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# Dedifferentiation of emotion regulation strategies in the aging brain

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**Different emotion regulation strategies are distinctly represented in the brains of younger adults. Decreasing a reaction to a negative situation by reinterpreting it (reappraisal) relies on cognitive control regions in the prefrontal cortex, while distracting away from a stressor involves more posterior medial structures. In this study, we used Multi-Voxel pattern analyses (MVPA) to examine whether reappraisal and distraction strategies have distinct representations in the older adult brain, or whether emotion regulation strategies become more dedifferentiated in later life. MVPA better differentiated the two emotion regulation strategies for younger adults than for older adults, and revealed the greatest age-related differences in differentiation in the posterior medial cortex (PMC). Univariate analyses revealed equal PMC recruitment across strategies for older adults, but greater activity during distraction than reappraisal for younger adults. The PMC is central to self-focused processing, and thus our findings are consistent with the possibility that focusing on the self may be a default mechanism across emotion regulation strategies for older people.**

**Keywords:** emotion regulation; dedifferentiation; reappraisal; distraction; aging

## INTRODUCTION

Reappraisal and distraction are two of the most effective strategies for diminishing negative emotional reactions identified to date (Augustine and Hemenover, 2009).

Reappraisal promotes engagement with a negative stimulus to generate a less negative reinterpretation of it (Gross, 1998). In contrast, distraction promotes disengagement with negative images by redirecting cognitive focus toward a secondary task, or thoughts unrelated to the stimulus (Parkinson and Totterdell, 1999). These two strategies are also among the most investigated in previous neuroimaging studies of younger and older adults separately (Van Reekum *et al.*, 2007; Urry *et al.*, 2009; McRae *et al.*, 2010; Kanske *et al.*, 2011), but only one functional magnetic resonance imaging (fMRI) report has investigated age differences in reappraisal directly (Winecoff *et al.*, 2011) and none to our knowledge have investigated age differences in distraction. Previous behavioral research indicates that distraction is equally useful in decreasing negative affect across age groups, while reappraisal is more effective for younger than older adults (Tucker *et al.*, 2012), but no studies to date have investigated age-related differences between these strategies in the brain.

fMRI studies in younger adults have revealed that reappraisal and distraction strategies rely on activity in some overlapping brain structures. Both strategies activate brain regions that decrease downstream amygdala activity, such as the lateral prefrontal cortex, posterior parietal cortex, and medial prefrontal cortex (Urry *et al.*, 2006; Banks *et al.*, 2007; Goldin *et al.*, 2008; Kanske *et al.*, 2011; Buhle *et al.*, 2013). Amygdala activity is associated with emotional reactivity (LeDoux, 2000; Phelps, 2006; Whalen, 2004), and down-regulation of the amygdala is, therefore, one index of emotion regulation success.

Reappraisal and distraction also recruit distinct regions, at least among younger people (McRae *et al.*, 2010; Kanske *et al.*, 2011). Using a functional connectivity analysis, Kanske *et al.* (2011) found different regions correlated with decreased activity in the left amygdala for reappraisal and distraction strategies. Areas including the medial parietal cortex were negatively associated with the amygdala during distraction, while other areas including executive processing regions of the prefrontal cortex (PFC) were negatively associated with the amygdala during reappraisal. This suggests that for younger adults, reappraisal and distraction down-regulate the amygdala activity through distinct brain networks.

While brain differences between reappraisal and distraction have not yet been evaluated in older adults, reappraisal seems to have similar neural representations across age groups. Some studies report no age differences in patterns and magnitude of prefrontal activation (Van Reekum *et al.*, 2007; Winecoff *et al.*, 2011), while other studies report recruitment of similar prefrontal regions during reappraisal, but decreased magnitude of activity within these regions for older adults (Urry *et al.*, 2006; Opitz *et al.*, 2012). Thus, it appears that reappraisal activates similar regions across age groups, but that the pattern of activation within these regions may subtly differ.

In this study, we were interested in whether reappraisal and distraction strategies would be differentiated in the same brain locations and show the same patterns of activation in older adults as in younger adults. To examine age-related differences in strategies, we considered both differences in the 'locations' in the brain that differentiated strategies best, as well as the differences between 'patterns' of activation across strategies.

We investigated age differences in the location of differentiation of reappraisal and distraction strategies by: (i) Detecting whether older adults differentiated the strategies within regions previously shown to discriminate between reappraisal and distraction for younger adults (Kanske *et al.*, 2011) and (ii) Determining whether older adults showed discrimination between emotion regulation strategies in areas other than those previously established in the literature.

Given possibly subtle brain differences between younger and older adults across strategies, we analyzed location differences with a multivariate technique known as Multi-Voxel pattern analysis (MVPA). MVPA is sensitive to distributed pattern differences between conditions across voxels (Norman *et al.*, 2006; Pereira *et al.*, 2009), and has been used in previous studies examining neural discrimination, because it provides an index of discrimination accuracy within specific regions of interest (ROIs). The method is also powerful due to its ability to localize brain areas that subtly discriminate conditions but

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that would go undetected in univariate analyses which only consider activation within one voxel at a time (Bandettini and Kriegeskorte, 2009; Raizada *et al.*, 2010). We were interested in uncovering differences in locations that discriminated reappraisal and distraction for older adults both in a priori ROIs, as well as conducting exploratory analyses (aka 'Searchlight analyses') that would have power to detect subtle differences in brain activity across strategies.

In addition, we were interested in examining the age-related differences in 'degree' of brain activity across reappraisal and distraction strategies. While MVPA analyses have greater power to uncover additional regions differentially involved across task conditions, univariate analyses also provide useful information regarding relative involvement of regions across task contexts (Jimura and Poldrack, 2012). Although MVPA can detect differences between conditions, it does not indicate which condition shows more or less of the differentiated activation patterns. Thus, we also conducted univariate analyses to test for differences in activation levels across the two regulation contexts and identify which condition yielded more activity in a particular region.

## METHOD

### Participants

Twelve students from the University of Southern California (USC; 6 men, aged 18–30 years, $M_{age} = 21.9 \pm 3.2$) and 14 older adults recruited from the community through the USC Healthy Minds volunteer database (6 men, aged 62–78, $M_{age} = 69.0 \pm 4.8$) participated in the study. The study was approved by the USC Institutional Review Board, and all participants gave written informed consent and were paid for their participation. Participants were right-handed and screened for any neurological and psychiatric illness, or conditions that may preclude them from being scanned in an MRI. Older adults were screened for cognitive impairment by a minimum score of 30 on the telephone interview for cognitive status (Brandt *et al.*, 1988). Two older adult participants were excluded from analyses due to inability to learn task instructions, indicated by post-questionnaire responses. Subsequent analyses are reported for 12 older adults (6 men, aged 62–78, $M_{age} = 69.5 \pm 4.81$).

### Emotion regulation task

The emotion regulation task was a modified version of previously reported emotion regulation paradigms contrasting distraction and reappraisal (McRae *et al.*, 2010; Kanske *et al.*, 2011). Participants viewed a slideshow of negative images, and were cued to perform one of two emotion regulation strategies on each trial. On distraction trials, participants imagined one specific self-referential, pleasant distraction image unrelated to the negative image shown. A few examples of positive distraction images included relaxing on a sandy beach during a vacation, and having a picnic with a significant other. During reappraisal trials, participants reinterpreted the negative image shown, and either focused on how the situation would work out in the end, or might not be as bad as it first seemed. Examples of reappraisal could include reinterpreting an image of a crying child as a child crying tears of joy, or focusing on how the child's sadness would be short-lived.

At the beginning of the session, participants were taught and practiced the two emotion regulation strategies, and were corrected if they confused the instructions. A single mild distraction image was mentally generated by each participant at the beginning of the practice session from memory, and used for the rest of the experiment. Post-experiment questionnaires confirmed that participants had used the same distraction image as during the practice. The practice images were not seen again during the experiment.

Sixty-four negative images from the International Affective Picture Systems (Lang *et al.*, 2008) were chosen based on normative ratings ($M_{valence} = 2.83$, $SD_{valence} = 0.623$, $M_{arousal} = 5.39$, $SD_{arousal} = 0.856$). Images were presented to subjects in four blocks, with order counterbalanced using E-prime software (Psychology Software Tools). On each trial, a negative image was presented on either the left or right side of the screen, and a cue to distract or reappraise was shown on the opposite side. The stimulus and cue remained on the screen for 10 s, during which participants either reappraised or distracted themselves from the image. For 4 s following each stimulus, participants indicated the intensity of the image post-regulation on a four-point scale using a button box (very mild, mild, intense, very intense; order counterbalanced across participants). A fixation cross was displayed for 10 s between trials (Figure 1).

Participants completed a total of four runs, each lasting 6.8 min. To avoid set shifting difficulty for older adults, a mixed block-event-related design was used, in which eight reappraisal or eight distraction trials were presented together in each block, and order was counterbalanced across runs. Participants were cued to the emotion regulation strategy to be used in the upcoming block, and were reminded of how to use the strategy (e.g. prior to a reappraise block: 'In the next few trials, you will REAPPRAISE. Remember to focus on how the situation will be alright, or is not as bad as it first seems.'). During the scanner task, participants silently enacted each strategy.

### Post-scan incidental memory test and questionnaires

After the scans ended, participants were asked to verbally recall as many images from the emotion regulation task as they could remember within a 10-min incidental memory task, and their responses were transcribed. Two separate raters coded descriptions of recalled items as corresponding to a specific image seen during the task, or as an intrusion never encountered in the experiment. In the event of discordant values, the first author separately coded the original transcription, blind to the responses of the two raters. In all cases, this new coding matched one of the original ratings, and resolved the mismatch.

At the end of the session, participants completed a post-task questionnaire, in which they defined both emotion regulation strategies. Participants described what they did to regulate their emotional reaction during a reappraisal trial and a distraction trial performed during the task. The post-task questionnaire was used as a manipulation check of strategy encoding, and participants who conflated the strategy definitions were excluded from the study analyses. Participants also completed a brief battery of individual difference measures reported in Supplementary Appendix A. Mood ratings were collected before and after the scanner task using the positive affect negative affect scales (PANAS; Watson *et al.*, 1988), and are reported in Supplementary Appendix B.

### MRI acquisition parameters

MRI data were collected on a 3-T scanner (Magnetom TIM Trio; Siemens Medical Solutions), with a 12-channel matrix head coil at the USC Dana and David Dornsife Neuroimaging Center. A high-resolution T1-weighted 3D image was acquired with 160 slices in sagittal orientation, with repetition time of 1950 ms, echo time of 2.26 ms, slice thickness of 1.0 mm, flip angle of 7°, and field of view of 256. Functional scans were collected with 41 slices, a repetition time of 2000 ms, echo time of 25 ms, slice thickness of 3.0 mm, flip angle of 90°, field of view of 192, and no interslice gap.

### fMRI preprocessing

Imaging data preprocessing was performed using the FMRIB Software Library (FSL) package (www.fmrib.ox.ac.uk/fsl) and included motion correction with MCFLIRT, high-pass temporal filtering equivalent to

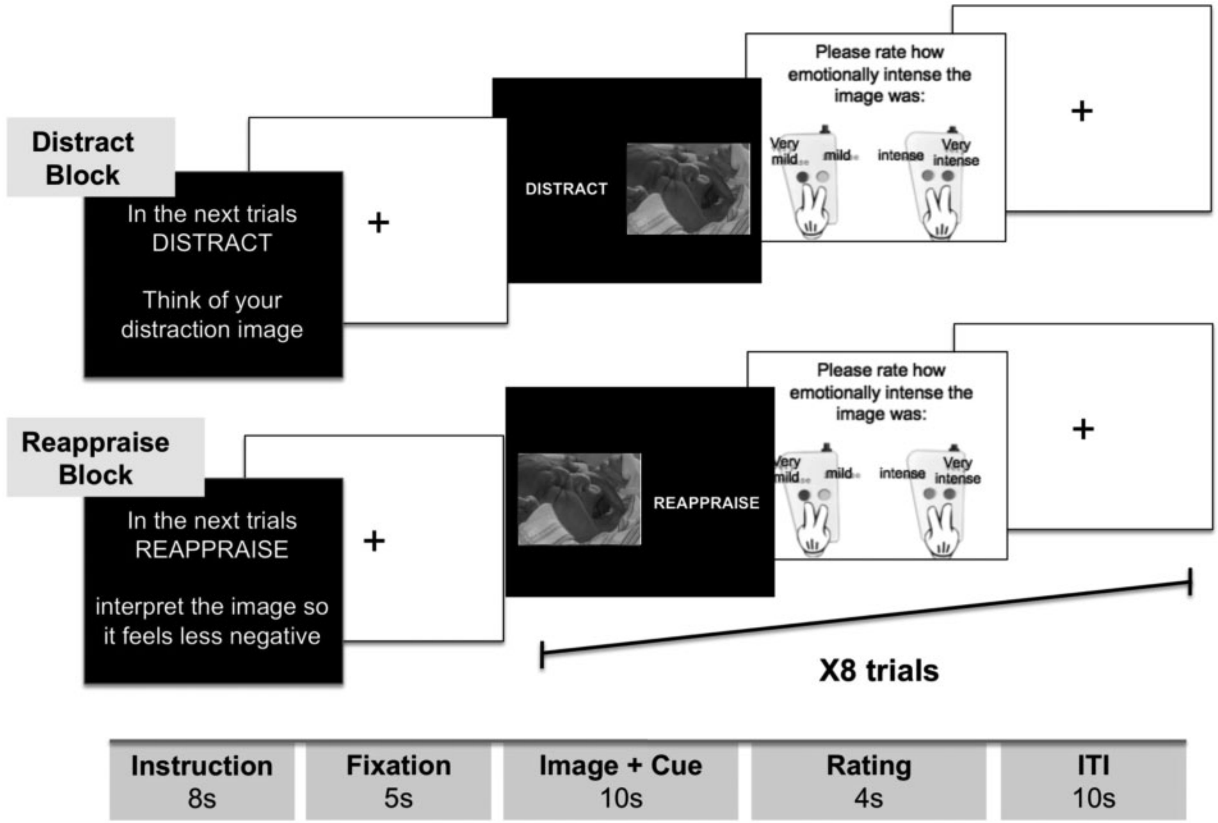


**Fig. 1.** Emotion regulation task schematic. Subjects performed four runs of the task. Each run was composed of one distract and one reappraise block, and each block contained eight trials of the same strategy type. Prior to each block, subjects were cued to which strategy they would be utilizing at each block start, and were reminded of the strategy meaning. On each trial, participants viewed a negative emotional image on either the left or right side of the screen (counterbalanced), and were presented with the strategy cue on the opposite side. Emotion regulation was sustained throughout the 10-s image duration. At the end of the trial, subjects rated the perceived intensity of the image post-regulation on a 4-item Likert scale.

100 s, slice-timing correction, and skull stripping of structural images with BET. Registration was performed with FLIRT, and functional images were registered to both the participant's high-resolution brain-extracted structural image and the standard Montreal Neurological Institute (MNI) 2-mm brain.

## MVPA preprocessing

We first modeled activity during each trial using a general linear model to generate beta-weight maps to serve as the input to the classifier algorithm. General linear modeling was conducted using FSL's FEAT (FSL; www.fmrib.ox.ac.uk/fsl). Spatial smoothing was not applied to the functional images, to allow classifications to be based on activation patterns within individual voxels, rather than the mean activity across multiple voxels. Individual functional runs were independently modeled at the first level. Each trial was coded by regressors of the 10-s stimulus duration and a nuisance regressor for the 4-s intensity rating period, convolved with a double-gamma hemodynamic response function, and highpass filtered. Time-series statistical analysis was performed using FILM with local autocorrelation correction (Woolrich *et al.*, 2001). Parameter estimate files for all runs were temporally concatenated, registered to the first volume of the first run, and *z*-scored by run.

## MVPA analyses

All MVPA analyses described below were conducted using the PyMVPA software package, and classifications were performed using linear support vector machine from LibSVM (http://www.csie.ntu.edu.tw/~cjlin/libsvm/).

### *MVPA ROI classification*

Based on the unique sets of regions associated with attenuation of the amygdala for reappraisal and distraction (Kanske *et al.*, 2011), we investigated strategy prediction accuracy for both age groups within these a priori emotion regulation regions (see Table 1 for regions). Spheres of 10-mm radius were constructed around the peak reported MNI coordinates for each of the a priori ROIs from Kanske *et al.* (2011) (Table 1), and each was transformed from standard space into each participant's native space. For each ROI, we performed a leave-one-out cross-validation approach, in which the classifier was trained on trials and strategy labels from three functional runs, and predicted strategy condition for trials in the remaining run based on the pattern of activation within the voxels of the given ROI. Each step of the cross-validation resulted in a classifier accuracy (performance), computed by dividing the number of correct classifier predictions by the number of trials classified. Four rounds of cross-validation were performed, and the prediction accuracies from each step were averaged together to produce a classification accuracy value between 0 and 1 for each ROI. Prediction accuracies across the reappraisal ROIs were averaged, and prediction accuracies from the distraction ROIs were averaged, to obtain prediction accuracy estimates for these two sets of regions.

### *Searchlight analyses*

To locate the regions in the brain that were most predictive of strategy condition, and to test for age differences in patterns of prediction without a priori considerations, searchlight classification analyses were performed for each participant (Kriegeskorte, 2006). Searchlight

**Table 1** Age differences in MVPA classification accuracies within reappraisal and distraction regions

| Region | MNI Coordinates | | | MVPA Classification | |
|---|---|---|---|---|---|
| | X | Y | Z | Younger Adult | Older Adult |
| Reappraisal | | | | | |
| Left superior medial frontal/BA 10 * | −6 | 63 | 15 | 0.72 (0.11) | 0.58 (0.11) |
| Left superior medial frontal/BA 9 * | 0 | 45 | 48 | 0.67 (0.12) | 0.54 (0.12) |
| Right superior frontal/ BA 6 | 21 | −12 | 75 | 0.59 (0.10) | 0.51 (0.12) |
| Left inferior orbitofrontal | −33 | 33 | −12 | 0.65 (0.11) | 0.58 (0.11) |
| Right inferior orbitofrontal * † | 33 | 36 | −12 | 0.70 (0.11) | 0.54 (0.10) |
| Right inferior parietal * | 54 | −69 | 33 | 0.67 (0.17) | 0.53 (0.06) |
| Left middle temporal | −45 | −9 | −18 | 0.58 (0.09) | 0.54 (0.09) |
| Right middle temporal | 63 | −15 | 15 | 0.61 (0.11) | 0.57 (0.11) |
| Left ventromedial frontal | −9 | 27 | −6 | 0.56 (0.11) | 0.55 (0.07) |
| Right amygdala | 36 | 0 | −18 | 0.59 (0.09) | 0.52 (0.12) |
| Mean reappraisal regions | | | | 0.64 (0.11) | 0.55 (0.10) |
| Distraction | | | | | |
| Right dorsomedial prefrontal * | 6 | 24 | 48 | 0.69 (0.12) | 0.56 (0.11) |
| Left middle frontal/BA 44 * | −48 | 27 | 30 | 0.73 (0.12) | 0.61 (0.09) |
| Left middle frontal/BA 6 * † | −54 | 6 | 36 | 0.72 (0.11) | 0.54 (0.10) |
| Right middle frontal/BA 44/46 * † | 48 | 30 | 36 | 0.70 (0.05) | 0.55 (0.10) |
| Left parietal | −42 | 39 | 45 | 0.63 (0.12) | 0.54 (0.11) |
| Right parietal * | 39 | −45 | 45 | 0.73 (0.08) | 0.59 (0.14) |
| Left precuneus * † | −24 | −60 | 42 | 0.77 (0.08) | 0.59 (0.09) |
| Right precuneus * † | 27 | −60 | 45 | 0.81 (0.10) | 0.60 (0.13) |
| Left occipital * | −24 | −99 | 9 | 0.74 (0.16) | 0.57 (0.13) |
| Right insula * | 36 | 24 | −3 | 0.64 (0.11) | 0.55 (0.08) |
| Mean distraction regions | | | | 0.72 (0.11) | 0.57 (0.11) |

*Note*: Regions with activity previously found to attenuate left amygdala activity more for reappraisal or distraction, based on Kanske *et al.*, 2011. Mean MVPA strategy classification accuracies for 10-mm spheres centered at each region for each age group are reported. * indicates significant age differences based on independent sample *t*-test at $P < 0.05$; † indicates significant age differences based on independent sample *t*-test at Bonferroni-corrected $P < 0.0025$.

spheres with a radius of four voxels, centered on each voxel in the brain were used as the inputs for a leave-one-out, cross-validation procedure. The accuracies for each round of cross-validation were averaged to provide a metric of overall classifier accuracy (performance) at each voxel location. Each voxel in the output map represents the overall classification accuracy for the sphere centered at that location.

Searchlight maps were registered to MNI standard space. Chance-level performance was subtracted from the overall classification map for each subject. Non-parametric statistical tests were used due to the non-normal distribution of prediction accuracy, using FSL's randomize tool. Monte Carlo permutations provided an estimated distribution with which to compute a significance threshold (Nichols and Holmes, 2002). To test for differences between searchlight maps across age groups, two-sample non-parametric permutation tests were run on the searchlight maps, with 10 000 random permutations.

### *Univariate analyses*

Spatial smoothing was performed with a Gaussian kernel of full width at half maximum of 6 mm. Individual functional runs were independently modeled by task regressors representing reappraisal trials, distraction trials, a nuisance regressor modeling the post-stimulus rating period, and nuisance regressors representing six head motion parameters. Regressors were convolved with a double-gamma hemodynamic response function, and high-pass temporal filtered. A second-level fixed-effect analysis was then performed to average the four functional runs for each participant.

For all analyses, $Z$ (Gaussianized $T/F$) statistic images were thresholded at the whole-brain level using clusters determined with $Z > 2.3$ voxel-wise thresholding and a family-wise error-corrected cluster significance threshold of $P = 0.05$. Follow-up percent signal change extractions were conducted with FSL's Featquery tool to clarify the nature of the interaction.

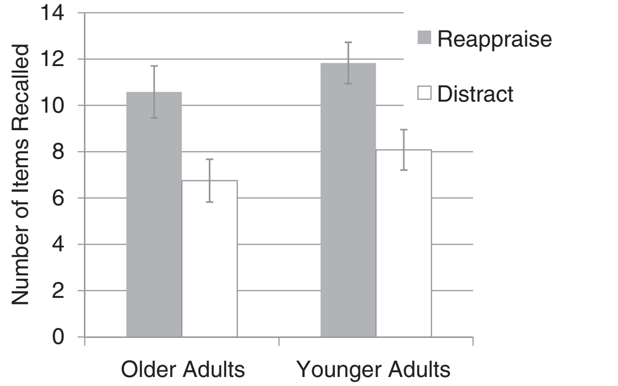


**Fig. 2.** Number of items freely recalled by strategy condition. For both older and younger adults, items encountered in the reappraise condition were more frequently recalled than items seen in the distract condition.

## RESULTS

### Behavioral results

#### *Post-stimulus image intensity ratings*

No differences were found between younger and older adults' post-stimulus image intensity ratings. ANOVAs, means and standard deviations for post-stimulus image intensity ratings are reported in the Supplementary Table S1.

#### *Incidental free-recall task*

Overall inter-rater reliability was high and demonstrated a significant two-way average measures interclass correlation, $ICC(2,2) = 0.97$, $P < 0.001$. The number of images recalled was analyzed in a 2 x 2 mixed ANOVA of age and strategy condition. Results revealed a significant main effect of strategy condition, with a greater number of items remembered from the reappraise condition ($M = 11.21$, $SD = 3.50$) than the distract condition ($M = 7.42$, $SD = 3.12$), $F(1,22) = 24.00$, $P < 0.001$, partial $\eta^2 = 0.52$. There was no significant main effect of age group, $F(1,22) = 1.34$, $P = 0.058$, partial $\eta^2 = 0.015$, nor an interaction between age group and strategy condition, $F(1,22) = 0.00$, $P = 0.96$, partial $\eta^2 = 0.00$ (Figure 2).

### Imaging results

#### *ROI analyses*

Strategy classification accuracies based on regions previously found to attenuate amygdala activity for reappraisal and distraction were averaged separately, and the average classification accuracies were compared statistically in a 2 x 2 mixed ANOVA of age and strategy condition (reappraisal regions, distraction regions). Results revealed a main effect of age, $F(1,22) = 20.94$, $P < 0.001$, partial $\eta^2 = 0.49$, as prediction accuracies were higher for younger adults ($M = 0.67$, $SD = 0.06$) than for older adults ($M = 0.56$, $SD = 0.06$). A significant main effect of condition was also found, $F(1,22) = 18.97$, $P < 0.001$, partial $\eta^2 = 0.46$ in which average predictions based on distraction regions ($M = 0.59$, $SD = 0.08$) outperformed average strategy prediction accuracies based on regions involved in reappraisal ($M = 0.54$, $SD = 0.15$). A significant age-by-condition interaction was found, $F(1,22) = 7.16$, $P < 0.01$, partial $\eta^2 = 0.21$; for younger adults,

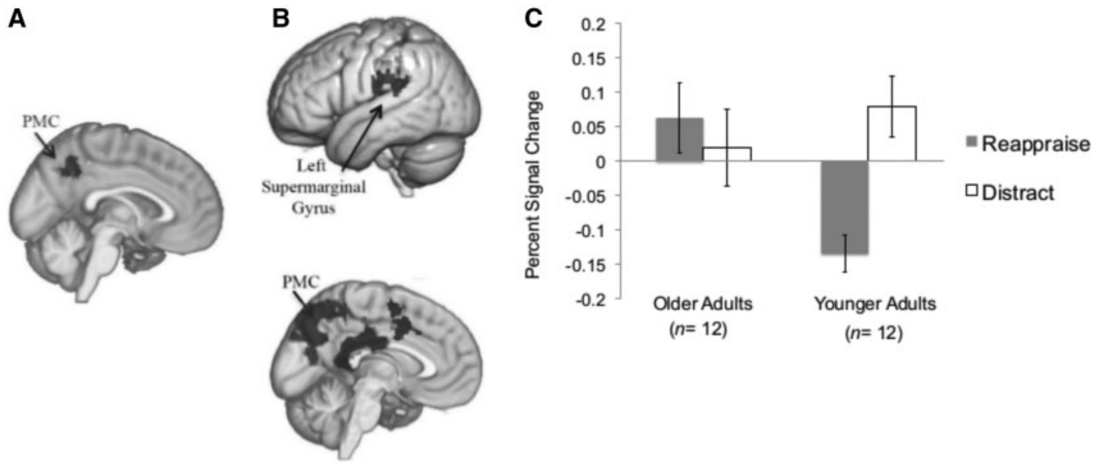


**Fig. 3.** Mean percent signal change for distraction and reappraisal across age groups. (A). Searchlight results of regions in PMC more effective at classifying strategies for younger than older adults, FWE= Family-wise error corrected (FWE-corrected) at $P < 0.001$ (B). Traditional GLM age-by-condition interactions reveal areas within PMC and supramarginal gyrus, cluster-thresholded $z = 2.3$, $P < 0.05$. (C). Post-hoc extraction of percent signal change from the cluster of regions included in the GLM interaction map for each subject was conducted for contrasts of Distract>Baseline and Reappraisal> Baseline.

distraction regions ($M = 0.72$, $SD = 0.11$) significantly outperformed reappraisal regions ($M = 0.64$, $SD = 0.11$) in predicting emotion regulation strategy condition, $t(11) = 3.93$, $P < 0.002$, but these regions only marginally differed for older adults (distraction: $M_{older} = 0.57$, $SD_{older} = 0.11$; reappraisal: $M_{older} = 0.55$, $SD_{older} = 0.10$), $t(11) = 1.90$, $P = 0.08$. In addition, one sample *t*-tests revealed that both distraction and reappraisal regions predicted strategy condition significantly above chance levels for both age groups, all four $t(11) > 2.50$, $P < 0.03$. Table 1 reports the strategy prediction accuracies across age groups for each ROI considered.

### Searchlight classification results

To identify the locations with the largest age differences in strategy classification in the brain, MVPA searchlight analyses and non-parametric tests were conducted across age groups. Given the broad nature of older adults' dedifferentiation, we used a stringent FWE-corrected threshold of $P < 0.001$ to identify the regions with the most significant age differences in strategy discriminability. Family-wise error was corrected using threshold-free cluster enhancement (Smith and Nichols, 2009 for details), and only clusters with more than 100 voxels are reported in the tables below. This analysis revealed a significant large cluster in the posterior medial cortex (PMC), including subregions within the bilateral precuneus cortex and posterior cingulate (reported in Figure 3A). No regions showed significantly more accurate strategy predictions for older adults than younger adults, even at a less conservative threshold of FWE-corrected $P < 0.05$.

### Univariate activation differences between reappraisal and distraction

Univariate analyses were conducted to clarify the nature of activity pattern differences during reappraisal and distraction across age groups. There were significant age-by-condition interaction effects within the precuneus, posterior cingulate, and left supramarginal gyrus (reported in Table 2).

**Table 2** Regions demonstrating age x condition interaction in GLM analyses

| Region | *Z*-statistic | *X* (MNI) | *Y* (MNI) | *Z* (MNI) | Hemisphere |
|---|---|---|---|---|---|
| Supramarginal gyrus, posterior | 4.64 | −48 | −42 | 32 | Left |
| Cingulate gyrus, posterior | 4.28 | 0 | −46 | 8 | Both |
| Precuneus cortex, posterior | 4.19 | 6 | −42 | 40 | Both |
| Precuneus cortex, posterior | 4.14 | −12 | −56 | 36 | Both |
| Precuneus cortex, posterior | 4.08 | −8 | −62 | 48 | Both |
| Precuneus cortex, posterior | 4.06 | −12 | −62 | 48 | Both |

*Note:* Peak maxima are reported at $P < 0.05$ level, cluster-thresholded $z = 2.3$. The mean percent signal change for each participant was extracted from these regions during reappraisal and distraction conditions, to investigate the nature of the interaction. Younger adults showed decreased activation of the precuneus, posterior cingulate, and left supramarginal gyrus during reappraisal than during distraction, but older adults showed no differences in activation between strategy conditions (Figure 3B, C).

## DISCUSSION

In this study, we investigated the differentiation of reappraisal (positive reinterpretation of negative stimuli) and distraction (pleasant imagery unrelated to stimuli) in brain activity associated with emotion regulation strategies for younger and older adults. Participants performed an fMRI emotion regulation task, and were tested on their memory for the regulated images afterwards. We investigated whether older adults would show differential activity during reappraisal and distraction in brain locations previously implicated in emotion regulation for younger adults. Our results revealed that, across many brain regions, the two strategies were more differentiated for younger than older adults. In particular, PMC, a key distraction processing region, showed the largest age differences in strategy discrimination. Univariate analyses confirmed that younger adults activate the PMC more during distraction than reappraisal, while older adults activate the PMC at similar levels across strategies.

### Emotion regulation strategies are less differentiated for older than younger adults

Activity in regions previously implicated in distraction and reappraisal processing (Kanske *et al.*, 2011) were found to discriminate between regulation strategies for both age groups above chance level (accuracy = 0.5), but showed significantly greater average strategy classification accuracies for younger adults. This suggests that reappraisal and distraction processing in these regions becomes more similar in later life. In addition, younger adults showed greater average strategy discrimination in distraction regions than in reappraisal regions, while older adults failed to show this difference. This suggests that for younger adults, distraction processing is specialized within regions such as the precuneus and parietal cortex. In contrast, older adults failed to show any difference in the classification accuracies across reappraisal and distraction regions. This suggests that while distraction is associated selectively with posterior regional activity for younger adults, these regions are less specialized by emotion regulation strategy for older adults.

Our findings are consistent with those in other domains. Across a wide variety of lower-level tasks, older adults tend to activate more distributed sets of regions that are less specialized for the task at hand than do younger adults, a dedifferentiation of neural processing with aging (Li and Lindenberger, 1999; Raz *et al.*, 2005). For instance, visual regions that respond more to one type of stimulus (e.g. faces, places and words) than others become less specialized, and activate across multiple stimulus categories among older adults (Grady *et al.*, 1992; Park *et al.*, 2004; Voss *et al.*, 2008). Likewise, face discrimination selectively relies on the right fusiform gyrus for younger adults, but is correlated to activity in widespread regions in the posterior cortex for older adults (Grady *et al.*, 2000). Dedifferentiation of brain activation patterns also occurs in PFC, such that a verbal working memory task that activates a focal region in left PFC in younger adults yields bilateral activation among older adults (Reuter-Lorenz *et al.*, 2000). Our ROI analyses suggest that, like these perceptual and cognitive functions, emotion regulation strategies become less distinct for older adults. It is also important to note that we found no age-related difference in post-trial affect ratings, suggesting that both older and younger people had similar emotion regulation outcomes. This provides evidence against the possibility that dedifferentiation is indexing an age-related difference in emotion regulation success.

To determine whether strategies might be more differentiated for older adults than younger adults in areas outside of these ROIs, an exploratory MVPA searchlight analysis was also conducted. Results revealed no regions more predictive of strategy condition for older adults than younger adults. Thus, it is not the case that older adults differentiate between reappraisal and distraction more distinctly than younger adults in regions of cortex outside of our a priori ROIs.

### PMC is differentially active for younger adults across strategies, but similarly active during both strategies for older adults

Searchlight analyses also revealed that the precuneus and posterior cingulate cortex—a complex known as the PMC— showed greater classification accuracies for younger than older adults. Building on the ROI analyses, this suggests that the largest differences between reappraisal and distraction representations are found within a structure previously implicated in distraction processing (Kanske *et al.*, 2011). In parallel, univariate analyses also revealed that younger adults activated the PMC less during reappraisal than distraction, but that older adults showed no difference in activation across strategies (Figure 3). Thus, the PMC was found to selectively activate to distraction for younger adults, but to be equally involved in implementing both strategies in older people.

The PMC is one of the most centrally connected nodes within a set of regions known as the default mode network (DMN), more active at rest than during task performance (Gusnard *et al.*, 2001; Fox *et al.*, 2005), and disengagement from these regions is crucial during task engagement. Previous findings reveal that unlike younger adults, older adults often fail to disengage from DMN regions during task performance (Lustig *et al.*, 2003; Grady *et al.*, 2006; Persson *et al.*, 2007; Park *et al.*, 2010; Sambataro *et al.*, 2010). In our task, older adults failed to disengage from PMC during reappraisal task performance, but our behavioral results suggest that both older and younger adults seem to encode images seen during the task similarly. Both age groups recalled more images encountered in the reappraise condition than in the distract condition, and there was no significant age-related interaction in terms of memory performance (Figure 2). Thus, memory findings argue against the notion that older adults' failure to disengage from the PMC represents age differences in relative task engagement.

Alternatively, failure to disengage from the PMC during reappraisal could reflect older adults' greater processing of the self in relation to task performance (Kensinger and Leclerc, 2009). Both younger and older adults recruited the PMC during distraction, as the task promoted focus on self-relevant pleasant memories. When reappraising, it is possible that older adults formed greater connections between the self and the external picture than younger adults. Thus, a default involvement of self-related processing could explain the similar areas and similar patterns of brain activation found for older adults across emotion regulation strategies. Relating the self to external images could enhance encoding of reappraised images, and refocusing attention to unrelated self-relevant memories could decrease encoding of external images during the distraction task. Thus, self-related processing may have provided environmental support for task engagement (reappraisal) and task disengagement (distraction), and possibly helped compensate for natural declines in task engagement with age. Future investigations should clarify whether reliance on self-related processing occurs in the absence of external strategy instructions, and whether this default strategy holds in automatic emotion regulation contexts.

However, it is important to note that previous studies have found self-relational processing to also increase activity in medial prefrontal structures during emotion regulation (Buhle *et al.*, 2013; Ochsner *et al.*, 2004; Svoboda *et al.*, 2006)—an area in which we failed to find an age-related difference in our experiment. A recent meta-analysis found that the medial frontal component of the DMN is more active when thinking about the self in isolation, while PMC regions are more active when thinking of the self in relation to familiar others (Qin and Northoff, 2011). Thus, involvement of the PMC during distraction may reflect recall of shared memories rather than contemplating the self in isolation.

### Summary and future directions

We investigated the neural differentiation of emotion regulation strategies with age, in an fMRI study of reappraisal and distraction strategies in younger and older adults. Our findings indicate that emotion regulation strategies become less discrete across the lifespan. However, it is important to note several limitations to this study that should be taken into consideration. The current study did not directly measure the degree of self-related processing in each condition, which restricts our interpretation of the results. Future studies should directly investigate the relationship between the degree of self-relational processing during each strategy, and whether the magnitude of self-processing predicts activity within the PMC. Future studies could also manipulate self-reflection during implementation of the regulation strategies, and track downstream changes in neural activity in the PMC. Uncovering the mechanism of PMC involvement in these regulation strategies is central to understanding how strategy representations change over the lifespan, and may help explain why there are age differences in preferences for different strategies (Shiota and Levenson, 2009; Tucker *et al.*, 2012; for a review see Mather, 2012).

Our sample included both women and men, and gender differences have previously been reported in tasks of emotion regulation. Women have been reported to activate prefrontal structures less than men during reappraisal of negative images (McRae *et al.*, 2008; Domes *et al.*, 2009; Mak *et al.*, 2009), and inclusion of both genders in the experiment may have increased heterogeneity across participants.

Further research with larger sample sizes (more sensitive to individual differences) should aim to clarify whether in addition to age, gender also may alter the discriminability of emotion regulation strategies.

In addition, it is important to note that this study had a small sample size. However, the effect sizes for findings of dedifferentiation for the two emotion regulation strategies among older adults compared with younger adults were quite large. According to Cohen's conventions, an $\eta^2$ of 0.14 is a large effect; our age differences in prediction accuracies for the target ROIs had $\eta^2$ values over 0.20 (Cohen, 1988). Likewise, in the searchlight analyses the PMC age differences in dedifferentiation survived a stringent threshold. Another limitation in the study design was the lack of a baseline condition in which participants passively viewed negative images. We opted to only include regulation trials in the design to increase power to train our MVPA classifiers, which limited the univariate contrasts we could investigate. Future studies should include a passive-viewing baseline condition, to be able to account for effects of initial arousal separately from effects of emotion regulation, and determine whether PMC differences exist at the level of initial reactivity to images, or during downstream regulation processing.

In summary, MVPA analyses showed the largest age-related difference in classification accuracy within the PMC, where there was greater predictive accuracy of strategy for younger than older adults. There also was greater discrimination across strategies for younger than older adults within specific brain regions previously implicated in emotion regulation processing. Thus, similar to the lower-level neural representations previously studied in the aging dedifferentiation literature (Goh, 2011), higher-level strategy representations of emotion regulation strategies also become less discretely represented across the lifespan. Univariate analyses further revealed age-related differences in PMC, in which younger adults showed less activity during reappraisal than distraction, while no significant difference was found across strategies for older adults in the PMC. These findings suggest that in contrast with younger adults, older adults have less discrete representations for reappraisal and distraction in the brain, and fail to disengage from PMC structures during reappraisal. Although we found this age-related difference in brain PMC involvement across strategies, both older and younger adults recalled reappraisal images more than distraction items. Given the lack of memory age differences in this study, we argue that sustained PMC activity across regulation strategies represents a default use of self-focused processing for older adults.

## SUPPLEMENTARY DATA

Supplementary data are available at *SCAN* online.

### Conflict of Interest

None declared.

## REFERENCES


Augustine, A.A., Hemenover, S.H. (2009). On the relative effectiveness of affect regulation strategies: a meta-analysis. *Cognition and Emotion*, *23*(6), 1181–220.

Bandettini, P.A., Kriegeskorte, N. (2009). Revealing representational content with pattern-information fMRI—an introductory guide. *Social Cognitive and Affective Neuroscience*, *4*(1), 101–9.

Banks, S.J., Eddy, K.T., Angstadt, M., Nathan, P.J., Phan, K.L. (2007). Amygdala-frontal connectivity during emotion regulation. *Social Cognitive and Affective Neuroscience*, *2*(4), 303–12.

Brandt, J., Spencer, M., Folstein, M. (1988). The telephone interview for cognitive status. *Cognitive and Behavioral Neurology*, *1*(2), 111–8.

Buhle, J.T., Silvers, J.A., Wager, T.D., et al. (2013). Cognitive reappraisal of emotion: a meta-analysis of human neuroimaging studies. *Cerebral Cortex*, *24*(11), 2981–90.

Cohen, J. (1988). *Statistical Power Analysis for the Behavioral Sciences*. New Jersey: Lawrence Erlbaum Associates, Publishers.

Domes, G., Schulze, L., Böttger, M., Grossmann, A., Hauenstein, K., Wirtz, P.H., et al. (2009). The neural correlates of sex differences in emotional reactivity and emotion regulation. *Human Brain Mapping*, *31*(5), 758–69.

Fox, M.D., Snyder, A.Z., Vincent, J.L., Corbetta, M., Van Essen, D.C., Raichle, M.E. (2005). The human brain is intrinsically organized into dynamic, anticorrelated functional networks. *Proceedings of the National Academy of Sciences*, *102*(27), 9673–8.

Gitelman, D.R. (2002). ILAB: a program for postexperimental eye movement analysis. *Behavior Research Methods, Instruments, & Computers*, *34*(4), 605–12.

Goh, J.O.S. (2011). Functional dedifferentiation and altered connectivity in older adults: neural accounts of cognitive aging. *Aging and Disease*, *2*(1), 30–48.

Goldin, P.R., McRae, K., Ramel, W., Gross, J.J. (2008). The neural bases of emotion regulation: reappraisal and suppression of negative emotion. *Biological Psychiatry*, *63*(6), 577–86.

Grady, C.L., Haxby, J.V., Horwitz, B., et al. (1992). Dissociation of object and spatial vision in human extrastriate cortex: age-related changes in activation of regional cerebral blood flow measured with [15 O] water and positron emission tomography. *Journal of Cognitive Neuroscience*, *4*(1), 23–34.

Grady, C.L., McIntosh, A.R., Horwitz, B., Rapoport, S.I. (2000). Age-related changes in the neural correlates of degraded and nondegraded face processing. *Cognitive Neuropsychology*, *17*(1-3), 165–86.

Grady, C.L., Springer, M.V., Hongwanishkul, D., McIntosh, A.R., Winocur, G. (2006). Age-related changes in brain activity across the adult lifespan. *Journal of Cognitive Neuroscience*, *18*(2), 227–41.

Gross, J.J. (1998). The emerging field of emotion regulation: an integrative review. *Review of General Psychology*, *2*(3), 271.

Gross, J.J., John, O.P. (2003). Individual differences in two emotion regulation processes: implications for affect, relationships, and well-being. *Journal of Personality and Social Psychology*, *85*(2), 348–62.

Gusnard, D.A., Akbudak, E., Shulman, G.L., Raichle, M.E. (2001). Medial prefrontal cortex and self-referential mental activity: relation to a default mode of brain function. *Proceedings of the National Academy of Sciences*, *98*(7), 4259–64.

Hassabis, D., Kumaran, D., Maguire, E.A. (2007). Using imagination to understand the neural basis of episodic memory. *The Journal of Neuroscience*, *27*(52), 14365–74.

Holdnack, H.A. (2001). *Wechsler Test of Adult Reading: WTAR. Psychological Corporation*. San Antonio, TX: The Psychological Corporation.

Jimura, K., Poldrack, R.A. (2012). Analyses of regional-average activation and multivoxel pattern information tell complementary stories. *Neuropsychologia*, *50*(4), 544–52.

Johnson, M.K., Raye, C.L., Mitchell, K.J., Touryan, S.R., Greene, E.J., Nolen-Hoeksema, S. (2006). Dissociating medial frontal and posterior cingulate activity during self-reflection. *Social Cognitive and Affective Neuroscience*, *1*(1), 56–64.

Kanske, P., Heissler, J., Schönfelder, S., Bongers, A. (2011). How to regulate emotion? Neural networks for reappraisal and distraction. *Cerebral Cortex*, *21*(6), 1379–88.

Kensinger, E.A., Leclerc, C.M. (2009). Age-related changes in the neural mechanisms supporting emotion processing and emotional memory. *European Journal of Cognitive Psychology*, *21*(2-3), 192–215.

Kriegeskorte, N. (2006). Information-based functional brain mapping. *Proceedings of the National Academy of Sciences*, *103*(10), 3863–68.

Lang, P.J., Bradley, M.M., Cuthbert, B.N. (2008). International affective picture system (IAPS): Affective ratings of pictures and instruction manual. Technical Report A-8. University of Florida, Gainesville, FL.

LeDoux, J.E. (2000). Emotion circuits in the brain. *Annual Review of Neuroscience*, *23*(1), 155–84.

Li, S.C., Lindenberger, U. (1999). *Cross-Level Unification: A Computational Exploration of the Link Between Deterioration of Neurotransmitter Systems and Dedifferentiation of Cognitive Abilities in Old Age*. Ashland: Hogrefe & Huber Publishers., pp. 103–146.

Lustig, C., Snyder, A.Z., Bhakta, M., et al. (2003). Functional deactivations: change with age and dementia of the Alzheimer type. *Proceedings of the National Academy of Sciences*, *100*(24), 14504–9.

Mather, M. (2012). The emotion paradox in the aging brain. *Annals of the New York Academy of Sciences*, *1251*(1), 33–49.

Mak, A., Hu, Z., Zhang, J., Xiao, Z., Lee, T. (2009). Sex-related differences in neural activity during emotion regulation. *Neuropsychologia*, *47*(13), 2900–8.

McRae, K., Ochsner, K.N., Mauss, I.B., Gabrieli, J.J., Gross, J.J. (2008). Gender differences in emotion regulation: An fMRI study of cognitive reappraisal. *Group Processes & Intergroup Relations*, *11*(2), 143–62.

McRae, K., Hughes, B., Chopra, S., Gabrieli, J. (2010). The neural bases of distraction and reappraisal. *Journal of Cognitive Neuroscience*, *22*(2), 248–62.

Nichols, T.E., Holmes, A.P. (2002). Nonparametric permutation tests for functional neuroimaging: a primer with examples. *Human brain mapping*, *15*(1), 1–25.

Norman, K.A., Polyn, S.M., Detre, G.J., Haxby, J.V. (2006). Beyond mind-reading: multi-voxel pattern analysis of fMRI data. *Trends in Cognitive Sciences*, *10*(9), 424–30.

Ochsner, K.N., Ray, R.D., Cooper, J.C., et al. (2004). For better or for worse: neural systems supporting the cognitive down- and up-regulation of negative emotion. *NeuroImage*, *23*(2), 483–99.

Opitz, P.C., Rauch, L.C., Terry, D.P., Urry, H.L. (2012). Prefrontal mediation of age differences in cognitive reappraisal. *Neurobiology of Aging*, *33*(4), 645–55.

Park, D.C., Polk, T.A., Park, R., Minear, M., Savage, A., Smith, M.R. (2004). Aging reduces neural specialization in ventral visual cortex. *Proceedings of the National Academy of Sciences of the United States of America*, *101*(35), 13091–5.

Park, J., Carp, J., Hebrank, A., Park, D.C., Polk, T.A. (2010). Neural specificity predicts fluid processing ability in older adults. *The Journal of Neuroscience*, *30*(27), 9253–9.

Parkinson, B., Totterdell, P. (1999). Classifying affect-regulation strategies. *Cognition and Emotion*, *13*(3), 277–303.

Pereira, F., Mitchell, T., Botvinick, M. (2009). Machine learning classifiers and fMRI: a tutorial overview. *NeuroImage*, *45*(1), S199–209.

Persson, J., Lustig, C., Nelson, J.K., Reuter-Lorenz, P.A. (2007). Age differences in deactivation: a link to cognitive control? *Journal of Cognitive Neuroscience*, *19*(6), 1021–32.

Phelps, E.A. (2006). Emotion and cognition: insights from studies of the human amygdala. *Annual Review of Psychology*, *57*, 27–53.

Qin, P., Northoff, G. (2011). How is our self related to midline regions and the default-mode network? *NeuroImage*, *57*(3), 1221–33.

Radloff, L.S. (1977). The CES-D scale a self-report depression scale for research in the general population. *Applied Psychological Measurement*, *1*(3), 385–401.

Raizada, R., Tsao, F.M., Liu, H.M., Kuhl, P.K. (2010). Quantifying the adequacy of neural representations for a cross-language phonetic discrimination task: prediction of individual differences. *Cerebral Cortex*, *20*(1), 1–12.

Raz, N., Lindenberger, U., Rodrigue, K.M., et al. (2005). Regional brain changes in aging healthy adults: general trends, individual differences and modifiers. *Cerebral Cortex*, *15*(11), 1676–89.

Reuter-Lorenz, P.A., Jonides, J., Smith, E.E., et al. (2000). Age differences in the frontal lateralization of verbal and spatial working memory revealed by PET. *Journal of Cognitive Neuroscience*, *12*(1), 174–87.

Sambataro, F., Murty, V.P., Callicott, J.H., et al. (2010). Age-related alterations in default mode network: impact on working memory performance. *Neurobiology of Aging*, *31*(5), 839–52.

Shiota, M.N., Levenson, R.W. (2009). Effects of aging on experimentally instructed detached reappraisal, positive reappraisal, and emotional behavior suppression. *Psychology and Aging*, *24*(4), 890–900.

Smith, S.M., Nichols, T.E. (2009). Threshold-free cluster enhancement: addressing problems of smoothing, threshold dependence and localisation in cluster inference. *Neuroimage*, *44*(1), 83–98.

Svoboda, E., McKinnon, M.C., Levine, B. (2006). The functional neuroanatomy of autobiographical memory: a meta-analysis. *Neuropsychologia*, *44*(12), 2189–208.

Tucker, A.M., Feuerstein, R., Mende-Siedlecki, P., Ochsner, K.N., Stern, Y. (2012). Double dissociation: circadian off-peak times increase emotional reactivity; aging impairs emotion regulation via reappraisal. *Emotion*, *12*(5), 869–74.

Urry, H.L., van Reekum, C.M., Johnstone, T., Davidson, R.J. (2009). Individual differences in some (but not all) medial prefrontal regions reflect cognitive demand while regulating unpleasant emotion. *NeuroImage*, *47*(3), 852–63.

Urry, H.L., van Reekum, C.M., Johnstone, T., et al. (2006). Amygdala and ventromedial prefrontal cortex are inversely coupled during regulation of negative affect and predict the diurnal pattern of cortisol secretion among older adults. *Journal of Neuroscience*, *26*(16), 4415–25.

Van Reekum, C.M., Johnstone, T., Urry, H.L., Thurow, M.E. (2007). Gaze fixations predict brain activation during the voluntary regulation of picture-induced negative affect. *NeuroImage*, *36*(3), 1041–55.

Voss, M.W., Erickson, K.I., Chaddock, L., et al. (2008). Dedifferentiation in the visual cortex: an fMRI investigation of individual differences in older adults. *Brain research*, *1244*, 121–31.

Watson, D., Clark, L.A., Tellegen, A. (1988). Development and validation of brief measures of positive and negative affect: the PANAS scales. *Journal of Personality and Social Psychology*, *54*(6), 1063–70.

Whalen, P.J. (2004). Human Amygdala responsivity to masked fearful eye whites. *Science*, *306*, 2061.

Winecoff, A., Labar, K.S., Madden, D.J., Cabeza, R., Huettel, S.A. (2011). Cognitive and neural contributors to emotion regulation in aging. *Social Cognitive and Affective Neuroscience*, *6*(2), 165–176.

Woolrich, M.W., Ripley, B.D., Brady, M., Smith, S.M. (2001). Temporal autocorrelation in univariate linear modeling of FMRI data. *NeuroImage*, *14*(6), 1370–86.