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Principal Component Analysis and Neural Predictors of Emotion Regulation

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Abstract

Reappraisal, a cognitive approach intended to alter an emotional response, is generally associated with prefrontal cortical recruitment and decreased limbic activity. However, the extent to which neurofunctional activity predicts successful reappraisal is unclear. During fMRI, 60 healthy participants completed a reappraisal paradigm, which included reappraising negative images to reduce emotional reactivity ('ReappNeg') and viewing negative images and experiencing the negative affect they evoke ('LookNeg'). After each trial, participants rated their emotional response on a Likert-type scale where higher values indicated more negative affect. Reappraisal ability was based on a difference value (ReappNeg-LookNeg) such that negative values signified successful reappraisal ('SR'; n=38) and positive values, unsuccessful reappraisal ('USR'; n=22). Neural activity based on ReappNeg-LookNeg conditions from 37 regions of interest encompassing cortical and limbic areas was submitted to Principal Component Analysis (PCA). Resulting PCA factors were submitted to discriminant function analysis to evaluate which factor(s) predicted SR and USR groups. Results showed a factor with high loadings for certain frontal areas (e.g., left dorsomedial prefrontal cortex) and limbic regions (e.g., bilateral amygdala) predicted 71.1% of cases in the SR group and 68.2% of cases in the USR group. Additionally, successful reappraisal corresponded with more activation in the factor with high loadings for frontal areas and less activity in the factor associated with limbic regions. Results are consistent with studies of individual differences where more prefrontal engagement and less limbic activity is associated with effectual reappraisal, but for the first time, a neural 'signature' for successful reappraisal has been demonstrated.

[1] Introduction

Reappraisal is a well-studied, complex emotion regulation strategy that modifies the emotional response to a salient stimulus or situation by changing its meaning [1]. As

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reappraisal necessitates reframing an emotional event in ways that alter the emotional consequence it would otherwise evoke, reappraisal is thought to engage a distributed network of brain regions encompassing cognitive control, attention, working memory, and emotion-processing systems [2]. In support, meta-analytic studies show reappraisal of negative stimuli (e.g., images with negative content) recruits a widespread network of regions that impinge on these processes such as lateral and medial prefrontal cortices, dorsal anterior cingulate cortex, and inferior frontal gyrus [3,4]. Regions involved in semantic functions (e.g., temporal lobe, angular gyrus) [5,6] are also recruited potentially directed at altering the meaning of a stimulus [4]. Reduced activity in emotion-related structures such as the amygdala [7] is frequently considered an index of effectual reappraisal as are prior reports of an inverse relationship between activation in the amygdala and the dorsolateral prefrontal cortex (PFC), dorsomedial PFC, orbitofrontal cortex [8], or ventrolateral PFC [9].

Though the inverse relationship between cortical engagement and amygdala activity is consistent with a ‘top-down’ model of emotion regulation [8,10,11], there are also reports of amygdala recruitment during reappraisal [12,13]. Inconsistent findings may reflect sub-processes that underlie regulation, one of which involves establishing and elaborating on the emotional meaning(s) of a stimulus so that it can be subsequently re-interpreted [12]. Thus, the extent to which neurofunctional activity in ‘bottom-up’ emotion processing regions reflect successful reappraisal is unclear.

Behaviorally, self-reported affective state based on a Likert-type scale is a common index of online reappraisal ability. In a seminal study by Ochsner and colleagues [2] greater reappraisal facility – larger difference between reappraising negative images (‘ReappNeg’) versus looking at negative images (‘LookNeg’) – corresponded with more activation in the dorsal anterior cingulate cortex (dACC) and supramarginal gyrus. Moreover, in a study that used the same metric of reappraisal (i.e., difference value between ReappNeg and LookNeg), activation in the dorsomedial PFC positively correlated with reappraisal ability [14]. Also, when evaluating brain-behavioral relationships circumscribed to reappraise-related ratings, as opposed to the difference between ReappNeg and LookNeg, regression analysis revealed activation in dACC, dorsolateral PFC, anterior insula, and ventrolateral PFC inversely corresponded with negative affective state [15]. Put another way, more activity in these regions was associated with less subjective emotional response to negative stimuli. Regression analysis has also shown that reappraise-related decreases in negative affective state corresponds with recruitment of regions in a distributed network encompassing frontal (e.g., lateral PFC, dorsomedial PFC), parietal (superior parietal lobule) occipital (superior occipital gyrus), temporal (superior temporal gyrus), and subcortical regions (e.g., putamen) [16]. While these data provide evidence of brain-behavioral relationships, findings are predominantly based on correlational designs or *a priori* regions of interest. Moreover, meta-analytic neuroimaging studies of reappraisal have not included behavioral measures [3,4], therefore, links between affective state and the cortical-limbic pathways that underlie reappraisal have yet to be fully characterized.

Another gap in the literature pertains to self-reported habitual reappraisal tendencies and online reappraisal capability via self-report. Habitual reappraisal is commonly assessed with the Emotion Regulation Questionnaire (ERQ) [1] where more frequent endorsements to

questions signifying reappraisal (e.g., “When I’m faced with a stressful situation, I make myself think about it in a way that helps me stay calm”) are associated with more positive mood, better interpersonal functioning, higher self-esteem, and other indicators of psychological well-being. Conversely, a greater tendency to rely on ‘expressive suppression’, namely, the inhibition of emotion-expression behavior to cope with emotions (e.g., “When I am feeling negative emotions, I make sure not to express them”) is associated with more negative mood, worse interpersonal functioning, lower self-esteem, and other indices of lower psychological well-being [1]. In further support of the adaptive value of reappraisal and maladaptive value of suppression, respectively, a meta-analysis of emotion regulation across clinical populations (anxiety, depression, eating disorders, and substance-related disorders) found reappraisal was negatively associated with psychopathology whereas suppression positively corresponded with psychopathology [17].

Results point to robust associations between reappraisal and psychological health in addition to the relevance of regulation in the context of mental health more broadly [18]. However, *frequency* of reappraisal does not necessarily imply *successful* reappraisal [19]. Accordingly, it is important to evaluate whether individuals who are effective at on-line reappraisal (i.e., reappraisal when directed) also engage in reappraisal more frequently in real-world settings relative to those who are not effective in terms of real-time reappraisal. The validity of reappraisal as a construct might also be enhanced by delineating a neural signature of successful reappraisal based on a cut-point. To date, reappraisal ability is a relative term and thus subject to varied interpretation; a behavioral benchmark denoting effectual reappraisal will aid in the development of a reappraisal-related biomarker that could be used to increase our understanding of emotion regulation.

Therefore, the objectives of the current study were to perform Principal Component Analysis (PCA) to examine the functional organization of regions implicated in reappraisal and use resulting PCA components to classify participants in terms of reappraisal ability (successful/unsuccessful). Participants completed a validated Emotion Regulation Task [20–25] and PCA was performed on reappraise-related activation derived from frontal, parietal, temporal, and limbic regions (reported in meta-analytic studies of reappraisal [3,4]). Occipital areas were included to evaluate the specificity of neural predictors in classifying groups as regions involved in visual processes are not robustly implicated in reappraisal [3,4]. PCA is a data-driven approach that reduces the redundancy of information (i.e., dimension reduction) while maximizing explanatory variance across measures and has been used in classification studies that utilize neuroimaging data (e.g., [26,27]).

Based on literature and theory, we hypothesized that the PCA data structure (i.e., linear combinations of regions) would be characterized by regions with similar functions; for example, that one factor would be largely associated with frontal areas involved in cognitive control and another strongly linked with limbic regions involved in emotional reactivity. We expected factors associated with frontal, parietal, temporal, and limbic regions, but not occipital regions, would differentiate successful reappraisers (SR) during fMRI from unsuccessful reappraisers (USR). Behaviorally, we hypothesized that because all participants were healthy, they would report more frequent use of reappraisal than suppression outside

the laboratory setting. We also explored whether the SR group endorsed more frequent use of reappraisal on a daily basis compared to the USR group.

[2] Method

[2.1] Participants

Participants between 18 and 65 years of age were recruited via community advertisements. Inclusion criteria for all participants included absence of current or history of an Axis I diagnoses as confirmed by the Structured Clinical Interview for DSM-IV [28] conducted by a master's-level clinician, absence of a major medical or neurologic illness as confirmed by a Board Certified physician, negative urine toxicology screen assessed prior to fMRI, and ability to give informed consent. Exclusion criteria for fMRI included: a) ferrous-containing metals within the body (e.g., aneurysm clips, shrapnel/retained particles); b) inability to tolerate small, enclosed spaces without anxiety (e.g., claustrophobia); and c) pregnancy (positive pregnancy test) or trying to become pregnant. To assess self-reported habitual reappraisal and suppression tendencies, all participants completed the Emotion Regulation Questionnaire [1]. The ERQ is a 10-item measure where higher scores signify greater frequency of reappraisal or suppression. Previous studies support the internal consistency and test-retest reliability of the ERQ subscales (alpha ranged from 0.68 to 0.80; [1]). Furthermore, the reappraisal and suppression subscales have demonstrated good convergent and discriminant validity [1], and confirmatory factor analyses support the two-factor structure [1,29].

This research was approved by the Institutional Review Board at the University of Illinois at Chicago and all procedures complied with the Helsinki Declaration. All participants provided written informed consent and were compensated for their time.

With regard to participant characteristics, gender distribution was 31.7% males and 68.3% females; 46.7% self-identified as Caucasian, 30% as Asian, 18.3% as African American, 3.3% as more than one race, and 1.7% as another race or unknown. Concerning ethnicity, 15% self-identified as Hispanic or Latino. The average age of participants was 25.6 ± 9.7 years and education level in years was 15.4 ± 2.7 .

[2.2] fMRI Task

During fMRI, participants completed a well-validated Emotion Regulation Task (ERT) using the strategy of cognitive reappraisal as the form of regulation [20–25]. ERT consisted of 64 unpleasant and 32 neutral International Affective Picture System images [30]. Eight 20 second (s) blocks of each condition (four images presented for 5 s each) were interspersed with 20 s baseline blocks (comprising a fixation cross). At the beginning of each block, participants were instructed to: 1) use reappraisal to reduce negative affect evoked by an aversive image (ReappNeg); 2) attend to, be aware of, and “feel what you naturally feel” when looking at an aversive image (LookNeg); or 3) view neutral images (LookNeut). The order of blocks was pseudo-randomized over 2 separate runs of 5 minutes each.

Consistent with prior studies [2,20–25] participants practiced each condition verbally with a researcher with images not used in the experiment prior to the scan to ensure understanding

of task instructions. For reappraisal, participants were provided examples to promote understanding of cognitive approaches to reduce a negative emotional response to an aversive image. For example, transforming the scenario depicted by an image into positive terms (e.g., women crying outside of a church could be alternatively interpreted as expressing tears of joy from a wedding ceremony rather than of sorrow from a funeral) and rationalizing or objectifying the content of the pictures (e.g., a woman with facial bruises could be translated as an actor wearing makeup rather than a victim of domestic abuse [15], p. 211).

[2.3] Behavioral Reappraisal Criterion

Immediately following each task block, participants were asked to rate “How negative do you feel?” on a 5-point scale (1 = not at all, 5 = extremely) via button response. To confirm participants followed task instructions, self-reported ratings of affective state were submitted to a 3 Condition (ReappNeg, LookNeg, LookNeut) repeated measures Analysis of Variance (ANOVA). The reappraisal criterion was based on a difference score. Specifically, since lower values denote less negative reactivity, negative values (i.e., less than 0) based on ReappNeg-LookNeg signified *successful reappraisal* and no difference, or positive values (i.e., 0 or greater; ReappNeg-LookNeg), indicated *unsuccessful reappraisal*.

[2.4] fMRI Data Acquisition and Preprocessing

Scanning was conducted on a 3 Tesla GE Discovery System (General Electric Healthcare; Waukesha, WI) using a standard radiofrequency coil. Blood oxygen-level dependent (BOLD)-functional images were acquired using a gradient-echo echo-planar imaging sequence with the following parameters: TR = 2s, TE = 25 ms, flip angle = 90°, field of view = 22×22 cm², acquisition matrix 64×64 ; 44 axial, 3-mm-thick slices with no gap. For anatomical localization, a high-resolution, T1-weighted volumetric anatomical scan was acquired.

Data from all participants met criteria for quality with minimal motion correction (movements were < 3 mm and < 3 degrees rotation in any one direction) and the first 4 volumes from each run were discarded to allow for T1 equilibration effects. Conventional preprocessing steps were used in Statistical Parametric Mapping (SPM8) software package (Wellcome Trust Centre for Neuroimaging, London www.fil.ion.ucl.ac.uk/spm). Briefly, images were temporally corrected to account for differences in slice time collection, spatially realigned to the first image of the first run, normalized to a Montreal Neurological Institute (MNI) template, resampled to $2 \times 2 \times 2$ mm voxels, and smoothed with an 8mm isotropic Gaussian kernel.

[2.5] fMRI Analyses

A general linear model was applied to the time series, convolved with the canonical hemodynamic response function and with a 128s high-pass filter. Nuisance regressors comprising 6 motion parameters were included to correct for motion artifacts. Blocks of ReappNeg, LookNeg, and LookNeut were modeled separately, the effects of which were estimated for each voxel for each participant and taken to the second level for random effects analysis. ReappNeg (vs. LookNeg) was the contrast of interest as both conditions comprised

negative stimuli; therefore, the effects of regulating emotional reactivity using reappraisal was contrasted with experiencing naturally the emotions elicited by negative images.

[2.6] Principal Component Analysis and Classification

The Automatic Anatomical Labeling system [31] was used to generate regions of interest (ROIs) within the frontal, parietal, temporal, occipital cortices, and limbic system, which totaled 37 regions (see Table 1). Activation (β weights, arbitrary units [a.u.]) derived from these ROIs [32] were submitted to PCA in the Statistical Package for the Social Sciences (SPSS) (Chicago, IL version 22). Eigenvalue coefficients greater than 0.60 [33] based on Varimax rotations indicated significant loading of ROIs on a factor. Resulting PCA Bartlett factor scores, each a composite of all ROIs with loadings of varying degrees, were submitted to stepwise discriminant function analysis in SPSS. Cross-validation (leave one out) was used to estimate accuracy in predicting reappraisal groups (successful/unsuccessful).

[3] Results

[3.1] Behavioral Results (manipulation check)

As expected, the 3 Condition (ReappNeg, LookNeg, LookNeut) repeated measures ANOVA was significant [$F(2, 118) = 87.87, p < 0.001$]. Follow-up paired t-tests to examine the direction of condition effects showed that affective state was less negative in the ReappNeg (2.19 ± 0.75) than LookNeg ($2.54 \pm 0.8.3$) [$t(59) = -3.77, p < 0.001$] condition. When viewing neutral images (i.e., LookNeut), affective state was less negative (1.24 ± 0.37) compared to either ReappNeg [$t(59) = 10.23, p < 0.001$] or LookNeg [$t(59) = 11.18, p < 0.001$] conditions.

[3.2] Reappraisal Groups

Among the 60 participants, difference values regarding affective state during ERT (ReappNeg-LookNeg) indicated 38 participants (63%) successfully employed reappraisal (negative values based on ReappNeg-LookNeg; average = -0.76 ± 0.49) and 22 (37%) were unsuccessful (average = 0.36 ± 0.45).

[3.3] Habitual Emotion Regulation

A paired two-tailed t-test performed with ERQ scores revealed all participants reported more frequent use of reappraisal (average = 33.5 ± 7.0) than suppression (average = 12.17 ± 4.5) [$t(59) = 20.12, p < 0.001$]. A two-tailed independent t-test showed that both successful and unsuccessful reappraisal groups endorsed similar rates of habitual reappraisal [$t(58) = 0.47, p = 0.64$] and suppression [$t(58) = 0.85, p = 0.40$].

[3.4] Data Structure

The PCA revealed 5 factors accounted for 89% of the total variance and all 37 ROIs were significantly correlated with each other (all r 's > 0.30 , all p 's < 0.05), therefore, none of the ROIs were excluded from the model. Prominent loadings of ROIs on Varimax rotations (i.e., eigenvalue coefficients > 0.60) and the percentage accounted in each factor of the 5-factor model were as follows: Factor 1 was largely associated with occipital regions (68% of total

variance; ‘occipital factor’); Factor 2 was strongly related with frontal areas (7.4% of total variance; ‘frontal factor’) comprising dorsomedial PFC, left frontal inferior triangularis, left dorsolateral PFC, left superior frontal gyrus, and left orbitofrontal inferior gyrus; Factor 3 was robustly linked with certain frontal regions (dACC, right DLPFC) and parietal areas (e.g., bilateral inferior and superior parietal lobule) (6.4% of total variance; ‘frontal-parietal factor’); Factor 4 had high loadings for bilateral superior temporal gyrus and bilateral anterior insula (4.4% of total variance; ‘temporal factor’); and Factor 5 had large loadings for limbic areas, particularly bilateral amygdala and parahippocampal gyrus (3% of total variance; ‘limbic factor’). See Table 2 for ROIs and all eigenvalue coefficients; see Figure 1 for depiction of loadings on factors.

[3.5] Classification

Stepwise discriminant analysis revealed that factors with substantial contributions from ‘frontal’ areas (Factor 2) and ‘limbic’ regions (Factor 5) significantly differentiated groups (Wilks $\lambda=0.80$, $\chi^2(2)=12.71$, $p<0.002$). Classification was not predicted by Factors 1, 3, or 4. The classification matrix showed Factors 2 and 5 correctly classified 71.1% of cases in the SR group and 68.2% of the cases in the USR group. Cross-validation findings suggested 70% of cases were correctly classified. Classification coefficients indicated the successful reappraisal group corresponded with more neural activity in the ‘frontal’ factor (0.28) and less activity in the ‘limbic’ factor (−0.31). In contrast, the unsuccessful reappraisal group was associated with less activity in the ‘frontal’ factor (−0.48) and more activity in the ‘limbic’ factor (0.54). See Figure 2.

[4] Discussion

In this study we used Principal Component Analysis (PCA) to examine the neurofunctional organization of regions implicated in reappraisal (i.e., grouping of regions on factors) and to identify which factors distinguished individuals who were effective at reducing negative affective state in the context of negative images via reappraisal from those who were not effectual. We also evaluated whether individuals who were successful at reappraisal ‘on-line’ (i.e., when instructed in a laboratory setting) also endorsed more habitual use of reappraisal in real-world settings relative to those who were unsuccessful. Behavioral findings across participants confirmed the manipulation of task conditions was effective as there was significantly less negative emotional reactivity when instructed to reappraise negative images (ReappNeg) relative to viewing negative images and naturally experiencing the emotions they evoke (LookNeg). Consistent with previous self-report methods of real-time emotion regulation performance, reappraisal ability was denoted by difference scores between ReappNeg and LookNeg [2,14]. However, in a departure from previous studies that focused on individual differences, a criterion for successful reappraisal was established (i.e.,

ReappNeg-LookNeg; values < 0) to evaluate neural predictors indicative of meaningful reappraisal ability. PCA results pointed to a 5-factor solution such that the coherence of frontal, limbic, parietal, temporal, and occipital regions generally mapped onto (i.e., had high loadings according to) their functional properties in ReappNeg-LookNeg, though factors were not entirely unique to the function of brain structures. For example, two factors had high loadings for frontal regions such that one predominantly corresponded with

dorsomedial prefrontal cortex (PFC), left dorsolateral PFC, and bilateral orbitofrontal gyri and the other with dorsal anterior cingulate cortex, right dorsolateral PFC and parietal areas. Discriminant function analysis revealed that the factor with the more distinctive loading for frontal regions differentiated successful reappraisers from unsuccessful reappraisers in addition to a factor robustly associated with limbic activity (bilateral amygdala, bilateral parahippocampus).

Findings extend previous studies. Prior research suggests there is a positive correlation between reappraisal frequency and well-being and a negative correlation between suppression frequency and well-being [1]. Evidence that healthy individuals reported greater use of reappraisal than suppression as indexed with the Emotion Regulation Questionnaire (ERQ) [1] is consistent with previous reports. Less is known, however, about habitual emotion regulation as it pertains to on-line regulation performance. In this study a relationship was not detected, which suggests frequency of reappraisal does not necessarily imply regulation facility [19]. Reasons for the incongruence between habitual reappraisal use and real-time reappraisal ability may depend on the way reappraisal was defined in either setting. For instance, as is conventional, participants were provided examples of reappraisal strategies prior to the fMRI task. In contrast, reappraisal as assessed with the ERQ [1] is relatively vague (e.g., “When I want to feel less negative emotion, I change the way I’m thinking about the situation”). Consequently, the cognitive approaches used on a day-to-day basis may be more diverse, or conflict with, the reappraisal strategies used in the experiment. Further study is needed to understand relationships between habitual emotion regulation tendencies and reappraisal capability.

PCA results suggest that a factor with high loadings for visual areas (i.e., bilateral middle, inferior, superior occipital regions) explained the majority of variance in the model, though right inferior temporal gyrus also had a large loading on this factor. As expected, a predominantly occipital-linked factor did not predict reappraisal success based on self-report during fMRI. However, in contrast to hypotheses, factors with high loadings for parietal and temporal areas failed to distinguish reappraisal groups, which may be due in part to the somewhat varied contribution of regions on factors. PCA was conducted on frontal, temporal, and parietal regions consistently observed in studies of reappraisal [3,4], yet the extent to which these regions reflect distinct latent constructs based on activation during reappraise (vs. looking at negative images) is unknown. Together with results showing classification of reappraisal facility (successful/unsuccessful) involved a factor with large loadings for certain frontal regions (e.g., dorsomedial PFC, bilateral orbitofrontal gyri) and another factor with limbic activity suggest smaller, distinct circuits within the larger networks may figure into a neural signature of successful reappraisal. It will be important for future studies to examine whether the functional organization and efficiency of networks (e.g., graph theory analysis) foretells reappraisal success.

Regardless, reappraisal success was predicted by more neural activity corresponding to a ‘frontal’ factor and less activity involving a ‘limbic’ factor. Also, unsuccessful reappraisal yielded the opposite frontal-limbic pattern of activity. Findings are in line with previous studies of individual differences demonstrating better reappraisal is associated with more frontal engagement and less amygdala activity [8,10,11,34]. Interestingly, while frontal

reappraisal-related recruitment has consistently been observed across studies [3,4], amygdala responsivity has been somewhat mixed due to reports of its engagement during reappraisal [12,13]. Our results indicate that when using a criterion for reappraisal, less activation in emotion processing regions is predictive of successful reappraisal. Also of note, while the amygdala is a common region of interest in studies of emotion regulation, a recent meta-analysis [4] showed reappraisal corresponded with less activity in the amygdala and parahippocampal gyrus suggesting decreased response in these regions is indicative of successful reappraisal. Thus, the correspondence between effectual reappraisal in our cohort and less activity in the limbic factor, which had high loadings on bilateral amygdala and bilateral parahippocampal gyrus is consistent with previous findings.

In terms of classification, evidence successful reappraisal was predicted by both more activation in a frontal factor and less activation in a limbic factor is in agreement with the dual-process model of emotion regulation, which posits voluntary, higher-order processes downregulate bottom-up, sensory-driven emotional reactivity [35]. Thus, results suggest successful reappraisal is characterized by effective top-down control. Also noteworthy are regions that had high loadings on the frontal factor that distinguished groups. For example, reappraisal-related activation in the dorsomedial PFC (DMPFC) had the highest loading, which has implications for activities that increase top-down control by modulating prefrontal activity such as mindfulness meditation known to benefit healthy individuals as well as individuals with psychiatric illness [36]. It also has inferences for psychotherapy, which is expected to reduce symptomatology by increasing emotion regulation capability. In support, a meta-analytic study of psychotherapy in anxiety and depression showed controlled-related DMPFC activity increased following psychotherapy [37,38]. Taken together, activation in the DMPFC and other frontal regions involved in controlled processes may set the stage for mindfulness meditation or psychotherapy. If accurate, a reappraisal biomarker may foretell who is likely to benefit from activities aimed at increasing adaptive emotion regulation.

This study is not without important limitations. First, the sample size in our study is relatively small, particularly when applying a data-driven analytic approach to identify predictors of reappraisal ability. Second, when using PCA, factors encompass a composite of all measures. Therefore, interpretations based on regions with high loadings does not imply that results are exclusive of other regions that were entered into the model. Third, the regions of interest submitted to PCA were circumscribed to those implicated in reappraisal; therefore, results may not replicate when all regions based on a conventional atlas are used. Fourth, with regard to on-line reappraisal, participants were given examples of cognitive approaches that provided alternative paths to cognitive change. Though the examples were used to aid in clarifying what was meant by ‘reappraisal’, the lack of a standard cognitive strategy (e.g., only positive reappraisal) could have introduced confounds.

Despite limitations, a PCA approach based on regions strongly implicated in reappraisal revealed activity during reappraise (vs. viewing negative images) generally aligned with frontal, temporal, parietal, limbic, and occipital functions. In terms of brain-based biomarkers, preliminary findings suggest factors meaningfully associated with certain frontal regions and limbic areas predicted reappraisal success when tested with discriminant function analysis. These data may aid in the development of a brain-based reappraisal

biomarker. In light of evidence reappraisal plays an important role in psychological well-being such a biomarker has clinical implications. For example, it could be used to advance our understanding of mechanisms involved in regulation, interventions aimed at improving regulation, and identifying individuals vulnerable to developing a psychiatric illness.

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Figure 1.
Pie chart illustrating Principal Component Analysis in terms of the total variance explained; extraction sums of squared loadings percent of variance.

Figure 2. Depiction of individual discriminant scores derived from Principal Component Analysis showing more activation in a ‘frontal factor’ and less activation in a ‘limbic factor’ predicted the successful reappraisal group.

Table 1**Regions of Interest in Principal Component Analysis**

Frontal Cortex	
L orbitofrontal inferior gyrus	
R orbitofrontal inferior gyrus	
L frontal inferior triangularis	
R frontal inferior triangularis	
L Dorsolateral prefrontal cortex	
R Dorsolateral prefrontal cortex	
L Superior frontal gyrus	
R Superior frontal gyrus	
Dorsal anterior cingulate cortex	
Dorsomedial prefrontal cortex	
Ventromedial prefrontal cortex	
Parietal Cortex	
L Inferior parietal lobule	
R Inferior parietal lobule	
L Superior parietal lobule	
R Superior parietal lobule	
L Angular gyrus	
R Angular gyrus	
Temporal Cortex	
L Inferior temporal gyrus	
R Inferior temporal gyrus	
L Middle temporal gyrus	
R Middle temporal gyrus	
L Superior temporal gyrus	
R Superior temporal gyrus	
L Anterior insula	
R Anterior insula	
Occipital Cortex	
L Inferior occipital gyrus	
R Inferior occipital gyrus	
L Middle occipital gyrus	
R Middle occipital gyrus	
L Superior occipital gyrus	
R Superior occipital gyrus	
Limbic System	

L Amygdala
R Amygdala
L Putamen
R Putamen
L Parahippocampal gyrus
R Parahippocampal gyrus

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Table 2
Reappraise (vs. Look Negative) Varimax Rotated Component Matrix with Regions of Interest

	Factors				
	1	2	3	4	5
L Middle occipital gyrus	0.845	0.283	0.238	0.150	0.271
L Inferior occipital gyrus	0.839	0.251	0.220	0.125	0.235
R Inferior occipital gyrus	0.837	0.334	0.217	0.172	0.109
R Middle occipital gyrus	0.834	0.305	0.218	0.158	0.255
R Superior occipital gyrus	0.764	0.200	0.373	0.231	0.258
L Superior occipital gyrus	0.756	0.123	0.428	0.233	0.221
R Inferior temporal gyrus	0.651	0.278	0.514	0.335	0.187
L Inferior temporal gyrus	0.566	0.252	0.564	0.196	0.389
Dorsomedial prefrontal cortex	0.233	0.833	0.372	0.144	0.113
L frontal inferior triangularis	0.363	0.772	0.228	0.110	0.275
L dorsolateral prefrontal cortex	0.250	0.755	0.521	0.136	0.184
L Superior frontal gyrus	0.163	0.748	0.492	0.127	0.143
L orbitofrontal inferior gyrus	0.295	0.744	0.093	0.316	0.333
R orbitofrontal inferior gyrus	0.464	0.645	0.139	0.462	0.156
L Angular gyrus	0.275	0.622	0.534	0.099	0.237
R frontal inferior triangularis	0.543	0.566	0.310	0.383	0.131
L Putamen	0.226	0.547	0.372	0.409	0.471
L Middle temporal gyrus	0.429	0.480	0.341	0.460	0.315

	Factors				
	1	2	3	4	5
R Inferior parietal lobule	0.334	0.259	0.794	0.227	0.109
L Inferior parietal lobule	0.367	0.299	0.763	0.151	0.301
Dorsal anterior cingulate cortex	0.226	0.345	0.747	0.353	0.237
R Angular gyrus	0.269	0.467	0.727	0.240	0.090
L Superior parietal lobule	0.576	0.173	0.703	0.200	0.175
R Superior frontal gyrus	0.254	0.524	0.686	0.287	0.079
R Superior parietal lobule	0.596	0.143	0.656	0.303	0.152
R dorsolateral prefrontal cortex	0.414	0.474	0.648	0.313	0.088
L Superior temporal gyrus	0.186	0.127	0.268	0.811	0.328
R Anterior insula	0.238	0.308	0.180	0.793	0.347
R Superior temporal gyrus	0.232	0.035	0.412	0.762	0.311
L Anterior insula	0.145	0.558	0.065	0.600	0.452
Ventromedial prefrontal cortex	0.224	0.500	0.236	0.572	0.128
R Putamen	0.232	0.406	0.413	0.560	0.416
R Middle temporal gyrus	0.478	0.378	0.391	0.549	0.241
L Parahippocampal gyrus	0.341	0.149	0.136	0.261	0.828
L Amygdala	0.202	0.369	0.131	0.219	0.817
R Amygdala	0.209	0.254	0.224	0.431	0.773
R Parahippocampal gyrus	0.395	0.107	0.220	0.354	0.755

Regions of interest with eigenvalue coefficients greater than 0.60 are in bold.