Changes in the neural representations of abstract science concepts after metaphoric reasoning

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Background

How are concepts represented?

- Abstract, science concepts
  - 'Causal motion' (e.g. *gravity, centripetal force*) predicted 75% activations in regions associated with visualizing colliding objects and movements of objects and actions [1]

Do the representations of concepts differ depending on the context?

- Context-independent core is invariant [2]
- Context-dependent portion can be changed

**Change of concept (learning) via metaphor**

- Education studies: Metaphors lead to more in-depth thinking about concepts [3-4]
  - Seventh graders learned animal cells and organelles metaphorically [3]
    E.g. *A cell is a city. Nucleus is city hall. Mitochondria is the power company.*

Gap in knowledge: Did the cognitive-neural representation of the concept change as a result of metaphoric reasoning?

Present Study

Hypothesis A concept framed in metaphoric and literal contexts will have differential representations, reflected by ERPs

Pilot data (Student honors thesis, N=30)
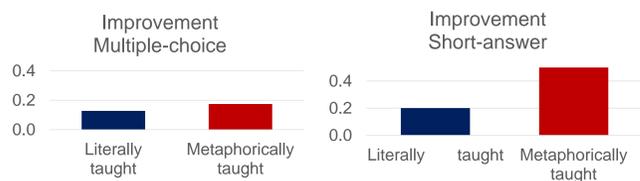
ERP predictions

- Larger late positivity from 400-600 ms [5]: Learned rare words (*gloaming*) > unlearned
- Larger late negativity from 500-700 ms [6]: Known words (*plenty*) trained with a novel meaning (*causing fever*)

Methods

Participants: 24 undergrads (ages 18-24, 14 female), each participated in two EEG sessions, within 1 week

Stimuli: 80 science concept words from astronomy, biology, chemistry, math, physics, etc …
40 pseudo words, resembling science words, matched in word length, transition freq., phonotactics.
80 Metaphoric and literal explanations were created.
Two norming tests ensured metaphor aptness (N=35): Mean=2.1, on a 1-3 scale (3=very apt).

Science knowledge assessment test: True-false and multiple-choice questions (replicated pilot data)

Pre-training EEG
- Science knowledge test
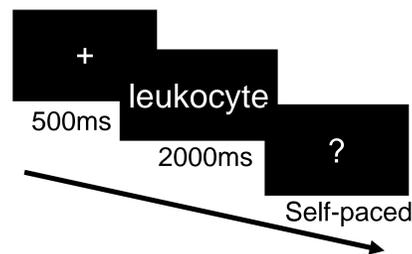
Training: One-on-one tutoring, offline

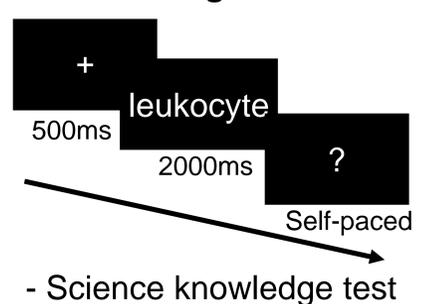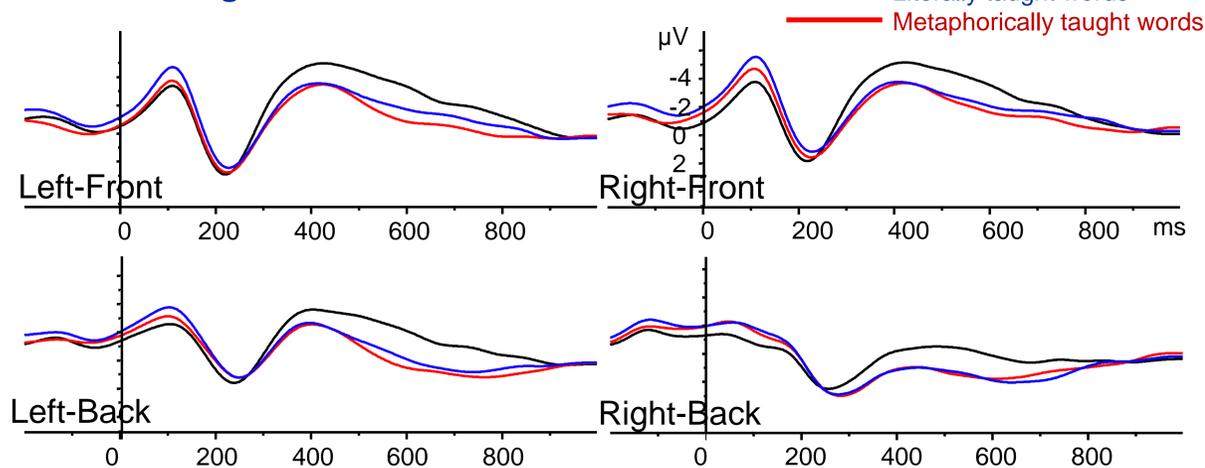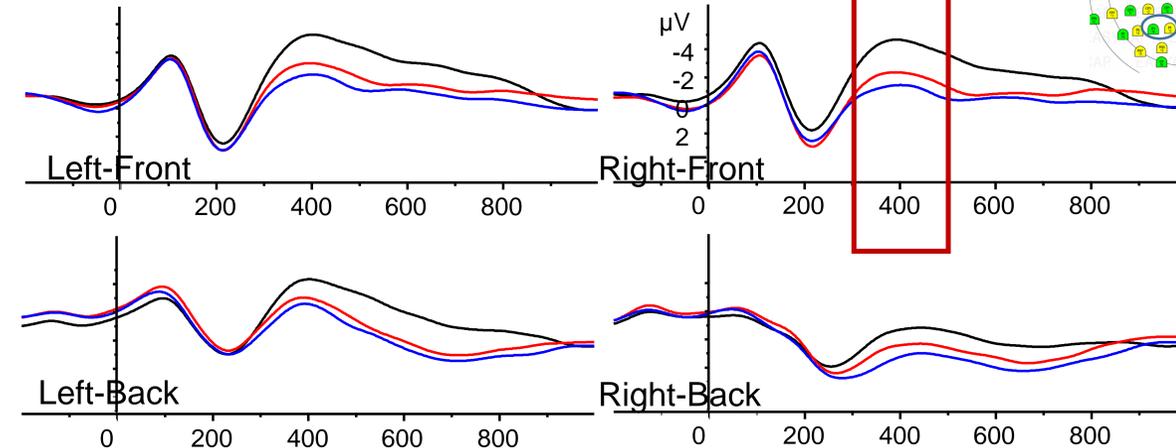| Literal	Metaphorical
A **leukocyte** is a colorless cell that eliminates foreign substances from the body. **Leukocytes help rid the body of illness or diseases.**	A **leukocyte** is a colorless cell that eliminates foreign substances from the body. **A leukocyte is the body's warrior that fights germs.**

Post-training EEG

- Science knowledge test

Results

Pre-training. N400: Pseudowords > words.

Legend: Pseudowords (black), Literally taught words (blue), Metaphorically taught words (red)

Left-Front, Right-Front, Left-Back, Right-Back

Post-training. N400: Metaphorically taught > literally taught words
Pseudowords > words

Left-Front, Right-Front, Left-Back, Right-Back

RM-ANOVA of 3 condition x 2 Left-Right x 2 Front-Back
Pre-training: Main effect of condition, $p<.05$
Post-training: Interaction & main condition effects, $p<.05$
Pairwise comparison metaphor vs. literal significant in the **Right Front** location: $F=4.435$, $p<.05$

Correlational analysis $r=.489$, $p<.05$

N400 effect vs. Science assessment scores After-Before
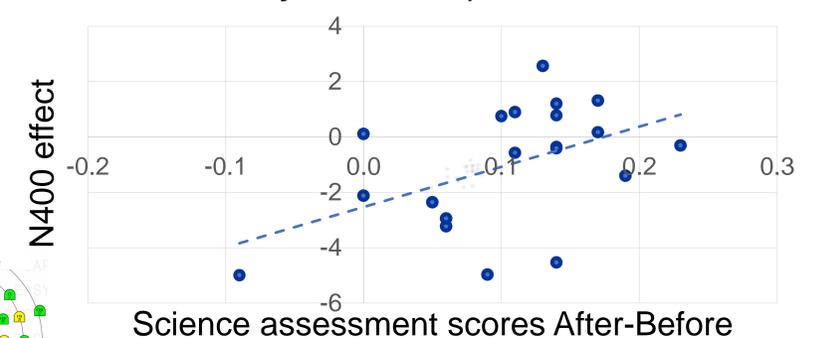
Discussion

- Richer meaning representation for metaphorically taught words than for literally taught words
  - Words with many meanings elicited larger N400s than words with few meanings [7]
- Metaphoric meaning instantiations may strengthen memory traces, which improves science knowledge

References: [1] Mason & Just 2016. [2] Barsalou, 1982. [3] Hansen et al. 2011. [4] Lancor 2015. [5] Perfetti et al. 2005. [6] Fang & Perfetti 2017. [7] Beretta et al., 2005.