The effect of a loss of sense of agency on apathy

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Abstract

This paper investigates whether a loss of sense of agency can increase apathy. To address this question, we employ two complementary experimental methods: (i) electroencephalography (EEG) using a 64-channel electrode cap to measure neural activity, and (ii) MRI combined with transcranial temporal interference stimulation (tTIS) targeting the ventral striatum, a region of the brain associated with motivation, via electrodes.

In both experiments, participants complete an interactive, effort-based decision-making tapping task in which their sense of agency is modulated. The goal is to examine the relationship between agency and apathy, as well as to characterize the neural mechanisms of apathy.

The current study is conducted with a healthy population, with future applications aimed at Parkinson's disease (PD) patients.

By investigating whether alterations in the sense of agency contribute to apathy, this research may provide a foundation for exploring strategies to modulate agency in ways that could ultimately help reduce apathy.

Contents

1 Introduction

Sense of agency refers to the subjective experience that voluntary actions produce intended outcomes. [1] In other words, it is the feeling of being in control.

Apathy is a loss of motivation, causing a reduction in goal-directed behaviour. [2] It is a common symptom in a variety of neurological disorders, including Parkinson's disease (PD), Alzheimer's disease, schizophrenia, and depression, highlighting its broad clinical relevance.

Existing research links apathy to the ventral striatum in the basal ganglia, a key region in the brain for reward processing and motivation. Dopamine in the ventral striatum is an essential component of the mesolimbic pathway, a dopaminergic circuit connecting the ventral tegmental area (VTA) to the ventral striatum. Dopamine deficits in this pathway are thought to contribute to the development of apathy. [2]

Apathy is a prevalent non-motor symptom of PD, affecting approximately 40% of patients. [3] Parkinson's disease is caused by the loss of dopaminergic neurons in the substantia nigra, a brain region critical for dopamine production. Dopamine is necessary for motor function, and plays a role in motivation, explaining why PD patients may exhibit apathy alongside the akinesia characteristic of the disease.

This study aims to investigate whether a loss of sense of agency can increase apathy. The participants, a sample of healthy 18–35-year-olds, will perform an effort-based decision-making tapping task in which their sense of agency is experimentally modulated.

The study employs two complementary methods: magnetic resonance imaging (MRI), which provides high spatial resolution, and electroencephalography (EEG), which offers high temporal resolution. Participants' state of apathy will be assessed during the task, and brain imaging data will be analysed to determine whether experimentally induced changes in sense of agency influence apathy.

We hypothesize that reducing participants' sense of agency during an effort-based decision-making task will decrease their motivation and increase their state of apathy.

2 Methodology

2.1 Study Recruitment

Participants for both studies were healthy individuals recruited through the EPFL Laboratory of Cognitive Neuroscience Research Participation System. Inclusion criteria were:

- Right-handed
- Aged 18–35 years
- Fluent in French and English
- Able to give informed consent
- No history of psychiatric or neurological disorders
- No history of drug abuse or addiction
- No drug use in the two weeks preceding the study
- No prior participation in a tapping task experiment

The EEG study targeted 30 participants for the final dataset, and the MRI study targeted 25 participants, with additional recruitment to account for potential dropouts or data needing to be excluded. Data collection for the EEG study is complete, while the MRI study has collected data from 10 of the 25 targeted participants.

2.2 Tapping Task

An effort-based decision-making tapping task was used in both the MRI and EEG studies to investigate motivation and sense of agency. In this task, participants repeatedly press a button with the same finger to move a red bar toward a blue target on the screen. Targets vary in height, representing different effort levels, with higher

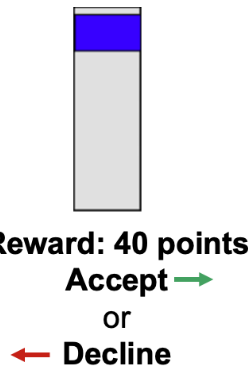

Figure 1: Image of a single trial in the tapping task. Participants see the target bar height (representing effort level), the potential reward for successful completion, and the option to accept or decline the trial.

targets requiring more taps. Each trial also displays a potential reward in points (1 point $\approx$ 0.1 CHF), allowing participants to make a cost-benefit analysis of the trial.

Participants' sense of agency is experimentally manipulated through two conditions: in half of the blocks, there is a delay condition, in which visual feedback of the bar is slowed, creating a visuomotor conflict that disrupts participants' sense of control. In the other half, there is no-delay condition, and the bar responds immediately to key presses. Blocks with and without visuomotor conflict are presented in a randomized order.

Before the main task, participants complete a calibration phase to measure maximum tapping speed. During the task, participants can accept or decline each trial based on the displayed effort and reward. Accepted trials only require completion 25% of the time, otherwise, the reward is automatically earned. Participants are unaware of this probability.

In the EEG study, participants complete 8 blocks of 135 trials each (1080 trials total). In the MRI study, participants complete 6 blocks, each lasting approximately 4 minutes. Blocks are organized by agency condition (delay vs. no-delay), and trials vary across three reward levels (Low, Medium, High) and three effort levels (Low, Medium, High).

At the end of each block, participants complete a series of 7-point Likert scale questionnaires to assess their self-reported apathy, effort, sense of agency, motivation, attention, and fatigue. Questions include items such as perceived control over the bar, task difficulty, effort exerted, satisfaction with performance, and overall tiredness.

After completing all the blocks, participants perform a final calibration to reassess maximum tapping speed, ensuring that differences in motivation are attributable to agency modulation rather than muscular fatigue.

By comparing acceptance rates and questionnaire responses between blocks with and without visuomotor conflict, we aim to determine whether a loss of sense of agency increases the state of apathy.

2.3 EEG Protocol

The EEG recordings were conducted in a room set up with the following equipment:

- 64-channel EEG cap
- 4 EOG electrodes and 2 ECG electrodes
- EEG amplifier (ANT Neuro)
- Laptop for EEG data collection
- Laptop for task execution
- 64-bit trigger cable and Arduino
- Electrode gel
- Syringes (to apply electrode gel)

A 64-channel EEG cap was fitted to the participant's head, and electrode gel was applied. Impedance was monitored through the EEG software and kept low to ensure strong connectivity and clear signal quality.

Four EOG electrodes and two ECG electrodes were then placed to monitor eye movements and cardiac activity, respectively. Two EOG electrodes were positioned at the outer corners of the eyes to capture horizontal movements, and two were placed above and below the left eye to capture blinks. One ECG electrode was placed on the upper left chest and the other on the lower right abdomen.

Once all electrodes were in place, signals were checked on the recording laptop. Participants were asked to look left and right, clench their jaw, and blink several times. If the corresponding artefacts were visible in the EEG data and overall signal quality was sufficient, the recording session proceeded.

The EEG recording began with two resting-state tasks: first, participants fixated on a central white cross on a black screen for five minutes in silence; second, they repeated the task while listening to white noise through headphones.

Participants then performed the effort-based decision-making tapping task.

After completing the task, participants filled out four questionnaires designed to assess their state of apathy. At the end of the session, they received hourly compensation as well as payment corresponding to the bonus points earned during the task.

2.4 MRI Protocol

The MRI study consisted of two sessions: an iTBS-tTIS session, in which the ventral striatum was stimulated using intermittent theta-burst stimulation delivered via transcranial temporal interference stimulation (tTIS), and a control session, in which participants received high-frequency (HF) stimulation. The study followed a double-blind design to prevent bias from either participants or researchers.

tTIS is produced by the interference of two high-frequency alternating currents with a slight frequency difference (e.g., 2000 and 2010 Hz). This interference generates a low-frequency "envelope" capable of stimulating a targeting brain region. tTIS is a novel, non-invasive stimulation method, which recent studies suggest may allow more precise stimulation of deep brain regions than conventional non-invasive approaches, such as transcranial alternating current stimulation (tACS). [4]

In the HF control condition, two identical high-frequency alternating currents are delivered simultaneously. Because the frequencies are the same, the interference cancels out, resulting in no effective stimulation.

The goal of applying iTBS-tTIS was to investigate whether stimulating the ventral striatum could modulate motivation, particularly increasing it.

Stimulation was delivered via four electrodes: two placed in anterior positions and two in posterior positions, controlled by two bipolar constant current stimulators (one for anterior, one for posterior).

At the beginning of the session, participants completed a set of questionnaires:

- Lille Apathy Rating Scale (LARS)
- Dimensional Apathy Scale (DAS)
- Questionnaire for Impulsive-Compulsive Disorders in Parkinson's Disease (QUIP)
- Hospital Anxiety and Depression Scale (HADS)

While participants completed the questionnaires, electrodes were applied and secured with a bandage. Impedance was measured separately for anterior and posterior pairs using a 2 Hz test signal split in a 1:1 ratio, and impedance values were kept below 12 kΩ to ensure adequate connectivity.

After this, the participant was positioned securely inside the MRI scanner and provided with a button box for the tapping task.

Inside the MRI, a T1-weighted structural scan was acquired to map brain anatomy.

Subsequently, a functional MRI (fMRI) scan was performed using a gradient-recalled echo (GRE) sequence. GRE sequences are highly sensitive to fluctuations in the magnetic field, allowing them to detect the blood-oxygen-level-dependent (BOLD) signal. This signal reflects changes in blood oxygenation, which enables identification of brain regions with increased neural activity based on local blood flow. [5]

Following this, participants underwent a 10-minute resting-state scan while fixating on a white cross on a black background. Resting-state establishes baseline activity in the default mode network and provides the functional connectivity between brain regions in the absence of a task.

Participants then completed practice and calibration trials before beginning the effort-based decision-making tapping task. During the task, participants received either iTBS-tTIS stimulation or HF stimulation, delivered at an intensity of 4 mA depending on the session.

After the task, another GRE sequence was acquired. Impedance was checked once more to verify that connectivity had been maintained throughout the session.

At the end of the study, participants received their hourly compensation as well as any additional payment corresponding to bonus points earned during the task.

3 Data Processing

3.1 EEG Processing

Currently, the EEG data is in a preliminary phase of preprocessing and analysis.

Preprocessing is performed in Python, beginning with the removal of segments not associated with task performance (e.g., pauses or setup periods).

The data is then band-pass filtered between 0.5 Hz and 50 Hz. The high-pass filter at 0.5 Hz removes very slow frequencies unrelated to neural activity, while the low-pass filter at 50 Hz reduces high-frequency noise, including muscle artefacts and line noise. [6] This ensures that the remaining signal primarily reflects brain activity within the standard frequency range of interest.

After this, each channel is inspected, and any flat channels are excluded from the data.

The data then undergoes independent component analysis (ICA), which separates the EEG signal into statistically independent components. These components are compared with the signals measured from the EOG and ECG electrodes; if they match, the corresponding artefacts are removed, and the channel is marked as “bad.”

Other noisy channels are identified if the signals frequently exceed amplitudes of 150 μV, and these are also marked as “bad.”

The “bad” channels are reconstructed through interpolation from nearby electrodes.

The next phase of data processing, which has not yet been carried out, will involve segmenting the EEG data into tapping trials with and without delay, and plotting the differences between the averaged signals across these conditions.

3.2 MRI Processing

The MRI effort-based decision-making tapping task results have undergone some preliminary analysis. The acceptance rate of each participant was averaged across the total number of trials and separated into delay conditions, effort levels, and reward levels.

However, the MRI imaging data has not yet undergone preprocessing or analysis. Once data collection is complete, the first step will involve co-registering the functional MRI (fMRI) scans (resting-state and task-related) with each participant’s T1-weighted structural MRI scan, ensuring that observed brain activity is accurately mapped onto anatomical regions.

Resting-state fMRI data will be analyzed to identify intrinsic connectivity networks, including the default mode network (DMN), which will serve as a baseline for comparison with task-related activity. [7]

For the task-based fMRI, neural activity will be modeled using the hemodynamic response function (HRF), which describes how localized changes in neural activity are reflected in blood-oxygen-level-dependent (BOLD) signals. [8] This approach will allow us to determine which brain regions show greater activation when participants perform the effort-based decision-making tapping task under delay versus no-delay conditions.

4 Results

Preliminary behavioral results from the MRI effort-based decision-making tapping task are reported below. These analyses focus on participants' acceptance rates across reward, effort, and agency conditions.

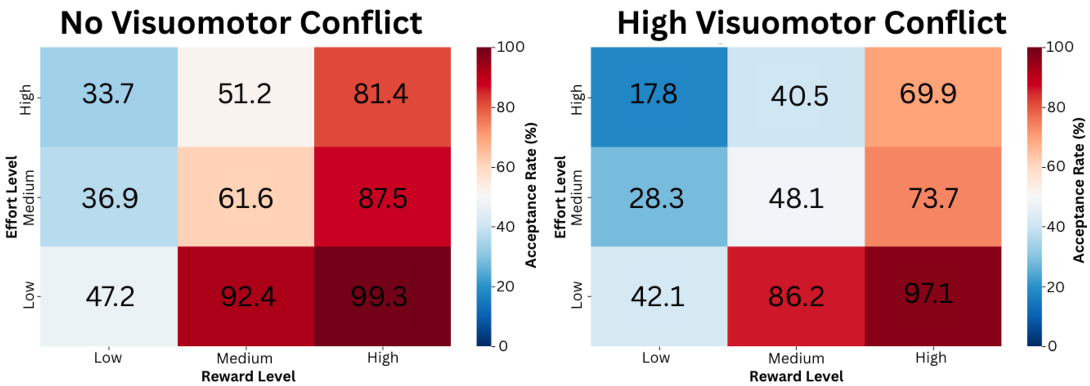

Figure 2: Heatmaps showing average acceptance rates for the effort-based decision-making tapping task, separated by effort level and reward level. Left: no-delay condition (no visuomotor conflict). Right: delay condition (visuomotor conflict).

These heatmaps display the average acceptance rate of the effort-based decision-making tapping task for each participant, combined across both stimulation and control sessions. Because the study is double-blinded and still ongoing, the data has not yet been separated by stimulation condition.

As expected, acceptance rates were highest in high-reward/low-effort trials and lowest in low-reward/high-effort trials.

When comparing agency conditions, participants exhibited globally higher acceptance rates in the no-delay condition (no visuomotor conflict) than in the delay condition (visuomotor conflict). This pattern suggests that a reduced sense of agency is associated with increased apathy, as reflected by diminished motivation to engage in the task.

5 Conclusion

This study investigates the relationship between sense of agency and apathy through an effort-based decision-making tapping task, combining EEG and MRI methodologies in healthy participants.

Although the project is still in its early stages and data analysis is ongoing, preliminary behavioral results already suggest a clear pattern: loss of agency, induced through visuomotor conflict, is associated with increased apathy, reflected in reduced task motivation.

The next phase of the research will involve extending this paradigm to clinical populations, particularly individuals with Parkinson's disease (PD). This is of particular relevance given that akinesia in PD has been linked to disruptions in the sense of agency, and apathy remains a debilitating and difficult-to-treat symptom in this population.

By understanding the mechanisms through which agency influences motivation, this work has the potential to inform the development of targeted interventions for apathy, both in PD and in related neuropsychiatric conditions.

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