Supporting Online Material for

Following the Crowd: Brain Substrates of Long-Term Memory Conformity

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Supporting Online Material

Methods

Task and stimuli

Participants: Thirty right handed subjects (12 females, average age 28.6 ± 0.77, (mean ± SEM)) participated in the study. One participant was omitted from further analysis because of suspected minor brain pathology and one due to head movements exceeding 4 mm. Only subjects who indicated no suspicion of the experimental manipulation when debriefed were included in the analysis (a final N = 20, 8 females, age 27.4 ± 1.0). All participants gave informed consent and were paid for their participation. The study was approved by the Institutional Review Board of the Sourasky Medical Center, Tel-Aviv.

***Stimuli*:** The stimuli consisted of a 40 minute eyewitness styled documentary following the activities of police deporting illegal immigrants. The film included scenes of forceful arrests of illegals and their families. The content had medium emotional valance as rated by participants (see results below).

Procedure (Fig. 1A)**:** The experiment was divided into four phases.

Encoding phase (day 0): The initial encoding of the movie was performed with groups of 5 unacquainted individuals. The participants introduced themselves to the group and a photograph was taken of each participant. The subjects were told that the experiment was testing memory and they would subsequently be asked questions concerning the content of the film. They were specifically instructed not to discuss the film or memory tests with others at any stage.

Memory *Test 1* (day 3): Memory *Test 1* was a computerized 400 question, two-forced choice, memory questionnaire on the film's content, conducted three days after the encoding phase. After providing each answer the subjects rated how confident they were in their responses. The confidence ratings were provided on a visual analog scale (VAS) ranging from 0 (guess) to 100 (absolute confidence) with 25 equating to low confidence, 50 to medium confidence and 75 to high confidence. The average accuracy was 69.1 ± 1.2% for all answers and 80.2 ± 2.0% for answers with medium to high confidence scores.

Manipulation phase (day 7, Fig. 1A): Subjects performed a memory test while in an fMRI scanner. On each trial the participants were presented with a memory question related to the film. The questions were identical to those in memory *Test 1*; however, to minimize scanning time, only 320 questions were included (randomly selected). The question, two possible answers and pictures of the co-observers, who had seen the film together with the subject, were displayed for 2.5 seconds (mode of presentation adapted from *S1*). This was followed by a blank screen for a jittered 2 second interval (range: 1-8 seconds). The design allowed subjects to try and retrieve what they remembered before the false information was presented. Analysis for this time window is presented in supplementary results. Next, the manipulated co-observers answers were displayed on the screen for 2.5 seconds. The participants were not allowed to answer during this period to ensure that they gave due consideration to the new information presented. After the 2.5 second interval the color of the question font changed indicating to the subjects that they now could respond. They then provided a response and on 66% of the trials (randomly assigned) also provided a confidence rating. Participants were instructed that the answers of their co-observers could be used to assist their retrieval process but that they ultimately were required to answer according to their own recollection. The scan was divided into 3 sessions with a 15 minute break between sessions.

The co-observer answers were pseudo-randomly allocated into 3 different categories as follows: (Fig. 1B).

1. Manipulation condition. For each subject, questions that were answered correctly by that subject in memory *Test 1* with a confidence rating from 70% to 140% of his/her average confidence rating were identified. 80 of these questions (randomly assigned) were included as manipulation questions in *Test 2*. The average confidence rating for all manipulation questions was 62.6 ± 2.3, lying between a medium (50) and high (75) confidence rating. In all manipulation questions the fake co-observer answers provided in memory *Test 2* were deliberately incorrect.

2. No-manipulation control condition. 25 different questions were randomly chosen from the same pool of questions as in category 1 above (average confidence rating 62.5 ± 3.3). For these questions the co-observers answers were not made available and instead the letter X was displayed.

3. Credibility condition. 215 different questions were randomly chosen from all questions in memory *Test 1*. Since it is not credible that all co-observers answers would always be unanimously in disagreement with the participants' remembered view it was necessary to add additional questions in which the co-observers answers appeared in different patterns. Thus, the sole purpose of the *credibility condition* was to ensure that the manipulation questions were believable to the subjects. Credibility questions were not subsequently analyzed in the fMRI data. Pilot data showed that using less credibility questions led participant to suspect the manipulation. The pattern of the falsified co-observer answers in this condition depended on the subject's answer and confidence in memory *Test 1* such that the greater the subject's confidence in his correct answer the greater the number of correct answers given by co-observers.

Image acquisition and analysis

Image acquisition. Imaging was performed on a 3T scanner. All images were acquired using a 12-channel head matrix coil. Three-dimensional T1-weighted anatomical scans were acquired with high resolution 1-mm slice thickness (3D MP-RAGE sequence, TR 2300 ms, TE 2.98 ms, 1 mm^3 voxels). For BOLD scanning T2*-weighted images were acquired using the following parameters: TR 2000 ms, TE 30 ms, Flip angle 80º, 35 oblique slices without gap, 30º towards coronal plane from AC PC, 3 × 3 × 4 mm voxel size covering the whole cerebrum.

Image analysis. Statistical Parametric Mapping (SPM5; Wellcome Trust Centre for Neuroimaging, London, UK, http://www.fil.ion.ucl.ac.uk/spm) was used to analyze the fMRI data. After discarding the first 3 dummy volumes, images were realigned to the first volume, unwarped, normalized to a standard EPI template based on the Montreal Neurological Institute (MNI) reference brain, resampled to 2mm×2mm×2mm voxels, and spatially smoothed with an isotropic 8 mm full width at half maximum (FWHM) Gaussian kernel.

For each participant, a time series was created indicating the temporal position of the different trial types. Data for individual trial types were convolved with the canonical hemodynamic response using a random effect general linear model (GLM). For the GLM, 11 regressors were constructed. Of these, 5 regressors were created for the critical time period when co-observer answers' were presented (results of this time window are included in the main text): a. *Persistent errors*: Manipulation trials for which participants initially answered correctly (*Test 1*) but gave incorrect answers in both *Test 2* and *Test 3*. b. *Transient errors*: Manipulation trials for which participants initially answered correctly (*Test 1*) and gave incorrect answers in *Test 2* but not in

Test 3. c. *Non-conformity*: Manipulation trials for which participants gave a correct answer in both *Test 1* and *Test 2*. d. *No-manipulation condition* questions. e. *Credibility condition* questions. These regressors were modeled as a boxcar from the time the co-observers' answers were presented until the participant responded. We allowed this boxcar to reach a maximum of 6.5 seconds. The 6.5 second maximum was included in order to focus our analysis on the initial time frame of social influence on the participants' decision (in 18.6 ± 2.3% of the trials participants' reaction was given after this time frame). Five additional regressors were created for the period of the question presentation. These 5 regressors again corresponded to the 5 experimental conditions (*persistent errors*, *transient errors*, *non-conformity*, *no-manipulation* and *credibility*). These regressors were modeled as a 2.5 sec boxcar. An additional regressor was created for the time window of the confidence rating phase and was modeled as a boxcar from the time of presentation of the VAS confidence scale until response. Note that differences in confidence ratings and reaction times were controlled for by adding a vector including each subject deferential values as covariates in the second level analysis for all contrasts.

Region of interest analysis. For all region of interest (ROI) analysis we extracted the mean parameter estimates averaged across the whole ROI for each experimental condition separately and entered them into a repeated measures ANOVA analysis with experimental condition (*persistent errors, transient errors, non-conformity* and *no-manipulation*) as a factor. When significant, this was followed by t-tests. Two types of ROI were used in our analysis:

a. *A-priori anatomical ROIs:* The a-priori anatomical ROIs were defined based on known anatomical landmarks according to the Talairach Daemon Atlas (*S2*) using the SPM WFU PickAtlas tool (*S3*). Anatomical ROIs were defined for the bilateral amygdala, bilateral para-hippocampus and bilateral anterior and posterior hippocampus. The hippocampus subdivision was defined according to previous literature (*S4*).

b. *Functional ROIs:* Functional ROIs were defined in the *social manipulation* experiment. The ROIs were regions that showed increased activation when additional information was present (*manipulation condition* > *no-manipulation condition*, $p < 0.00005$ $k > 50$). For the *non-social manipulation* experiment we identified voxels where activity was grater in the *non-social manipulation* vs. the *no-manipulation conditions* within the functional ROIs identified above (small volume correction (SVC), FWE < 0.05).

Functional connectivity analysis. A whole-brain psychophysiological interaction (PPI) analysis was conducted to identify if target brain regions showed a significant difference in functional coupling with the left amygdala in the different conditions of interest (i.e. *persistent errors*, *transient errors, non-conformity* and *no manipulation condition*). Our target regions were the anatomically defined hippocampal complex ROIs. The regressors in the PPI analysis included: 1. The activation time course of the volume of interest (i.e. physiological variable; the BOLD signal). 2. A regressor representing the psychological variable of interest (i.e. the different experimental conditions). 3. A regressor representing the cross product of the previous two (the psychophysiological interaction term, PPI). The first 2 regressors were added as covariates to the model whilst the last regressor was the regressor of interest. For each subject, we averaged the parameter estimates of the PPI regressor across the whole target ROI for each condition of interest separately and conducted a repeated measures ANOVA analysis with experimental condition (*persistent errors, transient errors, non-conformity* and *no-manipulation*) as a factor (for previous literature on method see *S5*-*S6*). When significant, this was followed by t-tests. Fig. 4A and Fig. 4B present functional connectivity results for the social and non-social experiment respectively.

Supplementary Results

Behavior

Confidence ratings. Confidence ratings in the *persistent* and *transient error*s did not differ before or after the manipulation stage (Fig. 2B). During the manipulation stage confidence ratings in *transient errors* dropped significantly, and were lower than for *persistent errors* (t (19) = 6.8, $p < 10^{-5}$). This may indicate that in the former case, while publicly conforming, participants still considered their response to be incorrect, whilst in the latter case they accepted the new information without conflict (*S7*). When social influence was removed, confidence levels for both *persistent* and *transient errors* reconverted to medium confidence levels. In the *non-conformity* trials, confidence dropped significantly as the participants maintained their opinion despite social pressure (*Test 2*), but increased again when social influence was removed (t (19) = 8.1 and t (19) = 4.7 respectively, $p < 0.0002$). Note that differences in confidence were controlled for in the fMRI analyses using a covariate.

Reaction times (RT). A repeated measures ANOVA, using experimental condition as a factor, revealed a significant difference in RTs (F (3, 57) = 6.1 p < 0.001). Shorter RT's were found in the *no-manipulation condition* compared to the 3 other conditions (i.e. *persistent errors*, *transient errors* and *non-conformity*), ($p < 0.002$). Longer RT's were found for *non-conformity* compared to *persistent error*s (t (19) = 2.5, $p < 0.02$). This pattern of reaction time may indicate an increasing level of conflict (*S8*). As aforementioned, these differences were controlled for by adding the deferential RT as a covariate in the second level analysis.

Debriefing results. Eight subjects were excluded from the analysis because they indicated suspicion that the co-observers answers presented in memory *Test 2* were fabricated. Subjects were excluded even if they indicated that their suspicion was weak and did not affect their behavior. We used this conservative inclusion threshold in order to avoid confounds related to uncovering the manipulation. Analysis of the excluded subjects revealed that they had significantly less conforming behavior compared to the included subjects (49.0 ± 4.5%, for excluded participants vs. 68.3 ± 2.9% for included participants t (26) = 3.2, $p < 0.005$). Memory performance in *Test 1* did not differ between excluded and included participants (t (26) = 1.7, $p > 0.1$).

All 20 participants included in the final analysis indicated that on memory *Test 3* they understood that the co-observer information viewed previously (on memory *Test 2*) was irrelevant. They indicated that, as instructed, they attempted on every trial to answer only from their own memory of the original movie. Consistent with previous studies (*S9*), debriefing indicated that participants regarded the *persistent memory errors* as vivid personal experiences. None of the participants were consciously aware of incorporating information provided by the co-observers into their own recollection. However, all 20 participants were aware that they sometimes reverted back to their original answer in the final test. Seventeen of the 20 participants indicated that this latter circumstance occurred only when they had "publicly" conformed.

Functional imaging

Brain activation during manipulation condition* vs. *no-manipulation condition.

Five brain regions showed enhanced activation during *manipulation* relative to *no-manipulation conditions* (Fig. *S1A* and Table *S1*, $p < 0.00005$, k > 50). These included four frontal regions; bilateral inferior frontal gyrus (IFG; BA 47; 32,22,-14; -32,16,-20), dorsal ACC (BA 32; 10,32,34), dorsal medial pre-frontal cortex (dmPFC, BA 8; 6,24,50) and an additional region in

the occipital cortex (BA 17; -10,-94,-6). Averaging activity in these regions revealed larger activity in all frontal regions during trials in which the participant did not conform as opposed to trials where they conformed (Fig *S1B*). There was no difference between trials that resulted in long lasting memory change and those resulting in only *transient errors* (with one exception in dmPFC). Conjoint activation in these frontal areas has been associated with conflict detection and cognitive control (*S10-S12*), such as when confronted by competition from irrelevant memories (*S13-S14*). Thus in contrast to the MTL, activity here may reflect the explicit decision of the participant not to conform or rising conflict levels, rather than long term memory modulation (this interpretation was supported by longer reaction time in the *non-conformity* condition). The occipital cortex region was found, presumably, because more complex visual stimulation was present during the *manipulation condition* (co-observers text answers were displayed) relative to the *no-manipulation condition* (only letter 'X' was displayed).

Brain activation during question presentation. The experimental protocol was designed to allow the participant to recall the information on their own before being exposed to social influence. To this end the question and possible answers were displayed for 2.5 second without the co-observers answers. Whole brain analysis during this time window ($p < 0.001$, $k = 10$) did not reveal any significant differences between the *persistent errors, transient errors* and the *non conformity* conditions.

Control Study I: Emotional arousal

Activation in the amygdala associated with emotional arousal has been repeatedly demonstrated in the literature (*S15-S17*). Ratings of emotional arousal have been previously correlated with independent measures of physiological arousal such as skin conductance response and amygdala activation (*S18*). To examine whether the elevated activation in the amygdala during trials that resulted in *persistent memory errors* were related to heightened emotional arousal we conducted an additional behavioral study collecting ratings of emotional arousal on a trial by trial basis from our participants on all three memory tests.

Design: 10 participants (6 females, average age 26.2 ± 1.3) were tested in the same behavioral protocol used in the main experiment with the following additions; in memory *Test 1* the participants were asked to retrospectively rate the emotional arousal they felt while watching the part of the movie associated with the question. In memory *Test 2* and memory *Test 3* the participants were asked to rate the emotional arousal they felt at the present moment. The participants rated using a VAS scale ranging from 0 (no emotional arousal) to 100 (very high emotional arousal), with 25 indicating low emotional arousal, 50 medium emotional arousal and 75 high emotional arousal.

Results: We preformed a repeated measures ANOVA analysis with experimental condition (*persistent errors, transient errors, non-conformity* and *no-manipulation*) as a factor. The average emotional rating in memory *Test 1* was 51.2 ± 2.3 indicating that the movie content was perceived as emotional on a medium level. We found no significant differences in emotional arousal ratings between the different conditions in memory *Test 2* or memory *Test 3*. In memory *Test 1* there was a significant effect (F (3,27) = 4.7, $p < 0.02$) which was driven by higher ratings for questions that will result in *non-conformity* relative to *transient errors* (t (9) = 3.2, $p < 0.05$), *persistent errors* (t (9) = 2.1, $p < 0.06$) and *no-manipulation* (t (9) = 2.8, $p < 0.05$). These results are consistent with previous literature demonstrating that highly emotional material is less likely to undergo

conformity (*S19*) and more likely to be accurately remembered (*S20*). Importantly, however, no difference was found between the *persistent* and *transient error* conditions.

Control Study II: Non-social manipulation

The question arises as to whether our findings are driven by a unique social context or rather demonstrate a more generalized reaction to misinformation (S*20-S22*). To this end we performed a control experiment using a non-social medium to convey misinformation, a technique commonly used for this purpose (*S1,S22-S23*).

Design: 20 participants (9 females, 28.1 ± 1.1) underwent a similar protocol to the one in our main experiment. However, in memory *Test 2*, instead of receiving answers from co-observers, subjects received the same information but were told that it originated from 4 different computer algorithms. The participants were told that the different algorithms had been tested and proven to provide an accuracy level equal to, and sometimes slightly higher than that of humans. Three participants were excluded from the analysis because they indicated suspicion of the manipulation, three participants were excluded due to technical problems and one participant was excluded due to claustrophobia in the scanner setting (final N of 13).

Behavioral Results: The conformity levels when answers were given by computers (*non-social manipulation condition*, 45.3 ± 4.7%), was significantly lower than in the *social manipulation condition* described in the main text (68.3 ± 2.9%), but significantly higher than when *no-manipulation* at all was presented (15.0 ± 2.4%), (t (38) = 4.2 and t (19) = -5.7 respectively, $p <$ 0.0002). When influence was removed (*Test 3*) in this non-social control, participants reverted back to their original, correct answer in 61.1 ± 2.6% of the previously conformed trials (*transient errors*), but maintained erroneous answers in 38.9% (*persistent errors*). There was no interaction between manipulation (*social/non-social*) and type of error (*persistent/transient*), ($p > 0.6$), suggesting that social manipulation increased both types of errors equally.

Functional imaging results

a. Persistent vs. *transient errors.* Greater activation during trials that resulted in *persistent* relative to *transient errors* (whole brain analysis, $p = 0.001$ $k = 10$) was found in 2 MTL regions; the left PHG and the right hippocampus (-24,-48,-12, $t = 4.6$ and 34,-20,-19, $t = 4.2$ respectively). Significant activation was also found in the caudate nucleus (26,20,32, $t = 6.9$) and the occipital cortex (30,-98,12, $t = 6.9$). No activation was found in the amygdala even when applying SVC. The reverse contrast (*transient errors > persistent errors*) did not reveal any significant result.

b. Non-social manipulation vs. no-manipulation condition. We examined whether the 5 regions identified in the main experiment as differentiating between *manipulation* and *no-manipulation* trials (Fig. S1A, Table S1) show the same pattern of activation in this control experiment. We contrasted *non-social manipulation* trials with *no-manipulation* trials in these ROIs. In all regions but one, enhanced activation was found during the *non-social manipulation condition* ($p < 0.05$, SVC, FWE). The regions were; right IFG (BA 45; 54,24,6), dMPFC (BA 8; 4,36,48), ACC (BA 32/9; peak voxel in 4,36,38) and the occipital cortex (BA 17; -2,-92,-4). Averaging activity in these regions **(**Fig. S1B) revealed that frontal areas showed heightened activation for the *non-conformity* trials relative to all other trials. No such differences were found in the occipital region. Thus activity in these regions demonstrated a similar pattern in the *social* and *non-social manipulations* consistent with a proposed role in non-specific conflict monitoring and decision making.

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Fig. S1.

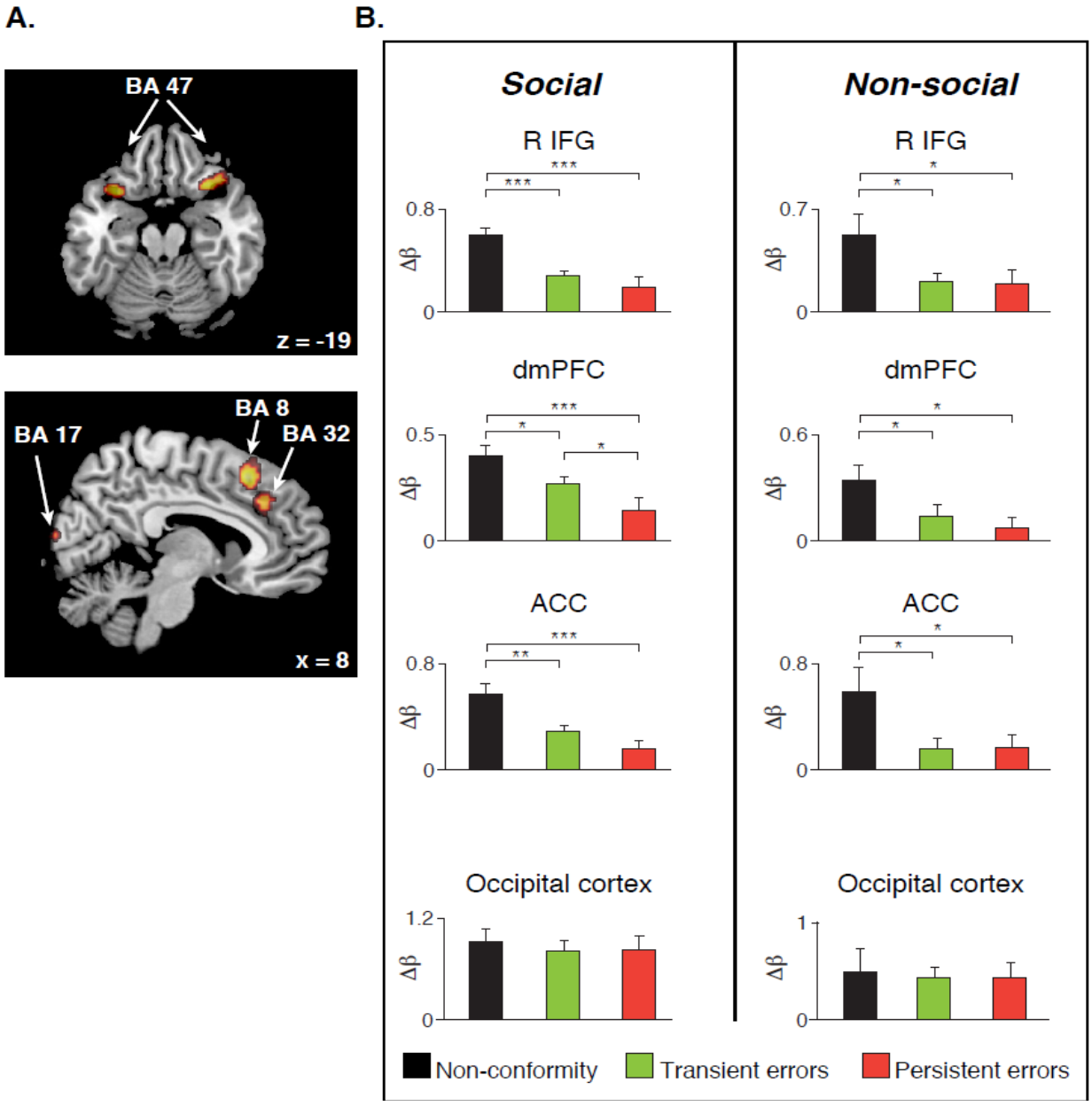

Fig. S1. **(A)** Regions identified by contrasting activation during the *social manipulation condition* relative to *no-manipulation condition* ($p < 0.00005$ uncorrected, $k > 50$, all areas also survived FWE $p < 0.05$ whole brain corrected); bilateral BA 47, BA 32, BA 8 and BA 17. **(B)** Of these regions, activity in frontal areas was greater in the *non-conformity* condition than either conformity conditions in both the *social* and *non-social manipulations*. The occipital cortex showed heightened activation for all conditions in which text answers were displayed regardless of the social context. The baseline in all figures is the *no-manipulation condition*. (* $p < 0.05$ ** $p < 0.005$ *** $p < 0.0005$)

Table S1 *Whole brain analysis in social experiment* (*social manipulation vs. no-manipulation conditions).*

Region	MNI			*t*	*p* (FWE corrected for whole brain)
	X	Y	Z		
Bi-lateral inferior frontal gyrus (peak at BA 47; extending into the ventrolateral prefrontal cortex)	32, -32	22 16	-14 20	9.0 7.8	0.004 0.019
Dorsal ACC (peak at BA 32, extending into the rostral ACC at a slightly lower threshold)	10	32	34	7.3	0.04
dmPFC, (peak at BA 8; extending into BA 6 and 32)	6	24	50	8.1	0.014
Occipital cortex (peak at BA 17)	-10	-94	-6	7.3	0.042