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Impact of Hypomanic Personality Traits on Brain Functional Connectivity During a Dynamic Theory-of-Mind Task

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Highlights:

- Severity of hypomanic traits was associated with right MFG and IFG activations;
- Hypomanic traits have an impact on brain connectivity during a ToM task;
- Stronger connectivity between the salience network and bilateral STG was observed.

Abstract

Hypomanic personality traits are present in the general population and represent a risk factor for developing bipolar disorder. This personality style, notably its social component, is linked to difficulties in theory of mind (i.e., ability to infer mental states). Exploring the neural correlates of mental states' inference in individuals with these personality traits can provide meaningful insights into the development of bipolar disorder. The aim of the present study was therefore to investigate the potential impact of hypomanic traits on brain activation and task-based connectivity strength during a dynamic theory of mind task in a nonclinical population. A total of 52 nonclinical participants were recruited, and hypomanic traits were assessed with the Hypomanic Personality Scale. The severity of hypomanic traits was positively associated with right middle and inferior frontal gyri activations (in high vs. low inference in nonemotional condition and emotion vs. no emotion in high inference, respectively). It was also associated with stronger connectivity between the salience network (i.e., bilateral putamen and pallidum) and bilateral superior temporal gyri (high inference in nonemotional condition), and between cerebellar and temporal areas (high inference in emotional condition). These changes may either reflect adaptations or differential processing, and further studies are therefore mandatory.

Keywords: fMRI, hypomania, inference, bipolar disorder, at-risk, neuroimaging.

1. Introduction

Among the predisposing factors to developing bipolar disorder (BD), the presence of hypomanic personality traits in young adults has been seen as a reliable predictor of mania (Kwapil et al., 2000; Walsh et al., 2015) and is assessed through the Hypomanic Personality Scale (HPS; Eckblad and Chapman, 1986), validated among college students (Klein et al., 1996), as well as family samples including individuals with BD (Johnson et al., 2015; Meyer, 2002; Savitz et al., 2008). The hypomanic personality style defines people who are in a mild manic state most of the time, but do not fulfill the DSM criteria for episodic hypomania (American Psychiatric Association, 2013; Eckblad and Chapman, 1986). Some of these traits are adaptive, as people are energetic, upbeat, gregarious, and hard-working, although they can also be irritable and risk-taking. Moreover, as soon as it was defined, some authors wondered whether this personality style might reflect an actual affective condition (Eckblad and Chapman, 1986). Hypomanic traits can indeed be understood as subsyndromal symptoms, and included in the bipolar spectrum from a dimensional perspective (Parker et al., 2014).

One interesting facet of this personality style, besides its direct link to mood symptoms, is its social component, sometimes called *social vitality* or *hypersociability* (Rawlings et al., 2000; Schalet et al., 2011). This dimension reflects both positive and maladaptive aspects, and has been related to cognitive aspects such as semantic ambiguity processing (Raucher-Chene et al., 2017), as well as psychopathological traits such as impulsivity (Schalet et al., 2011). This social potency and vivaciousness can be set against the theory of mind (ToM) impairments observed in people with hypomanic traits (Terrien et al., 2014). More specifically, ToM skills, namely the ability to represent one's own and other people's mental states (emotions, intentions, beliefs), can be predicted by the presence of hypomanic traits, especially in men (Terrien et al., 2014). Emotional context integration also seems to be modified by the

presence of these traits. In Terrien et al. (2015a)'s study, participants with hypomanic traits had difficulty integrating negative emotional contexts, but exhibited enhanced integration of positive emotional contexts. The above studies highlighted the value of assessing this population with more ecological tasks, to capture the social processing anomalies encountered in everyday life. More naturalistic social stimuli could be used to detect subtle, more finely-grained impairments, especially when combined with neuroimaging (Redcay and Moraczewski, 2020; Zhang et al., 2021).

A number of tasks have been used to explore the neural correlates of ToM, defining a core network associating the medial prefrontal cortex, bilateral temporoparietal junction, and precuneus, but each type of ToM task also elicits activity in specific brain regions (Molenberghs et al., 2016; Schurz et al., 2014). As these tasks tend to be static, they cannot capture the richness of social interactions, thereby limiting the application of their results in real life (Redcay and Moraczewski, 2020). For this reason, new tasks have been developed, featuring videos to make them more ecological (Henry et al., 2021; Serra-Mayoral et al., 2021). Ecological validity therefore refers to the potential for generalizability (i.e. the extent to which assessment results relate to and/or predict behaviors outside the test environment) and representativeness (i.e. the extent to which assessments resemble the everyday contexts in which behaviors will be required) (Dawson and Marcotte, 2017). For example, the Dynamic Inference Task (DIT; Henry et al., 2021) explores the neural correlates of different aspects of ToM (i.e., degree of inference, presence of emotion, gaze direction) identified in everyday-life interactions. In the general population, this task elicits neural activation in temporoparietal and prefrontal regions, internal temporal areas around the amygdala, and the right dorsomedial part of the superior frontal gyrus (Henry et al., 2021).

Besides task-related brain activation analyses, one complementary approach consists in assessing functional connectivity between brain regions (Wang et al., 2021). Task-dependent

functional connectivity can shed light on the interactions between regions that subtend ToM (McCormick et al., 2018; Schurz et al., 2020; Zillekens et al., 2019), and could help to delineate the impact of personality traits on ToM processes. A study conducted among individuals with BD and their unaffected relatives revealed reduced frontotemporoparietal connectivity in both groups, whereas increased connectivity between the right middle temporal gyrus and medial prefrontal cortex was only observed in the unaffected relatives (Willert et al., 2015), pointing to the presence of a compensatory process. As difficulties in ToM are already observed in individuals with hypomanic traits, it is possible that the neural network is also modified. To the best of our knowledge, no study has yet conducted a task-dependent functional connectivity analysis to explore the association between the neural correlates of ToM and hypomanic personality traits.

The present study therefore investigated the potential impact of hypomanic traits on brain activation and task-based connectivity strength during a video ToM task in a nonclinical population. For this purpose, we used the Dynamic Inference Task, which requires participants to attribute a mental state to an inferred social situation with different social cues (i.e., emotional expression, gaze direction). As such, it seems an appropriate means of exploring the neural correlates of social interactions (Henry et al., 2021). We hypothesize that activation of temporoparietal regions would be altered, as well as connectivity in a frontotemporoparietal network as described by Willert et al. (2015) in a clinical population.

2. Method

2.1. Participants

We recruited 52 nonclinical French participants from the local community through advertisements. To be included in the study, participants had to be aged over 18 years, right-handed, native French speakers, and free of sensory disabilities (i.e., eyesight and hearing)

that could not be corrected. Exclusion criteria were a history (participant or first-degree relative) of a psychotic disorder or BD, substance abuse or dependence within the previous 6 months, a severe medical disorder that might interfere with the assessment (e.g., neurological disorder, hypothyroidism, or severe head injury), and any MRI contraindication. Participants were screened for eligibility by trained psychiatrists. The Mini-International Neuropsychiatric Interview was used to assess current or past psychiatric history (Sheehan et al., 1998).

Sociodemographic data (i.e., age, sex at birth, and education level) were collected.

Depressive symptoms were assessed with the Hamilton Depression Rating Scale (Hamilton, 1967). Finally, global functioning was scored with the Global Assessment of Functioning Scale (American Psychiatric Association, 2000).

The study was approved by the regional institutional review board (CPP Grand Est I no. 2016/09) and was conducted in accordance with the Declaration of Helsinki. All participants gave their written informed consent after the presentation of the experimental procedure and received financial compensation for their participation.

2.2. Hypomanic Personality Scale

The French version of the HPS (Eckblad and Chapman, 1986; Terrien et al., 2015b) was used to assess the presence and severity of hypomanic personality traits. This self-report questionnaire contains 48 true-false items and has good psychometric properties (Terrien et al., 2015b). Several models (i.e., 3- to 5-factor structures) have been proposed to capture the multidimensionality of this scale, but no consensus has yet been reached (Rawlings et al., 2000; Schalet et al., 2011; Stanton et al., 2019). Berson et al. (2022) recently recommended using the whole scale to assess the bipolar spectrum psychopathology and risk for BD. One of the initial pool of 52 healthy participants was excluded from the analyses, owing to missing HPS responses.

2.3. Dynamic Inference Task

This task consists of 24 videos involving a character talking about an everyday situation (for a detailed description of the task, see Henry et al., 2021). Briefly, participants were required to attribute mental states to human actors, immediately after observing their verbal and nonverbal expressions. The task allowed us to manipulate the degree of inference (high vs. low), the presence of emotion (emotional vs. nonemotional), and the character's gaze direction (direct vs. averted). The detailed procedure is summarized in Figure 1.

2.4. Functional MRI data acquisition

Imaging was performed on a 3T Siemens Skyra (Siemens Healthcare, Erlangen, Germany). For each participant, we acquired anatomical whole-brain T1-weighted images parallel to the AC-PC line with a tilt of -30° , using a 3D gradient-echo pulse sequence with the following parameters: TR = 28 ms; TE = 6 ms; flip angle = 27° ; FOV = 250 mm, 36 slices, slice thickness = 4.50 mm, reconstructed voxel resolution = 1 x 1 x 4.5 mm. Functional data were acquired in an ascending-slice 2D-T2-weighted EPI sequence sensitive to blood-oxygen-level-dependent (BOLD) contrast, in the same axial plane as the T1-weighted structural images (2D-T2-FFE-EPI; TR = 2000 ms, TE = 30 ms, flip angle = 90° , FOV = 240 mm; 36 axial slices, slice thickness = 4.50 mm, reconstructed voxel resolution = 3 x 3 x 4.5 mm).

2.5. Functional MRI data analysis

2.5.1. Preprocessing

Image processing and statistical analyses were conducted using statistical parametric mapping implemented in SPM12 (<http://www.fil.ion.ucl.ac.uk/spm/software/spm12/>). The first six volumes in each session were discarded (leaving 234 volumes in each session), to allow for T1 equilibration effects. One participant was excluded at this stage after a quality check of the scans (i.e., corrupted raw data). Functional images of the 50 remaining

participants were spatially realigned to the mean functional image of the series, and a slice-timing correction was then applied. At this step, potential outlier scans were identified using Artifact Detection Tools (ART) algorithms. Scans showing a global BOLD signal more than five standard deviations from the mean, or motion exceeding a 0.9-mm threshold (representing 5-10% of all scans), were marked as outlier scans and included as nuisance regressors. Mean absolute movement of all scans was 0.09 mm [0-0.94] and 0 degree [0-0.02]. Images were directly segmented and normalized to the standard anatomical space of the Montreal Neurological Institute. Resample resolution was set at 2 x 2 x 2 mm. Finally, spatial smoothing was performed with an isotropic three-dimensional Gaussian filter with a full width at half maximum of 8 mm.

2.5.2. Dynamic Inference Task processing

At the first level, we defined a design matrix with separate regressors for each experimental condition resulting from the combination of the three factors: degree of inference (high vs. low), emotion (emotional vs. nonemotional), and gaze direction (direct vs. averted) for both the video clip and the inference sentence. We added sex as a covariance regressor and nuisance regressors, including motion regressors extracted from the realignment processing and scan outliers, where applicable. Data were high-pass filtered at 128 Hz to remove low-frequency drifts. From this first level, we adopted a two-step approach: we first computed three contrasts, and then analyzed each term of our contrasts of interest. The first one compared the high-inference condition with the low-inference one in the nonemotional condition. The purpose of this contrast was to assess mental state attribution when no emotional state had to be inferred. The second one compared the emotional condition with the nonemotional one in the high-inference condition. This contrast served to assess the effect of emotion processing in the high-inference condition. The last contrast compared the direct

gaze condition with the averted gaze one in the nonemotional condition, and was designed to assess the general effect of self-involvement.

We entered the resulting images into separate one-sample models including regressors such as HPS score and age. As negative correlations had been demonstrated between age and hypomanic traits in previous studies (Raucher-Ch  n   et al., 2018), we decided to control for the effect of hypomanic trait by age in all our analyses. Monte Carlo simulation was used to determine the cluster extent threshold needed to reach $p < 0.05$ corrected (Slotnick, 2017; Slotnick et al., 2003). For each contrast, we modeled a functional image matrix below a $p = .001$ voxelwise threshold and an appropriate estimation of the full width at half maximum kernel (high-inference vs. low-inference in nonemotional condition = 8.25; emotional vs. nonemotional in high-inference condition = 7.75; direct gaze vs. averted gaze in nonemotional condition = 8.25). FWHM estimations were obtained following Slotnik's recommendations. Specifically, FWHM were computed from the `img_xcorr` script. This script computed FWHM in all three dimensions of data. Its approach differed from AFNI as it does not rely on incorrect assumptions as gaussian-sized clusters. The cluster size for each contrast of interest was determined following 5000 simulations (high-inference vs. low-inference in nonemotional condition = 61; emotional vs. nonemotional in high-inference condition = 51; direct gaze vs. averted gaze in nonemotional condition = 61). As no directional relationship was hypothesized, we computed F contrasts. Clusters that were significantly activated were labeled using the Anatomy toolbox (Eickhoff et al., 2006; Eickhoff et al., 2007; Eickhoff et al., 2005).

2.5.3. *Connectivity processing*

We ran connectivity analyses to test for the functional connectivity of the task under the effect of hypomanic traits controlled by age. This was tested through a region of interest

(ROI)-to-ROI connectivity (RRC) analysis. Analyses were performed using the CONN toolbox (version 21a; RRID: SCR_009550 www.nitrc.org/projects/conn; Whitfield-Gabrieli and Nieto-Castanon, 2012). We used the preprocessed images from the whole-brain activation analysis. Following CONN's denoising step, we applied a linear regression of noise effects from several confounds in the BOLD signal and a band-pass filter (0.008 Hz to infinity) to each participant's images. The confounds included were a signal from cerebrospinal fluid and white matter from the initial anatomical preprocessing steps, and realignment parameters and scrubbing regressors from the ART processing. To reduce the constant and linear effects of the acquisition session, the main effect of each modeled condition was also entered as a confound.

We computed weighted RRC measures to assess the effect of hypomanic traits controlled by age on task-based connectivity strength. At the first level, time-series data were weighted by a canonical hemodynamic response convolved with a condition-specific boxcar function. Data corresponding to Fisher-transformed bivariate correlation coefficients between ROIs were entered in subsequent generalized linear model analyses including the total HPS score as a predictor and age as a control variable for each contrast of interest and each term of the contrasts (analyses of the main effects of the contrasts of interest are set out in supplementary data). The Harvard--Oxford atlas included in the CONN toolbox (Desikan et al., 2006) was used to determine the ROIs. As the present study was exploratory in nature, all ROIs were retained for the analyses. Spatial pairwise clustering analysis was used to estimate statistical significance, based on ROI permutation/randomization. This approach is close to the network-based statistic, but improves localizing resolution (Zalesky et al., 2012). The threshold was set at default values: $p < .01$ uncorrected for connections, and $p < .05$ false discovery rate (FDR) corrected for cluster level.

3. Results

3.1. Whole-brain activation

The characteristics of the final sample ($N = 50$; 30 males and 20 females) are described in Table 1. Behavioral data showed that participants had a mean response accuracy of 87.11% ($SD = 10.67$) and performance was not correlated to the HPS score ($r(48) = -0.11$; $p = 0.434$). For high inference versus low inference in the nonemotional condition, hypomanic traits had a positive effect on activation of the right middle frontal gyrus: $[46\ 22\ 40]$; $k = 66$; $F(1, 46) = 21.16$. For emotion versus no emotion in the high inference condition, a positive effect was detected in the orbital part of the right inferior frontal gyrus: $[42\ 42\ -16]$; $k = 60$; $F(1, 46) = 20.64$, and in the left postcentral gyrus: $[-18\ -28\ 76]$; $k = 71$; $F(1, 46) = 17.20$. No other significant result was found for any contrast of interest or term at the corrected thresholds.

3.2. ROI-to-ROI connectivity analysis

3.2.1. High inference versus low inference in nonemotional condition

No significant result was observed for the effect of hypomanic traits on this contrast of interest. A positive effect was noted for the high inference term in two clusters (Fig. 2, Table 2). Thus, the effect of hypomanic traits was noted on the connectivity between areas involved in the salience network (bilateral putamen and pallidum) and the bilateral superior temporal areas. A positive effect was also noted on the connectivity between cerebellar areas and sensorimotor areas. No statistically significant effect of hypomanic traits on the RRC matrix was noted for the low inference term.

3.2.2. Emotion versus no emotion in high-inference condition

No significant result was observed for the effect of hypomanic traits on this contrast of interest. As the second term of the contrast (i.e., no emotion in high-inference condition term) is equivalent to the first term of the preceding contrast (i.e., high inference in nonemotional condition), we only report here the effect of hypomanic traits on the presence of emotion in

the high-inference condition. A positive effect of hypomanic traits was observed on connectivity between cerebellar areas and bilateral superior temporal areas, such as the anterior and posterior parts of the superior temporal gyrus (STG) and temporal regions involved in auditory processing (Fig. 3; Table 3).

3.2.3. Direct versus averted gaze in nonemotional condition

No significant effect of hypomanic traits was noted in either the contrast or in each term of the contrast.

4. Discussion

The current study highlighted the positive effect of hypomanic traits in nonclinical participants on right MFG activation during a dynamic ToM task, in the absence of emotion in the high- versus low-inference conditions and on right IFG in the contrast of emotion versus no emotion in the high-inference condition. Moreover, in the high-inference condition, the presence of hypomanic traits was associated with stronger connectivity between the salience network (i.e., bilateral putamen and pallidum) and bilateral superior temporal areas in the absence of emotion, and between cerebellar and temporal areas (i.e., bilateral superior temporal areas and regions involved in auditory processing) in the presence of emotion.

In the present study, only one region located in the right lateral prefrontal cortex (i.e., right MFG) was significantly overactivated in the presence of hypomanic traits when contrasting inference in nonemotional condition. Interestingly, this region is highlighted in the four-component model of social interaction that was recently developed by Wu et al. (2020). The right MFG is more specifically involved in receiving input on the mental states of self and others (mentalizing process) and regulating confidence about these mental states (metacognitive process). This theoretical model is in line with the results of Grant et al. (2018), who reported activation of the right MFG when contrasting other versus self-threat in

a second-order ToM task, but did not find any group difference in this region when comparing patients with BD and controls. Hence, studies exploring the neural correlates of ToM impairment in BD have found decreased activation in regions that are part of the mirror system (i.e., inferior frontal gyri and insula), but not in this area (Cusi et al., 2012). Therefore, the increased activation observed in the current study in this nonclinical population might sign a compensatory process to maintain the metacognitive abilities required by the task's conditions.

When contrasting emotion in the high-inference condition, the right IFG was overactivated in the presence of hypomanic traits. Considering the laterality of the activation, a segmentation analysis of the right IFG into different clusters highlighted the implication of the anterior of this region in social cognition, notably emotion processing (Hartwigsen et al., 2019). A meta-analysis of relatives of BD patients also showed increased activation of this region during cognitive tasks (Cattarinussi et al., 2019), which was interpreted as a potential resilience process (i.e., a neural process that can compensate for the negative effects of predisposition and disease expression mechanisms); interestingly, the IFG has been suggested as a marker of resilience of BD in different neuroimaging modalities (i.e., structural (Kempton et al., 2009) and perfusion (Krüger et al., 2006)).

The connectivity features revealed by the present study show how the presence of hypomanic traits can increase the strength of connections between some regions involved in social processes, such as the posterior part of the STG. The latter's connections with the anterior cingulate cortex have been highlighted in the context of reorienting social attention, and with the posterior part of the prefrontal cortex during a false-belief video task (Schurz et al., 2020). In the high-inference condition of the present study, the bilateral STG was more strongly connected to the part of the salience network located in subcortical regions. This increased connectivity may reflect increased sensitivity to motivational signals in the presence of

cognitive demand. Attributing greater salience to sensory input (e.g., auditory stimuli) may make it easier to deal with the inference task. When Willert et al. (2015) explored functional connectivity during a ToM task in patients with BD and their relatives, they observed weaker connectivity between frontotemporoparietal regions, but also stronger connectivity between temporofrontal regions in relatives (though not in patients). This enhanced coupling was interpreted as a compensatory mechanism that may prevent at-risk individuals from developing BD. If we consider our sample as representing individuals with subsyndromic symptoms, the modified coupling we observed may have represented a preliminary stage of brain reorganization in the early phases of BD.

Some parts of the cerebellum were also involved in the connectivity changes in the nonemotional and emotional high inference terms. Hence, besides its central role in the control of motor behavior, region also helps to interpret goal-directed actions, based on people's movements (Van Overwalle et al., 2020). More specifically, lobule IX of the cerebellum seems to be more directly involved in tasks requiring abstraction in mentalizing (Metoki et al., 2022; Van Overwalle et al., 2014). Functional and structural connectivity (explored using probabilistic tractography) between cerebellar areas and the mentalizing network have also been highlighted in the general population, supporting the social role of this region as part of a broader network (Metoki et al., 2022).

The present study had some limitations that need to be addressed. First, the size of the sample was small allowing us to conduct exploratory analyses that will require confirmation in a larger sample. The number of participants did not allow us to conduct analyses by sex or gender, even though the literature suggests that there is gender- and sex-related variability in ToM processing but sex at birth was integrated into our covariates. Second, there was low variance in the HPS score, as the population was not selected on the basis of scores but randomly recruited, in an attempt to represent the general population as part of our ecological

approach. Nevertheless, positive results were observed in the presence of hypomanic traits, and future studies could use the same task to assess other at-risk populations, as well as clinical populations, in order to compare the neural correlates at each stage. Third, connectivity analyses must be interpreted with caution, mainly due to the use of default connection uncorrected threshold. In the absence of strong mainstream guidelines about thresholding in the spatial pairwise clustering method (Zalesky et al., 2012), default settings were applied. Replications with greater effect sizes are required to comfort the present results. Fourth, there are several methods of connectivity analysis with different conceptual backgrounds, and with potentially different results, depending on the chosen factors (e.g., thresholds or ROIs). In the present study, connectivity analyses were task-related, reducing the risk of unreliability compared with intrinsic functional connectivity analyses (Buckner et al., 2013). Moreover, spatial pairwise clustering tends to reduce the subjectivity associated with other approaches, such as seed region selection or dimensionality determination in independent component analysis (Zalesky et al., 2012).

Exploring the impact of hypomanic personality traits on brain activation and connectivity strength during a dynamic ToM task, the present study highlighted increased activation in the right MFG and IFG and stronger connectivity between different regions involved in inference processing. These alterations may reflect adaptations to maintain performance or differential processing prior to the onset of clinical symptoms. Further studies among populations at clinical or familial risk could confirm these initial findings and provide a better insight into the cognitive processes underlying BD development. The stakes are high in understanding social cognitive processing and its neural correlates in populations at risk of BD, in order to improve BD treatments, such as neuromodulation (i.e., regions to stimulate) or psychosocial interventions (i.e., focus of the intervention).

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Table 1

Sociodemographic and Clinical Characteristics of the Group (N = 50)

	Mean (SD)	Range
Age (years)	40.82 (12.80)	18-62
Education (years)	12.26 (1.9)	9-20
HPS score	9.38 (6.61)	1-28
Ham-D score	1.80 (2.28)	0-10
GAF	85.40 (7.01)	65-95

Note. HPS: Hypomanic Personality Scale; Ham-D: Hamilton Depression Rating Scale; GAF: Global Assessment of Functioning.

Table 2

Effect of Hypomanic Personality Traits on Brain Connectivity in High Inference Condition

		Statistic	<i>p</i> -unc	<i>p</i> -FDR	<i>p</i> -FWE
Cluster		Mass = 148.65	0.001	0.038	0.088
Putamen_L	pSTG_R	T(46) = 3.68	0.001	0.378	
Putamen_L	pSTG_L	T(46) = 3.27	0.002	0.668	
Putamen_L	aSTG_L	T(46) = 3.06	0.004	0.817	
Pallidum_L	aSTG_L	T(46) = 3.05	0.004	0.817	
Putamen_R	pSTG_L	T(46) = 2.86	0.006	0.858	
Pallidum_L	pSTG_R	T(46) = 2.83	0.007	0.868	
Putamen_R	pSTG_R	T(46) = 2.83	0.007	0.868	
Pallidum_L	pSTG_L	T(46) = 2.69	0.010	0.868	
Cluster		Mass = 148.21	0.001	0.038	0.088
SMA_R	Cereb9_R	T(46) =3.83	0.004	0.378	
PreCG_R	Cereb9_R	T(46) =3.75	0.001	0.378	
SMA_L	Cereb9_R	T(46) =3.16	0.003	0.758	
PreCG_L	Cereb9_L	T(46) =3.09	0.004	0.792	
SMA_L	Cereb9_L	T(46) =2.96	0.005	0.839	
PreCG_R	Cereb9_L	T(46) =2.95	0.005	0.839	
SMA_R	Cereb9_L	T(46) =2.90	0.006	0.839	

Note. Cereb9: Cerebellum 9; PreCG: precentral gyrus; SMA: supplementary motor area; STG: superior temporal gyrus (a: anterior part; p: posterior part); L: left; R: right.

Table 3

Effect of Hypomanic Personality Traits on Brain Connectivity in Presence of Emotion in High-Inference Condition

Cluster		Statistic	p -unc	p -FDR	p -FWE
Cluster		Mass = 252.55	0.001	0.032	0.025
aSTG_R	Ver12	T(46)=5.60	0.001	0.010	
HG_L	Ver12	T(46)=4.66	0.001	0.117	
PT_R	Ver12	T(46)=3.91	0.001	0.253	
pSTG_R	Ver12	T(46)=3.90	0.001	0.253	
PT_L	Ver12	T(46)=3.86	0.001	0.253	
aSTG_L	Ver12	T(46)=3.23	0.002	0.469	
aSTG_L	Ver12	T(46)=2.99	0.001	0.599	
pSTG_L	Ver12	T(46)=2.91	0.010	0.612	

Note. Cereb3: Cerebellum 3; HG: Heschl's gyrus; PT: planum temporale; STG: superior temporal gyrus (a: anterior part; p: posterior part); Ver12: Vermis 12; L: left; R: right.

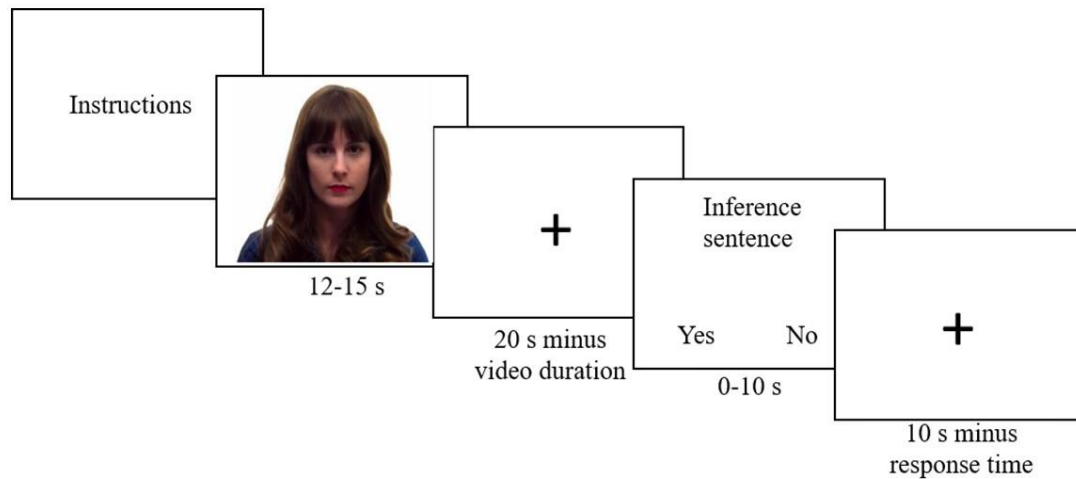


Figure 1. *Dynamic Inference Task design*. Adapted from Henry et al. (2021).

Twenty-four trials were presented to the participants. The instructions were: “A person tells you a story. Try to guess what happened to them.” Each trial consists of a short video clip with an actor talking. At the end of each trial, participants had to provide a yes or no answer related to the video.

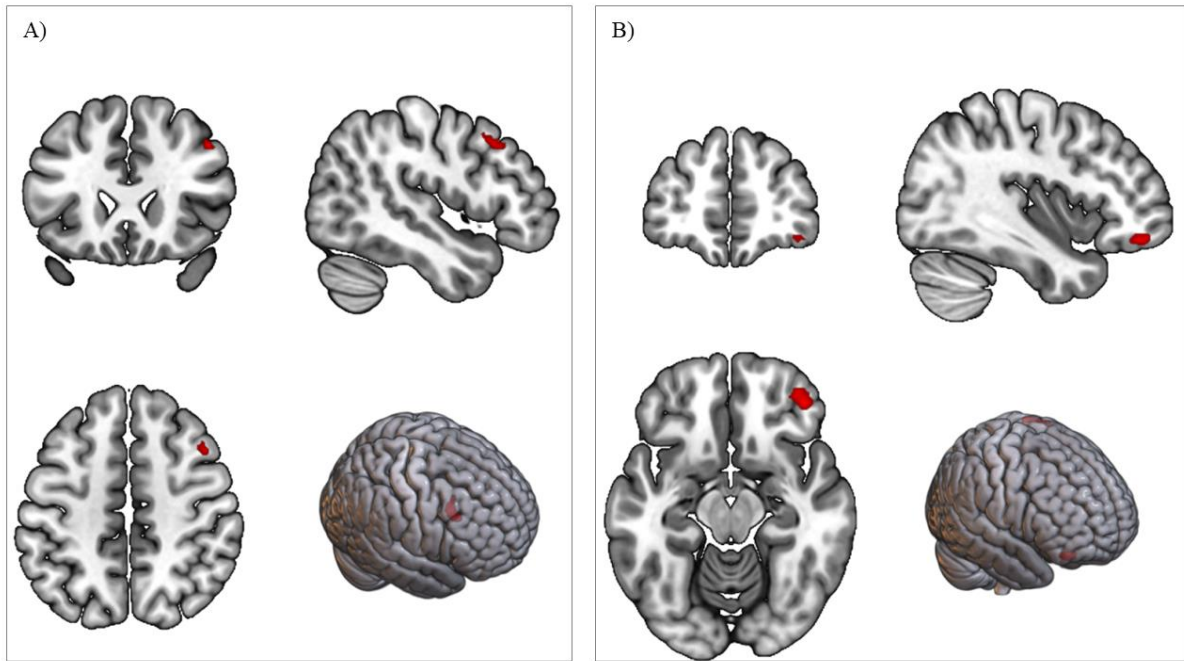


Figure 2. Main effects of the HPS score on task-related activations

Part A) Activation for the high vs. low-inference contrast in the nonemotional condition. The positive association with the HPS score is observed in the right middle frontal gyrus. Part B) Activation for the emotional vs. nonemotional contrast in the high-inference condition. The positive association with the HPS score is observed in the right inferior frontal gyrus.

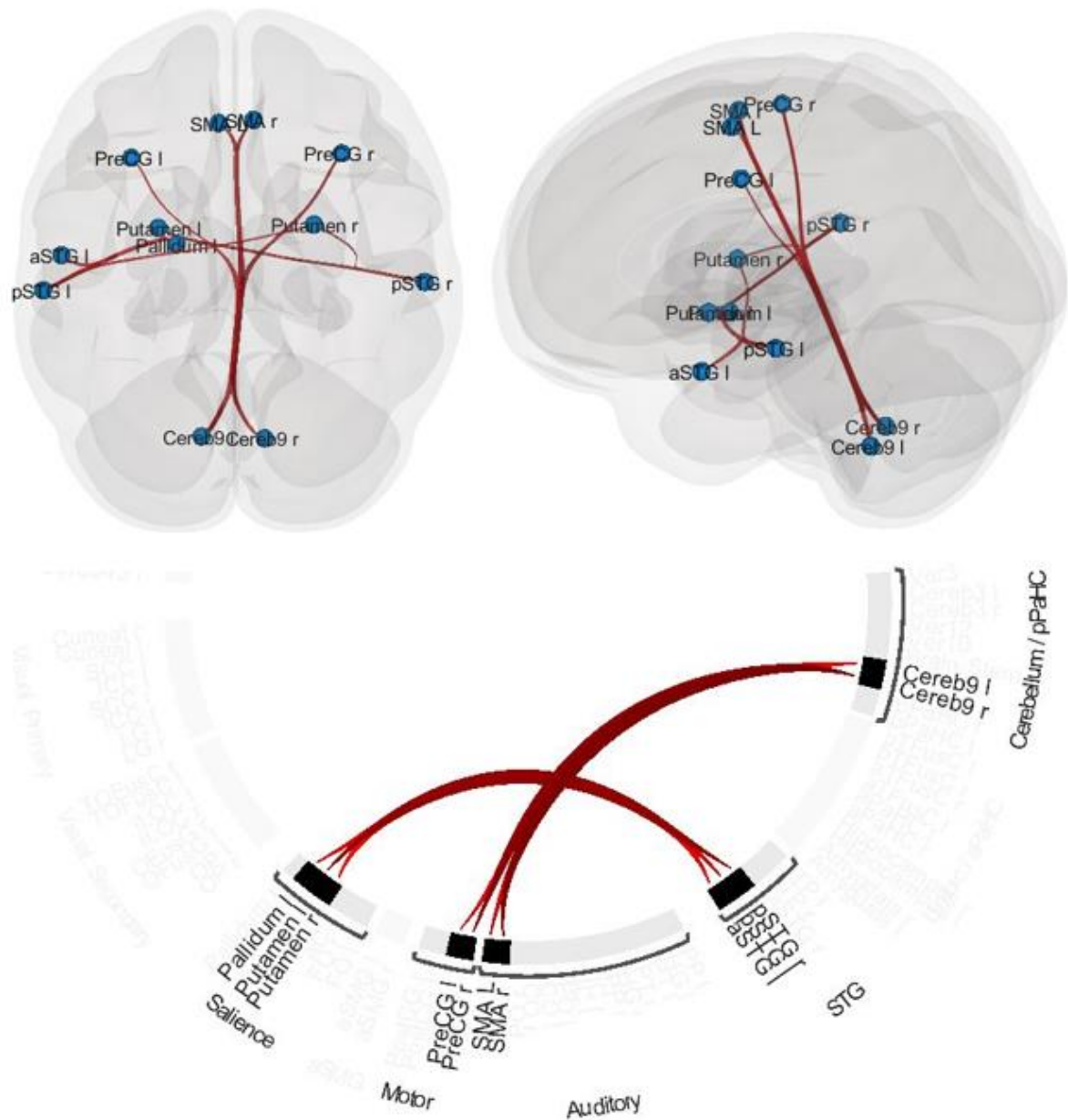


Figure 3. *Effect of hypomanic traits on high inference.*

The lower portion of the figure shows significant connections among all ROIs, arranged in a circle. It represents the brain areas that were more strongly connected when the HPS score was higher, in the high-inference condition. The same connections are represented on a glass brain (horizontal plane on the left and sagittal plane on the right) in the upper portion of the figure. The nodes in blue are the ROIs, and the edges in red the connections. The figure was built using the CONN toolbox.

Abbreviations. Cereb: cerebellum; HG: Heschl's gyrus; PreCG: precentral gyrus; SMA: supplementary motor area; STG: superior temporal gyrus (a: anterior part; p: posterior part); L: left; R: right.

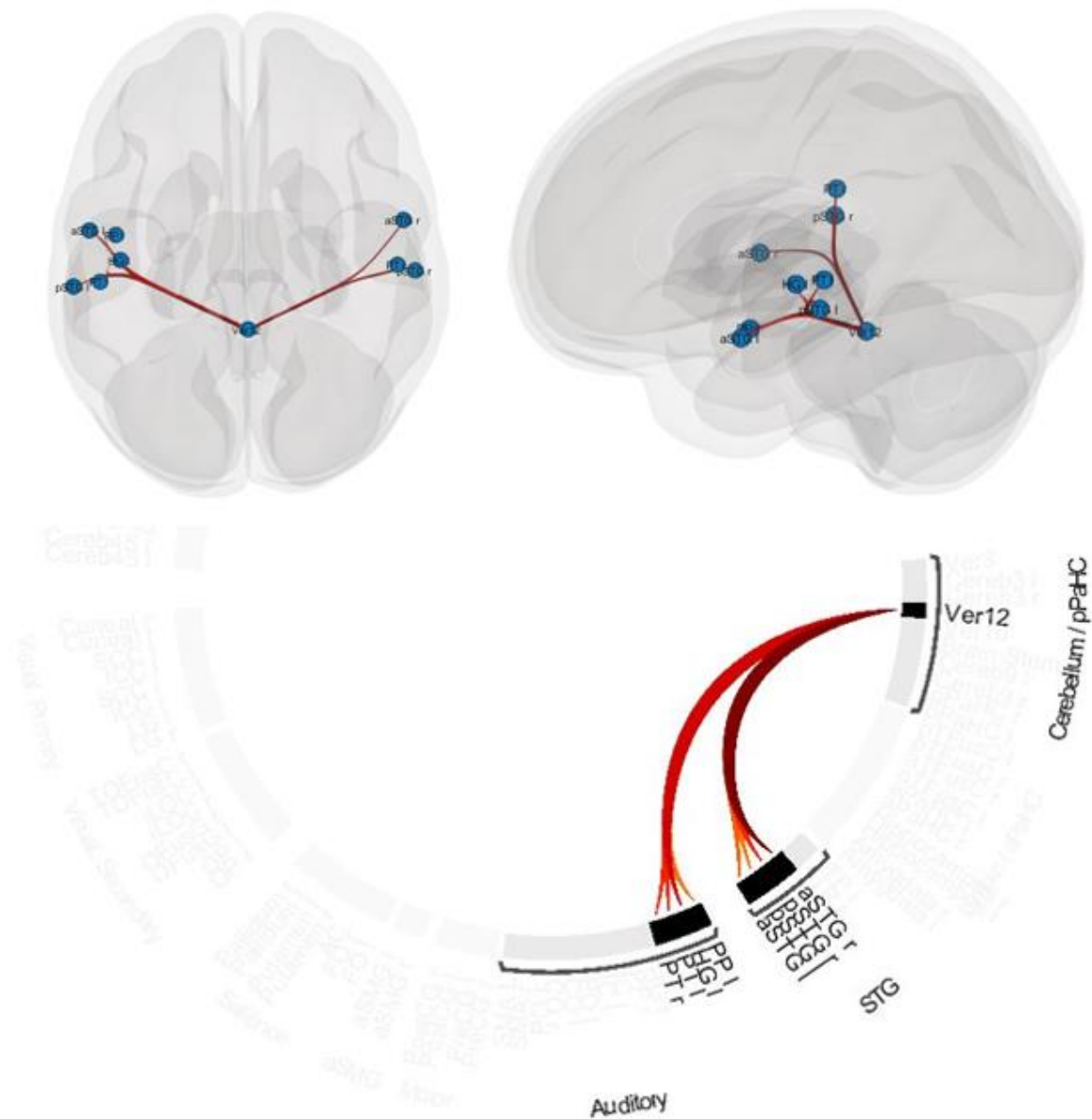


Figure 4. *Effect of hypomanic traits on presence of emotion in high-inference condition.*

The lower portion of the figure shows significant connections among all ROIs, arranged in a circle. It represents the brain areas that were more strongly connected when the HPS score was higher, in the presence of emotion in the high-inference condition. The same connections are represented on a glass brain (horizontal plane on the left and sagittal plane on the right) in the upper portion of the figure. The nodes in blue are the ROIs, and the edges in red the connections. The figure was built using the CONN toolbox.

Abbreviations. Cereb: cerebellum; HG: Heschl's gyrus; PP: planum polare; PT: planum temporale; STG: superior temporal gyrus (a: anterior part; p: posterior part); Ver: vermis; L: left; R: right.

Supplementary Material

Impact of Hypomanic Personality Traits on Brain Functional Connectivity During a Dynamic Theory-of-Mind Task

Dynamic Inference Task description

Stimuli consisted of 24 video clips, each lasting 12-15 s, showing a male/female actor talking about a personal experience. Three variables are manipulated: a) degree of inference (high-inference condition vs. low-inference condition), b) emotional expression (emotional condition vs. nonemotional condition), and c) gaze direction (direct condition vs. averted condition).

Degree of inference. There were 12 high-inference trials and 12 low-inference trials. In the high-inference video clips, the male/female actors reported their mental state but not the triggering event. As the context of the situation was not clearly explained, the reasons for the mental state remained ambiguous and therefore required a higher level of inference. In the low-inference video clips, the male/female actors gave clear information about what had happened to them.

Emotional expression. In the high-inference trials, the actors and the scripts conveyed emotion (angry or happy) in half the trials (emotional condition), but not in the other half (nonemotional condition).

Gaze direction. In half of the videos, the actors were directly facing the participant (i.e., camera; direct condition), while in the other half, the actors were facing approximately 30–35° away from the camera, in the direction of another presumed person.

Main effects of contrasts of interest

High versus low inference in nonemotional condition (HLN)

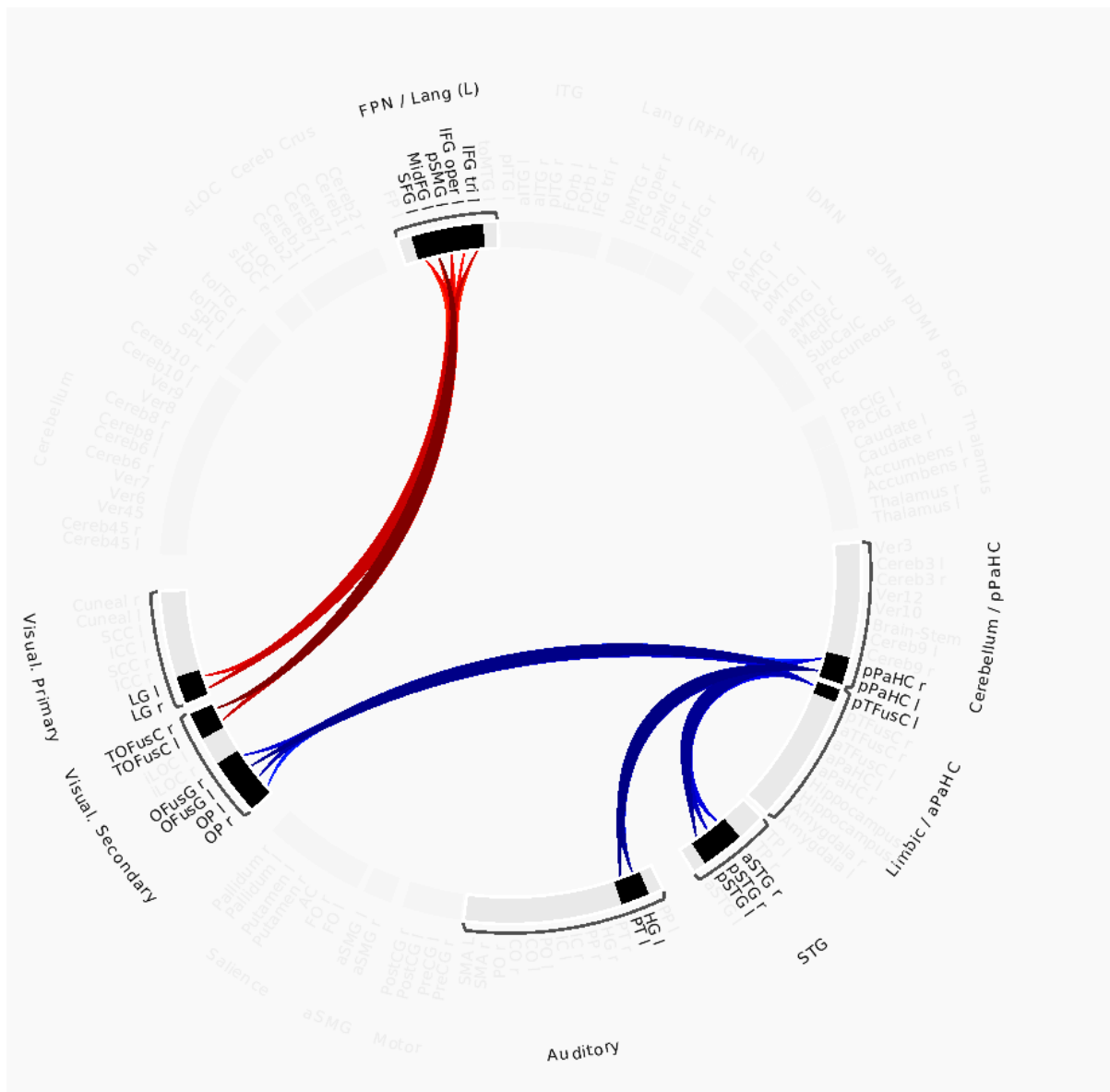


Figure S1. Main effect of HLN contrast.

Red lines represent positive effects of the contrast, and blue lines negative ones.

This analysis revealed stronger connectivity between structures belonging to language networks and structures associated with primary visual processing for high inference. Negative effects (i.e., weaker connectivity for high vs. low inference) were observed on connections from parahippocampal regions to secondary visual regions, superior temporal regions, and auditory processing regions.

Presence versus absence of emotion in high-inference condition (ENH)

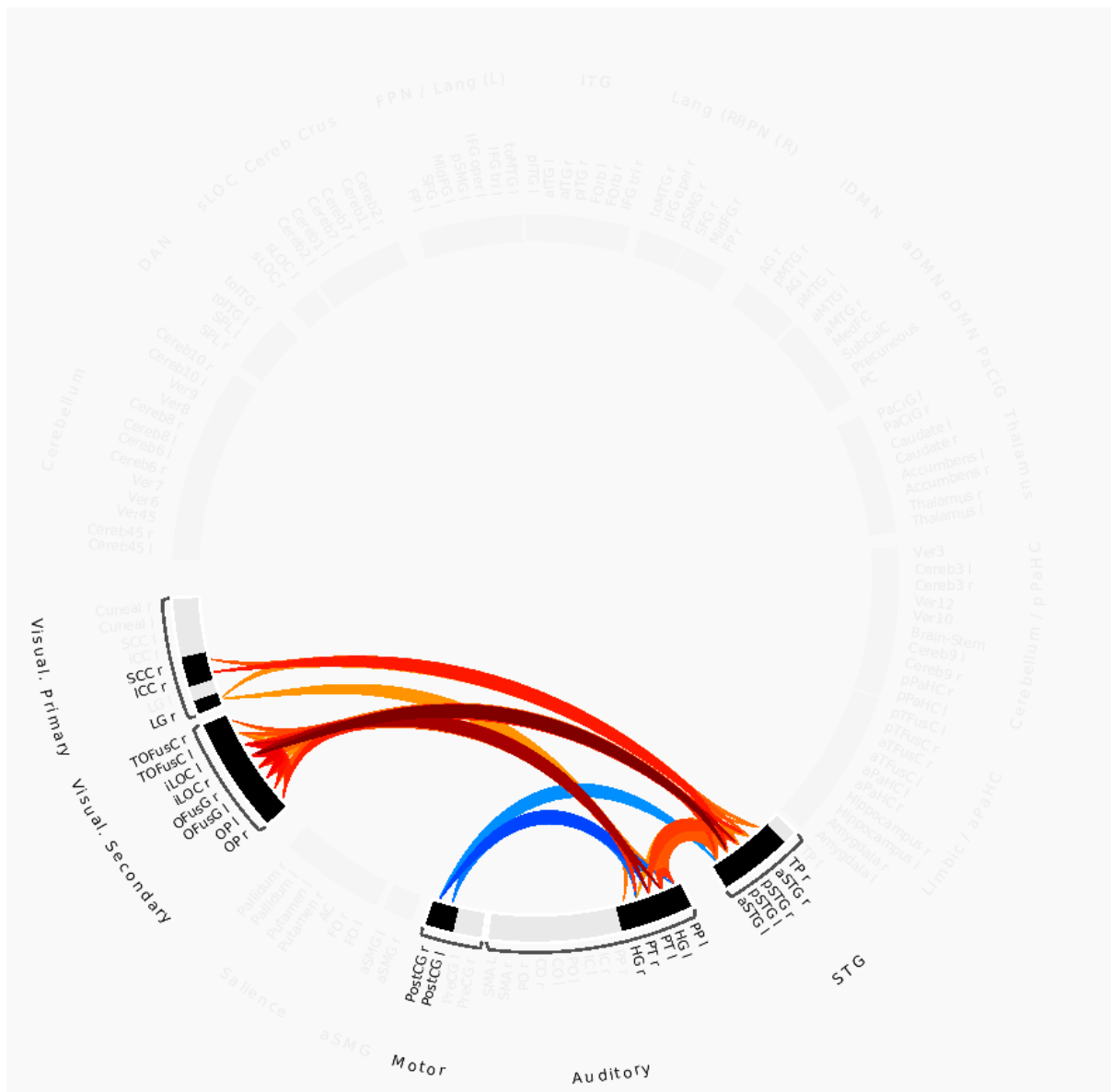


Figure 2. Main effect of ENH contrast.

Red and orange lines represent positive effects of the contrast, and blue lines negative ones.

Results highlighted a positive effect of emotion on connectivity between primary and secondary visual processing regions and both auditory processing regions and bilateral superior temporal regions, as well as between the latter two. A negative effect (i.e., weaker connectivity for the presence vs. absence of emotion) was found between motor regions and both auditory regions and the anterior part of the left superior temporal gyrus.

Directed versus averted gaze in nonemotional condition (DAN)

No significant result was found.

Significant connectivity results at exploratory connection thresholds

Table S1. Main effect of HPS on the connectivity of brain regions in the High inference condition, at $p=0.005$ uncorrected connection threshold.

			Statistic Mass/T(46) value	p-unc	p-FDR	p-FWE
Cluster			131.40	0.001	0.036	0.053
	SMA_R	Cereb9_R	3.83	0.001	0.378	
	PreCG_R	Cereb9_R	3.75	0.001	0.378	
	SMA_L	Cereb9_R	3.16	0.003	0.758	
	PreCG_R	Cereb9_L	3.09	0.003	0.792	
	SMA_L	Cereb9_L	2.96	0.005	0.839	
	PreCG_R	Cereb9_L	2.95	0.005	0.839	
Cluster			104.28	0.003	0.036	0.121
	Putamen_L	HG_L	4.34	0.001	0.329	
	Putamen_L	PT_L	3.77	0.001	0.378	
	Pallidum_L	HG_L	3.12	0.003	0.758	
	Pallidum_L	PT_L	3.04	0.004	0.817	
Cluster			102.49	0.004	0.04	0.127
	PostCG_L	pSMG_L	3.93	0.001	0.378	
	PreCG_R	pSMG_L	3.53	0.001	0.482	
	PreCG_L	pSMG_L	3.48	0.001	0.526	
	PostCG_R	pSMG_L	3.34	0.002	0.668	

Note. Cereb9: Cerebellum 9; HG: Heschel gyrus; PostCG: Postcentral Gyrus; PreCG: Precentral Gyrus; PT: planum temporale; SMA: Supplementary Motor Area; pSMG: Supramarginal Gyrus, posterior division; L: Left; R: Right; connection threshold: $p=0.005$ uncorrected; cluster threshold: $p=0.05$ FDR corrected.

No significant result survives at $p=0.001$ uncorrected connection threshold.