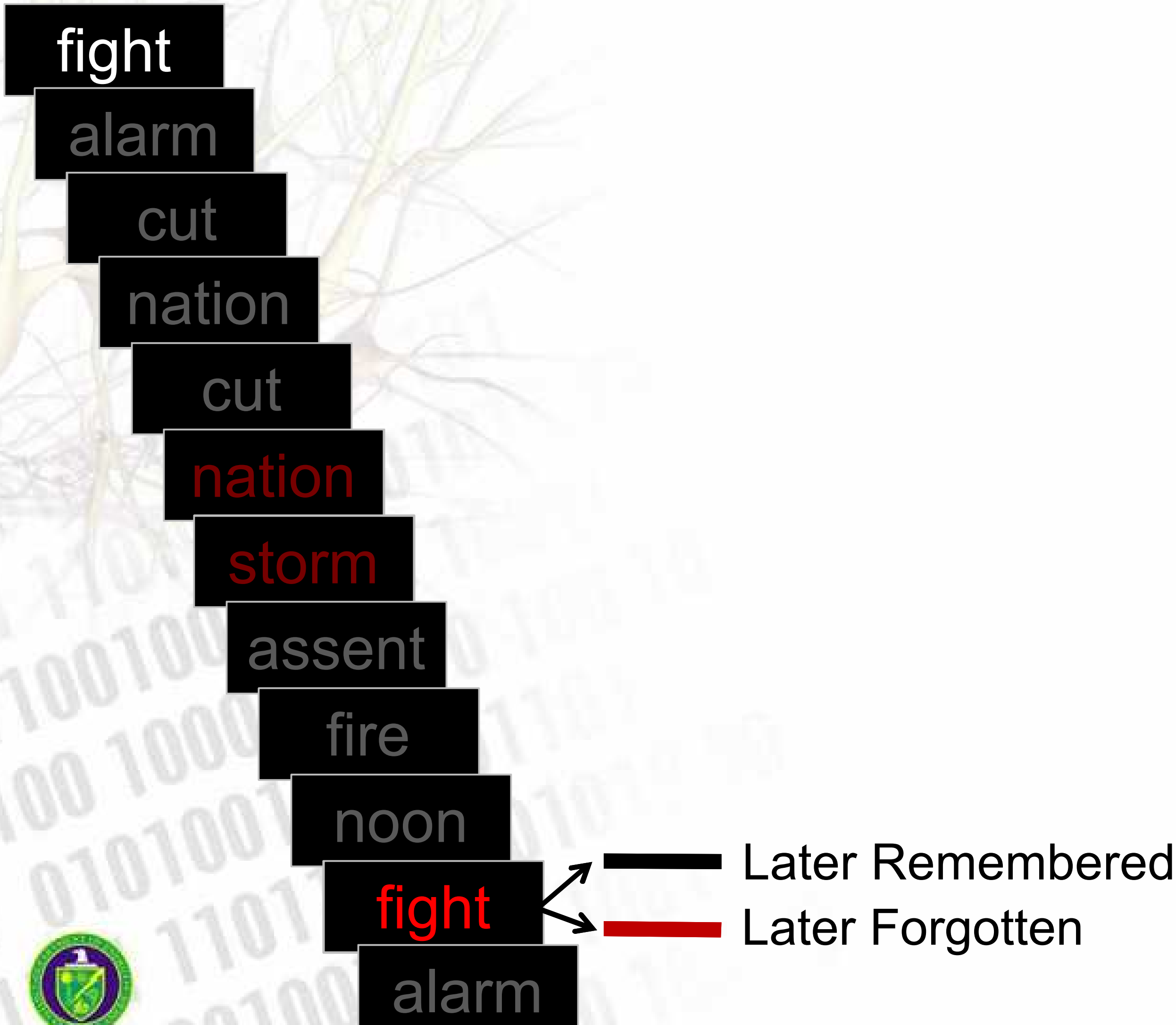

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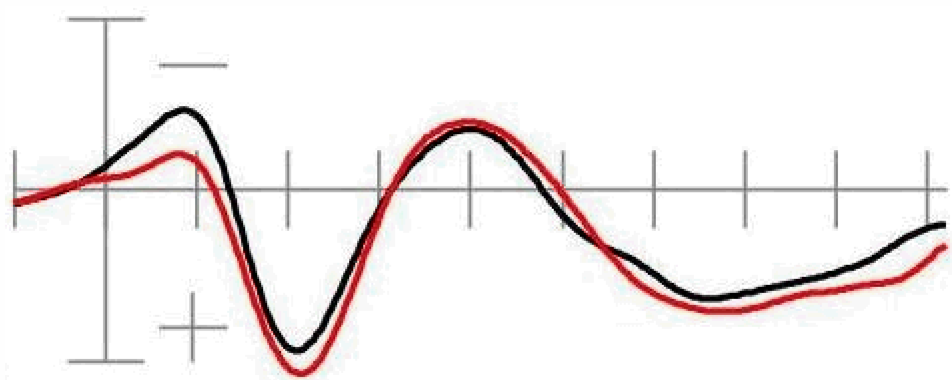

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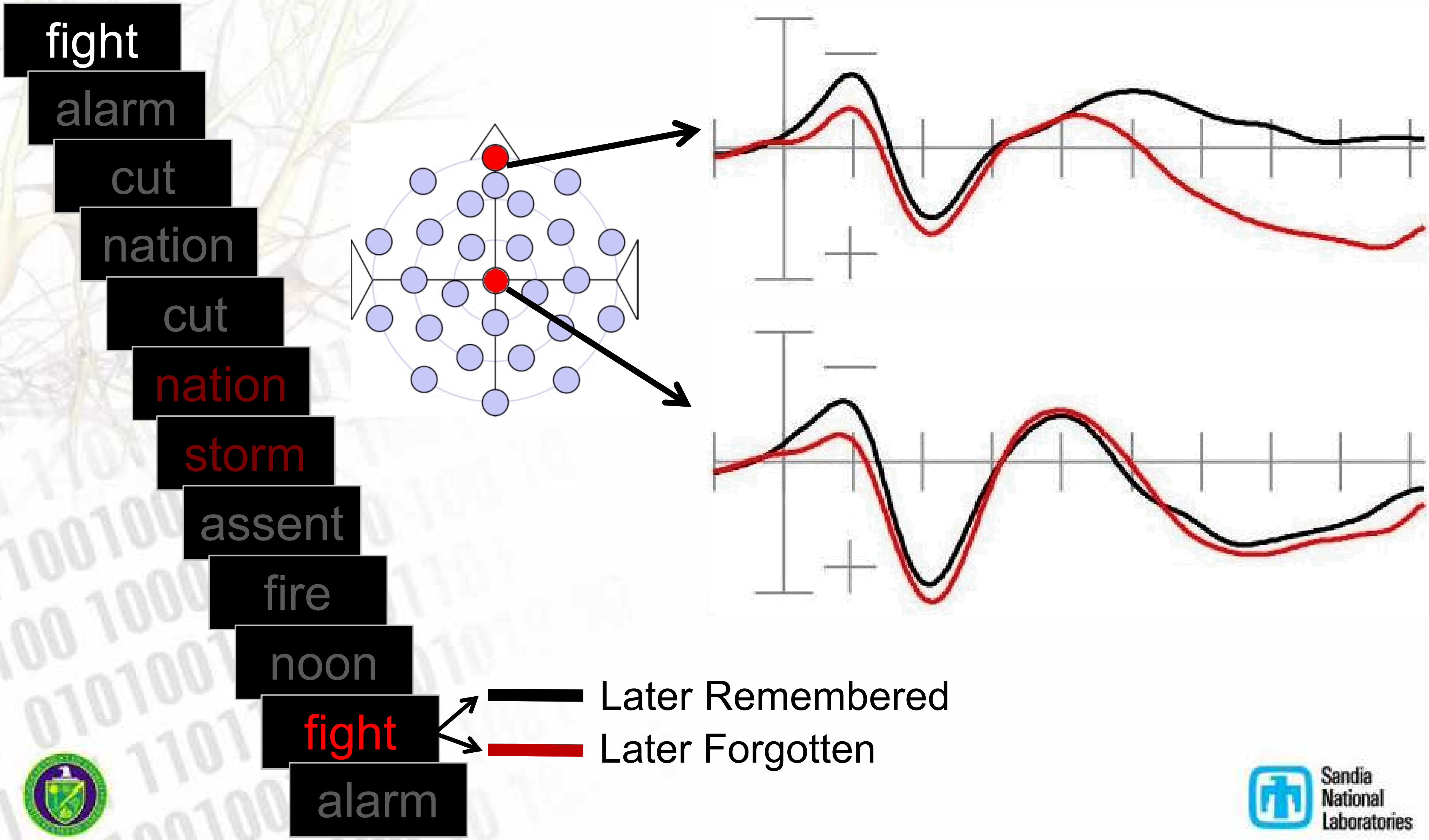

Summary of Experiment 1 Findings

- New information about Dm Effect
- Study-study conditions
  - Two routes to similar memory performance?
- Study-test conditions
  - Frontal negativity component
- Conference presentations:
  - Matzen, L. E. & Federmeier, K. D. (2010, June). Repetitions and reminding: A novel analysis of the Dm Effect. Presentation at the First Interbrain Symposium and International ICA Conference, Jyväskylä, Finland.

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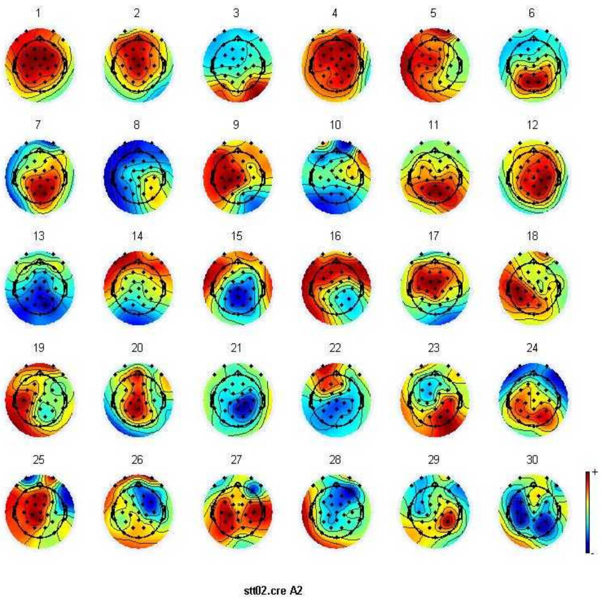
Next Steps

- Computational Modeling
- Exploring individual differences
- Experiments 2 and 3
- Designing interventions



Summary of Effort