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Experiment Title: Effect of graph learning on stimulus discrimination

Research Project: Network structure influences the strength of learned neural representations

Purpose and Approach

When responding to a sequence of visual cues whose ordering is determined by an underlying set of possible transitions between these cues (e.g. each cue can only be followed by a certain subset of other cues, represented as a structured walk on a graph), human learners exhibit biases in their response times driven by higher-order properties of these graphs such as whether elements are clustered (Kahn 2018). Ongoing research suggests that, in addition to influencing behavior, graph structure can influence the neural representations of the associated visual cues: walks on modular graph structures, previously shown to induce overall lower reaction times, also induce more dissociable neural representations in visual cortices as seen using fMRI.

This increased dissociation suggests that, in addition to the reaction time decrease when responding to individual stimuli, visual discrimination between stimuli might be enhanced. Preliminary data suggests that reaction times on pairs of stimuli, when subjects judge whether two stimuli are identical or different (see study design below) are highly correlated with the neural dissimilarity of those shapes, where higher neural dissimilarity is associated with faster reaction times. The purpose of this project is to investigate whether, after exposure to visual stimuli following a structured walk on a graph, graphs that induced more distinguishable neural responses also lead to better visual discrimination between stimuli.

Subjects

We will collect a dataset of 50 healthy subjects: 25 for the modular and 25 for the ring-lattice group. In line with the neuroimaging subject pool, subjects will be right-handed, ages 18-35 and with no known psychiatric disorders and past neurological medical history. We will additionally exclude all subjects who took part in the neuroimaging experiment.

Each subject will be studied during two sessions on consecutive days.

Subject Preparation

The experimenter will situate the subject in front of the laptop and begin the experiment, which includes instructions on each day for performing the task. The experimenter will only clarify what is mentioned in the instructions. Subjects will wear headphones – during Session 1 this is only to block out sound, but Session 2 includes auditory cues for the task.

Testing could take place in a variety of settings, including in an on-campus laboratory, as well as in off-campus settings (home, coffee shop, etc). We will endeavor to test subjects in the same setting during Sessions 1 and 2, but this is not a requirement of the experiment.

Presentation

Subjects will observe sequences of stimuli presented on an Apple laptop and will respond to the stimuli on the laptop keyboard.

Stimuli and Responses

Subjects will be trained and tested on a set of 15 visual stimuli, and 15 one- or two-key combinations, using the keys 'space', 'j', 'k', 'l', and ';'. Stimuli are generated in MATLAB using ShapeToolbox, by perturbing a sphere with sinusoids. Each shape consists of two oscillations. Each oscillation can vary in amplitude (either 0.2 or 1), angle (0, 30, 60, or 90degrees), frequency (2, 4, 8, 10, or 12 cycles/2π), and the second oscillation can also vary in phase relative to the first oscillation (0 or 45 degrees). Out of the set of 3200 permutations, we selected a set of 15 visually distinct shapes. In order to study responses to high-level image features such as three-dimensional shape rather than retinotopic position or object size, we generate 5 variations of each image, differing in both size and rotation, allowing us to isolate responses invariant to these changes. Sizes and rotations: (100%, 0°), (90%, 5°), (100%, 10°), (90%, 15°), (100%, 20°)

Each of the 15 shapes and motor responses is assigned to one of 15 nodes in an assigned graph. Each mapping is random and unique to that participant. There are two possible graphs: a ring-lattice, where 15 nodes are arranged in a ring and each is connected to its two nearest neighbors in each direction, and a modular graph, where 15 nodes are arranged into three densely connected clusters, with one edge connecting each pair of clusters.

Session 1 Design

In Session 1, participants will complete 5 runs of 300 trials, during which the display shows five square outlines, corresponding to the five response keys ('space', 'j', 'k', 'l', and ';'). Trial order is generated based on a walk through the graph – in other words, if the stimulus (and associated motor response) of the current trial correspond to node **X** in the graph, then the stimulus (and associated motor response) of the next trial correspond to one of the neighbors of **X**, continuing in an unbroken sequence for 300 trials.

On each trial, participants will be prompted with both the visual stimulus and the chord for that trial, with the stimulus preceding the chord. First, the stimulus for the current trial is displayed within the black border of each square, identically for each of the 5 squares. 0.5s later, the target squares are highlighted in red. Either the visual stimulus or the highlighted squares can be used by the participant - both provide identical information about which buttons to press.

However, the stimulus is shown earlier to encourage participants to attend to the stimulus in addition to the highlighted squares.

Participants will be instructed to respond as quickly as possible. Trials in this section are self-paced, meaning that the stimulus remains on the screen until the participant presses the correct chord, and the total session length depends on the subject's speed of responses. As soon as the correct chord is pressed, the next trial appears with no delay. If the participant responds incorrectly, 'Incorrect' will appear on the screen, but the trial will still not advance until the correct chord was pressed.

Session 2 Design

In Session 2, participants will complete 8 runs of 210 trials. On each trial, two of the fifteen stimuli are shown side-by-side. Rather than testing on all 105 unique shape pairs, each subject will be tested on 1 of 5 sets of 21 shape pairs. The stimuli are either variations of the same shape, or different shapes, and the participant must indicate as quickly as possible whether the shapes are different (by pressing 'f') or identical (by pressing 'j'). Stimulus onset timing is jittered, varying from 800ms to 1.3s after the start of the trial. Stimuli remain on the screen for 500ms until being replaced by a fixation target. Subjects have an additional 1.5s to respond after the stimuli disappear. Subjects are additionally presented with auditory cues: a 440Hz beep indicates the start of every stimulus display, a 300Hz beep is played to indicate an incorrect response, and a 250Hz beep is played to indicate that the subject failed to respond in time.

Analysis

For each subject, we will calculate the mean inverse reaction time when responding to each pair of stimuli, excluding incorrect responses, as a measure of visual dissimilarity. We will ask whether reaction times significantly differ as a function of the graph that generated the sequence observed by that subject.

Exclusion Criteria

We will exclude subjects on the basis of poor performance. If the subject responds correctly to less than 75% of trials in either session, either by failing to respond or by responding incorrectly, all data from that subject will be excluded and a replacement subject will be recruited.

If a subject is unable to complete their second session on the day following their first session, then their data will be discarded and a replacement subject will be recruited.

References

Kahn, Ari E., Elisabeth A. Karuza, Jean M. Vettel, and Danielle S. Bassett. “Network Constraints on Learnability of Probabilistic Motor Sequences.” *Nature Human Behaviour* 2, no. 12 (December 2018): 936–47.