



Neighborhood affluence is not associated with positive and negative valence processing in adults with mood and anxiety disorders: A Bayesian inference approach

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ABSTRACT

Survey-based studies show that neighborhood disadvantage is associated with community reported mental health problems. However, fewer studies have examined whether neighborhood characteristics have measurable impact on mental health status of individuals in general and whether neighborhood characteristics impact positive/negative valence processing at both behavioral and brain levels. This study addressed these questions by investigating effects of census-based neighborhood affluence on self-reported symptoms, brain functions, and structures associated with positive/negative valence processing in a sample of individuals with mood and anxiety disorders ($n = 262$). Employing a Bayesian inference approach, our investigation demonstrates that neighborhood affluence fails to be associated with positive/negative valence processing measured across multiple modalities, with the only effects of neighborhood affluence identified in trait anxiety scores. These findings highlight that while community-based relationships between neighborhood characteristics and mental health problems are strong, it is much less clear that these characteristics have a measurable impact on the individual.

1. Introduction

A growing literature reports that neighborhood disadvantage has a profoundly negative impact on physical and mental health, above and beyond individual-level effects (Jencks and Mayer, 1990; Rudolph et al., 2014). For instance, neighborhood disadvantage is often associated with coronary heart disease (Chi et al., 2016), cancer (Palumbo et al., 2016), depression (Kim, 2010; Latkin and Curry, 2003; Ross, 2000; Santiago et al., 2011), anxiety (Cerdá et al., 2017; Santiago et al., 2011; Stockdale et al., 2007), and substance use (Boardman et al., 2001; Karriker-Jaffe, 2013). Despite compelling evidence for the relationship between neighborhood disadvantage and poor health, the neural correlates of neighborhood effects remain largely unknown. The goal of this investigation was to determine whether there is a direct relationship between neighborhood defined affluence and individual differences in symptoms and brain processing in a sample of individuals with mood and/or anxiety disorders.

There are at least two potential neuropsychological pathways by which neighborhood disadvantage facilitates mood and anxiety problems, namely altered negative and positive valence processing. On the

one hand, neighborhood disadvantage is linked with increased exposure to life stressors (e.g., violence) as well as enhanced vulnerability to deleterious effects of stressful life events (Aneshensel and Sucoff, 1996; Attar et al., 1994; Wilson et al., 2004). Likewise, there is evidence showing that effects of neighborhood disadvantage on mental health problems are mediated by stressful life events at the community level (Boardman et al., 2001; Ross, 2000). Furthermore, recent human brain imaging studies reveal that neighborhood disadvantage exhibits associations with altered brain morphology and functional connectivity in amygdala, hippocampus, and insula (Saxbe et al., 2018; Whittle et al., 2017). Saxbe et al.'s study (2018) indicates that neighborhood disadvantage measured as community violence exposure is related to smaller hippocampus and amygdala volumes as well as stronger resting state connectivity between hippocampus and insula. These regions are important for negative valence processing and often exhibit functional or structural perturbation among mood/anxiety disorders (Brühl et al., 2014; Etkin and Wager, 2007; Soares and Mann, 1997). Therefore, functional and structural alterations in these regions might mediate the effects of neighborhood on mood/anxiety problems. Notably, however, Gianaros et al. (2017) report that neighborhood disadvantage is not

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correlated to morphology of subcortical regions that are implicated in negative valence processing.

On the other hand, an accumulating body of evidence indicates that residing in disadvantaged neighborhoods accompanies alternations in reward processing, although current evidence is mixed (Gonzalez et al., 2016; Marshall et al., 2018). For instance, several studies demonstrate that family- or neighborhood-level disadvantage mainly impacts reward regulation in prefrontal regions (e.g., medial prefrontal cortex [mPFC]) rather than reward responding in striatal areas such as caudate and nucleus accumbens (NAcc) (Marshall et al., 2018; Muscatell, 2018; Romens et al., 2015). Socioeconomic disadvantage is positively correlated with mPFC activity during reward anticipation, implicating heightened suppression of striatal reward responding that leads to blunted reward sensitivity (Forbes et al., 2009). In accordance with these findings, heightened reward-related mPFC activity could mediate the relationship between socioeconomic disadvantage and depression symptoms (Romens et al., 2015). Likewise, neighborhood disadvantage is associated with reduced resting-state functional connectivity in fronto-striatal circuitry, and the reduced connectivity could mediate the association between neighborhood disadvantage and anxiety (Marshall et al., 2018). Hence, recent evidence suggests that neighborhood disadvantage mainly impacts regulatory responses to reward processing (but see also Gonzalez et al., 2016). Together, recent brain imaging studies suggest the hypothesis that neighborhood disadvantage alters negative and positive valence processing that are closely related to depression and anxiety.

The current work examined this hypothesis by assessing the effects of census-based neighborhood affluence on symptoms and brain functions/structures implicated in negative and positive valence processing among individuals with mood and/or anxiety disorders. We used a latent variable approach to identify factors that comprehensively quantify neighborhood characteristics (for details, see also Forthman et al., 2019). In particular, multivariate quantitative characterization of the neighborhood was derived by performing a factor analysis on the 2011–2015 American Community Survey data. Neighborhood affluence, the focus of the current study, was one of the robust factors showing the greatest loadings from neighborhood-level income and education.

Our work provides several advantages compared to previous studies of neighborhood-health relationships. First, the effects of neighborhood affluence were examined at multiple levels, from self-reported symptoms (e.g., positive and negative affect), to brain functions of reward and loss anticipation during a monetary incentive delay (MID) task (Knutson et al., 2001b), and brain morphology in regions important for positive and negative valence processing (e.g., striatum, amygdala). This multiple-level approach provides more holistic measurements and allows for convergent evidence on neighborhood effects to be revealed, which may provide a better understanding on the complex interplay between neighborhood affluence/disadvantage and symptoms, brain functions and structures. Second, Bayesian inference was employed to quantify the evidence on the presence or the absence of the neighborhood effects. In the Bayesian framework, a Bayes factor (BF_{10}) was computed as a ratio of the amount of evidence the data provides for alternative (H_1) and null (H_0) hypotheses. Hence, BF_{10} scores allow for quantifying support both for the H_1 hypothesis and for the H_0 hypothesis (Jeffreys, 1998; Rouder et al., 2009; Wagenmakers et al., 2010). The application of Bayes factors rather than P -values has been recently advocated in multiple disciplines (Biel and Friedrich, 2018; Dienes, 2016; Han and Park, 2018; Wagenmakers et al., 2018), due to reasons that (i) interpretations of Bayes factors are more straightforward than P -values, since a P quantifies the discrepancy between the data and the null hypothesis without directly involves the alternative hypothesis while a Bayes factor directly evaluates the likelihood of the alternative hypothesis against that of the null hypothesis (Goodman, 2008; Wagenmakers, 2007); and (ii) there is an increasing acknowledgment on the importance of null findings (Atkinson et al., 2018;

Moreau et al., 2018; Oldehinkel, 2018), and the Bayesian inference approach allows for accepting H_0 hypothesis. Finally, the current study is the first to examine the effects of neighborhood affluence using a clinical sample of patients diagnosed with mood or anxiety disorders, which could offer more direct assessment of the specific clinical impact of neighborhood affluence.

Based on existing evidence, it was hypothesized that lower neighborhood affluence would be associated with more severe symptoms of depression and anxiety (Cerdá et al., 2017; Santiago et al., 2011). We expected that these potential clinical effects would be accompanied by: (i) enhanced insula activity to loss anticipation (Wu et al., 2014) and attenuated striatal activation to reward anticipation (Arrondo et al., 2015), which are respectively linked to trait negative arousal scores (Wu et al., 2014) and anhedonia/depressive symptoms (Arrondo et al., 2015); and (ii) enhanced mPFC responses to reward anticipation, as consistently observed in previous studies (Marshall et al., 2018; Muscatell, 2018; Romens et al., 2015). Likewise, neighborhood disadvantage was expected to alter brain morphology in regions important for negative/positive processing, such that lower neighborhood affluence might be linked with smaller amygdala, hippocampus, and insula volumes, as identified in several previous studies (Saxbe et al., 2018; Whittle et al., 2017). Finally, we also explored whether neighborhood affluence was associated with altered morphology in mPFC and striatal areas, such as NAcc and caudate, due to critical roles of these regions in reward processing (Haber and Knutson, 2010).

2. Materials and methods

2.1. Participants

Participants were comprised of the first 500 subjects of the Tulsa 1000 (T-1000) study, which assesses and longitudinally tracks 1000 adults. The reason why the first 500 subjects were employed in the current study is that The Tulsa-1000 was still an on-going project when the current manuscript was prepared. We aim to replicate the current results with the second half of the T-1000 participants when the study is completed. The T-1000 study aims to use the National Institute of Mental Health (NIMH) Research Domain Criteria (RDoC) framework to establish a robust and reliable dimensional set of variables quantifying the primary domains proposed by the RDoC, including the positive and negative valence systems (Victor et al., 2018). The T-1000 study was conducted at the Laureate Institute for Brain Research and approved by the Western Institutional Review Board. All participants provided written informed consent and were financially compensated. Participants with mood and/or anxiety issues were categorized using the following dimensional psychopathology cutoffs: Patient Health Questionnaire (PHQ-9) ≥ 10 (Kroenke et al., 2001) and/or Overall Anxiety Severity and Impairment Scale (OASIS) ≥ 8 (Campbell-Sills et al., 2009). In addition, participants completed a diagnostic interview using an abbreviated version of the Mini International Neuropsychiatric Interview (Sheehan et al., 1998). Among the 500 subjects, 262 participants (Fig. S1 and Table S1) met DSM-5 criteria for at least one mood and/or anxiety disorder and were included in the current analyses (Fig. S2 and Table S2). These participants were referred from local treatment facilities or seeking treatment for anxiety and/or depressive symptoms.

2.2. Experimental procedure and task

2.2.1. Demographics

Participants were asked to indicate their age, contact information (e.g. address), ethnicity, gender, average income, education level, and occupational status. Neighborhood affluence was measured based on U.S. Census data, which were geocoded to participants' residential addresses. Specifically, participants' neighborhood affluence was determined in two steps (Forthman et al., 2019): First, the factor neighborhood affluence (and four other factors: singletons in neighborhood,

African-Americans in neighborhood, seniors in neighborhood, and noncitizens in neighborhood) was determined by factor analysis using tract-level data from the American Community Survey (ACS). In particular, we used a latent variable approach to identify factors that comprehensively quantify neighborhood characteristics, such that multivariate quantitative characterization of the neighborhood was derived by performing a factor analysis on the 2011–2015 ACS data (for details, see also [Forthman et al., 2019](#)). Details on the ACS data extraction, variable selection and factor were provided in the supplementary methods. Second, neighborhood affluence score was then assigned to each participant based on the resident tract.

2.2.2. Self-report questionnaires

Participants completed the following self-report questionnaires to assess positive and negative valence domains: (i) the PHQ-9 rates each of 9 DSM-IV criteria of depression from “0” (not at all) to “3” (nearly every day). Scores of 1–4 indicate minimal depression, 5–9 mild depression, 10–14 moderate depression, 15–19 moderately severe depression, and 20–27 severe depression ([Kroenke et al., 2001](#)); (ii) the OASIS is a 5-item questionnaire indexing anxiety-related severity and impairment across anxiety disorders. Each item is scored on a 5-point scale and the ratings are summed to obtain a total score. A cut-score of 8 correctly classifies 87% of individuals with an anxiety diagnosis or not ([Campbell-Sills et al., 2009](#)); (iii) the Ruminative Responses Scale (RRS) measures dispositional tendencies to ruminate in response to negative affect, including 22 questions regarding sad mood involving the self, one's symptoms, and possible causes and consequences of sad mood. Responses are rated on a 4-point scale ([Nolen-Hoeksema and Morrow, 1991](#)); (iv) the State-Trait Anxiety Inventory (STAI) consists of a “state” subscale to measure temporary anxiety symptoms and a “trait” subscale to measure more long-standing anxiety proneness. Each subscale includes 20 items rating at 4-point scales ([Spielberger, 1983](#)); (v) the Positive and Negative Affect Schedule (PANAS) comprises 20-items assessing forms of PA and NA using 5-point scales ([Watson and Clark, 1999](#)); (vi) the Temporal Experience of Pleasure Scale (TEPS) is a measure of anticipatory and consummatory pleasure consisting of 18 items rated on a 6-point scale ([Gard et al., 2006](#)).

2.2.3. MID task

To measure neural responses to rewards and losses, participants were asked to complete the monetary incentive delay task (MID), a well-established measure of reward processing ([Knutson et al., 2001a; Knutson et al., 2001b](#)). This task dissociates anticipatory and consummatory phases of reward processing and has been shown to reliably recruit brain areas associated with regulating approach-related response tendencies and reward sensitivity (e.g. ventral striatum). On each trial, participants were given a cue indicating potential reward (circle), loss (square), or no reward/loss (circle or square). In order to receive a specified reward or avoid a loss, participants are required to press a button within a certain duration of time (adapted for individual participant reaction times [RT]) following presentation of a white square (target cue). Task difficulty was based on RT collected during a practice session, and was calibrated such that each participant should succeed on about 66% of trials. The degree of potential reward or loss was varied on three levels indicated by the number of horizontal lines in a cue. That is, one line denoted the lowest reward/loss value (no reward/loss), two lines an intermediate reward/loss, and three lines the highest reward/loss. Participants could gain or lose points and earned an average of \$30 from the task, which they were paid at the end of the session. The primary measures of interest were (i) anticipation of reward vs. no-reward; and (ii) anticipation of loss vs. no-loss. This task included 2 runs each lasting 568 s and consisting of 90 trials.

2.3. Data acquisition

Images were acquired with a GE MRI750 3T scanner at the Laureate

institute for Brain Research. The MID task scanning consisted of 284 contiguous echo-planar imaging (EPI) volumes using the following parameters: TR/TE = 2000/27 ms, FOV/slice = 240/2.9 mm, 128 × 128 matrix, and 39 axial slices. In addition, high-resolution structural images were acquired through a 3D axial T1-weighted magnetization-prepared rapid acquisition with gradient-echo (MPRAGE) sequence, using the following parameters: TR/TE = 5/2.0 12 ms, FOV/slice = 240 × 192/0.9 mm, and 186 axial slices.

2.4. Statistical analysis

In general, Bayes factor (BF_{10}) was used to quantify evidence in favor of alternative against the null hypothesis (i.e., neighborhood affluence is effective vs. not effective). Here, BF scores above 1 denote evidence for H1 over H0, whereas BF scores below 1 indicate the opposite. By convention ([Wagenmakers et al., 2018](#)), the strength of evidence for alternative or null hypothesis is regarded as noteworthy when BF scores are above 3 or below 0.33, respectively. When BF scores are between 0.33 and 3, evidence for alternative or null hypothesis is considered as inconclusive or only anecdotal. Thus, BF scores were thresholded at 3 and 0.33 for supporting the alternative or null hypothesis, respectively; since $\log(BF)$ (where natural logarithm was used henceforth) was calculated for all analyses, corresponding thresholds were set at 1.1 and -1.1 . In other words, the selected thresholds correspond to the alternative hypothesis being greater than three times more likely than the null hypothesis or in reverse that the null hypothesis is three times more likely than the alternative hypothesis. To obtain the BF scores, we employed the regression BF function from the BayesFactor package (version 0.9.12)¹ in R ([Morey et al., 2015](#)), with the default setting for all parameters. The default prior distributions for the BayesFactor is the combination of the Cauchy on effect size and the Jeffreys prior on variance, which is also referred as the JZS prior (see also [Rouder et al., 2009](#)). The JZS prior was developed to minimize assumptions about the range of effect size ([Morey and Rouder, 2011; Rouder et al., 2009](#)).

2.4.1. Symptom analysis

Effects of neighborhood affluence on symptoms (PHQ9, OASIS, RRS, STAI, PANAS, and TEPS) were examined using a regression model with age, gender, ethnicity, individual income, education, and employment status as covariates. The effect of neighborhood affluence on each symptom measure was tested separately.

2.4.2. Functional imaging data

Neuroimaging data analyses were performed with the analysis of functional neuroimaging (AFNI, <http://afni.nimh.nih.gov>) software package ([Cox, 1996](#)). The first 3 volumes of the functional images were discarded for signal equilibrium and participants' adaptation to scanning noise. Subsequent data preprocessing included despiking, slice timing correction, co-registration to anatomical volumes, motion correction, smoothing ($5 \times 5 \times 5 \text{ mm}^3$ full width at half maximum), and normalization to the standard Montreal Neurological Institute space (MNI template, resampling voxel size was $2 \times 2 \times 2 \text{ mm}^3$).

A two-level general linear model (GLM) was used to analyze the functional data. For the first level, boxcar regressors were defined for each subject and for each epoch of the time course. The regressors modeled the blood-oxygen-level dependent (BOLD) response to the epoch of anticipation (4 s) in six conditions (15 trials per condition per run): large reward, small reward, no reward, large loss, small loss, and no loss. Furthermore, contrasts associated with anticipation of reward ($[1 \ 1 \ -2 \ 0 \ 0 \ 0]$) and loss ($[0 \ 0 \ 0 \ 1 \ 1 \ -2]$) were calculated for the second-level analyses. For the second level, effects of neighborhood affluence on neural responses to the anticipation of reward and loss were

¹ <https://richarddmores.github.io/BayesFactor/>

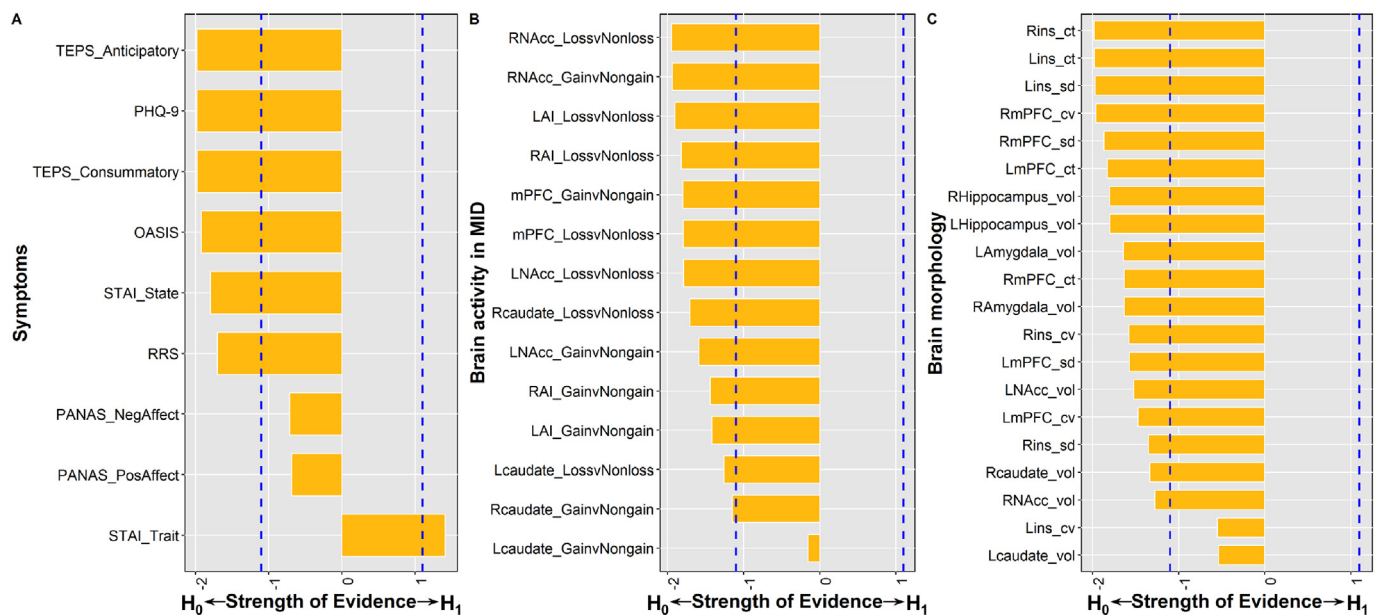


Fig. 1. Strength of evidence (i.e. log (BF) scores) regarding the effect of neighborhood affluence on symptoms (A), brain activity in the monetary incentive delay (MID) task (B), and brain morphology (C). Blue dashed lines indicate thresholds (i.e., -1.1 and 1.1). BF, Bayes factor; TEPS, temporal experience of pleasure scale; PHQ, Patient Health Questionnaire; OASIS, overall anxiety severity and impairment scale; STAI, State-Trait Anxiety Inventory; RRS, ruminative responses scale; PANAS, Positive and Negative Affect Schedule; L, left; R, right; NAcc, nucleus accumbens; AI, anterior insula; mPFC, medial prefrontal cortex; ins, insula; ct, cortical thickness, cv, cortical volumes; sd, sulcal depth; vol, volume. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

estimated with age, gender, ethnicity, individual income, education, and employment status as covariates. For the region-of-interest (ROI) analyses, the average BF scores were computed for the voxels within regions important for the anticipation of reward and loss, including the NAcc, caudate, insula, and mPFC (Fouragnan et al., 2018; Knutson et al., 2001a). These functional ROIs were defined as corresponding regions in a widely-used functional brain atlas (Power et al., 2011).

For the whole-brain analyses, BF scores pertaining to the effect of neighborhood affluence were computed for each voxel in the BayesFactor package. The computation was restricted on a group mask generated as the conjunction of all subject masks. To further illustrate brain regions and functions which were modulated by the neighborhood affluence, clusters with $\text{no} < 50$ voxels (with cluster-defining threshold of $\log(\text{BF}_{10}) > 1.1$) were selected. In addition, functions of brain maps associated with neighborhood effects on reward or loss anticipation were decoded using the Neurosynth Image Decoder (neurosynth.org; Yarkoni et al., 2011). The Neurosynth database (status: 507891 activations reported in 14,371 studies) provides automatically generated meta-analytic maps (activation patterns) for thousands of psychological terms, extracted through text-mining techniques (Yarkoni et al., 2011). Hence, the decoder function permits the calculation of voxel-wise Pearson correlations between a given unthresholded functional map (unthresholded t maps associated with neighborhood effects in our case) and each of the term-based meta-analysis maps in the Neurosynth database. As such, the decoder function allows for identifying the most frequent psychological concepts associated with a given neural pattern (Gorgolewski et al., 2015). The top 10 psychological terms that were associated with neighborhood effects on reward or loss anticipation were illustrated.

2.4.3. Structural MRI data

Data analysis was conducted using the FreeSurfer image analysis suite (version 6.0.0, <http://surfer.nmr.mgh.harvard.edu/>), with automated algorithms for the volumetric segmentation of subcortical structures and cortical measures. In brief, the MRI data were first normalized to a standard anatomical template and corrected for bias-

field inhomogeneities. Resulting volumes were skull stripped with a watershed algorithm (Ségonne et al., 2004) and then segmented into the subcortical white matter and deep GM volumetric structures (Fischl et al., 2002, 2004). The initial tessellation was formed by re-constructing the GM/white matter boundary as well as the outer cortical surface (pial surface) (Dale et al., 1999; Fischl and Dale, 2000). Next, a series of deformation procedures was implemented, including surface inflation (Dale et al., 1999), registration to a spherical atlas (Fischl et al., 1999), and parcellation of the cerebral cortex into units based on gyral and sulcal structures (Fischl et al., 2004). Finally, several morphological features were computed at each vertex on the pial surface, including cortical thickness, cortical volume, and sulcal depth. Specifically, cortical thickness was computed as the closest distance between the white and pial surfaces. Cortical volume was defined as the sum of the volumes of the individual triangles that lie within the neighborhood of the vertex, in which the volume of each triangle was calculated as the product of its area and the thickness at the center of the triangle. Sulcal depth was computed as the displacement from each vertex to the average surface. For subcortical brain structures, automated segmentation yields a volume measurement in units of 1-mm cubic voxels (Fischl et al., 2002). Morphological measures were calculated for brain regions implicated in positive and negative valence systems, including NAcc, caudate, anterior insula, amygdala, hippocampus, and mPFC (Morris and Cuthbert, 2012). Effects of neighborhood affluence on these structural measures were estimated with age, gender, ethnicity, individual income, education, employment status, and intracranial volume as covariates.

3. Results

3.1. Symptoms

Among questionnaires (Fig. 1A and Table S3), log (BF) scores were below -1.1 for anticipatory and consummatory subscales of the TEPS, STAI state anxiety, RRS, PHQ-9, and OASIS scores, providing the evidence that there was no effect of neighborhood affluence on these

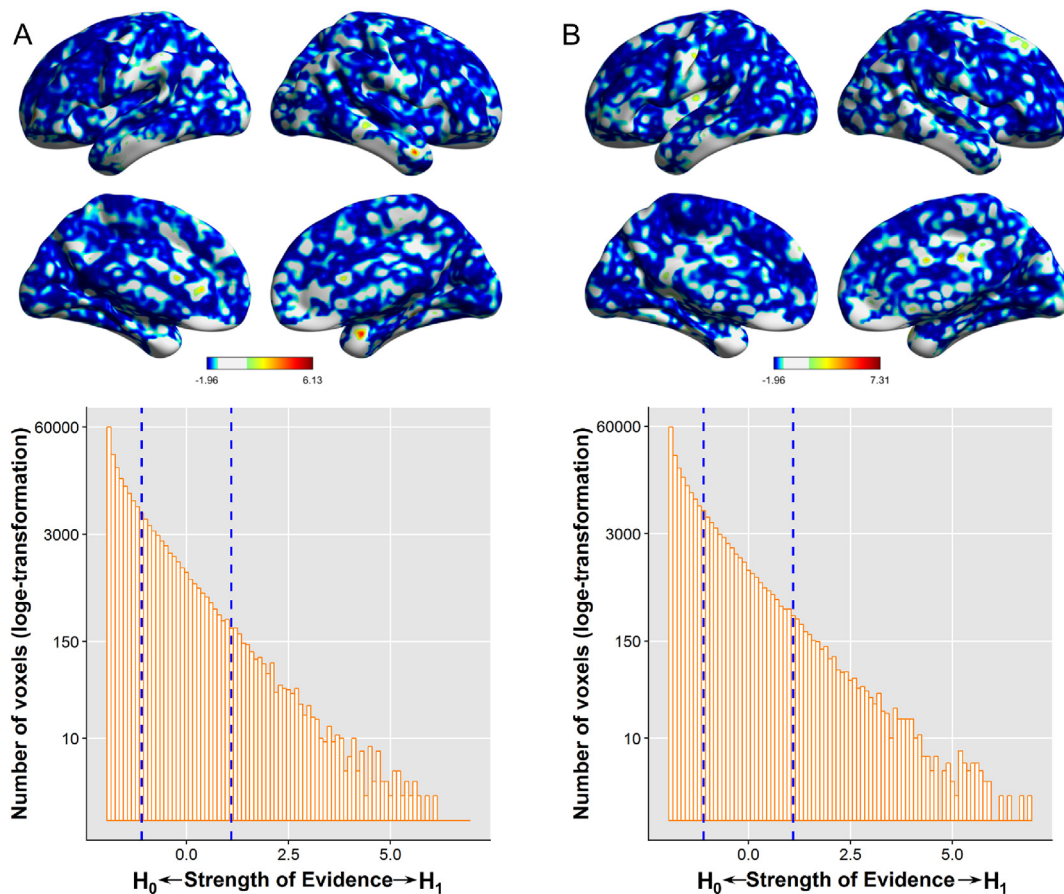


Fig. 2. Whole-brain analysis for the effects of neighborhood affluence on neural responses to reward (A) or loss (B) anticipation in the monetary incentive delay (MID) task. Brain maps illustrate log (BF) scores at each voxel (thresholded at -1.1 and 1.1). Histograms illustrate the distribution of log (BF) scores across the whole brain, the pattern of which shows that there are more voxels showing strong evidence in favor of no effects of neighborhood affluence than those showing strong evidence in favor of neighborhood affluence effects. Blue dashed lines indicate thresholds. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

measures. For PA and NA, log (BF) scores were between -1.1 and 0 , providing anecdotal evidence that neighborhood affluence did not impact these measures. Finally, log (BF) scores were above 1.1 for STAI trait anxiety, revealing evidence that neighborhood affluence was negatively correlated with trait anxiety. The scatter plots of corresponding results are illustrated in Fig. S3.

3.2. Brain activations

3.2.1. ROI analysis

Log (BF) scores of brain activity in all ROIs were below zero (Fig. 1B and Table S3), providing anecdotal to moderate evidence that neighborhood affluence had no effect on brain activity of these ROIs in response to reward or loss anticipation. The scatter plots of corresponding results are illustrated in Fig. S4 and S5.

3.2.2. Whole brain

For both reward and loss anticipation (Fig. 2), log (BF) scores associated with neighborhood effects were below zero in most brain regions.

For reward anticipation, clusters (voxel number > 50) that exhibited effects of neighborhood affluence were mainly located in superior frontal gyrus (SFG), supramarginal gyrus (SMG), middle temporal gyrus (MTG), and cerebellum (Fig. 3A and Table 1). Neighborhood affluence exhibited positive correlations with neural responses in SFG and cerebellum (Fig. S6), and negative correlations with neural responses in SMG and MTG (Fig. S6). Furthermore, a one-

sample *t*-test revealed that activations of all of these regions were enhanced in response to reward anticipation compared to the no reward condition (Fig. S7A and C). Finally, functional decoding revealed that effects of neighborhood affluence on reward anticipation were mainly associated with terms related to "somatosensory", "finger", "movement", "sensorimotor", "hand", "pain", "motor imagery", "tactile", "execution", and "tapping" (Fig. 3A).

For loss anticipation, clusters (voxel number > 50) that exhibited effects of neighborhood affluence were mainly located in SFG, rolandic operculum (ROL), posterior cingulate cortex (PCC), temporal pole (TP), MTG, and fusiform gyrus (FG) (Fig. 3B and Table 1). Neighborhood affluence was positively correlated with neural responses in ROL and PCC, and negatively correlated with neural responses in other regions (Fig. S8). Furthermore, one-sample *t*-tests revealed that none of these regions except ROL showed different activity in response to loss anticipation versus the no loss condition (Fig. S7B and D). The activity of ROL showed lower activations in response to loss anticipation than the no loss condition. Finally, functional decoding revealed that neighborhood effects on loss anticipation were primarily associated with "pain", "speech production", "secondary somatosensory", "production", "vocal", "tactile", "speech", "auditory", "stimulation", and "oral" terms (Fig. 3B).

Together, these findings complement ROI analyses suggesting that neighborhood affluence had no effect on neural responses in brain regions that are previously implicated in reward or loss anticipation.

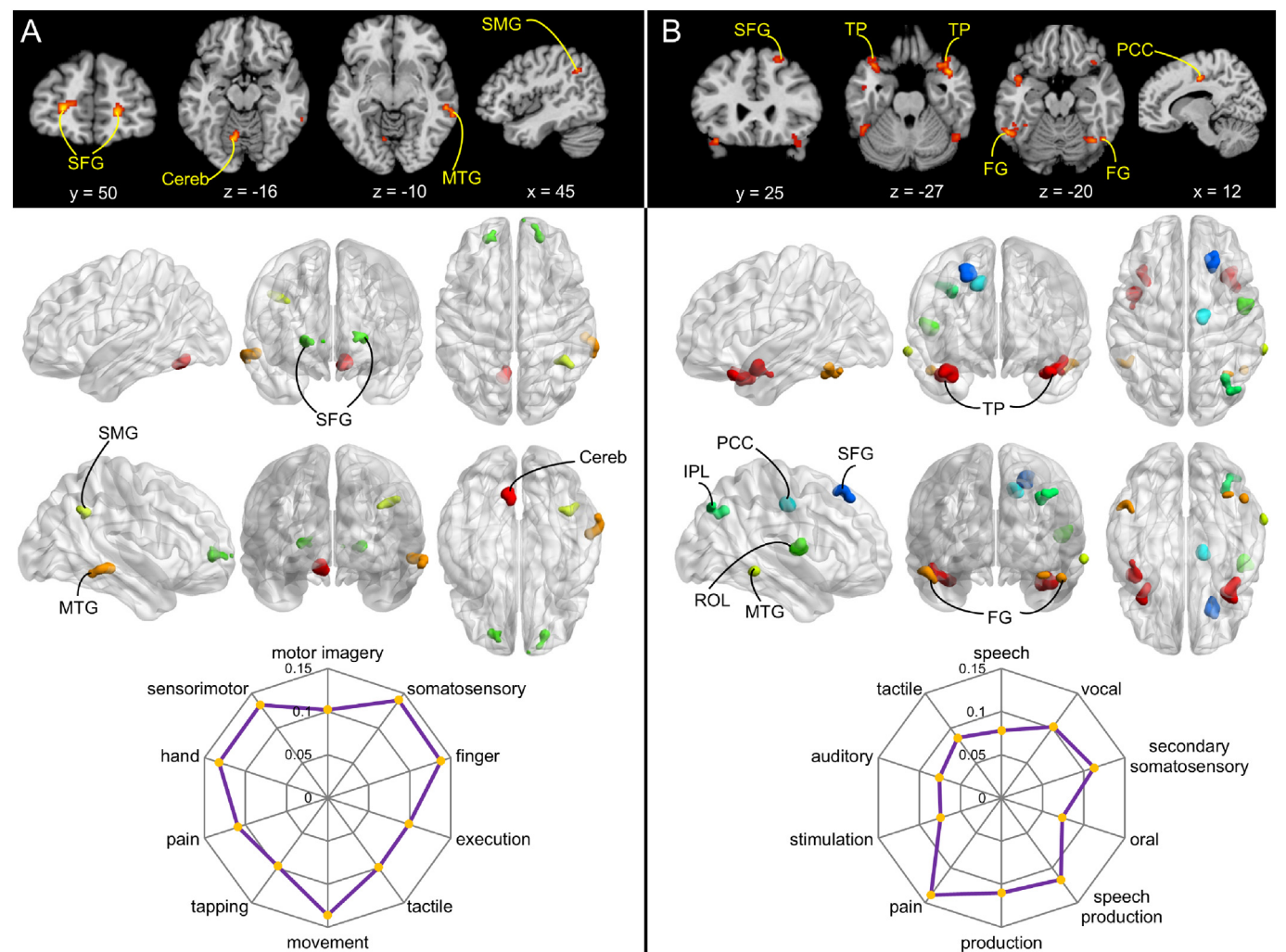


Fig. 3. Clusters exhibiting effects of neighborhood affluence during reward (A) or loss (B) anticipation. These maps present the same results as those in the Fig. 2, except that only clusters showing the presence of the effects of neighborhood affluence ($\log(\text{BF}) > 1.1$) and consisting of at least 50 voxels are illustrated. Radar charts illustrate the top 10 topics associated with effects of neighborhood affluence on reward or loss anticipation. SFG, superior frontal gyrus; Cereb, Cerebellum; MTG, middle temporal gyrus; SMG, supramarginal gyrus; TP, temporal pole; FG, fusiform gyrus; PCC, posterior cingulate cortex; IPL, inferior parietal lobule; ROL, rolandic operculum.

Table 1
Clusters exhibiting effects of neighborhood affluence during reward or loss anticipation. Only clusters consisting of at least 50 voxels are illustrated.

Laterality	Brain regions	MNI coordinates (mm)			Peak log (BF) score	Cluster size (voxels)
		x	y	z		
Reward anticipation						
R	Superior frontal gyrus	21	53	3	5.18	75
L	Superior frontal gyrus	−23	51	3	5.56	62
R	Supramarginal gyrus	41	−51	35	3.24	60
R	Middle temporal gyrus	59	−31	−9	3.56	53
L	cerebellum	−9	−65	−13	5.69	65
Loss anticipation						
R	Superior frontal gyrus	27	31	55	3.33	76
R	Rolandic operculum	49	−5	9	7.31	52
R	Posterior cingulate cortex	15	−13	43	6.93	52
R	Inferior parietal lobule	33	−65	39	3.42	60
R	Temporal pole	43	11	−25	6.67	147
L	Temporal pole	−35	15	−25	4.37	55
L	Temporal pole	−43	7	−21	4.56	76
R	Middle temporal gyrus	67	−41	−9	6.19	52
R	Fusiform gyrus	51	−59	−23	5.17	101
L	Fusiform gyrus	−55	−53	−17	6.42	139

L, left; R, right; MNI, Montreal Neurological Institute; BF, Bayes factor.

3.3. Brain morphology

Log (BF) scores of structural measures in all ROIs were below zero (Fig. 1C and Table 1), providing anecdotal to moderate evidence that there was no effect of neighborhood affluence on the brain morphology in these ROIs (The correlation coefficients of corresponding results are illustrated in Figs. S9–S11).

4. Discussion

This investigation aimed to examine the effects of neighborhood affluence on symptoms, brain functions and structures associated with positive and negative valence processing in a sample of adults with mood and/or anxiety disorders. The Bayesian inference approach enabled us to quantify evidence for both the presence and absence of the effects of neighborhood. Our findings provide evidence that – on an individual subject level – neighborhood affluence is not associated with most behavioral and brain measures of positive and negative processing, from self-reported symptoms to brain functions and structures. This finding contrasts with those of others who have reported strong association on a community level between neighborhood characteristics and mental health. There are several potential explanations for the discrepancy between current null findings and prior significant results of neighborhood disadvantage effects.

First, while our study measured the neighborhood disadvantage/affluence using census-based data from the ACS, several other studies employ subjective appraisal of the neighborhood based on self-reports (Gonzalez et al., 2016; Saxbe et al., 2018). Specifically, participants in Gonzalez et al. (2016) are asked to report neighborhood quality using a questionnaire, and participants in Saxbe et al. (2018) report on community violence exposure. Hence, it is possible that objective and subjective measures of neighborhood disadvantage are associated with differential neuropsychological consequences within residents. In line with this possibility, another study employing census-based measures of neighborhood disadvantage also fails to identify associations between neighborhood disadvantage and brain morphology in subcortical regions, similar to the current findings (Gianaros et al., 2017). Furthermore, there is evidence showing differential effects of objective and subjective neighborhood disadvantage on mental health, such that perceived neighborhood quality is most strongly linked with self-reported symptoms and mediates the association between objective neighborhood disadvantage and health (O'neil et al., 2001; Weden et al., 2008; Wen et al., 2006). Further studies are needed to examine the interplay between objective and subjective measures of neighborhood disadvantage at both behavioral and brain levels.

Second, it is possible that effects of neighborhood disadvantage are more profound during early developmental periods (e.g. childhood and adolescence) compared to adulthood (examined in the current study). Indeed, several neuroimaging studies demonstrate the impact of neighborhood disadvantage among childhood or adolescence on brain functions and structures associated with positive and negative valence processing (Gonzalez et al., 2016; Marshall et al., 2018; Saxbe et al., 2018; Whittle et al., 2017). In contrast, other studies focusing on adult neighborhood disadvantage mainly identify neighborhood effects on brain morphology in cortical regions, such as language-related areas (Gianaros et al., 2017; Krishnadas et al., 2013). Therefore, recent neuroimaging evidence seems to support a differential role of neighborhood disadvantage at childhood/adolescence and adulthood stages. Notably, however, many survey-based studies demonstrate the relationship between neighborhood disadvantage and positive/negative valence processing across a wide age range (e.g. Ellen and Turner, 1997; Latkin and Curry, 2003; Menec et al., 2010). Further efforts are thus required to symmetrically and directly compare the effects of neighborhood disadvantage across the lifespan. For instance, it would be important to record historical neighborhood disadvantage at different developmental stages to examine their distinct or common effects

on the current psychiatric symptoms.

Third, the current study focused on neighborhood affluence showing the greatest loadings from neighborhood-level income and education, the effects of which are most extensively examined in the literature (Arcaya et al., 2016; Leventhal and Brooks-Gunn, 2000). However, many other neighborhood characteristics not examined may have profound effects on mental health and associated alterations in positive/negative valence processing. For instance, higher neighborhood green space is related to lower depression and anxiety symptoms, since green space may facilitate recovery from mental fatigue and reductions in stress (Beyer et al., 2014; Brown et al., 2018). Likewise, pollution in the neighborhood is another important determinant of mental health, such that both air and noise pollution are positively correlated with individual psychological distress (Dzhambov et al., 2017; Sass et al., 2017). Moreover, social cohesion is associated with lower levels of depression (Echeverría et al., 2008), whereas residential stability is positively correlated with depressive symptoms (Aneshensel et al., 2007). Therefore, future brain imaging studies may examine whether these physical and social characteristics of neighborhood on mental health are mediated by alterations in positive/negative valence processing at multiple levels.

Finally, it may be important to point out that the current findings are based on a Tulsa Oklahoma sample. Although the effects of neighborhood disadvantage have been frequently examined as a universal phenomenon, it is possible that cultural and geographic characteristics across different areas may interact with the neighborhood effects. For instance, Oklahoma has experienced a rise in seismicity since 2010 due to wastewater injection, which is associated with increased proportion of Google search episodes for anxiety (Casey et al., 2018). It remains unclear how this might interact with effects of community-level affluence, but such environmental factors would be important to consider in future studies. Therefore, current and previous findings derived from a single area need to be interpreted with caution. This issue could be addressed by future meta-analytic studies synthesizing results from multiple areas and increased number of multi-site neuroimaging studies (e.g. the ABCD study). Likewise, another characteristic of the current sample is that participants were drawn from a clinical population, which differed from previous studies employing participants sampled from general populations (e.g., Gianaros et al., 2017). Therefore, future studies are needed to examine whether effects of neighborhood affluence are more profound among general or subclinical populations compared to clinical samples.

Despite evidence showing that neighborhood affluence had no effect on most measures associated with positive and negative processing, we did identify evidence regarding neighborhood effects on trait anxiety and brain activations within frontal, temporal, and parietal regions. First, the negative correlation between neighborhood affluence and trait anxiety is broadly in line with previous observations showing that residing in advantageous neighborhood accompanies lower levels of mental health problems (Cerdá et al., 2017; Kim, 2010; Latkin and Curry, 2003; Ross, 2000; Santiago et al., 2011; Stockdale et al., 2007). However, one should interpret this finding with caution, since the anxiety-neighborhood affluence relationship did not converge with results for other symptom measures or functional/structural brain data. A possible interpretation of the trait anxiety result is that the current study conducted a series of tests, and this result may have emerged by chance. The Bayesian inference does not implement multiple comparison correction (Han and Park, 2018), and we will address this issue by examining whether this particular finding can be replicated in the second half T1000 participants. Second, we identified neighborhood effects within several frontal, parietal, and temporal regions during reward and loss anticipation. However, functional decoding analyses indicate that these regions may be more recruited by action preparation or anticipation of motor responding than by reward/loss anticipation per se.

Taken together, our results identify little evidence supporting that

neighborhood affluence modulates positive/negative valence processing measured across multiple modalities. These findings suggest that varying definitions of neighborhood affluence may contribute to mixed findings with respect to brain and symptom relationships; as a result, the reliability of neighborhood effects on individual mental health requires further investigation.

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Conflict of interest

None of the authors has conflicts of interests to declare.

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