Enhancing Learning via ‘Novelty Insertion’

Employing the neuroscience of learning to create more effective pedagogical approaches

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Our lab is interested in cortical plasticity
We find evidence of plasticity even late in the developmental timeline...

e.g. Progressive cortical de-correlation following sight onset
Soumitra
Although we now have evidence of plasticity, we do not really know what triggers this plasticity.

A possibility: ‘Plasticity on Demand’

When learning demands are increased, the brain responds by enhancing its capacity to change.

Exposure to novelty is one way of increasing learning demands…

… does novelty lead to enhanced plasticity?
Absolute Coding of Stimulus Novelty in the Human Substantia Nigra/VTA

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Summary

Novelty exploration can enhance hippocampal plasticity in animals through dopaminergic neuromodulation arising in the substantia nigra/ventral tegmental area (SN/VTA). This enhancement can outlast the exploration phase by several minutes. Currently, little is known about dopaminergic novelty processing and its relationship to hippocampal function in humans. In two functional magnetic resonance imaging (fMRI) studies, SN/VTA activations in humans were indeed driven by stimulus novelty rather than other forms of stimulus salience such as rareness, negative emotional valence, or targetness of familiar stimuli, whereas hippocampal responses were less selective. SN/VTA novelty responses were scaled according to absolute rather than relative novelty in a given context, unlike adaptive SN/VTA responses recently reported for reward outcome in animal studies. Finally, novelty enhanced learning and perihinal/parahippocampal processing of familiar items presented in the same context. Thus, the human SN/VTA can code absolute stimulus novelty and might contribute to enhancing learning in the context of novelty.

response (Dommett et al., 2005; Horvitz, 2000; Redgrave et al., 1999). These other forms of salience can be reported by stimuli that are familiar and are therefore not contingent upon stimulus novelty. A preferential response of the dopaminergic midbrain to stimulus novelty would indicate a special biological relevance for novelty as a motivating (Kakade and Dayan, 2002; Schultz, 1998) and/or reinforcing (Reed et al., 1996) stimulus dimension also in humans.

A number of brain regions that provide input into the dopaminergic midbrain are capable of processing not only stimulus novelty but also other forms of stimulus salience. Most notably, the hippocampus and the amygdala are held to be closely functionally linked to the dopaminergic midbrain (Lisman and Grace, 2005) as components of a wider functional dopaminergic system termed the mesolimbic dopaminergic system. The hippocampus appears capable of comparing incoming information with stored memories (Lisman and Grace, 2005) and is sensitive to stimulus novelty (Duzel et al., 2003; Tulving et al., 1996) as well as to other forms of salience such as deviance or rareness and targetness even if reported by highly familiar stimuli (Crottaz-Herbette et al., 2005; Halgren et al., 1980). The amygdala, a structure that, together with noradrenergic nuclei of the brain stem, is critically involved in generating arousal to emotionally salient stimuli and in improving long-term memory for such stimuli (McGaugh, 2004), has a direct projection to the dopaminergic midbrain (Pitkanen, 2000). This projection is functionally relevant for displaying responses to biologically salient stimuli, for instance, for displaying orienting responses in appetitive conditioning (Lee et al., 2005). The orienting response, in turn, includes both autonomic (Lee et al., 2005) and motor (Holland, 1977) components.

An important approach to better understand the functional link between novelty processing and dopaminergic neuromodulation in humans would be to clarify whether the substantia nigra/ventral tegmental area
Project Hypothesis:
Novelty insertion in instructional videos might enhance their learning

Specific Goals:
- To create variants of instructional videos with novelty/familiarity insertion
- To determine whether novelty insertion heightens engagement
- To determine whether novelty insertion enhances learning
Pilot Overview

N = 10

Group 1

Group 2

Break

Break

Lecture  Novel Video  Familiar Video
Video Samples
Pilot Overview

N = 10

Group 1
Pre-assessment

ECG

Group 2
Pre-assessment

Break

Break

Post-assessment

Lecture Novel Video Familiar Video

minutes

0 2 4 6 8 10 12 14 16 18

0 2 4 6 8 10 12 14 16 18

0 2 4 6 8 10 12 14 16 18

0 2 4 6 8 10 12 14 16 18

EDA
Result Scenarios

Cannot control for arousal and make statement about effect of novelty: **not enough data!**

**H₀**: no relationship between novelty and learning

**H₁**: novelty enhances learning independently of arousal
Physiological Recordings

Electrocardiogram (ECG)

Electrodermal Activity (EDA)
Signal Processing

- Extract phasic signal
- Peak detection

Raw EDA

- Normalized by baseline
- Applied window functions
- Averaged across participants
- Calculated slope for some metrics
- Calculated statistics

Raw ECG

- R-Peak detection
- RR interval calculation

Point Process Model of Heart Rate Variability

Optimizing the indices
By investigating:
- Sliding window size and shape
- Cropping response window to different lengths
- Latencies of signals relative to each other and subject
- Normalized by baseline
- Applied window functions
- Averaged across participants
- Calculated slope for some metrics
- Calculated statistics
Comparison of Arousal Across Experiment
Some Questions About Arousal
Does video type affect arousal?

Using EDA peak rate slope as an index of arousal:

\[ N > L > F \]

- **N** = average arousal during novel insertion
- **F** = average arousal during familiar insertion
- **L** = average arousal during lecture
Does elapsed time affect arousal?

P1, P2 = arousal during first and second halves of experiment, regardless of if there were novel or familiar insertions

Using **EDA peak rate slope** as an index of arousal:

P1 = P2
Synthesizing Arousal and Performance Results
Result Scenarios

H₀: no relationship between novelty and learning

H₁: novelty enhances learning independently of arousal

Cannot control for arousal and make statement about effect of novelty: not enough data!
Pilot results suggest that novelty may enhance learning while controlling for arousal.
Limitations

- Low statistical power
- Within-subject design
- High variability lecture content
- Few controlled factors between “novel” and “familiar” videos
Next Steps
Next Phase

N = 30

Group 1

Pre-assessment

Break

Post-assessment

Group 2

Break
Possible Future Steps
Possible Future Designs

N > 30

Pre-assessment

Group 1

Group 2

LTM-assessment

Post-assessment

Break

Break
Remote Experimentation

- Online study
- Portable Sensor Box
Summary

• Created experiment structure for studying learning in online lectures

• Found preliminary results suggesting a possible positive effect of novelty on learning

• We are working on a variety of improved techniques to provide better statistical power and experimental control

• We hope that this project can inform the development of more effective online learning
Acknowledgements

- Pawan Sinha
- Riccardo Barbieri
- Sidney Diamond
- Annie Cardinaux
- Matt Groth
- Lara Cavinato

All who we have consulted including Kyle Keane, Anna Musser, Dana Doyal, and more

- Kana Okano and Steven Shannon for helping us to use the EEG Laboratory of the Martinos Imaging Center at MIT

- MIT Integrated Learning Initiative (MITILI)

- All of our participants!
If you or someone you know would like to participate in our next experiment, please email anniec@mit.edu, thank you!