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Tracing Brain Functional Connectivity During Observation of Others' Preferences could point to Occurrence of Behavioral Contagion

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Abstract
Behavioral contagion (BC) is defined as the mimic and adopt of others' preferences after observing. This type of contagion has crucial role in changing behaviors of the individuals and groups. Our fMRI task-based study had been organized to understand about this phenomenon. Our task was developed on the basis of dictator game (DG) which is a behavioral economic paradigm. The task had three sessions, before, observation and after. During the three sessions, the participants were scanned for fMRI. In behavioral analysis we found some participants had shown BC after observing others' preferences but some hadn't. In this part of the study, we have tried to find the reasons for this difference between the Contagion and No-Contagion groups. To this end, the adjacency matrices of the two groups were compared in the resting state, session 1 and session 2. There was no significant difference between the adjacency matrices of the groups in the resting state. No significant difference was found when comparing sessions 1 either. However, in session 2, two completely different patterns were observed for the Contagion and No-Contagion groups. It is interesting to note that the pattern of No-Contagion group showed fourteen reduced connectivity, with most of the resources located in different layers of the frontal gyrus. The pattern of the Contagion group showed eight increased connectivity with different resources. We believe that these results provide a good insight into behavioral contagion and could prepare a predictor for the occurrence (or non-occurrence) of behavioral contagion in individuals.

Keywords*:* Behavioral Contagion, fMRI, Adjacency Matrices, Dictator Game

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1. Introduction

Behavioral contagion (BC) refers to the tendency to adopt and copy the behavior of others after observing these behaviors without intending to do so. Behavioral contagion results in behaviors being transferred from one individual to others and can affect groups and social behaviors. This phenomenon is one of the most important parameters in changing individual and social behaviors. Despite these important functions, most of the brain mechanisms involved are still unknown. Most studies have reported that some subjects have shown no behavioral contagion (Abraham et al., 2020; Foulk, Woolum & Erez, 2016; & LoBue et al., 2022). Despite the prevalence of BC, not all individuals are affected. What are the reasons for this difference between individuals? What is the neural mechanism for the difference between subjects with and without contagion?

Researchers have suggested various reasons and factors depending on their field. Some have discussed the influence of social context on behavior adoption (Christakis & Fowler, 2009) and some have suggested that an individual's emotional state may influence his or her susceptibility to behavioral contagion (Hatfield, Cacioppo & Rapson, 1994). In our study, we used the fMRI scanner and a modified version of the dictator game as a task to assess these differences in behavioral contagion. To this end, behavioral analysis was used to extract the changes in participants' preferences (before and after) by comparing sessions 1 and 3. In this step, the Behavioral Contagion Rate (BCR) was defined to show the extent of contagion. Based on a BCR threshold, participants were categorized into two groups, labeled as Contagion and No-Contagion. In the next steps, the adjacency matrices of the participants in the groups were calculated and then statistically analyzed.

2. Materials and methods

Participants

31 healthy right-handed participants (15 men) (mean age=28.22 years and age range=18-40 years) took part in the study. They had at least a BSc degree. They had no history of psychiatric or neurological diseases or disorders and no reported drug use. During the final analysis steps, one of them was excluded from the study due to a technical defect. When incorporating figures into your manuscript, ensure that each figure is labeled with a specific title, such as "**Figure 1**," "**Figure 2**," and so on. Provide a brief descriptive caption for each figure to clarify its content and relevance. All figures must be clear, sharp, and of high quality. If the quality of the images decreases when inserted into the Word file, please also submit the original image files separately to maintain their resolution.

Experimental procedure

All participants were selected for our study based on the above criteria. They were familiarized with the three independent sessions of task. The duration of each session was fifteen minutes. All participants were selected for our study on the basis of the above criteria. They were familiarized with the three independent sessions of task. The duration of each session was fifteen minutes. There was a 2-minute break between sessions. There was no jittering in the task steps. Each session consisted of 66 trials in which participants were presented with two patterns for splitting a gift between the participant (called as "Self") and an unknown person (called as

"Other"). They had to choose one of the two patterns on each trial. During the performance of the task and the selection of preferences, the participants were scanned to obtain fMRI data. Before the task began, participants were scanned for seven minutes in a resting state with their eyes open. After scanning, all behavioral data were analyzed to distinguish two groups: Groups with and without contagion (called as Contagion and No-Contagion). In the next step, the fMRI data of resting states, sessions 1 and sessions 2 of the two groups were analyzed separately and their adjacency matrices were extracted. The statistical analysis was the last step. In this analysis, an independent t-test was performed to determine the changes in the resting states, sessions 1 and sessions 2, of the two groups that may have caused these different characteristics (Figure 1).

Figure 1 *Experimental procedure*

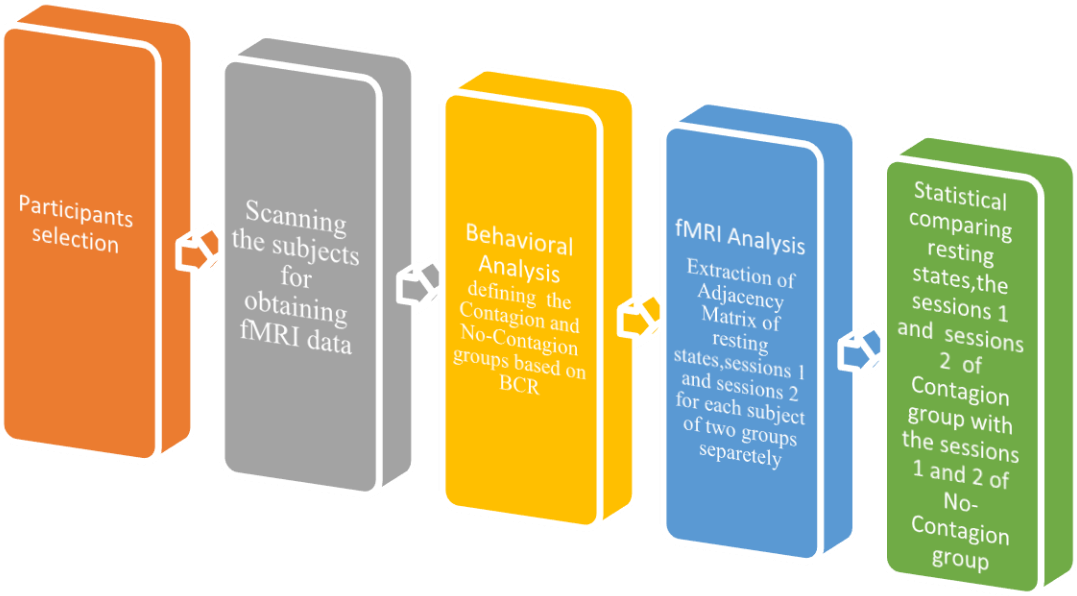


Image Acquisition

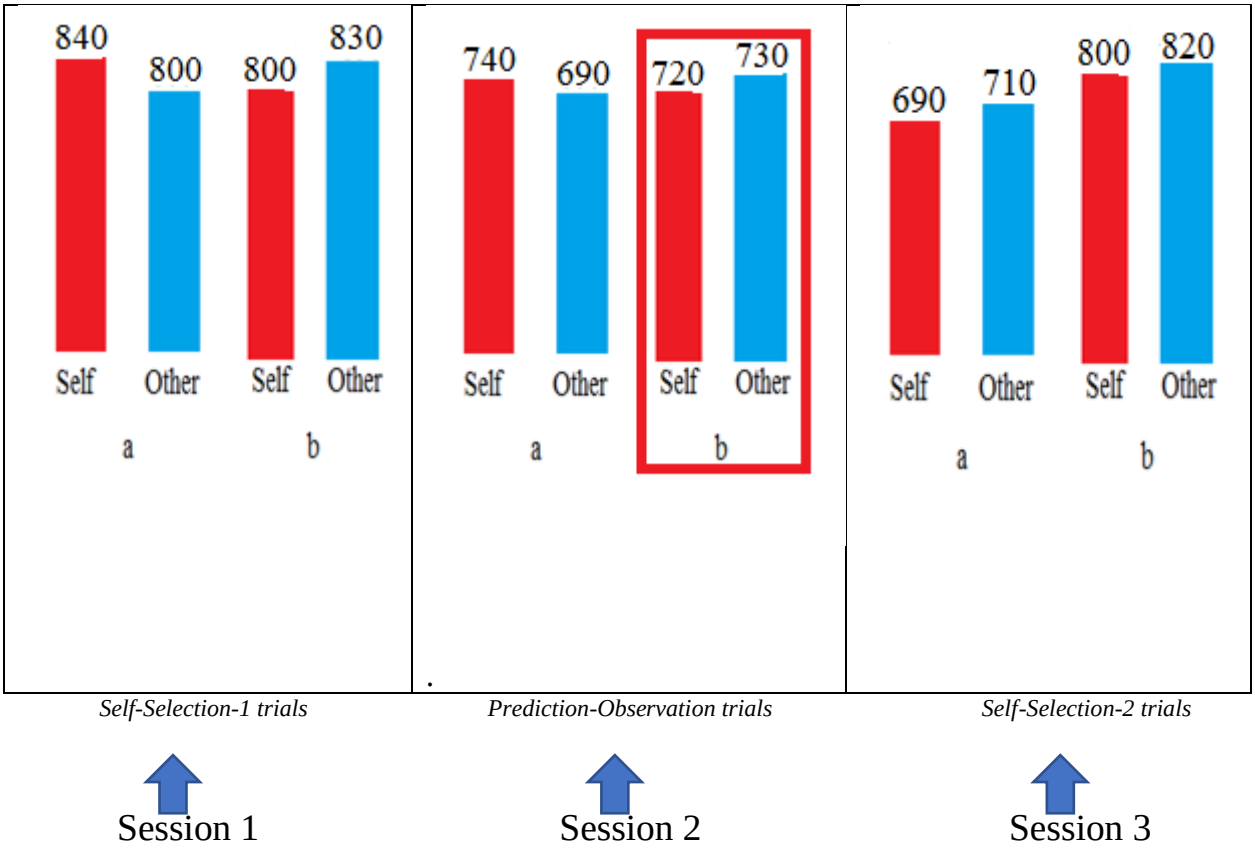
Our scanning for this study was done with a 3 Tesla Siemens Prisma scanner with a 32-channel head coil. The used parameters for acquiring the T1-weighted images were voxel size = 1.0×1.0×1.0 mm^3, flip angle = 7°, TR = 1800.0 ms as repetition time, TE = 3.5 ms indicating the echo time.

The parameters for fMRI scanning were: voxel size = 3.0x3.0x3.0 mm^3, FOV= 240 mm as the field of view, flip angle = 80 °, TR=2000 ms, TE= 32 ms, slice number = 35, and slice thickness = 3.00 mm.

Experimental Stimuli

The dictator game (DG) as a well-known experimental paradigm is the semantic structure of our task. In this paradigm there are two active and passive persons. In our task, which was developed as a version of the DG, there were three sessions with 66 trials for each session. In each trial of sessions 1 and 3, participants were asked to choose one of two patterns showing the way a gift was divided between the participant (called as 'Self') and an unknown passive person (called as 'Other') (Figure 2).

Figure 2 *In sessions 1 and 3 (called as Self-Selections-1 and Self-Selections-2 trials), participants had to choose their preferences. In session 2 (Prediction-Observation trials), the participants had to guess the choices of an unknown person in each trial. If the guess was correct, a blue square appeared around the choice, otherwise a red square appeared. In this session, the participant should become familiar to others' preferences with high attention.*



In the second session trials, referred to as "Prediction-Observation trials," each participant was asked to predict the preferences of an unknown person. To generate the unknown person's preferences, the task extracted the parameters of the Fehr-Schmidt model based on each participant's preferences in session 1. These parameters were then adjusted so that the generated preferences of the unknown person differed from those of the participant.

The hidden goal of the second session was to actively familiarize participants with the unknown person's preferences.

Technically, the first and third sessions (referred to as "Self-Selections-1" and "Self-Selections-2" trials) are identical. The changes in participants' preferences between sessions 1 and 3 (caused by observing the unknown person's preferences) demonstrated behavioral contagion. While the task was running, the participants' brain activity was scanned. The task was developed using MATLAB (R2021a; The MathWorks Inc., Natick, MA, USA) and Psychtoolbox-3 (Clavien & Klein, 2010).

Fehr and Schmidt Model

The Fehr and Schmidt (FS)Model is a theory about fairness and reciprocity in the field of economical behavior. This model tries to explain how the economic decisions were affected by the individuals' preferences for fairness. This model suggests that in inequality situations, the individuals have behaviors toward fairness and dislike both of advantageous and disadvantageous inequity. The model predicts that people make decisions to minimize the economic inequity. The FS model has a utility function to quantify the relationship of effective parameters which allows researchers to measure and analyzing the influence of preferences on socioeconomic behaviors. The general form of this utility function is:

$$Ui=Mi - \alpha i \max[(Mj- Mi), 0]- \beta i \max[(Mi - Mj),0] \qquad i \neq j$$

Ui represents the utility function of individual *i*. *Mi* and *Mj* are the payoff of individual *i* and the other, respectively. α and β denote the weights that are related to the differences between the payoff of individual (*Mi*) and the other's payoff (*Mj*) (Fehr & Schmidt, 1999, 2000; Fehr, Naef, & Schmidt, 2006; Rohde, 2010).

3. Data analysis

Behavioral Analysis

After obtaining the fMRI data, the behavioral data were analyzed. In our algorithm, we calculated the similarity between the preferences in session 1 and the generated preferences of the unknown person in session 2. Additionally, we calculated the similarity between the preferences in session 3 and the generated preferences in session 2. The Behavioral Contagion Rate (BCR) was the difference between these similarities.

$$BCR = N_{s2\&\ s3} - Ns_{1\&s2} \qquad (2)$$

In the above equation, s and N represent the sessions and the number of similarities between sessions, respectively. A threshold for the occurrence of behavioral contagion was set at 4 (more than 5% of trials). Using this threshold, participants were categorized into Contagion and No-Contagion groups. Our results of the connectivity analysis of the fMRI data confirmed this threshold for the occurrence of BC.

Neuroimaging Analysis

In this step, the CONN functional connectivity toolbox (version 22a; Whitfield-Gabrieli & Nieto-

Castanon, 2012) implemented in MATLAB was used to analyze the fMRI data. After setting up the fMRI and MRI data and conditions in CONN, the default preprocessing was performed. The main steps of this preprocessing typically include functional realignment and unwarp, slice timing correction, structural segmentation and normalization, functional normalization, and spatial smoothing. Using the default preprocessing, CONN provides a basis for functional connectivity and statistical analysis. Then the default atlas in CONN was replaced by the Schaefer-400 brain atlas. This atlas divides the cortex into 400 different regions, providing a finer view for connectivity analysis. Our study had a pre-post design including three sessions. In next step, the subjects' adjacency matrices of three sessions for two groups were extracted (Nieto-Castanon, 2020a, 2020b; Nieto-Castanon & Whitfield-Gabrieli, 2022; Smith et al., 2023).

Statistical Analysis

In the behavioral analysis corresponding to the threshold for BCR, participants were divided into two groups: Contagion and No-Contagion. The purpose was to investigate whether the differences between the two groups were due to differing baseline states of brain activity or differences in the way stimuli are processed in their brains. To address this question, we conducted a statistical analysis comparing the resting states of the two groups. Additionally, we compared session 1 between the two groups and session 2 between the two groups.

The independent t-test showed no significant difference in the resting states and sessions 1 between the groups. However, significant differences were observed in sessions 2 ("Prediction-Observation Trials") between the Contagion and No-Contagion groups.

In this study, several statistical procedures were conducted to test the hypothesis about connectivity differences during behavioral contagion for resting states, sessions 1, and sessions of two groups separately.

The independent t-test was one method used in our analysis. The independent t-test (also known as a two-sample t-test) is used to determine whether there is a significant difference between the means of two independent groups. Due to the unequal variances between the two groups, Welch's t-test (as a type of independent t-test) was used (Cohen, 1988).

The t-statistic (also known as the t-value) is a measure used to determine the significant difference between the means of two groups in hypothesis tests. It is particularly useful when the sample size is small or the standard deviation of the population is unknown (Field, 2013).

To account for multiple comparisons, corrected p-values were calculated using the False Discovery Rate (FDR) method. The FDR method manages the rate of false positives among the significant results (Benjamini & Hochberg, 1995).

4. Results

In behavioral analysis, a threshold was defined which in further analysis became the base. Two groups with and without contagion (called Contagion and No-Contagion) groups were differentiated by this threshold. Our hypothesis was about the differences between these groups which cause the occurrence (or not) of BC. To study the probable differences, the adjacency matrices of the participants of two groups in resting states, sessions 1 and sessions 2 were extracted using the ROI-to-ROI approach. To analyze the data, we performed independent t-tests

to compare the adjacency matrices of the resting states between the Contagion group (400, 400, 16) and No-Contagion group (400, 400, 13), the adjacency matrices from sessions 1 between the two groups, and the adjacency matrices from sessions 2 between the two groups. There was no significant difference between two groups in resting state and session1.

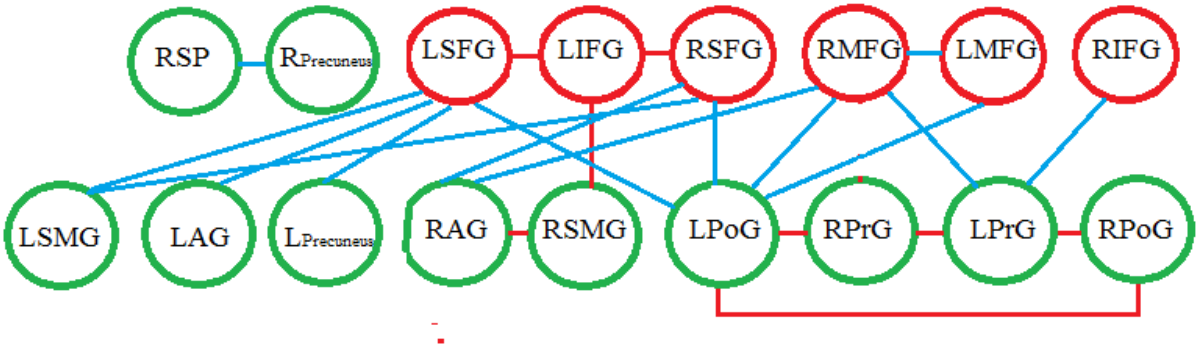
But for sessions 2 of groups, there were twenty-two significant connectivity between the clusters of two groups(p-value<0.05). The positive t-statistic values indicate that Contagion group has eight strong connections between these regions compared to No-Contagion group (Table.1). In such way, the negative t-statistic values indicate that No-Contagion group has fourteen strong connections between these regions (Table.1).

Table.1: *Differences Between Adjacency Matrices of Contagion and No-Contagion Groups: The table shows the t-statistic values indicating the strength of connectivity between regions for both groups. Positive t-statistics signify stronger connections in the Contagion group, whereas negative t-statistics denote stronger connections in the No-Contagion group.*

	Connections	t-statistic	p-value	FDR-corrected p-value
1	Right Angular Gyrus to Right Supramarginal Gyrus	8.164	1.67e-08	0.002
2	Left Postcentral Gyrus to Right Precentral Gyrus	8.359	1.21e-08	0.001
3	Right Postcentral Gyrus with Left Precentral Gyrus	7.525	1.78e-07	0.02
4	Left Superior Frontal Gyrus with Left Inferior Frontal Gyrus	8.195	6.92e-08	0.01
5	Left Inferior Frontal Gyrus with Right Superior Frontal Gyrus	9.689	4.86e-09	0.00
6	Left Precentral Gyrus with Right Precentral Gyrus	9.251	1.92e-09	0.00
7	Left Postcentral Gyrus to Right Postcentral Gyrus	6.896	2.68e-07	0.04
8	Right Supramarginal Gyrus with Left Inferior Frontal Gyrus	6.987	2.66e-07	0.04
9	Right Superior Parietal Lobule to Right Precuneus	-7.304	7.73e-08	0.01
10	Right Superior Frontal Gyrus to Right Angular Gyrus	-8.357	9.47e-09	0.00
11	Left Superior Frontal Gyrus to Left Precuneus	-8.793	1.95e-08	0.00
12	Left Superior Frontal Gyrus to Left Angular Gyrus	-7.707	1.45e-07	0.02
13	Left Superior Frontal Gyrus to Left Supramarginal Gyrus	-9.05	5.06e-09	0.00

14	Left Superior Frontal Gyrus to Left Postcentral Gyrus	-6.928	2.00e-07	0.03
15	Right Superior Frontal Gyrus to Left Supramarginal Gyrus	-7.451	8.05e-08	0.01
16	Right Middle Frontal Gyrus to Right Angular Gyrus	-7.129	1.32e-07	0.02
17	Right Inferior Frontal Gyrus to Left Precentral Gyrus	-7.851	2.06e-08	0.00
18	Right Middle Frontal Gyrus to Left Postcentral Gyrus	-7.666	4.44e-08	0.00
19	Right Superior Frontal Gyrus to Left Precentral Gyrus	-7.666	3.02e-08	0.00
20	Left Middle Frontal Gyrus to Left Postcentral Gyrus	-7.351	6.62e-08	0.01
21	Left Middle Frontal Gyrus with Right Middle Frontal Gyrus	-7.415	5.63e-08	0.00
22	Left Middle Frontal Gyrus to Left Inferior Frontal Gyrus	-8.100	1.10e-07	0.01

Figure 3: *Increased and decreased connectivity between different brain regions during task performance for two groups. Red circles represent different regions in the frontal gyrus, while green circles denote other cortical regions. Red connections indicate increased connectivity, and blue lines represent decreased connectivity. Abbreviations: LSFG (Left Superior Frontal Gyrus), LIFG (Left Inferior Frontal Gyrus), LMFG (Left Middle Frontal Gyrus), LSMG (Left Supramarginal Gyrus), LAG (Left Angular Gyrus), LPrecuneus (Left Precuneus), LPoG (Left Postcentral Gyrus), LPrG (Left Precentral Gyrus), RSFG (Right Superior Frontal Gyrus), RPoG (Right Postcentral Gyrus), RPrG (Right Precentral Gyrus), RMFG (Right Middle Frontal Gyrus), RIFG (Right Inferior Frontal Gyrus), RSPL (Right Superior Parietal Lobule), RSMG (Right Supramarginal Gyrus), RPrecuneus (Right Precuneus), RAG (Right Angular Gyrus).*



5. Discussion

In this study, we examined the differences between the Contagion and No-Contagion groups to identify the occurrence or absence of BC. The comparison of adjacency matrices between the resting states of the two groups showed no significant differences. Similarly, no significant differences were found when comparing the fMRI data from the first sessions of the task between the two groups. These findings suggest that, prior to the second session, the functional connectivity within the brain regions was similar across both groups, both between the resting states of the two groups separately and between the first sessions of the groups.

This baseline similarity is crucial, as it indicates that any changes observed in session 3 are due to session 2 itself rather than pre-existing differences between the groups. These results support the reliability of our experimental design, ensuring that subsequent analyses will effectively highlight the effects of session 2 on the observed outcomes.

In analysis of the two groups' fMRI data, the differences were recognized in the second sessions (Prediction-Observation trials). There are significant differences between 22 pairs of clusters of groups (Figure 3). In session 2 of the Contagion group, the differences were related to ten clusters and eight increased connectivity. However, the pattern for the No-Contagion group was different. The analysis shows that the No-Contagion group had fourteen stronger connections between specific brain regions. This means that the changes in connectivity in the second sessions follow one of two different patterns for the groups. This leads to more pronounced interactions between these areas and the occurrence or non-occurrence of contagion in the third sessions for the Contagion and No-Contagion groups.

6. Limitations and Future Directions

We would like to conduct this study using other modalities, such as EEG, to confirm (or refute) our results. Additionally, we are considering the role of sex and age in the differences between the Contagion and No-Contagion groups. Furthermore, applying TES and rTMS as interventions could be a novel avenue for future research.

7. Conclusion

In behavioral analysis of our fMRI task-based study about behavioral contagion, we found the participants were divided into two different groups (labeled as Contagion and No-Contagion). To find the reasons of this difference in contagion, we assessed statistically the adjacency matrices of resting states of two groups, then for sessions 1 of groups and finally sessions 2 of groups were assessed.

Comparisons of the resting states and session 1 data revealed no significant differences between the groups. However, the original difference between the groups was discovered in session 2, referred to as the "Prediction-Observation Trials". Our findings suggest that the difference in the occurrence or absence of behavioral contagion is related to how the brain processes the observation of others' preferences

Ethical Approval

All methods of the study were adapted to the standards, protocols and regulations of the

Declaration of Helsinki. The ICSS Ethics Committee approved all steps of the study (the IRB number is IR.UT.IRICSS.REC.1400.034). All participants signed the informed consent form. They were free to leave the study at any step of the study.

Availability of Data

All datasets, python codes and supporting information are available at https://github.com/M-Mobasseri/-Behavioral-contagion. For any required further information, please contact the authors.

Author Contributions

Our study was designed by RK. RK supervised the data gathering and validation of the results. He also edited the manuscript. MM assisted with experimental design and performed data gathering and analysis. He wrote the first draft, and revised the final manuscript. AV designed and developed the original task. GJ and JH helped in the validation of the results.

Competing Interests

The authors declare that none of them have competing interests.

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