

**BAR-ILAN UNIVERSITY**

# **Modeling Social Synchrony Perception in Naturalistic Viewing Using fMRI**

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## Abstract

As highly social creatures, our capacity to comprehend and react promptly to the social signals of others is a vital part of our day to day life and is crucial for our survival and well-being. The social brain, a network of brain regions devoted to social information processing, is thought to be playing a pivotal role in this ability. This network is composed of functional regions (nodes) including the posterior Superior Temporal gyri (pSTG), Fusiform Face Areas (FFA), Anterior Cingulate Cortex (ACC), medial Prefrontal Cortex (mPFC), anterior Insula (AI), Amygdala, Precuneus and others. This research aimed to examine the function of the social brain and the interplay of its nodes in perceiving and interpreting the synchrony of social cues and gestures in a naturalistic viewing paradigm using neuroimaging.

To investigate whether these nodes of the social brain are implicated in the perception of social synchrony, we utilized the StudyForrest open fMRI dataset, which encompasses annotations for various aspects of the movie “Forrest Gump,” including dialogue, music, setting, shot transitions, and audio-visual confounds. In addition, we generated a new annotation for faces by applying a face detection algorithm to presented stimuli (movie segments). Moreover, we introduced new predictors of perceived social synchrony in four domains: gaze, touch, affect, and general behavioral synchrony. These predictors were derived from participants’ ongoing ratings of characters’ social synchrony during selected segments of the movie, obtained through an independent behavioral experiment.

We modeled the previously collected fMRI data with all fitted annotations and newly created predictors to dissect the neural processing of social synchrony perception by breaking down various facets of social cues (gaze, touch, and affect) using statistical measures of agreement. We hypothesized that (A) participants would agree on perceived synchrony of social cues as well as general behavioral synchrony (described as the aggregate of all social cues), that (B) the neural processing of such synchrony perception involves different functional nodes within the social brain, and that (C) while the perception of general social synchrony can be described as the sum of the three other domains, the neural patterns of perceived social synchrony are distinct to each domain and differ from the perception of general social synchrony.

Our behavioral findings suggest a significant consensus among participants ( $n=82$ ) when assessing the degree of social synchrony between characters viewed in a motion picture. We subsequently conducted a quantitative examination of similarities within and differences across conditions to confirm that general, gaze, touch, and affect social synchrony retain a degree of independence. In our univariate analysis, employing a General Linear Model (GLM) with a Regions of Interest approach (ROIs), we illustrate the involvement of the pSTG, LOC, FFA, and Insula, along with other clusters within social brain nodes when perceiving social synchrony ( $N=15$ ). We delved further into the interactions of these nodes using a multivariate approach - Representational Similarity Analysis (RSA) and revealed that the neural patterns of gaze, touch, and affect synchrony perception diverge from those of general synchrony perception in various regions, including social brain nodes.

While most insights from this study serve to reinforce existing research of social cognition and the Social Brain hypothesis, they nevertheless pave the way for a fresh trajectory in the field of naturalistic viewing fMRI research: offering reproducible and affordable analysis methods by leveraging and broadening the scope of existing open-source datasets and employing a comprehensive examination that is rooted in both theoretical constructs and a data-driven approach. This research establishes a powerful and adaptable framework for future exploration of social synchrony perception, its underlying neural mechanisms, and the broader field of cognitive neuroscience.

# Introduction

## **Social Interactions in Human Life**

Social interactions play a crucial role in human life, shaping our experiences and our identity (Cozolino, 2014). From early childhood, social interactions help to form a sense of self and provide a foundation for future relationships (Ulmer-Yaniv et al., 2022; Telzer et al., 2018). Thus, they are considered one of the most important aspects of human development and well-being and are extensively researched in developmental neuroscience (Frith and Wolpert, 2004; Norman et al. 2012). A meta-analysis about the impact of social relationships on mortality risk found that social isolation and loneliness increase the risk of premature death and heart disease (Holt-Lunstad et al., 2010). Another study demonstrated that loneliness is a risk factor for depression and has a negative impact on physical health (Cacioppo et al. 2006).

Social interactions are important for cognitive development and learning (Vygotskiï and Cole, 1978). According to Vygotsky's social development theory, the interactions between individuals provide opportunities for learning and development through collaboration, negotiation, and problem-solving. These interactions help individuals develop critical thinking skills and improve their ability to understand and analyze information. Finally, social interactions are essential for the development of social skills and social norms (Schaich Borg et al., 2006). It's only through social interactions that individuals learn how to communicate effectively, how to empathize with others and how to respect the opinions and feelings of others (Hurst et al., 2013). Through social interactions, one learns about the norms of their society, such as the values and customs that are considered appropriate (Hofstede, 2001).



## **The Social Brain**

The human brain is equipped with a specialized network of regions that responds to social information. This network, referred to as “the Social Brain”, is responsible for allowing us to interact with other individuals, understand their emotions, and make social judgments (Hari and Kujala, 2009). The Social Brain hypothesis posits that the human brain has evolved to process social information and that this ability is essential for survival and reproduction (Atzil et al., 2018; Cozolino, 2014). Neuroimaging studies have provided support for this hypothesis by showing changes in brain activity and structure in regions associated with various aspects of social processing and behavior. These include ‘Theory of Mind’ (ToM. i.e., the ability to understand and attribute mental states, such as beliefs and intentions, to oneself and others), which recruits the medial prefrontal cortex, temporal parietal junction, and superior temporal sulcus, and empathy (i.e., the ability to understand and share the emotions of others) which recruits the anterior cingulate cortex and insula (Gallagher & Frith, 2003; Kanske et al., 2015; Tsoory 2011). Other Studies have shown that the social brain is highly active when we engage in social interactions, such as reading emotional expressions (Adolphs, 2002; Grecucci et al., 2013), interpreting tone of voice (Grossmann, 2015), and processing body language (Canderan 2020).

Other aspects of social perception recruit additional regions in the brain, such as the fusiform gyrus, which engages in face recognition and is activated when we view faces (Kanwisher, 2010). Another aspect is the perception of biological motion, as bodily gestures provide information about individuals’ physical intent, allowing us to understand the actions of others and respond accordingly. Previous research indicated that the lateral occipital cortices, and specifically the extra striate body area, are activated whether we perform or observe someone else performing the same action (Filimon et al., 2007; McMahon et al., 2024). These are thought to play a critical role in social learning of body movement, as they are engaged with the processing of others’ physical behavior as well as our own.

The development of the social brain is crucial for understanding social cues (like facial expressions, body movements, speech patterns, eye contact, and spatial proximity) and producing appropriate social cues of our own to create social synchrony with others. This ability is essential for social interaction and communication, and when impaired, it is often referred as social cognitive dysfunction and is associated with several psychiatric and neurological disorders:

One such disorder is autism spectrum disorder (ASD), where individuals frequently face challenges in social interaction and communication. Research has shown differences in brain regions involved in social cognition, such as the amygdala and fusiform gyrus, between individuals with ASD and those without (Sato and Uono, 2019).

Depression, a mood disorder, can lead to social cognitive dysfunction by affecting individuals to withdraw from social interactions, resulting with feelings of loneliness and isolation. Previous research has revealed neurobiological differences in brain regions involved in emotional processing and regulation, such as the amygdala and hippocampus, in individuals with depression (Pandya et al, 2012).

Finally, traumatic brain injury (TBI) can cause social cognitive dysfunction, resulting in difficulties with social interaction, communication, and empathy. The famous case of Phineas Gage (Ratiu et al, 2004) highlights how a lesion in the frontal lobe can affect social behavior. Similar cases have since demonstrated a link between lesions in the frontal and temporal lobes and lower social cognition skills. This suggests that social connections are deeply ingrained in our biology and are essential for our well-being.

Overall, the social brain provides us with the cognitive and emotional tools we need to engage in successful social interactions (Frith et al.,2010). Without it, our ability to form relationships and communicate with others would be severely impaired. Understanding these differences in the activity of nodes within the social brain network could benefit the development of treatments and interventions aimed at improving social skills and reducing the negative consequences of social cognitive dysfunction.

## **Naturalistic Viewing (Movie fMRI)**

In recent years, neuroimaging techniques such as functional magnetic resonance imaging (fMRI) have made it possible to study the neural basis of social cognition (Decety and Lamm, 2007). Among these techniques, naturalistic viewing paradigms have gained popularity due to their ability to present social stimuli that closely resemble real-life interactions (Spiers and Maguire, 2007). This approach allows researchers to examine the neural processing of complex social information and to identify the regions of the brain that are specifically involved in social perception (Lee Masson and Isik, 2021).

Naturalistic viewing paradigms typically involve presenting participants with short movie clips or dynamic social scenes, often from feature films, while recording their brain activity with fMRI. These stimuli are carefully selected to elicit various aspects of social cognition, such as empathy, perspective-taking, and emotion regulation (Grecucci et al., 2013). By analyzing the brain responses to these stimuli, researchers can gain insight into the neural mechanisms that underlie social perception and how these processes are impacted by individual differences, such as personality and social cognition styles (Kanai and Rees 2011). Numerous studies had previously tried to uncover the neural dynamics of the social brain using naturalistic viewing fMRI paradigms with different stimuli sets. All of which found observed changes in activity, structure or connectivity between anatomical regions associated with the social brain network: the amygdala, insula, prefrontal cortex (Camacho, 2019), superior temporal sulcus (Lahnakoski et al., 2012; Isik et al., 2017)) and mPFC (Wagner et al., 2016).

Naturalistic fMRI paradigms offer a valuable tool for investigating the neural mechanisms involved in perceiving social interactions of others. By presenting participants with dynamic and emotionally rich social stimuli, these paradigms enable researchers to study the brain's processing of complex social information in a manner that closely resembles real-life interactions. The results from movie fMRI studies are more robust when compared to resting-state fMRI and task fMRI (Meer et al., 2020; Kringelbach, 2023), mainly due to the task-free nature of the paradigm (fewer motor artefacts) and the incorporation of detailed annotation of events as they unfold in time as explanatory variables. Utilizing open datasets such as the NNDB (Aliko et al 2020) and StudyForrest (Hanke et al., 2014), which

employs naturalistic viewing of feature films while recording BOLD signal from a large group of participants, we suggest a simple, affordable and reproducible method for the research of social synchrony perception.

### **The Current Study**

The aim of this research is to investigate the role of the social brain in perceiving and processing social synchrony of others. We utilize the StudyForrest open fMRI dataset, along with released annotations for various features of the movie "Forrest Gump". These include speech, music, location, shot boundaries and audio-visual confounds. We also provide new annotation of faces by adapting a face detection algorithm to account for the number of faces appearing on screen during the movie. Our study further introduces new predictors of perceived social synchrony: gaze (when retaining eye contact or look in the same direction), touch (when physical proximity increases and gestures are coupled), affect (when emotional states are compatible) and general synchrony (when evaluating the overall level of social synchrony between individuals taking all previous aspects into account), in the effort of investigating the neural dynamics of functional nodes within the social brain when processing observed social interactions of others. We hypothesis that perceived general behavioral synchrony is related to and encompasses gaze, touch and affect synchrony perception, but is not equal to the sum of its parts.

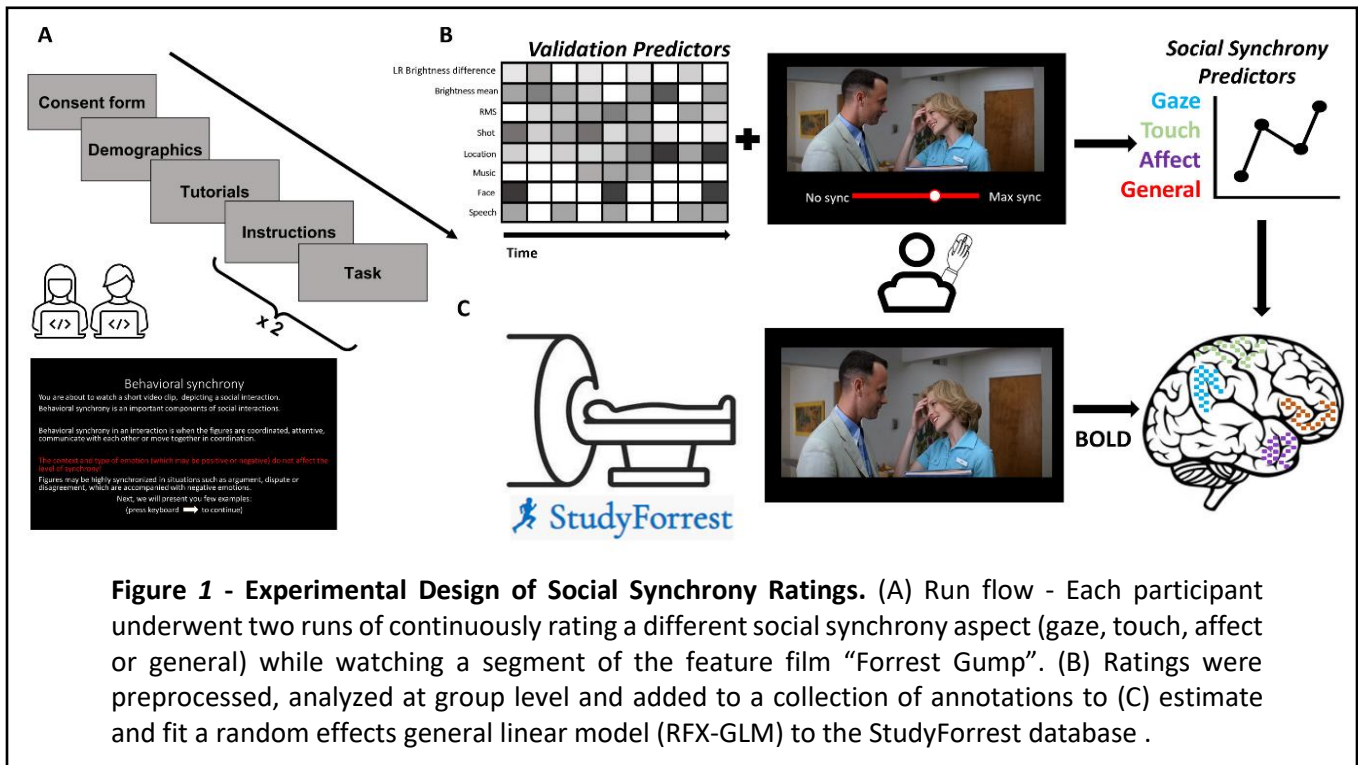
This research aimed to gain deeper understanding of the mechanisms which underlie the neural processing of social synchrony perception. By modeling fMRI data using the collected and newly generated predictors, we explored the neural patterns of the social brain network during social synchrony perception using uni and multivariate analysis. This work, including the behavioral experiment, preprocessing, analysis and result presentation scripts are fully available online at [github.com/ArielBundy/SyncForrest](https://github.com/ArielBundy/SyncForrest).

## **Behavioral Social Synchrony Experiment**

### **Materials and Methods**

**Participants and stimuli.** 82 subjects (68 females, mean age of 21.92, SD=3.83) participated in our behavioral experiment, 47 of which had declared they previously watched the feature film "Forrest Gump". All participants gave written informed consent

and received academic credit or 50 NIS for their participation in the experiment. The experiment was approved by the ethical committee of the Gonda Multidisciplinary Brain Research Center. Presented movie segments (segments 3 and 7, see [nature.com/articles/sdata20143](https://www.nature.com/articles/sdata20143) for more detail) were selected based on a separate pilot experiment, showing differences in ratings of all synchrony aspects in these segments as well as participants' positive engagement feedback.



**Experimental design.** At the start of the experiment, participants answered a brief demographics questionnaire with the following fields: gender, age, living environment (alone\with spouse\with parents) and indicated if they had previously watched the feature film “Forrest Gump”. Next, for system and user verification, two tutorials of general operation instructed participants to move the slider on screen using the mouse according to a specified rule while watching a cartoon: in the first, participants were told to move the slider all the way to the left if a wolf appeared on screen and all the way to the right if a sheep appeared. During the second video, participants were instructed to move the slider all the way to the right if they heard a narrator’s voice and all the way to the left if not. Upon successfully completing both tutorials, the first out of two experimental runs began. Runs started with a short instructions section, which informed participants of their task (rating either gaze, touch, affect or general synchrony) and provided examples for different levels of social synchrony using pictures and short video snippets. When ready, participants pressed the spacebar to begin the task. Synchrony tasks and movie segments were drawn randomly in such a way that participants rated two out of four aspects of social synchrony, one for each segment of the movie included in this study. At the end of both runs, a small pop up window indicated the experiment has ended.

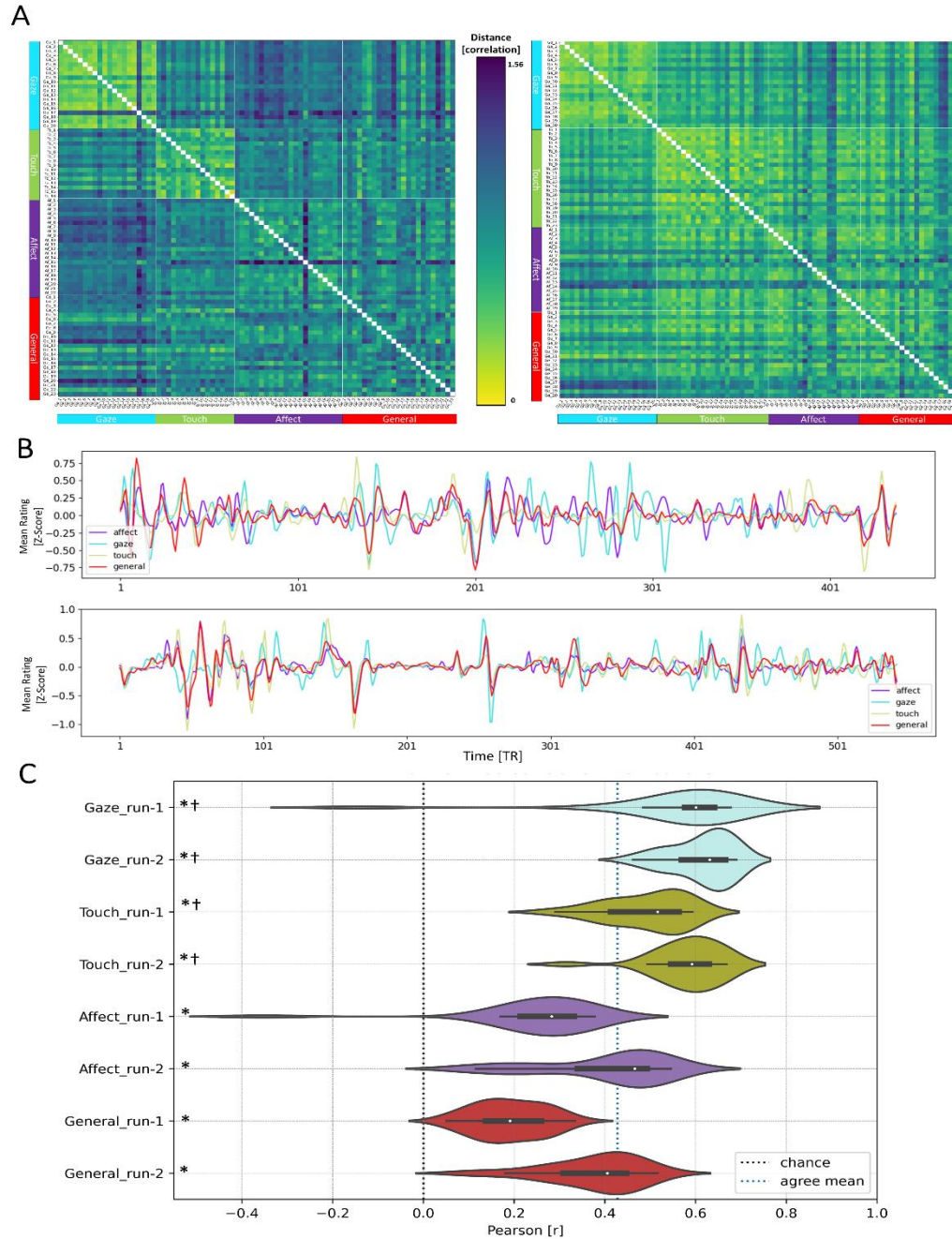
**Preprocessing and analysis.** Prior to preprocessing, we verified the output and excluded incomplete runs. We then linearly interpolated the data to account for missing values and smoothed it using a 5 sample (0.5 seconds) window. All ratings were grouped by task domain (gaze\touch\affect\general synchrony) and runs, resulting with a minimum of 39 and a maximum of 43 complete ratings for each task. We implemented z-scoring within ratings run, averaged across participants and z-scored the mean ratings’ time course to create four social synchrony predictors for both runs. We performed two sets of one sided t-test (Bonferroni corrected) on r-to-z transformed pairwise-correlation distributions to determine: (A) agreement (mean correlation) of social synchrony perception in each task and run is above chance (greater than zero) and (B) above mean agreement score to investigate dissimilarities across conditions. We further investigated agreement and confidence of ratings using descriptive statistics, a variance test (ANOVA) and post hoc implemented by JASP (JASP Team, 2024, computer software), to examine the relations of

social synchrony agreement in our predefined domains. To have a better understanding of the created social synchrony predictors, we visualize the distance matrices of each run sectioned by task along with the correlation matrices of our model.

## Results

Results of the two sets of one way t-tests (above chance level and agreement mean, defined as the mean pairwise correlations across all tasks and runs,  $\mu = 0.427$ ) for each task indicated that agreement of all runs and tasks is significantly greater than chance level ( $p < 0.005$ , Bonferroni corrected), while only gaze and touch agreement scores (for both runs) are significantly greater than the mean agreement score ( $p < 0.005$ , Bonferroni corrected).

Two one way ANOVA tests were calculated to assess the impact of social synchrony task (gaze\|affect\|touch\|general) and run (run-1 vs. run-2) on agreement scores, calculated as the fisher transformed mean pairwise correlation of participants social synchrony ratings. It revealed a main effect for task ( $F(3) = 69.169$ ,  $p < 0.0001$ ,  $\eta^2 = 0.57$ ) with higher agreement scores for gaze ( $\mu = 0.58$ ,  $\sigma = 0.12$ ) and touch ( $\mu = 0.53$ ,  $\sigma = 0.08$ ) than for affect ( $\mu = 0.32$ ,  $\sigma = 0.14$ ) and general synchrony ( $\mu = 0.28$ ,  $\sigma = 0.09$ ). In addition, a main effect for 'run' was found ( $F(1) = 43.97$ ,  $p < 0.0001$ ,  $\eta^2 = 0.221$ ), with higher agreement scores for run 2 compared to run 1 when collapsing over all tasks ( $p < 0.001$ , Bonferroni corrected). No significant interaction between 'run' and 'task' was found ( $p = 0.054$ ). Games-Howell post-hoc comparisons revealed a significant difference in mean agreement between gaze and affect, gaze and general, touch and affect and touch and general (all  $p < 0.001$  Bonferroni corrected) but not for the remaining comparisons (gaze and touch, affect and general). For further details, see supplementary material.



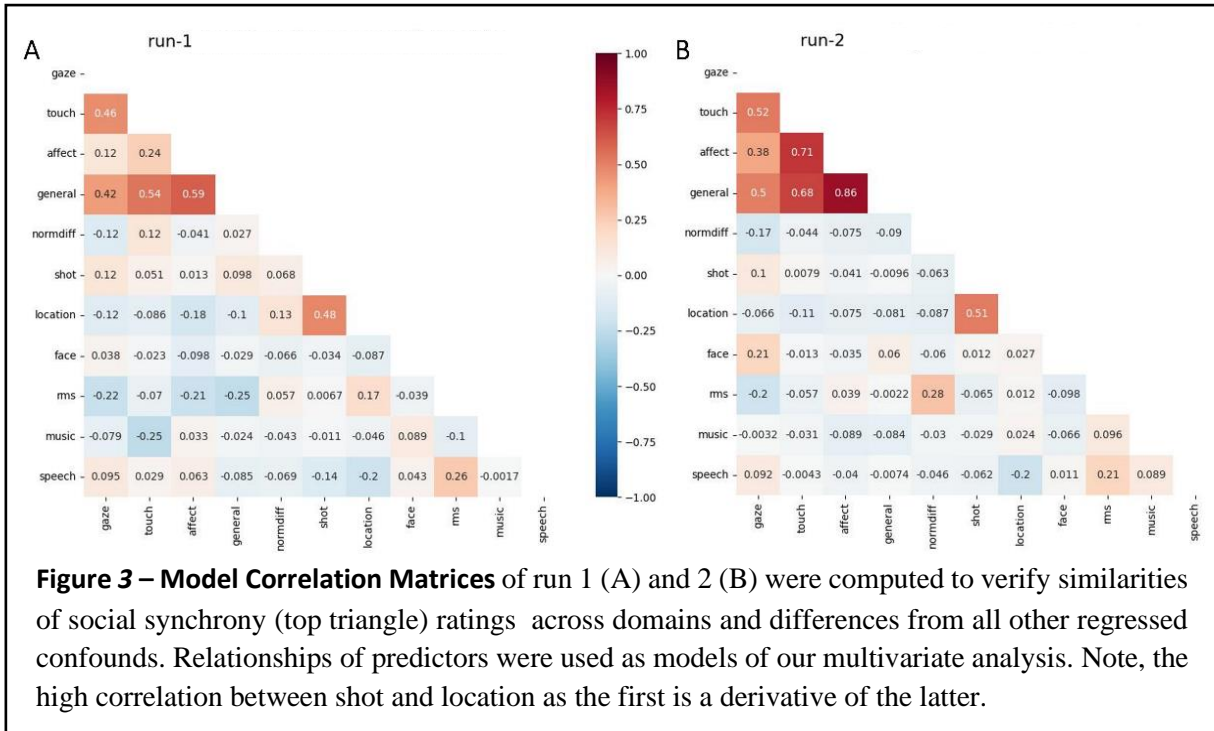
**Figure 2 - Behavioral Results.** (A) Representational (correlation-based) distance matrices of run 1 (left) and 2 (right). (B) Demeaned social synchrony predictor time courses for run 1 (top) and 2 (bottom) (C) Pairwise correlation distribution of each task and each run. \* Indicate significantly above chance level, † indicate significantly above agreement mean. Note, ratings of run 2 are more similar across conditions and the low agreement level of affect and general domains during run 1.



# Social Synchrony Modeling

## Materials and Methods

**Participants.** We utilized pre collected neural data (T1 and T2 weighted images) from the publicly available StuddyForrest dataset, containing fifteen participants (6 females, mean age: 28.5,  $\sigma = 5.07$ ). All participants scanned were right-handed, with normal or corrected to normal vision and based on self-report, without any neurological or psychiatric history. Participants were fully instructed about the nature of the original study, gave their informed consent for participation in the study as well as for public sharing of all obtained data in anonymized form, and received monetary compensation. Further detail about data collection of this open dataset can be found at [StuddyForrest.org](http://StuddyForrest.org).



**Figure 3 – Model Correlation Matrices** of run 1 (A) and 2 (B) were computed to verify similarities of social synchrony (top triangle) ratings across domains and differences from all other regressed confounds. Relationships of predictors were used as models of our multivariate analysis. Note, the high correlation between shot and location as the first is a derivative of the latter.

**Preprocessing and ROI Analysis.** We obtained the raw folders of all subjects recorded while watching the feature film ‘Forrest Gump’ from the publicly available StudyForrest project and implemented a FSL (fMRI processing software, Smith et al., 2004; Woolrich et al. 2009; Jenkinson et al., 2012) based nypipe preprocessing and analysis pipeline (toolbox for python), which closely resembles fMRIPrep (Esteban et al., 2019). First, structural images were corrected for intensity non-uniformity and spatially normalized to MNI space

(MNI152 standard-space T1-weighted average structural template image), following by brain tissue segmentation of cerebrospinal fluid (CSF), white matter (WM), and grey matter (GM). Functional images were motion corrected, co-registered to the structural image, normalized to MNI space, and spatially smoothed with a 6 mm Gaussian kernel, for further details regarding our pipeline, see figure 4.

We selected parcellations from the lateralized Harvard-Oxford cortical and subcortical structural atlas as regions of interest in our ROI analysis, for which we extracted the mean beta value of all voxels within a specific region from single subject contrasts of all participants (N=15) and performed a two-sided t-test ( $p < 0.001$ , Bonferroni corrected), implemented using ‘nibabel’ for python.

***Models and predictors.*** Two segments of the movie “Forrest Gump” were chosen as our stimuli (for detailed timetable see Haneke, 2014) and have been reproduced to have the same boundaries and frame rate as the original study using command line code. We then verified reproduced segments using public annotations of speech (Häusler and Haneke, 2021), music and location (Häusler and Haneke 2016). As the appearance of faces in visual stimuli lies within the scope of this study but no face annotation has been published, we created a new face-appearance annotation by implementing a face detection algorithm (‘face-recognition’ toolbox for python) on selected movie segments. The output of this script is the z-scored number of faces appearing on screen at a sampling rate of 4 Hz (every 0.25 seconds).

We adjusted all annotations to fit our analysis pipeline using Python (Jupyter notebooks) and incorporated them in our analysis as explanatory variables. After verification of annotations we computed a random effects general linear model (RFX-GLM) of all social synchrony predictors after regressing audiovisual confounds (mean change in brightness across all screen pixels, auditory amplitude, difference of amplitude between left and right ear), shot and location transitions, speech (sentence long events), number of faces on screen (z-scored) and background music.

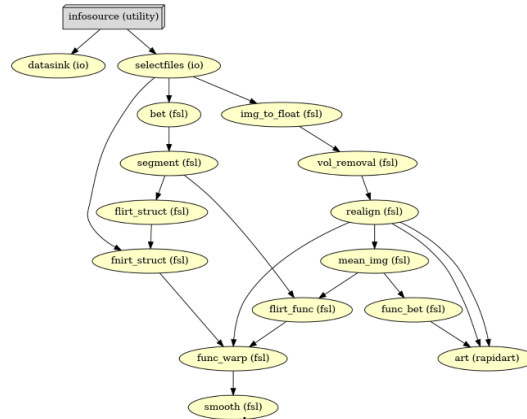
Our multivariate analysis was performed using ‘nilearn’ toolbox for python, closely following an example code available online as a jupyter notebook written by Luke Chang

(see [dartbrains.org/content/RSA.html](http://dartbrains.org/content/RSA.html)). We hypothesized three models of possible neural patterns in social brain nodes: (A) nodes in which general is dissimilar to other perceived synchronies, (B) Theory of Mind vs Body (nodes displaying a similar neural pattern for second order inferences, like others' state of mind, and do not distinct between different bodily gestures such as gaze and physical proximity) and (C) Subjective Ratings, computed as the mean correlation of social synchrony predictors across runs. Distance (correlation based) and similarity (1-distance) of conditions were extracted and Spearman correlated to our hypothesized models in all brain parcellations, then tested for significance using a one sample permutation test (two sided, 5000 iterations,  $p < 0.0002$  Bonferroni corrected). We include results of the hypothesized relationships of movie confounds for validation, as well as the computed mean correlation of our models within social ROIs across all participants.

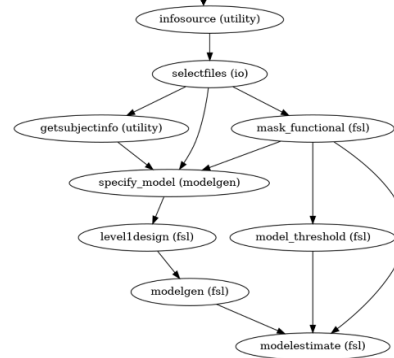
**Regions of interest selection.** For our univariate analysis, we selected regions based on social brain nodes reported in previous research. These include: the Frontal Medial Cortex (FMC), Insula (Ins), posterior Superior Middle Gyrus (pSTG), inferior Lateral Occipital Cortex (LOC), Anterior Cingulate Cortex (ACC), Precuneus (Prec), Fusiform area (FFA) and Amygdala (Amyg) of both hemispheres. We further describe significant group-mean activations for contrasts of perceived social synchrony in social brain nodes and present them as whole-brain contrasts, depicting all voxels' t-scores and outlining significant clusters. Considering the nature of our exploratory analysis, we chose to utilize the same atlas in our multivariate analysis to ensure direct comparison results, while simultaneously balancing between granularity and computational power (as this atlas is comprised of 110 anatomically segmented regions).

**Results.** Results include group averaged contrast maps of social synchrony derived from our RFX-GLM, corrected for multiple comparisons using cluster-size correction (thresholded at  $p < 0.001$ ) and visualized using a separate notebook to produce slice views and interactive figures. Results of the RSA are presented in the analysis notebook, corrected for multiple comparisons using Bonferroni correction ( $p < 0.0002$ ).

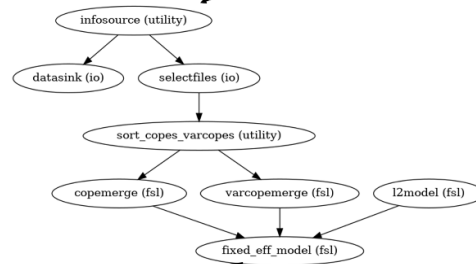
## Preprocessing



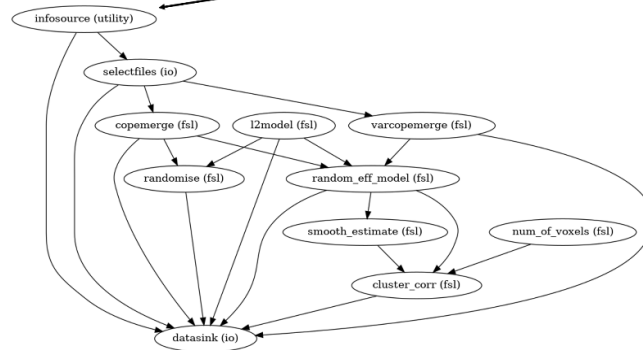
## 1st Level



## 2nd Level (FFX)



## 3rd Level (RFX)

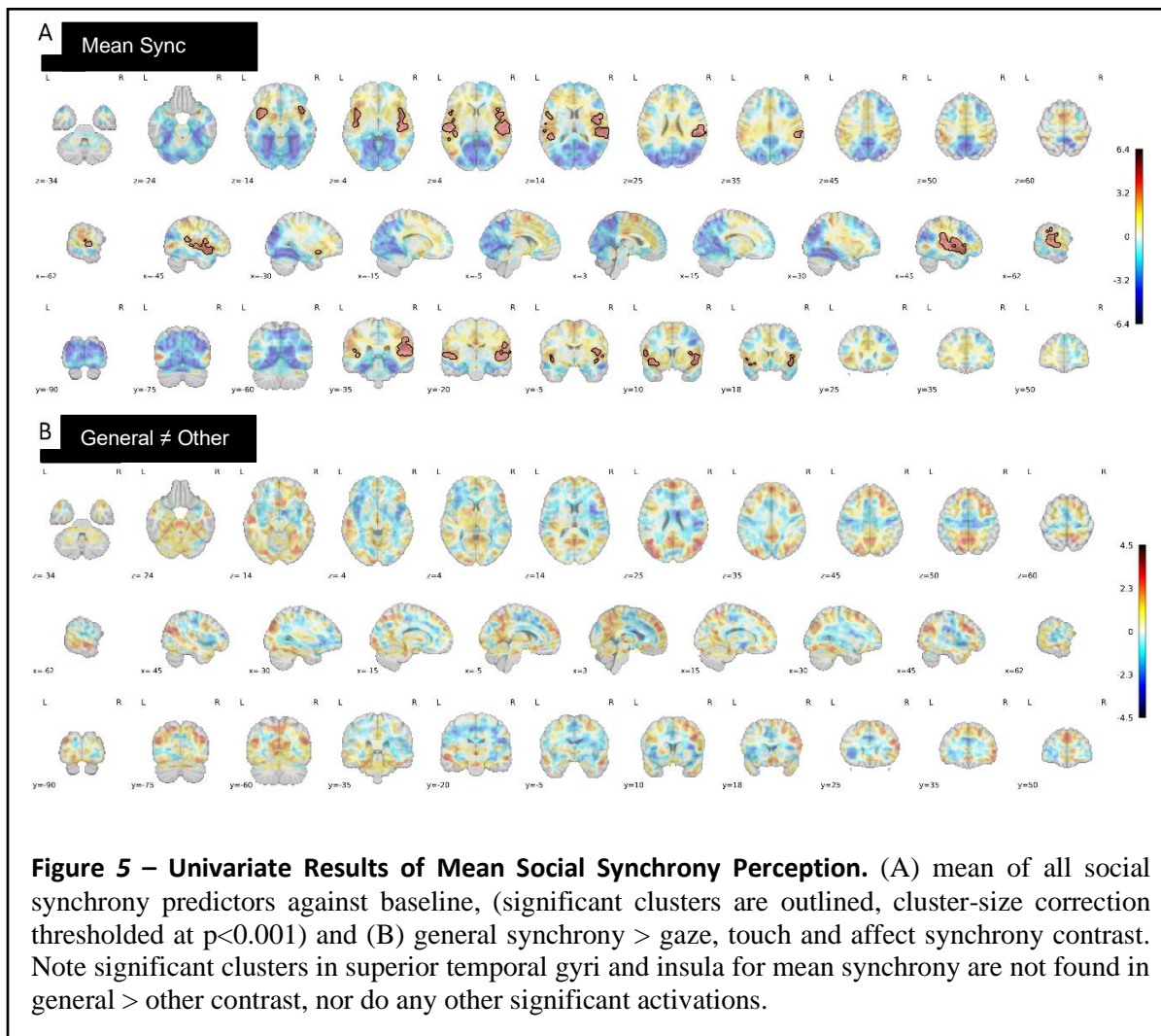


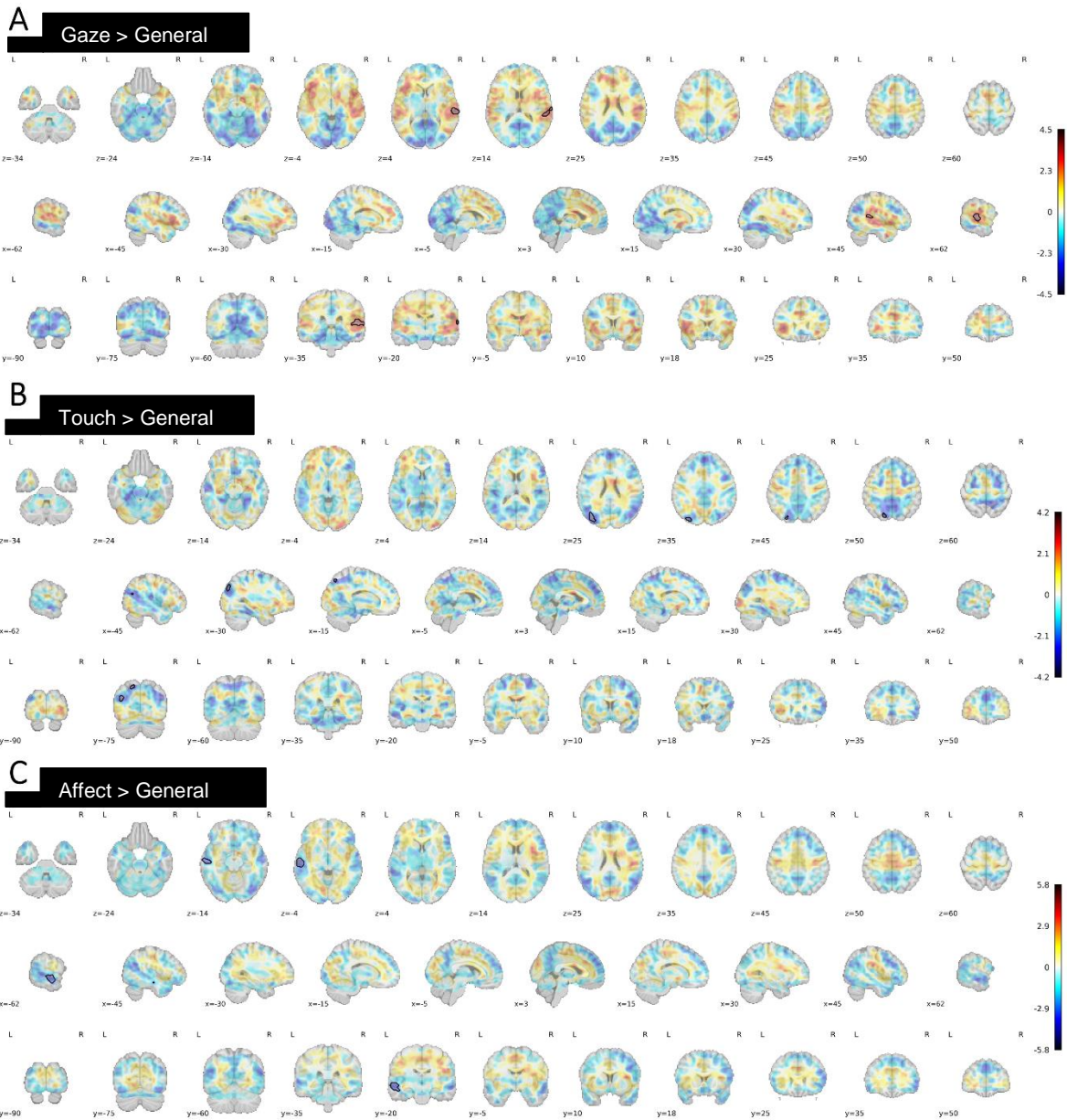
**Figure 4 – fMRI pipeline** - constructed using nypipe toolbox (python) for automated and reproducible fMRI analysis (fully available at [github.com/ArielBundy/SyncForrest](https://github.com/ArielBundy/SyncForrest)).

## Results

### Univariate Analysis – Group mean contrasts

Examining the average of all perceived social synchrony contrast (defined as all synchrony against baseline) revealed significant activations in clusters within bilateral STG, MTG and Insula, as well as in the right Rolandic Operculum and Supramarginal gyrus. The ‘General  $\neq$  Other’ contrast, defined as the difference between general synchrony perception and the mean of subdomains of social synchrony, yielded no significant activations throughout the brain. Despite this, we present the whole brain model to evaluate our ROI selection (see figure 5).

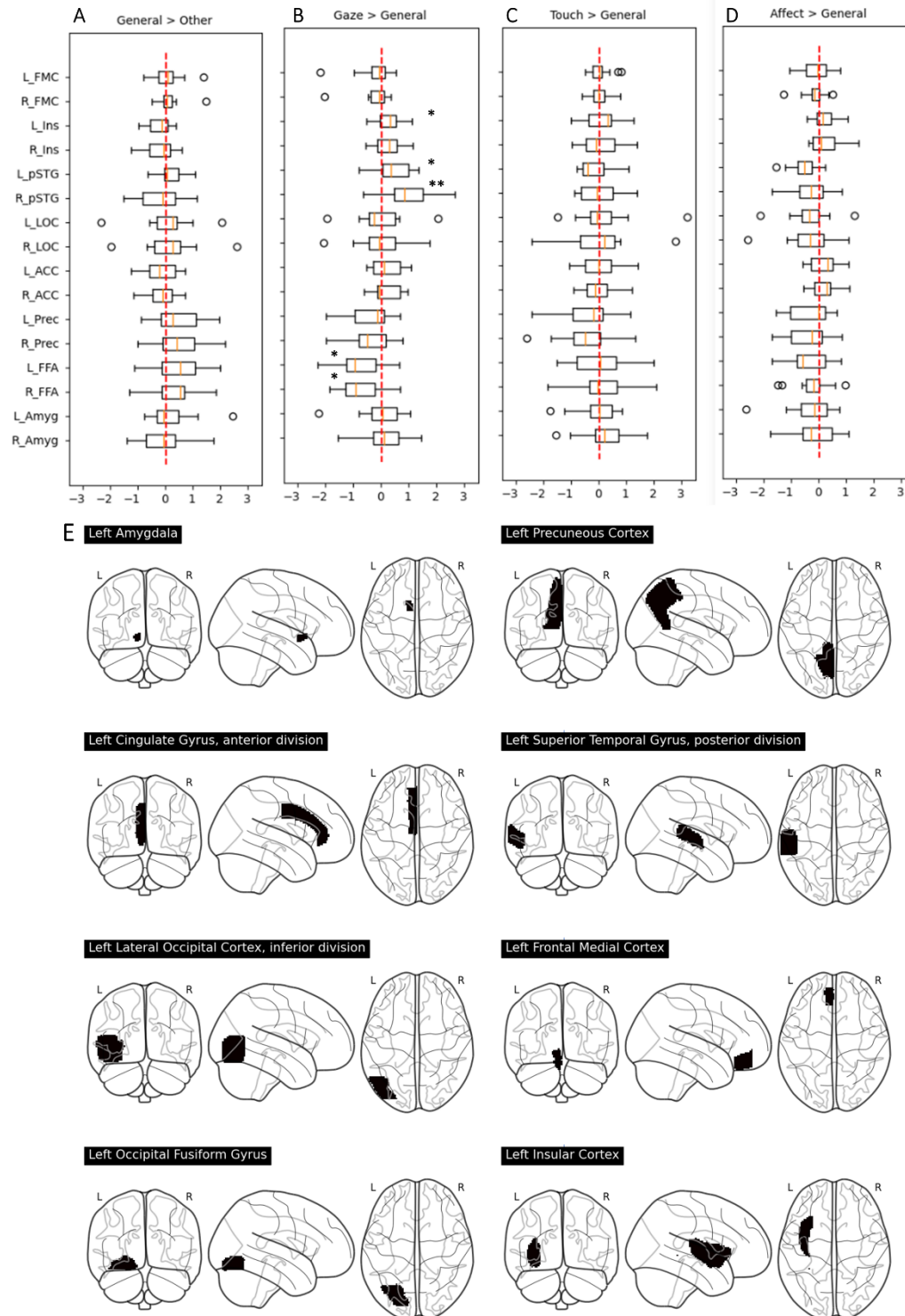




**Figure 6 – Univariate Results of Social Synchrony Domains.** Group mean contrasts of (A) gaze  $\neq$  general synchrony, (B) touch  $\neq$  general synchrony and (C) affect  $\neq$  general synchrony (significant clusters are outlined, cluster-size correction thresholded at  $p < 0.001$ ).

When examining social domains separately against general synchrony (see figure 6), we observe activations of significant clusters in right MTG for gaze, deactivations of clusters in left MTG (for affect) and deactivations in superior parietal cortex and lateral occipital cortex (for touch).





**Figure 7 – Univariate Results: ROI Analysis.** Two sided t-tests of (A) General  $\neq$  other, (B) gaze  $\neq$  general, (C) touch  $\neq$  general, and (D) affect  $\neq$  general neural activity within (E) social ROIs. Note only left hemisphere ROIs are displayed but both were analyzed and corrected for. \*  $p < 0.025$ , \*\*  $p < 0.0015$  (Bonferroni corrected).

## Univariate Analysis – ROI neural activity

Results of our ROI analysis further indicate the involvement of the right STG (BF=43.8,  $p<0.001$ ) in gaze synchrony perception and the left STG in general compared to affect synchrony perception (BF 117.8,  $p<0.001$ ). Other ROIs did not survive Bonferroni correction, such as the left Insula, the occipital Fusiform Gyrus and STG for gaze synchrony perception. For more detail, see figure 7 and table 1.

### A General ≠ Other

| ROI Name  | Mean      | T-Stat    | P-Value  | Confidence Interval | Uncorrected | Bonf | BF    |
|---|-----------|-----------|----------|---------------------|-------------|------|-------|
| Left Frontal Medial Cortex                        | 0.114540  | 0.882926  | 0.392185 | [-0.164 0.393]      | 0           | 0    | 0.367 |
| Right Frontal Medial Cortex                       | 0.130440  | 1.150799  | 0.299092 | [-0.113 0.374]      | 0           | 0    | 0.46  |
| Left Insular Cortex                               | -0.224537 | -1.952901 | 0.071157 | [-0.471 0.022]      | 0           | 0    | 1.174 |
| Right Insular Cortex                              | -0.230585 | -1.507924 | 0.153806 | [-0.559 0.097]      | 0           | 0    | 0.669 |
| Left Superior Temporal Gyrus, posterior division  | 0.166942  | 1.255795  | 0.229745 | [-0.118 0.452]      | 0           | 0    | 0.51  |
| Right Superior Temporal Gyrus, posterior division | -0.202331 | -1.028804 | 0.321019 | [-0.624 0.219]      | 0           | 0    | 0.413 |
| Left Lateral Occipital Cortex, inferior division  | 0.110990  | 0.448162  | 0.660893 | [-0.42 0.642]       | 0           | 0    | 0.287 |
| Right Lateral Occipital Cortex, inferior division | 0.177810  | 0.685477  | 0.504236 | [-0.379 0.734]      | 0           | 0    | 0.322 |
| Left Cingulate Gyrus, anterior division           | -0.161782 | -1.031115 | 0.319972 | [-0.498 0.175]      | 0           | 0    | 0.414 |
| Right Cingulate Gyrus, anterior division          | -0.109686 | -0.779845 | 0.448468 | [-0.411 0.192]      | 0           | 0    | 0.342 |
| Left Precuneus Cortex                             | 0.449491  | 1.977643  | 0.067999 | [-0.038 0.937]      | 0           | 0    | 1.215 |
| Right Precuneus Cortex                            | 0.502174  | 2.131029  | 0.051296 | [-0.003 1.008]      | 0           | 0    | 1.507 |
| Left Occipital Fusiform Gyrus                     | 0.422572  | 1.801153  | 0.093251 | [-0.081 0.926]      | 0           | 0    | 0.959 |
| Right Occipital Fusiform Gyrus                    | 0.335246  | 1.562702  | 0.140439 | [-0.125 0.795]      | 0           | 0    | 0.713 |
| Left Amygdala                                     | 0.152364  | 0.717998  | 0.484569 | [-0.303 0.908]      | 0           | 0    | 0.329 |
| Right Amygdala                                    | -0.031385 | -0.145808 | 0.886152 | [-0.493 0.43]       | 0           | 0    | 0.265 |

### B Gaze ≠ General

| ROI Name  | Mean      | T-Stat    | P-Value  | Confidence Interval | Uncorrected | Bonf | BF     |
|---|-----------|-----------|----------|---------------------|-------------|------|--------|
| Left Frontal Medial Cortex                        | -0.207948 | -1.200494 | 0.249867 | [-0.579 0.164]      | 0           | 0    | 0.483  |
| Right Frontal Medial Cortex                       | -0.212559 | -1.436350 | 0.172672 | [-0.53 0.105]       | 0           | 0    | 0.617  |
| Left Insular Cortex                               | 0.294242  | 2.610287  | 0.020561 | [0.052 0.536]       | 1           | 0    | 3.099  |
| Right Insular Cortex                              | 0.265494  | 2.047432  | 0.059861 | [-0.013 0.544]      | 0           | 0    | 1.339  |
| Left Superior Temporal Gyrus, posterior division  | 0.408735  | 2.536875  | 0.023713 | [0.063 0.754]       | 1           | 0    | 2.764  |
| Right Superior Temporal Gyrus, posterior division | 0.913048  | 4.215337  | 0.000864 | [0.448 1.378]       | 1           | 1    | 43.869 |
| Left Lateral Occipital Cortex, inferior division  | -0.016662 | -0.072379 | 0.943324 | [-0.51 0.477]       | 0           | 0    | 0.263  |
| Right Lateral Occipital Cortex, inferior division | -0.000576 | -0.002443 | 0.998085 | [-0.506 0.505]      | 0           | 0    | 0.262  |
| Left Cingulate Gyrus, anterior division           | 0.242167  | 1.659959  | 0.119759 | [-0.071 0.556]      | 0           | 0    | 0.799  |
| Right Cingulate Gyrus, anterior division          | 0.198316  | 1.505641  | 0.154385 | [-0.084 0.481]      | 0           | 0    | 0.667  |
| Left Precuneus Cortex                             | -0.461526 | -2.120391 | 0.052319 | [-0.928 0.005]      | 0           | 0    | 1.484  |
| Right Precuneus Cortex                            | -0.455584 | -2.015587 | 0.063457 | [-0.94 0.029]       | 0           | 0    | 1.28   |
| Left Occipital Fusiform Gyrus                     | -0.794589 | -3.519356 | 0.003402 | [-1.279 -0.31]      | 1           | 0    | 13.667 |
| Right Occipital Fusiform Gyrus                    | -0.747556 | -3.529003 | 0.003337 | [-1.202 -0.293]     | 1           | 0    | 13.889 |
| Left Amygdala                                     | -0.013344 | -0.062937 | 0.950707 | [-0.468 0.441]      | 0           | 0    | 0.263  |
| Right Amygdala                                    | 0.180398  | 0.858243  | 0.405213 | [-0.27 0.631]       | 0           | 0    | 0.361  |

### C Touch ≠ General

| ROI Name  | Mean      | T-Stat    | P-Value  | Confidence Interval | Uncorrected | Bonf | BF    |
|---|-----------|-----------|----------|---------------------|-------------|------|-------|
| Left Frontal Medial Cortex                        | 0.034589  | 0.357620  | 0.725961 | [-0.173 0.242]      | 0           | 0    | 0.278 |
| Right Frontal Medial Cortex                       | 0.044483  | 0.470266  | 0.645407 | [-0.158 0.247]      | 0           | 0    | 0.289 |
| Left Insular Cortex                               | 0.088083  | 0.556375  | 0.586738 | [-0.251 0.428]      | 0           | 0    | 0.301 |
| Right Insular Cortex                              | 0.067102  | 0.461627  | 0.651440 | [-0.318 0.492]      | 0           | 0    | 0.288 |
| Left Superior Temporal Gyrus, posterior division  | -0.180443 | -1.165641 | 0.263235 | [-0.512 0.152]      | 0           | 0    | 0.467 |
| Right Superior Temporal Gyrus, posterior division | 0.020302  | 0.104893  | 0.917948 | [-0.395 0.435]      | 0           | 0    | 0.264 |
| Left Lateral Occipital Cortex, inferior division  | 0.149082  | 0.539901  | 0.597749 | [-0.443 0.741]      | 0           | 0    | 0.298 |
| Right Lateral Occipital Cortex, inferior division | 0.031116  | 0.106470  | 0.918720 | [-0.596 0.658]      | 0           | 0    | 0.264 |
| Left Cingulate Gyrus, anterior division           | -0.011105 | -0.060626 | 0.995277 | [-0.394 0.392]      | 0           | 0    | 0.262 |
| Right Cingulate Gyrus, anterior division          | -0.042304 | -0.263402 | 0.796078 | [-0.387 0.302]      | 0           | 0    | 0.271 |
| Left Precuneus Cortex                             | -0.407162 | -1.693213 | 0.112538 | [-0.923 0.109]      | 0           | 0    | 0.836 |
| Right Precuneus Cortex                            | -0.494160 | -1.999238 | 0.065379 | [-1.024 0.036]      | 0           | 0    | 1.252 |
| Left Occipital Fusiform Gyrus                     | 0.055021  | 0.209498  | 0.837085 | [-0.508 0.618]      | 0           | 0    | 0.288 |
| Right Occipital Fusiform Gyrus                    | 0.123739  | 0.491597  | 0.630622 | [-0.416 0.664]      | 0           | 0    | 0.282 |
| Left Amygdala                                     | -0.083794 | -0.453131 | 0.657398 | [-0.48 0.313]       | 0           | 0    | 0.287 |
| Right Amygdala                                    | 0.173204  | 0.837375  | 0.416448 | [-0.27 0.617]       | 0           | 0    | 0.356 |

### D Affect ≠ General

| ROI Name  | Mean      | T-Stat    | P-Value  | Confidence Interval | Uncorrected | Bonf | BF      |
|---|-----------|-----------|----------|---------------------|-------------|------|---------|
| Left Frontal Medial Cortex                        | -0.123147 | -0.938039 | 0.364127 | [-0.405 0.158]      | 0           | 0    | 0.383   |
| Right Frontal Medial Cortex                       | -0.155056 | -1.445334 | 0.170375 | [-0.385 0.075]      | 0           | 0    | 0.623   |
| Left Insular Cortex                               | 0.236104  | 1.971078  | 0.068814 | [-0.021 0.493]      | 0           | 0    | 1.204   |
| Right Insular Cortex                              | 0.272827  | 1.778582  | 0.097023 | [-0.056 0.602]      | 0           | 0    | 0.932   |
| Left Superior Temporal Gyrus, posterior division  | -0.555165 | -4.812733 | 0.000276 | [-0.803 -0.308]     | 1           | 1    | 117.888 |
| Right Superior Temporal Gyrus, posterior division | -0.267237 | -1.443458 | 0.170894 | [-0.664 0.13]       | 0           | 0    | 0.622   |
| Left Lateral Occipital Cortex, inferior division  | -0.326653 | -1.665471 | 0.118028 | [-0.747 0.094]      | 0           | 0    | 0.808   |
| Right Lateral Occipital Cortex, inferior division | -0.403800 | -1.857194 | 0.084446 | [-0.87 0.053]       | 0           | 0    | 1.033   |
| Left Cingulate Gyrus, anterior division           | 0.224280  | 1.632309  | 0.124896 | [-0.07 0.519]       | 0           | 0    | 0.775   |
| Right Cingulate Gyrus, anterior division          | 0.172685  | 1.330111  | 0.204745 | [-0.106 0.451]      | 0           | 0    | 0.55    |
| Left Precuneus Cortex                             | -0.319806 | -1.624163 | 0.126634 | [-0.742 0.103]      | 0           | 0    | 0.768   |
| Right Precuneus Cortex                            | -0.371289 | -1.791926 | 0.094777 | [-0.816 0.073]      | 0           | 0    | 0.948   |
| Left Occipital Fusiform Gyrus                     | -0.342064 | -1.871559 | 0.082311 | [-0.734 0.05]       | 0           | 0    | 1.052   |
| Right Occipital Fusiform Gyrus                    | -0.219603 | -1.329791 | 0.204848 | [-0.574 0.135]      | 0           | 0    | 0.55    |
| Left Amygdala                                     | -0.273778 | -1.225324 | 0.240668 | [-0.753 0.205]      | 0           | 0    | 0.494   |
| Right Amygdala                                    | -0.192578 | -0.902268 | 0.382176 | [-0.65 0.265]       | 0           | 0    | 0.373   |

**Table 1 – Social Synchrony Perception in ROIs.** Statistics of the two sided t-tests, performed using mean beta values extracted from our ROIs in all social synchrony perception contrasts. Results include the Bayes Factor (BF) derived from a Bayesian t test.

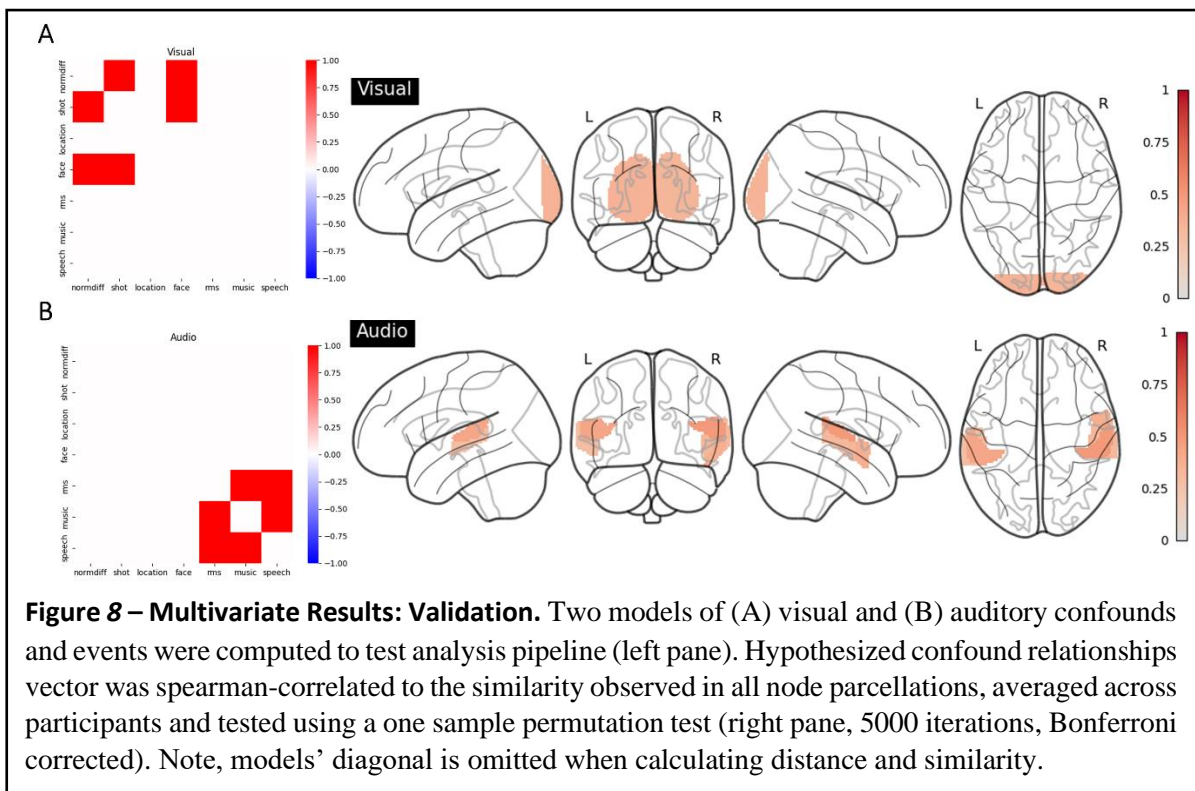
## Multivariate Analysis – Representational Similarity (RSA).

Validation of our multivariate analysis (figure 8) revealed significant correlations (Spearman's rho,  $\rho$ ) of neural patterns for visual confounds in bilateral occipital pole (left  $\rho=0.33$ , right  $\rho=0.32$ ). Significant similarities of audio confounds were observed in bilateral Planum Temporale (left  $\rho=0.39$ , right  $\rho=0.43$ ) and STG (anterior left  $\rho=0.35$ , posterior left  $\rho=0.26$ , posterior right  $\rho=0.31$ ).

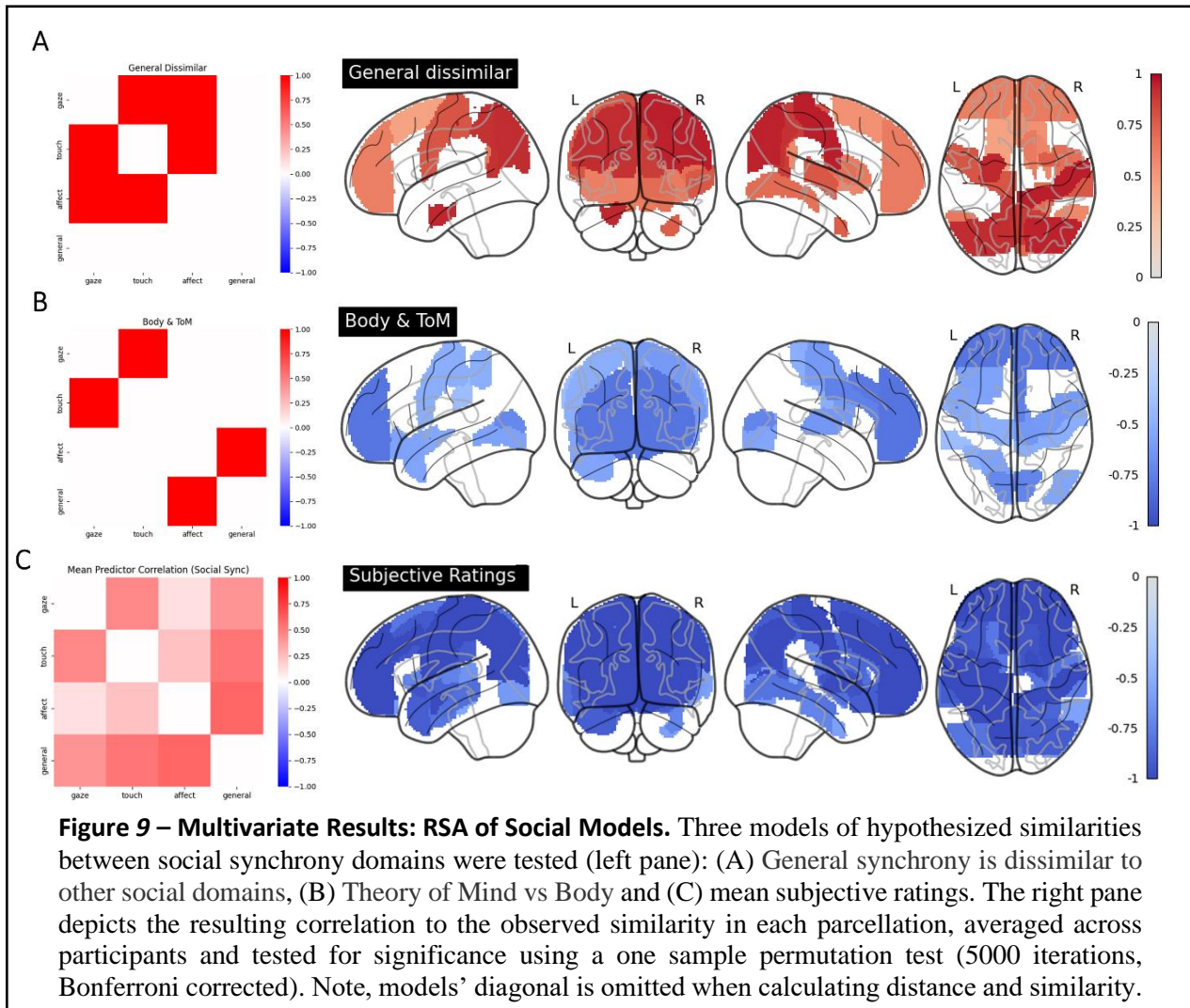
RSA of social synchrony models (figure 9) revealed that general synchrony perception is significantly dissimilar to other social synchrony domains throughout the brain, especially



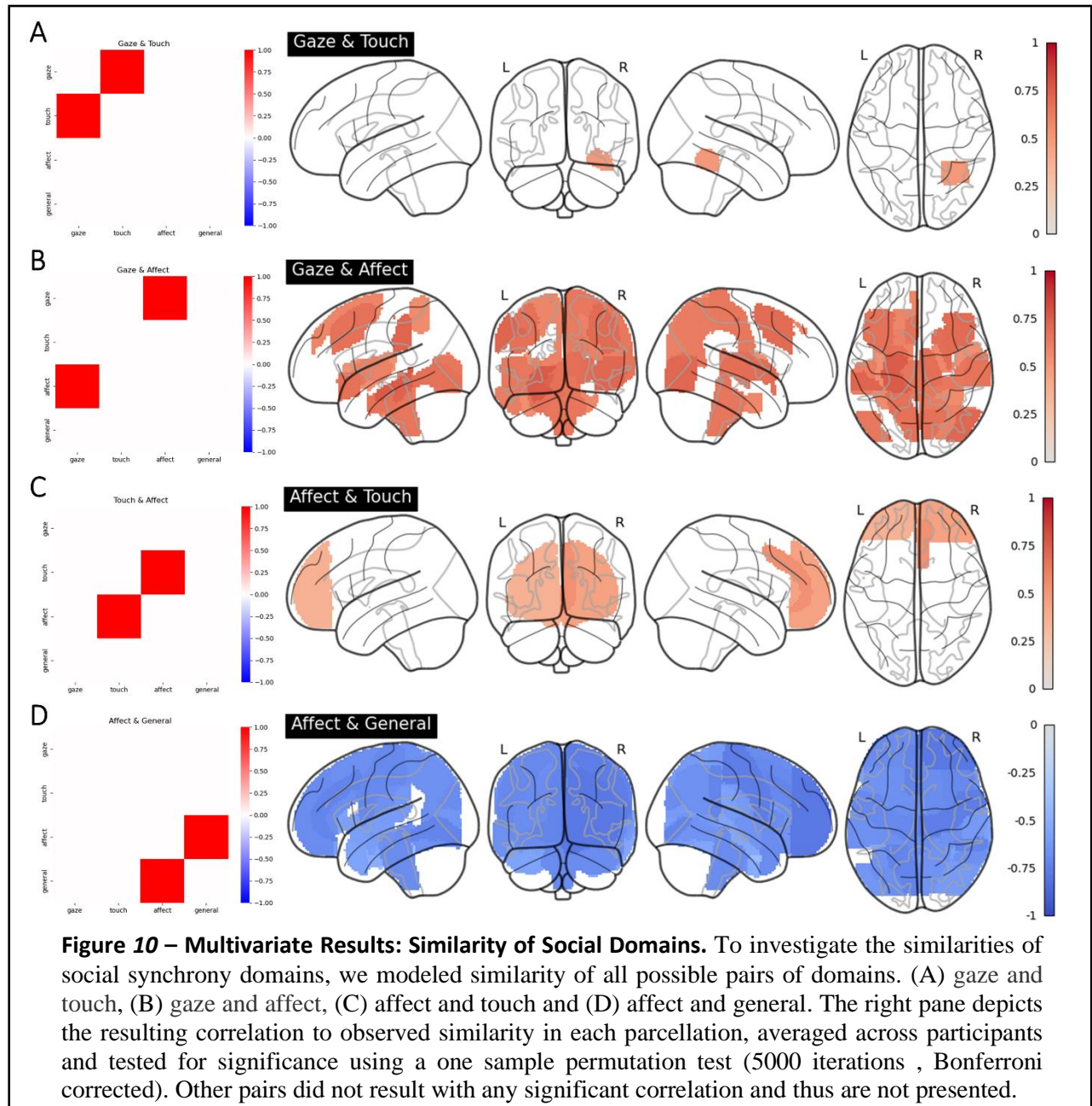
in posterior regions. The highest correlations to this model were observed in the Precuneus ( $\rho=0.63$ ), superior LOC ( $\rho=0.65$ ), right postcentral gyrus ( $\rho=0.65$ ) and left posterior parahippocampal gyrus ( $\rho=0.64$ ). For a full list of regions see supplementary. When examining the theory driven model of ‘Body vs ToM’, attempting to capture nodes with similar activity for bodily gestures (gaze and touch), apart from similarity in activity when making higher order inferences (others’ synchrony of emotional state and overall synchrony) revealed brain-wide negative correlations, specifically in anterior regions. These include the right paracingulate gyrus ( $\rho=-0.62$ ), the frontal pole ( $\rho=-0.61$ ) and right anterior cingulate cortex ( $\rho=-0.58$ ).



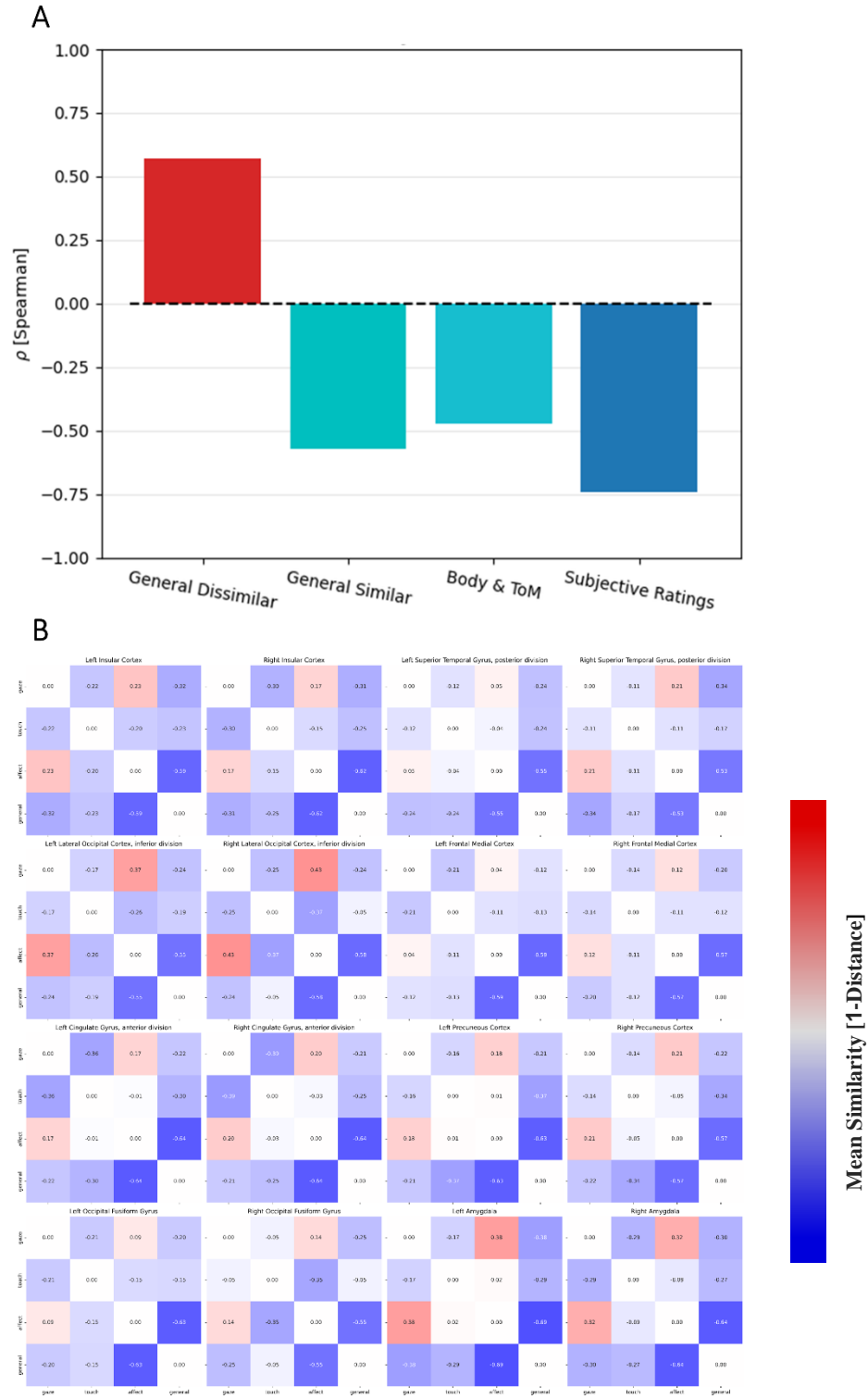
The data-driven ‘Subjective Ratings’ model yielded strong negative correlations across the brain, for a full list see supplementary. These negative correlations imply that participants neural pattern is highly dissimilar to subjective ratings relations of social synchrony domains.



When inspecting similarities in perception of different social domains (figure 10), we observed a clear distinction of neural activity between affect and general social synchrony, resulting with negative correlations across the brain. Most notable regions include the right frontal pole ( $\rho=-0.65$ ), postcentral gyrus ( $\rho=-0.55$ ), the Left occipital fusiform gyrus ( $\rho=-0.57$ ) and the right supramarginal gyrus ( $\rho=-0.62$ ). Touch and gaze synchrony were similar in the right temporooccipital fusiform cortex ( $\rho=0.44$ ) while touch and affect synchrony shared similarity in the frontal pole ( $\rho=0.4$ ) and the right paracingulate gyrus ( $\rho=0.46$ ). Similarities of gaze and affect synchrony were located at the inferior LOC ( $\rho=0.58$ ), the left amygdala ( $\rho=0.55$ ) the para hippocampal gyrus ( $\rho=0.59$ ) and the right hippocampus ( $\rho=0.6$ ), among other regions. for a full list, see supplementary.



To quantify how well our models fit in social brain regions, we computed the mean rho across our ROIs (figure 11) and revealed that the ‘General Dissimilar’ model was the highest correlated model evaluated (mean  $\rho=0.57$ , note that we did not test for significance of models). We further include the optimal neural pattern (defined as the average of observed conditions similarity across participants) of social synchrony perception in each of our selected regions.



**Figure 11 – Multivariate results: Mean similarity of Social Brain Nodes.** To explore the interactions of the social brain nodes in perceiving social synchrony, we computed (A) the mean models' spearman correlation across all ROIs and participants, and the (B) optimal neural pattern (defined as the mean observed similarity, 1-correlation based distance) in individual ROIs.

## Discussion

This research aimed to investigate the role of the social brain in perceiving and processing social synchrony of others using a combined theory and data driven approach. We utilized the StudyForrest open fMRI dataset, along with newly generated annotations for the appearance of faces and social synchrony perception. Our findings provide insights into the behavioral and neural mechanisms underlying the perception of social synchrony and the interplay of different functional nodes within the social brain.

Our behavioral experiment revealed a significant consensus among participants when assessing the degree of social synchrony between characters viewed in a motion picture. This suggests that humans exhibit a high degree of agreement in their perception of social cues, potentially reflecting the existence of shared neural mechanisms for processing these social signals. Furthermore, the observed differences in agreement scores across different social domains (gaze and touch showing higher agreement compared to affect and general synchrony) suggest that the perception of certain aspects of social synchrony might be more readily apparent and less susceptible to individual differences in interpretation.

The univariate analysis, using a General Linear Model (GLM) with a Regions of Interest (ROI) approach, revealed the involvement of the pSTG, FFA, and left Insula, along with other clusters within social brain nodes, when perceiving social synchrony. These findings are consistent with previous research highlighting the role of these regions in various aspects of social cognition, including face processing (FFA), biological motion perception (pSTG, superior LOC), and emotional empathy (Insula) (Kanwisher, 2010; Lee Masson et al., 2024, Kanske et al., 2015). Interestingly, while the "General  $\neq$  Other" contrast did not yield any significant activations, it did reveal differences across social brain regions. This result suggests that the neural processing underlying the perception of general social synchrony might not be simply the sum of its individual components (gaze, touch, and affect) and the relationship between them is nonlinear.

A multivariate analysis employing Representational Similarity (RSA) provided further insights into the neural representations of social synchrony within the social brain. We observed that the neural patterns associated with the perception of general social synchrony

were significantly dissimilar to those of other specific social domains (gaze, touch and affect), particularly in posterior regions such as the precuneus and superior LOC. This finding suggests that general social synchrony perception might involve distinct neural processing mechanisms compared to the perception of individual social cues. Additionally, the RSA analysis revealed negative correlations for the "Body vs. ToM" model, suggesting that the neural activity associated with processing bodily gestures (gaze and touch) is distinct from that involved in making inferences about others' mental states (affect and general synchrony). Examination of domain pairs revealed limited similarities of gaze and touch synchrony in temporooccipital Fusiform Cortex, touch and affect synchrony in frontal poles and extended similarities of gaze and affect synchrony in inferior LOC, left Amygdala, PHG and other regions. These findings challenge the notion that a single, unified neural system underpins all aspects of social perception.

While this study provides valuable insights into the neural mechanisms of social synchrony perception, some limitations need to be acknowledged. First, the sample size in our neuroimaging analysis was relatively small, limiting the generalizability of our findings. Future studies attempting to model more segments of this dataset, or other studies with larger cohorts are warranted to confirm these results and explore potential individual differences in neural processing. Second, the use of a naturalistic movie paradigm, while offering advantages in ecological validity, also introduces challenges in controlling extraneous variables and ensuring participants' sustained attention throughout the movie. Future studies could explore alternative experimental paradigms that provide greater control over stimulus presentation and participant engagement. Finally, the present study focused on the perception of social synchrony in pre-recorded movie stimuli. Future research could investigate the neural correlates of social synchrony perception in real-time social interactions, which might involve additional cognitive processes and neural mechanisms compared to passive observation.

In conclusion, this research sheds light on the neural mechanisms underlying the perception of social synchrony and the interplay of different functional nodes within the social brain.

Our findings highlight the complex and multifaceted nature of social cognition, with distinct neural processing mechanisms for different aspects of social synchrony perception. These results highlight our ability to process the synchrony of others, allowing us to understand and infer social context in real time both implicitly and explicitly. Our study demonstrates affordable and reproducible methods for novel fMRI research in the field of cognitive neuroscience, utilizing and extending unique open source databases.

Future research directions include investigating these processes in larger and more diverse samples, exploring potential individual differences, and utilizing alternative paradigms to gain a more comprehensive understanding of the neural basis of social synchrony in real-world interactions.



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## תקציר

כיצורים חברתיים, היכולת שלנו להבין ולהגיב במהירות לאותות חברתיים של אחרים היא חלק חיוני מחיי היומיום שלנו וחשובה מאוד להישרדות ולרווחה שלנו. המוח החברתי, רשת של אזורים מוח המוקדשים לעיבוד מידע חברתי, נחשב לממלא תפקיד מרכזי ביכולת זו. רשת זו מורכבת מאזורים פונקציונליים (צמתים) הכוללים את החלקים האחוריים של הגירי הטמפורליים העליונים (pSTG), בליטת פיוזיפורם (FFA), פיתול החגורה הקדמי (ACC), קליפת המוח הקדם-מצחית (mPFC), האינסולה הקדמית (AI), האמיגדלה, הפרהקוניוס (Precuneus) ועוד. מחקר זה נועד לבחון את תפקודו של המוח החברתי ואת הקשר ההדדי בין אזורים הכלולים ברשת זו בתפישה של סינכרוניות חברתית באמצעות פרדיגמת צפייה טבעית.

כדי לחקור האם אזורים אלו של המוח החברתי מעורבים בתפישת הסינכרוניות החברתית, השתמשנו בנתוני התהודה המגנטית (fMRI) הפתוחים של פרויקט StudyForrest, הכוללים תיוגים עבור היבטים שונים של הסרט "פורסט גאמפ", כולל דיאלוג, מוזיקה, תפאורה, מעברים בין צילומים ומשתנים תפישתיים של עוצמת השמע ובהירות התמונה הכללית. בנוסף, יצרנו תיוג חדש עבור הופעת פנים על ידי יישום אלגוריתם זיהוי פנים לקטעי הסרט שהוצגו. יתרה מכך, הוספנו מנבאים חדשים של סינכרוניות חברתית בארבעה תחומים: מבט, מגע, רגש וסינכרוניות התנהגותית כללית. מנבאים אלו נגזרו מהדירוגים המתמשכים של המשתתפים לגבי הסינכרוניות החברתית של הדמויות במהלך קטעים נבחרים מהסרט, שהושגו באמצעות ניסוי התנהגותי עצמאי.

ניתחנו את נתוני הדימות שנאספו בעבר עם כל התיוגים שהותאמו והמנבאים החדשים שנוצרו, כדי לנתח את העיבוד העצבי של תפישת הסינכרוניות החברתית, על ידי פירוק היבטים שונים של רמזים חברתיים (מבט, מגע ורגש) באמצעות אמצעי הסכמה סטטיסטיים. העלינו השערה ש- (א) המשתתפים יסכימו לגבי הסינכרוניות הנתפשת של רמזים חברתיים, כמו גם לגבי סינכרוניות התנהגותית כללית, המוגדרת כצירוף של כל הרמזים החברתיים, ש- (ב) העיבוד העצבי של תפישת סינכרוניות כזו כולל אזורים פונקציונליים שונים של המוח החברתי, ו- (ג) בעוד שתפישת סינכרוניות חברתית כללית ניתנת לתיאור כסכום של שלושת התחומים האחרים, התבניות העצביות של מרכיבי סינכרוניות חברתית שונים מתפישת הסינכרוניות החברתית הכללית.

ממצאי ההתנהגות שלנו מראים הסכמה רחבה בקרב משתתפים (82) בעת הערכת מידת הסינכרוניות החברתית בין הדמויות שנצפו בסרט. לאחר מכן, ביצענו בדיקה איכותית של דמיון ושוני בין תנאים כדי לאשר שסינכרוניות חברתית כללית, מבט, מגע ורגש שומרות על מידה מסוימת של עצמאות. בניתוח חד-משתני, תוך שימוש במודל לינארי כללי (GLM) עם גישת אזורי העניין (ROI), אנחנו מדגימים את המעורבות של FFA, pSTG והאינסולה השמאלית, יחד עם אשכולות נוספים בתוך אזורים של המוח החברתי בעת תפיסת סינכרוניות חברתית (15 נבדקים). בהמשך, צללנו עמוק יותר אל תוך האינטראקציות בין צמתים אלו באמצעות גישה רב-משתנית - ניתוח דמיון ייצוגי (RSA), וגילנו כי התבניות העצביות של תפישת סינכרוניות מבט, מגע ורגש שונות מאלו של תפישת סינכרוניות כללית באזורים של המוח החברתי.

בעוד שרוב התובנות ממחקר זה מחזקות מחקרים קיימים בתחום הקוגניציה החברתית וההשערה של "המוח החברתי", הן גם סוללות את הדרך לנתיב חדש בתחום מחקרי הדימות באופן שקל לשחזור ובעלות נמוכה: על ידי ניצול והרחבת היקף של מאגרי נתונים קיימים בקוד פתוח ויישום מתודולוגיה מקיפה המבוססת על שני עוגנים - תיאוריות קיימות וגישה מונחית נתונים. סקירה מקיפה זו של נתונים מבטיחה מסגרת איתנה וגמישה לחקירות עתידיות בתחום של מדעי המוח החברתי.



עבודה זו נעשתה בהדרכתו של ד"ר רועי סלומון וד"ר אדם זיידל ביחידה ללימודים בין תחומיים,

המרכז הרב תחומי לחקר המוח על שם לסלי וסוזן גונדה (גולדשמיד),

אוניברסיטת בר-אילן

# אוניברסיטת בר-אילן

## מידול תפישת סנכרון חברתי בעת צפייה טבעית בעזרת הדמיית תהודה מגנטית תפקודית

### אריאל שקד

עבודה זו מוגשת כחלק מהדרישות לשם קבלת תואר מוסמך ביחידה ללימודים בין תחומיים,  
המרכז הרב תחומי לחקר המוח על שם לסלי וסוזן גונדה (גולדשמיד) של אוניברסיטת בר-אילן

תשפ"ד

רמת גן