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Superior emotional regulating effects of creative cognitive reappraisal

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ABSTRACT

Although the effects of cognitive reappraisal in regulating negative emotion are generally well documented, its regulatory effects are usually not very strong because the ordinary reappraisals employed in previous studies were insufficient to overcome the mental set or response bias toward negative situations. In this study, we developed a new strategy employing creative reappraisals that provides an insightful reinterpretation of the negative stimulus. We believe this approach, through adopting a guided (creative) reappraisal rather than self-generation strategy, will greatly improve the emotion regulation effect of reappraisal through activating the neural networks representing the process of deep and structural mental representational change accompanied by the feeling of positive emotion and mental reward. The behavioral results suggested that 1) regarding the transient regulatory effect, creative reappraisal resulted in a positive rating for standardized negative pictures; 2) creative reappraisal had a long-lasting effect in reducing negative affect. In parallel with these behavioral results, the imaging data indicated that 1) creative reappraisal was specifically associated with greater engagement of the amygdala and hippocampus as well as regions in the ventral striatum, and 2) the engagement of the amygdala predicted the transient regulatory effect of creative reappraisal, while the involvement of the hippocampus and the ventral striatum predicted long-term regulatory effects. These findings suggest that the superior regulatory effect of creative reappraisal could be mediated by amygdala-based salient emotional arousal, hippocampus-based new association formation, and striatum-based mental rewarding to lead to a novel and positive experience that could be kept in long-term memory. This research indicates the key role of creative insight in reappraisal and presents a novel and highly efficient reappraisal strategy.

1. Introduction

The ability to control emotional responses and initiate adaptive behavior is important for physical and mental well-being (Gross and John, 2003). Cognitive reappraisal, as an effective strategy to regulate negative emotion, enables individuals to reinterpret the subjective meaning of an emotionally evocative event and thereby alter its emotional impact (Aldao et al., 2010; Augustine and Hemenover, 2009; Webb et al., 2012). According to the representational change theory of cognitive reappraisal, this strategy is able to downregulate negative emotion because it represents or restructures the current situation by changing one's mental set and information processing model toward the unfavorable stimulus (Ochsner and Gross, 2005).

However, effective representational change (Ohlsson, 1984, 1992) is usually not easily achieved because individuals typically have predominant attention and response bias toward an unfavorable or stressful situation that originates from their maladaptive thoughts and beliefs and is firmly stored in long-term semantic and procedural memory systems (Bar-Haim et al., 2007). These biases or tendencies can place strong constraints on individuals' mental representations of an unfavorable situation and limit their ability to generate truly novel and efficient reappraisals that would greatly change their feeling toward the negative

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stimulus. This is somewhat similar to the situation in insight problem solving, wherein individuals initially form an inappropriate or maladjusted mental representation of the problem they attempt to solve; under this circumstance, an original and thorough representational change is critical to overcome the difficulty (Knoblich et al., 1999; Luo and Niki, 2003; Wu et al., 2013).

Therefore, we suggest that the most successful reappraisals are quite possibly creative ones that provide novel and suitable perspectives to understand negative events/situations. These creative reappraisals can result in thorough representational change and better emotion regulation effects. A typical example of this idea is Steve Jobs's way of understanding death: “Death is very likely to be the single best invention of life because death is life's change agent”. Jobs's wording provides a novel and meaningful reinterpretation of death that emphasizes the value of death from an evolutionary perspective that may be more helpful for soothing the fear of one's inevitable destiny relative to other ordinary comforts. In fact, the components of creative insight are generally recognized in the practice of psychological therapy, and these components are believed to play key roles in the persuasive solution to mental distress (Elliott, 2007; Elliott et al., 1994).

Recent studies have revealed links between creativity and cognitive reappraisal. It was found that the ability to generate cognitive reappraisal is positively associated with openness to experience and scores for divergent thinking, implying a shared psychological mechanism for reappraisal generation and creative ideation (Weber et al., 2014). ERP and fMRI studies have also consistently found that the processes of generating cognitive reappraisal and creative thinking share similar neural correlates or processing methods. Fink and colleagues compared the generation processes of cognitive reappraisal by asking participants to generate alternative appraisals for anger-evoking events (cognitive reappraisal tasks) and verbal creative ideation (alternative uses tasks). The authors found that these two tasks elicited similar brain activations in the left prefrontal cortex (Perchtold et al., 2017) and had similar distribution patterns of alpha power (Fink et al., 2017). In our previous study, the relationship between cognitive reappraisal creativity and its effectiveness in regulating negative emotion was directly assessed and proven. We found a positive correlation between the ratings of reappraisal creativity and its regulatory effectiveness (Wu et al., 2017), implying that creativity may play an essential role in cognitive reappraisal.

We performed a preliminary study to estimate the creativity level of the cognitive reappraisals employed in the available studies. First, a total of 123 cognitive reappraisal studies published from 2001 to 2018 were identified utilizing a search of keyword of “cognitive reappraisal” in PubMed. Six papers were deleted from further analysis due to unclear descriptions of reappraisal strategies/examples. Elaborate descriptions of reappraisal strategies/examples are listed in S2. According to the evaluation of six professional psychological counselors who were blinded to experiment's aim, the creativity level (defined as providing an insightful reinterpretation that is both novel and appropriate for the target unpleasant stimulus or events) of these reappraisal materials was mainly at the low to moderate level (mean = 2.52, $SD = 1.05$, Likert 9 point, 1 “extremely uncreative” to 9 “extremely creative”). The inter-rater reliability among the raters was high (Cronbach's alpha = 0.816). Considering the main aim of previous studies was to generate some cognitive reappraisal to regulate emotion, rather than to generate something creative, it is natural to find the reappraisal previous studies used was not so creative. However, if the role of creativity could be critical in determining a given reappraisal's power of emotion regulation, just as it was proposed in the present study, then the relatively low level of creativity of previous reappraisal studies could have underestimated the regulatory effect of the reappraisal strategy, and the related cognitive neuroscience studies could be insufficient to provide a reasonable and comprehensive understanding on the neural basis of reappraisal by only using these ordinary reappraisal materials. In other words, in the present study we predicted that if we utilize reappraisal materials with high creativity, it is possible to enhance the effectiveness of emotional regulation and reveal the brain mechanisms of reappraisal that was greatly different from the ordinary reappraisal in previous studies.

In this study, we developed highly creative reappraisal materials for the unpleasant International Affective Picture System (IAPS) pictures (Lang et al., 2008) and compared their regulatory effects and neural processes with ordinary or low creative reappraisals. Given that our previous study (Wu et al., 2017) found that it is not easy for individuals to generate high creative reappraisals to negative IAPS pictures on their own in a limited time (only 31.9% of the reappraisals were rated as “highly creative” by the participants themselves, and this ratio would decline to 0.5% if the judgements were made by the psychological counseling graduate students who have experiences in guiding one to apply emotion regulation strategy, ≥ 7 on a 9-point scale), we prepared ideal high and low creative (ordinary) reappraisals for the negative IAPS pictures in advance and presented these well-prepared sentences together with the corresponding IAPS picture during MRI scanning. Compared with the self-generated reappraisal strategy, the advantage of the guided reappraisal strategy is that we can precisely obtain the type of reappraisal, especially creative reappraisals that may be difficult to obtain in a self-generated manner. This experimental design enabled us to accurately measure the onset time, which is important for the event-related fMRI approach. The disadvantage of this guided reappraisal approach, however, is that the participants simply perform the reappraisal by following the instructions that are explicitly presented to them. Although following a creative reappraisal is not identical to generating one independently, it seems to involve similar processes, particularly the cognitive restructuring that has been regarded as the key component of creative insight (Luo and Knoblich, 2007; Weisberg, 1995). This guided paradigm has been used in studies on insightful problem solving and cognitive reappraisal (Allard and Kensinger, 2014; Dougherty et al., 2015).

This study predicts that providing participants well-prepared highly creative reappraisal may not only result in better regulatory effects and a longer regulatory period than other conditions but also facilitate truly cognitive restructuring, which could greatly change negative emotions. Moreover, with respect to the neural correlates of reappraisals, although previous studies on ordinary reappraisals (Ochsner et al., 2012) have generally identified the role of cognitive control mediated by the prefrontal cortex (PFC) regions, the role of representational change mediated by the temporal and parietal regions and the role of emotion arousal and body feelings mediated by the subcortical hubs such as the amygdala and insula, the neural correlates of creative reappraisal may be different from those of ordinary reappraisals. For example, in contrast to the general recognition that the effect of reappraisals is to downregulate negative emotional arousal toward unfavorable situations, which are typically associated with decreased activation in key regions, especially in the amygdala, creative reappraisal may not only alleviate negative emotion but also induce deep cognitive restructuring, positive emotion and mental rewards that could be well maintained in long-term memory. This idea implies that the process of creative emotion regulation would mobilize more executive functions mediated by the prefrontal cortex (Amodio and Frith, 2006; Ochsner and Gross, 2005; Ochsner et al., 2012; Wager and Smith, 2003), evoke more positive feelings and reward-related activations (Wager et al., 2008), and even be accompanied by more extensive memory-related processing, which participates in the encoding of insightful experiences (Ludmer et al., 2011; Luo and Niki, 2003).

2. Materials and methods

2.1. Participants

Thirty-one college students (17 females; age: 24 ± 2.01, range from 21 to 27) were paid to participate in this study. Data from 8 participants were deleted (23 included in the formal analysis): one participant was lost due to corrupted files; five participants were discarded for excessive movement (more than 3 mm of maximal translation in any direction of x, y, z or 3 degrees of maximal rotation) (the reason for this relatively high ratio of excessive movement was participants reported they felt excited when read some wonderful reappraisal sentences and this may result in body movement); and two participants were discarded due to psychological reasons (they could not appreciate and accept the reappraisal of negative pictures). All participants have normal or corrected-to-normal vision, are right handed, and are native Chinese speakers. The experimental protocol was approved by the Institutional Review Board of the Institute of Biophysics, Chinese Academy of Sciences. Written informed consent was obtained from all participants before the experiment.

2.2. Materials

2.2.1. Negative stimulus materials

The formal fMRI experimental procedure used 75 unpleasant IAPS images and covered a variety of negative stimuli and situations, such as threat/attack scenes, animals and disgusting things. The mean valence rating was 2.56 ($SD = 0.52$; *max*: 3.55, *min*: 1.51), and the mean arousal rating was 5.43 ($SD = 0.85$; *max*: 7.35, *min*: 3.93) on a 9-point scale.

2.2.2. Reappraisal materials

Given that generating genuine creative reappraisals for the negative pictures was not easy for individuals independently (Wu et al., 2017), two other groups of individuals generated and evaluated a list of highly creative reappraisals for negative IAPS pictures in advance, and we presented these well-prepared materials to the subjects in the formal experiment. This triggering approach has been applied in exploring the neural correlates of insight problem solving (Huang et al., 2015, 2018; Luo and Niki, 2003; Mai et al., 2004; Tang et al., 2016; Wu et al., 2013) and reappraisals (e.g., Foti and Hajcak) (2008). Although studying the process of passively reading and comprehending creative reappraisals provided by the experimenter was not as ideal as investigating the process of generating creative reappraisals by individual subjects, this triggering approach could provide a reasonable solution to the dilemma of studying the neural correlates of insightful restructuring. Because truly insightful restructuring is difficult to be obtained on one's own, the only way to get the self-generated insight problem solving is to reduce the task difficulty, however, these adjustment will greatly reduce the true components of insightful restructuring and the accuracy of the event onset time that is technically required by the neuroimaging approach, especially the event-related onset. In contrast, if we want to obtain the true components of insightful restructuring and time-lock these events with an accurate onset time, we must present participants with well-prepared materials at the expense of the idea generation process (Luo et al., 2006).

To prepare the creative reappraisal materials, we recruited 75 participants who showed high creativity and interest in participating in the task to generate creative cognitive reappraisal for the negative images. The final database included 946 reappraisal sentences; the lengths of these sentences were 30–40 Chinese characters, and the number of reappraisals of each negative picture was 8–23 (more information about how the data were collected can be found in a previous study by Wu et al., 2017). Then, another 45 participants evaluated these reappraisals/interpretations on three dimensions: creativity (the extent to which the participant felt that these reappraisals were novel and unexpected), appropriateness (the extent to which the description was appropriate for or fit with the scene depicted in the picture) and effectiveness (the extent to which the description could improve one's feelings and emotions when looking at the picture) (Wu et al., 2017).

The present study investigated the neural correlates of creative cognitive reappraisal by contrasting the processing of ordinary reappraisal with creative reappraisal. We provided participants with three types of well-prepared reappraisal sentences for unpleasant IAPS pictures, including creative reappraisals, ordinary reappraisals, and objective descriptions of the images. For each picture, we selected creative reappraisals from 946 sentences that were evaluated as highly creative, effective, and appropriate by participants as the materials for the condition of creative reappraisal (creativeness rating: $M = 6.56$, $SD = 1.57$; effectiveness rating: $M = 6.46$, $SD = 1.71$; and appropriateness rating: $M = 5.97$, $SD = 1.85$). Furthermore, for each picture, we generated sentences for ordinary reappraisals and objective descriptions with length and complexity similar to those of the creative reappraisals (numbers of Chinese characters for each type of sentence: $M_{creative\ reappraisal} = 32.29$, $SD_{creative\ reappraisal} = 3.56$; $M_{ordinary\ reappraisal} = 31.87$, $SD_{ordinary\ reappraisal} = 2.02$; $M_{objective\ description} = 31.75$, $SD_{objective\ description} = 1.82$; $F\ (2,\ 148) = 1.908$, $p = 0.17$). The ordinary reappraisal descriptions were created following the most commonly used reappraisal strategies, such as "they are getting help" (explicitly positive) or "the tragedy would never happen again" (changing future circumstances) (McRae et al., 2012). The objective descriptions described the content of pictures without any cognitive reappraisal attempts. Therefore, three types of descriptions (creative, ordinary, and objective description) were provided for each of the 75 pictures.

A defining feature of highly creative reappraisal is to trigger an "Aha!" experience, which can result in a new interpretation of a situation and occurs in a relatively sudden and unpredictable manner (Sternberg and Davidson, 1995). In the current study, we defined the "Aha!" experience as follows: (a) the key component of the "Aha!" experience was mental restructuring, which provided a new perspective that was significantly different from one's initial thoughts and was suitable for the given situation; (b) the "Aha!" experience was accompanied by a strong emotional release and refreshed emotional feelings ("Aha! So that is what it is!" "Eureka!"). We assumed that most creative reappraisal could lead to an "Aha!" experience, while only some ordinary reappraisals could do so.

In the pilot study to evaluate whether the reappraisal descriptions could evoke people's insightful restructuring of the scene depicted by the picture, 30 participants (14 female) with a mean age of 22.4 years ($SD = 2.27$, range = 19–28) were required to judge, on a yes-or-no forced selection task, whether each description of its target picture could lead to an "Aha!" reaction. The 75 pictures were pseudo-randomly assigned into three conditions for each participant. To avoid confusion among different types of reappraisal descriptions of the same target picture, each participant could see only one type of reappraisal for a given picture. The results indicated that 90.0% of creative reappraisals were able to trigger an "Aha!" experience. The percentage for ordinary reappraisal was 58.2%, and the percentage for objective descriptions was 0.08% [main effects of condition: $F\ (2,\ 58) = 280.53$, $p < 0.001$]. Post hoc comparisons indicated that creative reappraisals were able to trigger significantly more "Aha!" experiences than ordinary reappraisals ($t\,(29) = 10.32$, $p < 0.001$, one-tailed), creative reappraisals were able to trigger significantly more "Aha!" experiences than objective descriptions ($t\ (29) = 29.18$, $p < 0.001$, one-tailed), and ordinary reappraisals were able to trigger significantly more "Aha!" experiences than objective descriptions ($t\ (29) = 11.30$, $p < 0.001$, one-tailed)].

Below are two examples of each type of sentence (Fig. 1C; for more examples, see Fig. S1):

A1. **Creative reappraisal**: Although she just threw up, she has great joy in her heart because she will finally have a baby (creativeness: $M = 7.60$, $SD = 1.30$).

A2. **Ordinary reappraisal:** While the vomit is a mess, fortunately, this is nothing serious, and she will get better after some rest (creativeness: $M = 4.80$, $SD = 1.32$).

A3. **Objective description**: The toilet is blocked by unidentified yellow objects, and the water cannot go down because of black objects floating in it (creativeness: $M = 2.80$, $SD = 0.50$).

B1. **Creative reappraisal:** Trying to open its mouth wide, the snake says to the veterinarian on the opposite side, "My tonsil is inflamed. Examine it" (creativeness: $M = 8.23$, $SD = 1.11$).

B2. **Ordinary reappraisal:** The researcher is studying the habits of a special snake. It is an uncommon breed and needs to be protected (creativeness: $M = 4.74$, $SD = 1.57$).

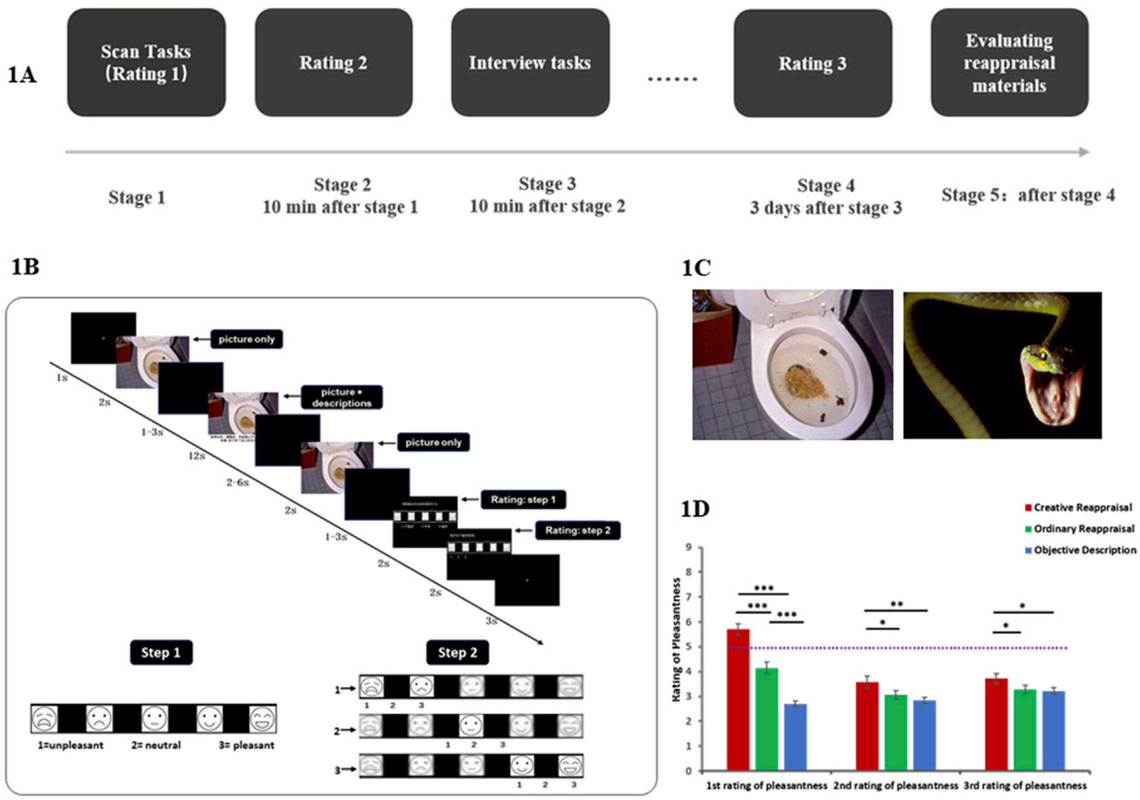

Fig. 1. A) Schematic of the experimental procedure. **B)** Two examples of negative figures. C) Procedures for the scanner task (stage 1). In a single trial, participants were first shown a picture for 2 s; after a 1-s delay, the picture reappeared on the screen together with 1 creative reappraisal/ordinary reappraisal/objective description for 12 s. After this key event of appraisal comprehension, the picture reappeared for 2 s, and participants were again required to passively view it during its presentation. This event was followed by emotional valence rating associated with the processing of the target picture. There were two steps in the rating scale. In rating 1, participants indicated whether their feelings regarding the picture were unpleasant, neutral, or pleasant. Then, for rating 2, participants were required to further specify the degree of emotional arousal. For example, if they rated their feeling as unpleasant in rating 1, then they were asked to further indicate whether it was slightly unpleasant, moderately unpleasant, or extremely unpleasant. The 2-step rating scores were then converted to a 9-point scale for further analysis (1 = very unpleasant; 9 = very pleasant). D) Comparisons of the pleasantness ratings for creative reappraisal, ordinary reappraisal, and objective descriptive 3 times (1st, 2nd, 3rd). For the pleasantness rating, 1 = very pleasant, 9 = very pleasant. 1st time = instant rating reading the description (scanner), 2nd time = second exposure to the negative pictures after 10 min, 3rd time = third exposure to the negative pictures after 3 days.

B3. **Objective description:** A grass-green snake raises up, opens its mouth wide and exposes its poisonous tongue, black eyes staring forward (creativeness: $M = 1.32$, $SD = 0.57$).

Notes: The creativeness scores of the three types of sentences were obtained based on participants' post-scan ratings.

2.3. Procedure

The entire experimental procedure consisted of 5 stages (Fig. 1A):

Stage 1: With MRI scanning, participants first viewed the negative pictures alone and then read a certain type of cognitive reappraisal (creative, ordinary or objective) with an image. Finally, participants evaluated their emotional valence associated with the pictures. Regarding the specific procedure for each trial, participants were first shown a picture for 2 s and were required to passively view the picture during its presentation. Then, after a 1- to 3-s unfilled delay, the picture reappeared on the screen together with its creative/ordinary/objective reappraisal for 12 s. Participants were required to attentively read the description in their mind at a natural speed to attempt to understand its meaning and implications for the target picture (this 12-s duration was determined by a pilot experiment, which showed that 96% of reappraisals/descriptions could be read and fully understood within this period). A 2- to 6-s unfilled delay followed this key event of reappraisal comprehension. Then, the picture was presented alone without any reappraisals or description sentences for 2 s, and participants were again required to passively view it during its presentation. This event was followed by a 1- to 3-s unfilled delay. Then, participants were required to indicate their emotional valence associated with the processing of the target picture. The evaluation of emotional valence emphasized that participants should report their direct and present true feelings toward the picture. The evaluation was accomplished in two steps. In the first step, participants indicated whether their feelings toward the picture were unpleasant, neutral, or pleasant. In the second step, participants were required to further specify the degree of emotional valence. For example, if they rated their feeling as unpleasant in step 1, then they were asked to further indicate whether it was slightly unpleasant, moderately unpleasant, or extremely unpleasant. If participants rated their feeling as neutral, then they needed to further judge whether the feeling tended to be unpleasant, pleasant or absolutely neutral. The rating scale was accompanied by 5 cartoon facial expressions [2 unpleasant faces (an unpleasant one and a very unpleasant one), 1 neutral face, and 2 pleasant faces (a happy one and a very happy one)] to promote the participants' understanding. The 2-step rating scores were then converted to a 9-point scale for further analysis (1 = very unpleasant; 9 = very pleasant). Participants' rating of pleasantness toward the pictures in Stage 1 was denoted as Rating [1] (Fig. 1B).

For each participant, the 75 pictures were randomly assigned to three conditions with 25 trials in each. Valence and arousal were not significantly different in the three conditions ($p_{all} > 0.05$). Each participant could see only one type of reappraisal for a given picture, thus avoiding possible interactions among different types of reappraisals of the same picture. Before the formal experimental session with fMRI scanning, participants received thorough instructions and were sufficiently trained by another set of similar materials with an identical procedure.

Stage 2 was conducted 10 min after Stage 1. In this stage, participants were shown 75 pictures again but without the reappraisals and were required to evaluate the pleasantness or unpleasantness of the pictures based on their immediate feelings using 9-point Likert scales. The purpose of this stage was to investigate whether the reappraisal's regulatory effects lasted over time. Participants' ratings of pleasantness regarding the pictures in Stage 2 were denoted as Rating [2].

Stage 3 was carried out 10 min after Stage 2. In Stage 3, we conducted an interview with each participant after the experiment regarding how he/she made his/her pleasantness or unpleasantness rating in Stage 1. Participants were shown the 75 pictures individually and asked the following questions: a) To what extent was your rating based on your first impression of the picture (i.e., the impression before you observed any reappraisal); b) To what extent was your rating based on the reappraisal descriptions. Participants were asked to answer these two questions using 5-point scales (1 = not at all, 5 = totally). Through these inquiries, we learned the extent to which the reappraisals could impact or alter the participants' original perception of the picture. If more reappraisals could alter the participants' original perception, then their rating would be less dependent on their initial impression and more dependent on the reappraisal. In particular, we predicted that creative reappraisals would be more likely than other reappraisals to transform the participants' initial unfavorable perceptions to more favorable, reappraisal-induced perceptions. Specifically, we calculated the efficacy of a given type of reappraisal in changing one's initial representation by subtracting the ratio of items whose evaluations were based on the first impression from that based on the presented reappraisals.

Stage 4 was conducted three days after Stage 3. The aim of Stage 4 was to investigate the long-term effects of reappraisal on the processing of unpleasant pictures. The requirements were the same as those of stage 2, in which participants were asked to view negative pictures again and immediately rate their feelings of pleasantness or unpleasantness. Participants' rating of pleasantness toward the pictures in Stage 3 was denoted as Rating [3].

Stage 5 was carried out after Stage 4. All 3 types of reappraisals/descriptions that we created for each picture were shown to the participants together with the target pictures, and the participants were asked to rate each reappraisal/description's level of creativeness, effectiveness, and appropriateness on a 9-point scale (1 = not at all, 9 = extremely). Creativeness, effectiveness, and appropriateness were rated separately, and the rating sequence was counterbalanced across participants.

2.4. Image acquisition

We performed fMRI on a Siemens 3T Trio MRI scanner (Siemens Medical Systems, Erlangen, Germany). Functional scans were acquired using T2*-weighted gradient echo, echo-planar pulse sequences. The following acquisition parameters were used in the fMRI protocol: TR = 2000 ms, TE = 30 ms, slice number = 32, flip angle = 90°, matrix size = 64 × 64, FOV = 220 mm × 220 mm, and voxel size = 3.4 mm × 3.4 mm × 3 mm. For each participant, functional data were acquired in three scanning sessions containing 415 vol per session. Stimuli were presented on an MR-compatible monitor using E-prime software (Psychology Software Tools). Participants were in a supine position with their heads snugly fixed by a belt and foam pads to minimize head motion.

2.5. Image analysis

2.5.1. Preprocessing

Imaging data were analyzed using SPM8 software (Statistical Parametric Mapping, Welcome Department of Cognitive Neurology, London, UK). Slice timing was corrected to account for differences in acquisition time. Images were then realigned to the first volume in the scanning using affine transformations. The images were further normalized and registered to a standard EPI template within SPM [Montreal Neurological Institute (MNI) space]. The images were resampled to a spatial resolution of 3 mm × 3 mm × 3 mm and then spatially smoothed using an 8-mm full-width at half maximum (FWHM) Gaussian kernel.

2.5.2. Whole-brain analysis

Fixed effects for each participant were analyzed under the assumptions of the general linear model at the first level; the resultant parameter images for each subject then entered a second-level analysis using one-way ANOVAs. The 12-s reappraisal period was our event of interest. We separated this 12-s duration into two periods, the early comprehension period (0–6 s) and the late elaboration stage (7–12 s). This decision was made based on our pilot behavioral study that showed that the average time to finish reading one reappraisal description was 5708 ms ($SD = 2695$ ms, $N = 28$), which was also consistent with the general theoretical hypothesis that suggested that a comprehension (cognitive) phase and an elaboration (affective) phase were contained in the processing of the unexpected new reinterpretation for a given situation (Wyer and Collins, 1992).

Individual statistical parametric maps were calculated for the following events to investigate BOLD signal changes: the early 0–6 s reappraisal phase, the late 7–12 s reappraisal phase and other watching and rating events. Each phase was modeled as a boxcar regressor convolved with the canonical hemodynamic response. The width of each boxcar function was set to the duration of its presentation. Movement parameters calculated during realignment were included as 6 parameters to control for movement artifacts. Other events were not the focus of this study and were entered in the first-level model only to prevent relevant BOLD signal changes.

Second-level analyses were performed using random-effects models based on the statistical maps obtained from the within-subject analyses to examine reproducible effects across all subjects. First, separate one-way ANOVAs were calculated on 3 levels of individual contrast images in the early comprehension stage ($creative_{early}$, $ordinary_{early}$, and $objective_{early}$) and in the late elaboration stage ($creative_{late}$, $ordinary_{late}$, $objective_{late}$). We also added paired-sample t-tests to compare the differences between the early stage and the late stage of the three conditions (creative reappraisal, ordinary reappraisal and objective reappraisal) separately. Family-wise error (FWE) correction at the cluster level was performed ($p < 0.05$, 10 voxels).

We further used participants' rating scores of emotional valences in the scanner as trial-by-trial covariates to rebuild the whole brain GLM model to identify regions that were linearly correlated with emotional valence. All three conditions (creative, ordinary, objective) were combined as one category, and the pleasant scores for each trial were added as covariates at the first level. For the pleasant rating covariates, we further scaled the scores with each participant's mean value removed to convert them into a set of scores fluctuating above and below zero and synchronized the scores at the onset of the early comprehension stage and the late elaboration stage, respectively. The sequence of the covariate was then convolved with a hemodynamic response function (HRF) before being incorporated into the design matrix. Therefore, we obtained new models of linear coupling between the pleasantness rating and brain activity in the early comprehension stage and the late elaboration stage separately ($p < 0.001$, uncorrected, 10 voxels).

2.5.3. ROI analysis

The regions of interest (ROIs), including the amygdala, hippocampus, ventral striatum/nucleus accumbens (VS/NAC) and midbrain, which are critical for emotional arousal, mental reward and insightful information encoding, were predicted to be involved in creative reappraisal. Voxels in these ROIs were identified using structurally defined templates as an inclusive mask, and functionally activated regions derived from the specific contrasts (e.g., the contrast of "Creative Condition - Objective Condition") were obtained within these regions. Structural templates included AAL templates for the bilateral amygdala and the bilateral hippocampus. Templates in WFU Pick Atlas Version 2.4 for the bilateral midbrain (http://fmri.wfubmc.edu/software/PickAtlas), and bilateral NAC/VS were defined using an 8-mm sphere centered on gray matter adjacent to the posterior ventral caudate head (left: $xyz = [-10\ 14–9]$, R = 8 mm; right: $xyz = [7\ 14–9]$), reported in a previous study (Wager et al., 2008). All functionally activated regions were selected from the late elaboration stage and were considered to have more affective components. The significance threshold was set to $p < 0.0001$ uncorrected at the voxel level.

Time courses were extracted within those ROIs for each participant in each experimental condition. Deconvolution of the percent signal change within ROIs was performed using a finite impulse response (FIR) function implemented with MarsBar (http://marsbar.sourceforge.net). The baseline of the pre-stimulus time course was defined as the onset of the 12-s event. The FIR signal change was estimated for 9 time points after the reappraisal event onset and extracted within each condition separately for each participant.

We correlated each participant's signal change within the ROIs with Rating [1], Rating [2], Rating [3] of pleasantness for the creative reappraisal condition to further investigate the relationship of creative reappraisal and subjective ratings of emotion in brain activations. We chose the peak signal change value in the entire time course to represent brain activities in creative reappraisal. We correlated signal change and behavioral data only in the creative reappraisal condition because activities within these regions were observed only in the creative condition. All peak values appeared between the 4–9 time points, consistent with our hypothesis that reading time required approximately 2–4 time points and a hemodynamic lag required approximately 2–3 time points.

3. Results

3.1. Behavioral data

3.1.1. Three instances of pleasantness ratings of the negative pictures (ratings 1, 2 and 3)

The participants were asked to rate their feelings toward each negative picture at three different time points as follows: (1) immediately after the presentation of the reappraisal for each picture (Rating [1]); (2) 10 min after finishing all of the reappraisal processing tasks (Rating [2]); and (3) three days after the reappraisal processing tasks (Rating [3]). Two-factor within-subject ANOVAs on pleasantness ratings for the 3 reappraisal conditions (creative, ordinary, and objective) and 3 rating times (Rating [1], Rating [2], and Rating [3]) revealed significant main effects of the reappraisal condition [F (2, 44) = 52.25, $p < 0.001$, $\eta_p^2 = 0.70$] and time [F (2, 44) = 21.14, $p < 0.001$, $\eta_p^2 = 0.49$] as well as significant interactions between time and condition [F (4, 88) = 47.68, $p < 0.001$, $\eta_p^2 = 0.68$]. Simple effect analysis using the Bonferroni correction indicated that for Rating [1], pictures with creative reappraisals were rated as more pleasant than those with ordinary reappraisals ($p < 0.001$) and objective descriptions ($p < 0.001$), and pictures with ordinary reappraisals were rated as more pleasant than those with objective descriptions ($p < 0.001$). For Rating [2], pictures with creative reappraisals were rated as more pleasant than those with ordinary reappraisals ($p < 0.05$) and those with objective descriptions ($p < 0.01$), but there was no difference between the ordinary reappraisal condition and the objective description condition. For Rating [3], pictures with creative reappraisals were rated as more pleasant than those with ordinary reappraisals ($p < 0.05$) and those with objective descriptions ($p < 0.05$), but there was no difference between the ordinary reappraisal condition and the objective description condition (Fig. 1D and Table S1).

Furthermore, we compared the mean Rating [1] of pleasantness for each condition with the median score (5, neutral on the 9-point Likert scale, more than 5 indicated positive emotion and less than 5 indicated negative emotion). The results suggested that the scores of Rating [1] under the creative reappraisal condition were significantly higher than the median score [t (22) = 3.03, $p < 0.01$; $M = 5.69$, $SD = 1.10$], the scores of Rating [1] under the ordinary reappraisal condition were significantly lower than the median score [t (22) = −3.46, $p < 0.01$; $M = 4.15$, $SD = 1.18$], and the scores of Rating [1] under the objective description condition were significantly lower than the median score [t (22) = −21.77, $p < 0.001$; $M = 2.70$, $SD = 0.51$]. This finding indicates that creative reappraisal may result in significant positive emotion toward the negative pictures, whereas objective descriptions and ordinary reappraisals may result in negative or slightly negative emotion only.

Rating [1] was performed in two steps. The participants were first required to rate whether their feelings toward the picture were "unpleasant", "neutral", or "pleasant" (see the Methods). We calculated the percentage of the "pleasant" selection in each condition (which implied the negative picture to be evaluated as a positive one) and found that for creative reappraisal, 43.19% of the trials were judged as "pleasant", while for ordinary reappraisal and objective descriptions, this percentage was 16.70% and 2.44%, respectively. A chi-square test revealed significant differences in the percentage of the three types of emotion states [χ^2 (2) = 40.67, $p < 0.001$].

3.1.2. Follow-up interview for reconstruction efficacy (stage 3)

The participants were also required to provide information regarding how they made their rating [1]. Each participant evaluated the following two scores for each picture on a 5-point scale (1 = not at all, 5 = totally): 1) To what extent was your rating of the pleasantness of the picture based on your first impression of the picture when you saw it without any interpretation sentence presented with it; 2) To what extent was your rating based on the reappraisal descriptions? The restructuring efficacy score was calculated as follows: restructuring efficacy = score based on the description − score based on the first impression. ANOVAs revealed significant main effects of condition [F (2, 44) = 11.63, $p < 0.001$, $\eta_p^2 = 0.53$]. A simple effect analysis with the Bonferroni correction indicated that the restructuring efficacy for creative reappraisals was significantly higher than that for ordinary reappraisals ($p < 0.01$) and objective descriptions ($p < 0.05$); however, there were no significant differences between ordinary reappraisals and objective descriptions.

3.1.3. Post-rating of the description materials in 3 dimensions (stage 5)

The participants were asked to rate the level of *creativeness*, *effectiveness* and *appropriateness* for all 3 types of text materials on a 9-point scale (1 = not at all, 9 = extremely) to confirm the validity of each description. ANOVAs showed significant differences for three conditions (creative, ordinary, objective) in all three indices [*creativeness*: F (2, 44) = 334.43, $p < 0.001$, $\eta_p^2 = 0.94$; *effectiveness*: F (2, 44) = 300.57, $p < 0.001$, $\eta_p^2 = 0.93$; *appropriateness*: F (2, 44) = 39.17, $p < 0.001$, $\eta_p^2 = 0.64$]. A simple effect analysis with the Bonferroni correction indicated that creative reappraisals were rated as significantly more creative than ordinary reappraisals ($p < 0.001$) and objective descriptions ($p < 0.001$), and ordinary reappraisals were rated as significantly more creative than objective descriptions ($p < 0.001$). Creative reappraisals were rated as significantly more effective than ordinary reappraisals ($p < 0.001$) and objective descriptions ($p < 0.001$), and ordinary reappraisals were rated as significantly more effective than objective descriptions ($p < 0.001$). In addition, creative reappraisals were rated as significantly less appropriate than ordinary reappraisals ($p < 0.001$) and objective descriptions ($p < 0.001$), and ordinary reappraisals were rated as significantly less appropriate than objective descriptions ($p < 0.001$). Although there were significant differences in the appropriateness ratings among the 3 conditions, all 3 types of descriptions were rated as basically acceptable (appropriateness rating more than 6 on a 9-point scale) (see Fig. S2 and Table S2).

3.2. Imaging data

For the imaging phases of interest (the 12-s presentation of pictures with descriptions that embodied the processing and integration of the reappraisal sentence with the picture), we first examined the effects of condition in the early comprehension stage (0–6 s) and the late elaboration stage (7–12s), computing the contrasts of "$creative_{early}$ vs. $ordinary_{early}$", "$ordinary_{early}$ vs. $objective_{early}$", "$creative_{late}$ vs. $ordinary_{late}$" and "$ordinary_{late}$ vs. $objective_{late}$".

Note: 1) Threshold of voxel levels: $T = 5.19$, $p < 0.05$ (FWE corrected), k = 10; MNI = Montreal Neurological Institute.

In the early stage, "$ordinary_{early}$ minus $objective_{early}$" contrasts involved significant activations within the dorsomedial prefrontal cortex (dmPFC), inferior parietal lobule, temporoparietal junction (TPJ), angular cortex, fusiform cortex and posterior cingulate cortex (Table S3 and Fig. S4); however, there were no superthreshold brain activities in the late elaboration stage.

In the early stage, "$creative_{early}$ minus $ordinary_{early}$" contrasts involved significant activations within the dorsolateral prefrontal cortex (dlPFC), ventrolateral prefrontal cortex (vlPFC), temporal lobe, thalamus, fusiform, midbrain (substantia nigra), parahippocampal gyrus and amygdala (Table 1 and Fig. 2). In the late stage, "$creative_{late}$ minus $ordinary_{late}$" contrasts involved significant activations within a wide range of visual/temporal cortices, dlPFC, dmPFC, fusiform cortex, hippocampus and parahippocampus (Table 2 and Fig. 3A).

Additional analysis was performed to investigate the differences between the early stage (0–6 s) and late stage (7–12 s) of three conditions separately. All three contrasts of the early stage minus the late stage ("$creative_{early}$ vs. $Creative_{late}$", "$ordinary_{early}$ vs. $ordinary_{late}$", and "$objective_{early}$ vs. $objective_{late}$") involved significant and similar activations with the middle temporal cortex (MTG), inferior frontal cortex (IFG), midbrain and cerebellum (Fig. S5 and Table S4). The contrasts of the late stage minus the early stage ("$creative_{late}$ vs. $Creative_{early}$", "$ordinary_{late}$ vs. $ordinary_{early}$", and "$objective_{late}$ vs. $objective_{early}$" all involved the precuneus/cuneus, middle frontal cortex (MFG) and medial frontal cortex (mPFC) (Table S5). However, the contrast of the late stage minus the early stage in the creative reappraisal involved activations of special brain regions with greater PFC, cerebellum and ACC (Fig. S6).

Trial-by-trial linear coupling of brain activity and pleasantness ratings was conducted. The results indicated that in the early stage, significant activations were found in the prefrontal cortex, MTG, thalamus, angular and cerebellum, and in the late stage, significant activations were found in the MTG, amygdala, parahippocampus, and midbrain (Fig. 4).

We chose the bilateral amygdala, bilateral hippocampus, bilateral NAC/VS and bilateral midbrain as our ROIs. The FIR time course, which represented brain activities in the 12-s reappraisal events, was averaged within each condition (Fig. 3B). ANOVAs revealed significant differences in the averaged signal change under the three conditions (creative, ordinary and objective) ($F_{all} > 6.39$, $p_{all} < 0.01$). Simple effect analysis indicated larger average signal changes in the creative reappraisal condition than in the ordinary condition and the objective condition for the bilateral amygdala, bilateral hippocampus, right NAC/VS and left midbrain ($p_{all} < 0.01$).

We chose the values of the peak signal change in the creative reappraisal condition and correlated them with Ratings [1], [2] and [3]. For Rating [1], the correlation between the pleasantness rating and activities in the left amygdala was significant ($r = 0.53$, $p < 0.01$). For Rating [2], the correlation between the pleasantness rating and activities was significant in the left amygdala ($r = 0.54$, $p < 0.01$), left hippocampus ($r = 0.52$, $p < 0.05$), right hippocampus ($r = 0.48$, $p < 0.05$), left NAC/VS ($r = 0.48$, $p < 0.05$), right NAC/VS ($r = 0.61$, $p < 0.01$), left midbrain ($r = 0.57$, $p < 0.01$), and right midbrain ($r = 0.47$, $p < 0.05$). For Rating [3], activation of the right NAC/VS was significantly correlated with the pleasantness rating ($r = 0.45$, $p < 0.05$) (Fig. 3B and Table S6).

Table 1
Brain regions associated with early creative reappraisal specificity (0–6 s, creative reappraisal - ordinary reappraisal).

Brain regions	MNI coordinates			T	K
	x	y	z		
Inferior Frontal Gyrus	54	36	6	7.73	192
Middle Frontal Gyrus	42	9	30	7.11	
Inferior Frontal Gyrus	51	24	24	5.91	
Middle Temporal Gyrus	−57	−51	6	7.69	200
Inferior Temporal Gyrus	−48	−54	−15	6.16	
Superior Temporal Gyrus	−54	−57	21	5.51	
Inferior Frontal Gyrus	−45	27	15	6.74	175
Inferior Frontal Gyrus	−45	6	30	6.69	
Inferior Frontal Gyrus	−45	15	27	6.64	
Parahippocampal Gyrus (Amygdala)	−18	−3	−21	6.49	16
Middle Temporal Gyrus	−54	−18	−12	6.21	48
Inferior Temporal Gyrus	−60	−9	−18	6.15	
Thalamus	−3	−15	0	6.20	13
Fusiform	−33	−33	−24	6.13	18
Middle Temporal Gyrus	−42	−78	27	6.06	32
Midbrain (Substantia Nigra)	−6	−27	−12	5.82	10
Inferior Frontal Gyrus	−36	33	−15	5.74	13

4. Discussion

This study explored the regulatory effects of creative reappraisal on emotion regulation and its neural correlates. Using a guided reappraisal paradigm, we found that the regulatory effects of creative reappraisals were superior to those of ordinary reappraisals. First, the emotion regulation effects elicited by creative reappraisal in the present study were better than those in any other previous reappraisal study. In our study, the effect size (Cohen's d, as a measure of the effectiveness of emotion regulation) of the comparison between transient creative reappraisal and objective description was 3.49, which was significantly higher than the effect size in a previous meta-analysis of cognitive reappraisal (all less than 0.95) (Augustine and Hemenover, 2009; Webb et al., 2012). Moreover, for the transient regulatory effect that was evaluated immediately after the presentation of the reappraisal, creative reappraisal temporally shifted the emotion value of the negative IAPS pictures to positive, while ordinary reappraisal downregulated negative emotion to a moderate level only. Although some previous studies also included a positive emotion evaluation in the rating scale (Foti and Hajcak, 2008; Hayes et al., 2010; Kanske et al., 2010), the authors observed only diminished negative affect (Goldin et al., 2008; McRae et al., 2012; Ochsner et al., 2004). However, in the present study, we found a dramatic transformation "from negative to positive". Second, for the long-lasting regulatory effect, the regulating effect of creative reappraisal lasted 3 days, whereas the regulatory effects of ordinary reappraisal faded soon after the presentation of the reappraisal (within 10 min). To our knowledge, this study is the first to identify a long-lasting effect of reappraisal over a few days. Only one previous reappraisal study that investigated the lasting effect showed an effect lasting for half an hour (MacNamara et al., 2011).

How can creative reappraisal generate dramatic and long-lasting regulated emotion effects? According to Beck's theory, negative thoughts occur automatically due to deeply ingrained dysfunctional beliefs developed early in life, and downregulating negative emotions by challenging all automatic thoughts is difficult (Beck et al., 1979). The process of cognitive restructuring is theoretically regarded as the key feature of creative insight and can be identified by comparing an initial mental representation with that in the final successful solution (Weisberg, 1995). The restructuring efficacy of creative reappraisals was significantly higher than that of ordinary reappraisals and objective descriptions, implying that creative reappraisals were the most powerful way to obtain efficient cognitive restructuring of a mental representation tendency toward negative IAPS pictures. For example, person's initial emotional response to see a picture of vomitus (Fig. 1C) is disgust; when the picture is reinterpreted as a sign of pregnancy for a woman who wants to have a baby (creative reappraisal), the negative feelings would be altered, even to positive emotion. The creative/insightful idea that are particularly appropriate for reinterpreting the situation in a new manner that can lead to apparently less negative cognitive-emotional

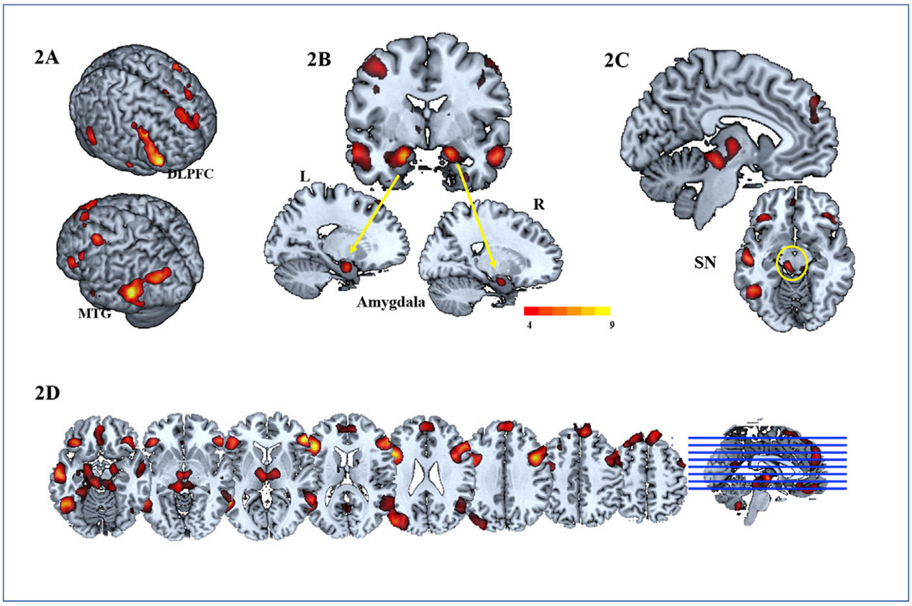

Fig. 2. Brain regions associated with creative reappraisal > ordinary reappraisal (early stage: 0–6 s).

Table 2
Brain regions associated with late creative reappraisal specificity (7–12 s, creative reappraisal-ordinary reappraisal).

Brain regions	MNI coordinates			*T*	K
	x	*y*	*z*		
Fusiform Gyrus	−30	−81	−18	7.64	2139
Inferior Occipital Gyrus	−30	−78	−9	7.42	
Inferior Occipital Gyrus	−42	−78	−9	6.99	
Middle Frontal Gyrus	−42	9	36	6.99	399
Inferior Frontal Gyrus	−39	15	24	6.39	
Inferior Frontal Gyrus	−51	18	18	5.95	
Middle Frontal Gyrus	51	18	39	6.53	207
Inferior Frontal Gyrus	45	12	39	6.28	
Inferior Frontal Gyrus	54	21	24	6.03	
Middle Occipital Gyrus	30	−72	24	6.22	103
Middle Occipital Gyrus	36	−75	15	5.87	
Middle Temporal Gyrus	−45	−42	3	6.15	46
Inferior Temporal Gyrus	−54	−48	−9	5.76	
Middle Temporal Gyrus	−51	−48	0	5.56	
Inferior Parietal Lobule	30	−54	45	6.11	56
Hippocampal Gyrus	−24	−30	−3	6.09	24
Parahippocampal Gyrus	−24	−24	−9	5.95	
Middle Frontal Gyrus	42	0	63	5.85	48
Middle Frontal Gyrus	27	−3	48	5.565	
Middle Temporal Gyrus	60	−42	−6	5.57	16
Middle Temporal Gyrus	48	−45	−6	5.40	
Superior Temporal Gyrus	−60	−54	9	5.56	10

Note: 1) Threshold of voxel levels: $T = 5.19$, $p < 0.05$ (FWE corrected), k = 10; MNI = Montreal Neurological Institute.

consequences. The representational change account of cognitive reappraisal emphasized the role of creativity and insightfulness in the emotional regulation strategy. Moreover, as an effective representational change strategy, creative cognitive reappraisal not only generate long-lasting regulated emotion effects, but also have a transfer of learning effect. Our recent related research has found that experience of learning creative reappraisals could be transferable to other new materials or situations. That is, participants would be more capable to generate creative and effective new reappraisals to the new unpleasant IPAS picture after learning the creative example.

In our research, we utilized guided cognitive reappraisals (reappraisal comprehension) rather than self-generated ones to investigate the effects of creativity in emotional regulations. By providing "ideal creative reappraisal", we found considerable effects of creativity in emotional regulation, which could change negative emotions to positive ones. This strategy of guided-reappraisal is similar with persuasion in psychotherapy (Foti and Hajcak, 2008; MacNamara et al., 2011), and more importantly, it could also have wide application if properly used. For example, we found for certain social communities or groups (like college students), they may share some common psychological problems or life confusions, and if we can provide some well-prepared creative reappraisals to these questions, that might be of some assistance. For example, the confusions of "Feeling frustrated because of beginning a career I dislike" is a somewhat common problem for some Chinese college freshman. We have tried to prepare some highly insightful metaphorical reinterpretations to these confusions (for example, to say "Success in life is not holding good cards but playing bad cards well" to the above-mentioned problem) and we found these interventions could be quite effective and promising (Yu et al., 2016, 2019). The other point we want to say is, for any cognitive reappraisal, the key component that really works or helps to change one's emotion, is the cognitive restructuring that leads to meaningful representational change of unfavorable situations, rather than the self-generated or non-self-generated process. In fact, a kind of reappraisal, no matter it was self-generated or provided by others, could always help to improve emotion if it could make an appropriate, novel and positive understanding of the negative stimulus. We can find many examples in human history that the social public's attitudes and feelings toward negative affairs were greatly altered or improved by the insightful points of view made by some highly creative individuals. In these cases, these points of view, were of course not made by the social public themselves, nevertheless, they also can make the key change. Our own results also proved the unpleasant emotion toward negative pictures were greatly improved by watching the creative reappraisals we prepared in advance, and its regulation effects could even be better than the self-generated ones (Wu et al., 2017).

Consistent with these behavioral results, brain imaging results indicated enhanced activation in the dopaminergic reward circuits, including the amygdala, midbrain/SN, and NAC/VS as well as the medial temporal lobe (MTL) regions (hippocampus and parahippocampus) in the creative reappraisal condition. Moreover, the activation levels in these areas could positively predict the immediate and/or delayed emotional regulatory effects of creative reappraisal.

Amygdala In the present study, significantly increased amygdala activation was associated with creative reappraisal, and these activations could positively predict the transient and delayed (10 min) regulatory

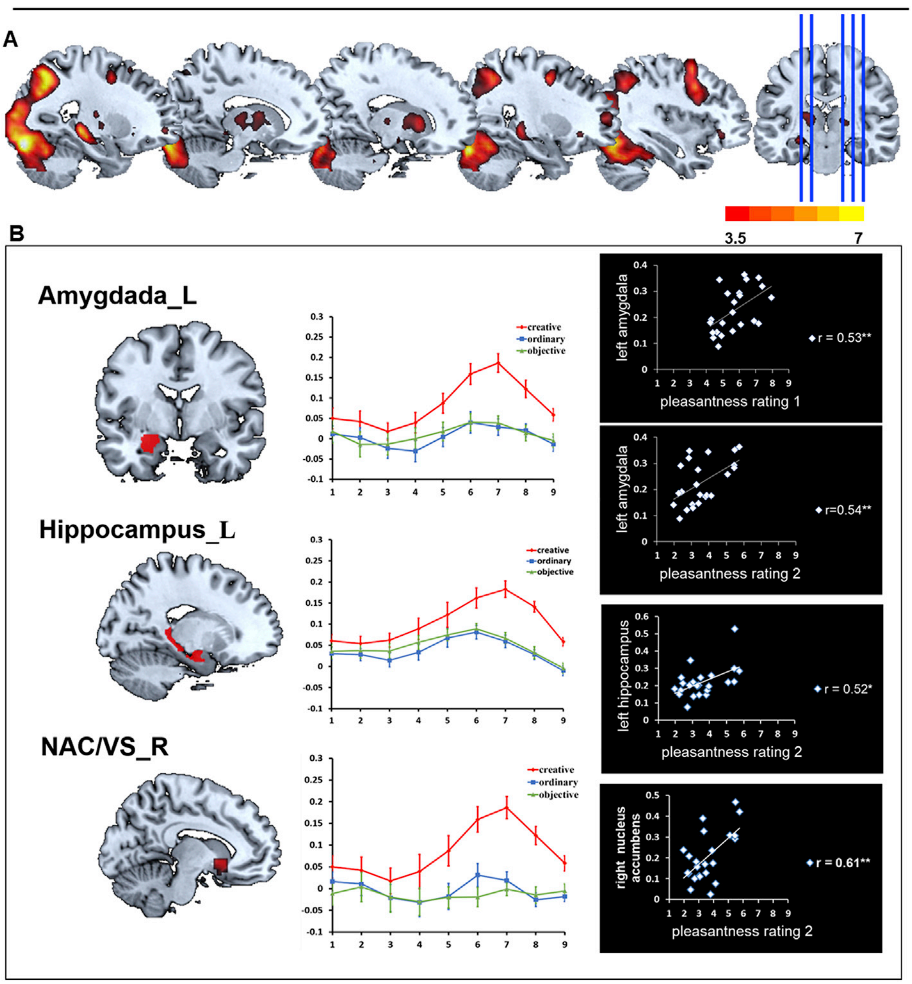

Fig. 3. A) Brain regions associated with creative reappraisal > ordinary reappraisal (late stage: 7–12 s); **B) Left:** Time course of the % signal change within the left amygdala, left hippocampus and right NAC/VS ROIs. Time courses begin at the onset of the 12-s events. With a 4- to 6-s hemodynamic response lag and a reading period of approximately 6 s, the peak percent signal change within the ROIs may be observed 12–14 s after the appearance of the sentence, as indicated in the figure. TR = 2 s; **Right:** Correlations between the peak percent signal change within the ROIs of the left amygdala, left hippocampus and right NAC/VS with pleasantness rating (rating 1 and 2) in the creative reappraisal condition. **indicates a significant difference at $p < 0.01$, *indicates a significant difference at $p < 0.05$.

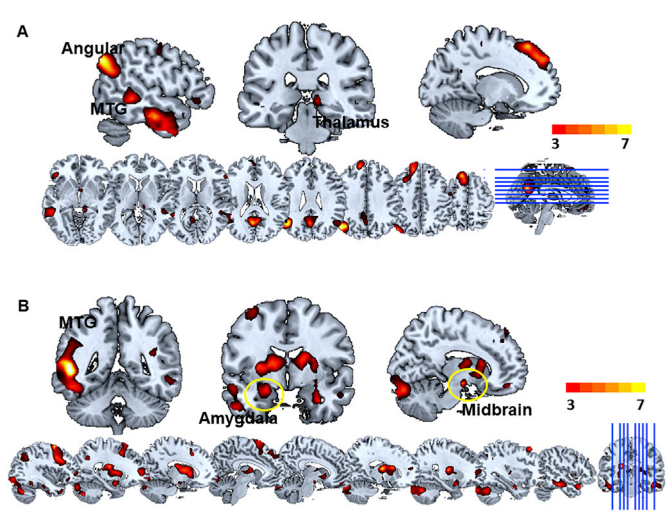

Fig. 4. Brain activations associate with pleasant rating in the scanner with the regressor analysis. A) early stage (0–6 s); B) late stage (7–12 s). $p < 0.001$, uncorrected, 10 voxels.

effects of creative reappraisal. This result is apparently inconsistent with nearly all previous studies on reappraisal. These studies found reduced amygdala activation and regarded this as a reliable indicator of efficient emotion regulation (Goldin et al., 2008; Kanske et al., 2010), which was negatively correlated with the effectiveness of reappraisal (Wager et al., 2008). To our knowledge, the only study to report positive amygdala activation during reappraisal was an experiment on children by Dougherty and colleagues (Dougherty et al., 2015). The authors found increased amygdala activation in the guided cognitive reappraisal condition. This result may be due to the following reasons: the guided reappraisal materials in the study were more persuasive than the usual ones, and children may be more capable of having pleasant feelings when successfully regulating negative emotion.

These findings lead to the question of why the amygdala plays different roles in different reappraisals. This difference can be attributed to the creativeness of reappraisals. In the majority of previous studies, reappraisals were usually made by participants independently, and the creativeness of the reappraisals was fairly low. Our previous behavioral study showed that only 0.5% of the reappraisals made by participants could be regarded as highly creative when judged by graduate students who majored in psychological counseling and had expertise in emotional regulation strategies (Wu et al., 2017). However, in this study, we adopted well-prepared, highly creative reappraisal sentences as materials. This highly creative component resulted in positive feelings toward negative pictures accompanied by positive amygdala activation. Although the function of the amygdala is generally recognized as processing evocative, arousing, and especially aversive events (Costafreda et al., 2008; Ochsner et al., 2004; Salzman and Fusi, 2010), studies have also found positive amygdala activation in response to pleasant stimuli (Garavan et al., 2001; Hamann et al., 2002; Salzman and Fusi, 2010), humorous stories (Bartolo et al., 2006; Chan et al., 2012; Goel and Dolan, 2001), and novel information (Blackford et al., 2010; Garavan et al., 2001; Hamann et al., 2002; Ludmer et al., 2011; Salzman and Fusi, 2010), implying that the function of the amygdala is not specific to negative emotion. Alternatively, the amygdala embodies the salience of emotional arousal regardless of its positive or negative emotional value (Anderson, 2003).

In line with the possibility that the activation of the amygdala is related to the salience of emotion, we found a common positive amygdala activation (x, y, z = −24, −3, −24) in both the initial encoding of negative pictures and the processing of creative reappraisal by performing conjunction analysis between the contrast of "(the presentation of) creative reappraisal > fixation (baseline)" and that of "negative picture presentation (i.e., the initial presentation of the negative pictures without any reappraisals) > fixation (baseline)", indicating that the amygdala is involved in both salient positive and negative emotions.

However, in contrast to most previous studies, our study did not find reduced amygdala activation in ordinary reappraisal, even when it was compared with the objective description. This finding could be related to the reference baseline of the objective description that we used in the contrast. Negative emotional responses can be suppressed when participants read picture descriptions (Liebermann et al., 2007). Moreover, the content of the pictures was depicted from a third person's point of view, which may affect the subjective involvement of participants. "Thinking objectively" could be a way of maintaining psychological distance from an unpleasant stimulus and feelings (Ochsner et al., 2004). Therefore, the lack of a difference in amygdala activation in the "ordinary reappraisal vs. objective description" contrast may be due to the latter condition also regulating amygdala activation to a certain extent.

MTL memory regions and midbrain reward regions MTL memory regions, including the hippocampus and parahippocampus, as well as reward regions, including the midbrain/SN and NAC/VS, were selectively activated in the processing of creative reappraisals. The activation levels of these regions could positively predict the delayed regulatory effects of creative reappraisals. Previous studies have demonstrated the function of the MTL in encoding novel stimuli (Grady et al., 1995; Tulving et al., 1994) and in forming new associations (Eichenbaum et al., 1994; Wallenstein et al., 1998), including those in insightful riddle solving (Huang et al., 2015; Luo and Niki, 2003) and in divergent numerical reasoning tasks while the novel rule was mapped (Wu et al., 2016). Thus, unsurprisingly, the present study revealed the involvement of the MTL in processing creative reappraisals. The function of reward regions in reappraisal was also proven. For example, mediation analyses showed that reappraisal-induced activation in the PFC was positively associated with activity in the NAC/VS, and successful regulation was related to increases in the NAC/VS pathway (Wager et al., 2008). Additionally, compared with women, men show less engagement of VS regions, implying that women generate positive affect to a greater extent to downregulate their negative responses (Goldin et al., 2008). In contrast to the amygdala activation that could predict immediate emotional regulatory effects of reappraisal, the activation in the MTL and reward regions predicted delayed effects. We found that NAC/VS activation could predict long-term regulatory effects even three days later. Based on the well-recognized role of the VS in reward learning (O'Doherty, 2004; Wager et al., 2008) as well as the role of the midbrain and hippocampal-midbrain coupling in mental reward processing (Shohamy and Wagner, 2008), we propose that the hippocampus-based novel association pathway and dopamine-driven reward circuits jointly contribute to motivation and memorization of the insightful representational change caused by creative reappraisal in one's mind.

Frontal and temporal regions Broad areas in the frontal cortex and temporal lobe were also involved in the processing of creative and/or ordinary reappraisals. For example, increased activation in the dmPFC and vlPFC areas was observed in the processing of creative or ordinary reappraisals compared with that of an objective description. The function of the dmPFC may be related to conflict or error monitoring and response selection (Amodio and Frith, 2006), and the function of the vlPFC may be related to the selection and inhibition of information (Ochsner et al., 2012). In the present study, both ordinary and creative reappraisals were incongruent with participants' first impressions of the presented pictures, which could lead to cognitive conflicts and the inhibition of natural emotional responses. Thus, both of these areas may be engaged in cognitive conflict monitoring and response selection in the reappraisal process. More importantly, dmPFC and vlPFC showed significant activities in the (creative > ordinary) contrasts. This may be due to the increased cognitive conflicts experienced when reading creative reappraisals.

The significantly increased activation of the dlPFC area was found only in creative reappraisal. The role of dlPFC in working memory and executive function has been widely recognized in previous imaging studies (Badre and Wagner, 2004; Egner and Hirsch, 2005). Its activation may reflect the cognitive efforts engaged in resolving conflicts and refreshing recently active representations within working memory (Egner and Hirsch, 2005). Therefore, the increased activation of dlPFC observed in creative reappraisal may be associated with the construction of the new interpretation of stimuli. It is worth noting that dlPFC was reliably activated in previous cognitive reappraisal studies (Ochsner et al., 2012). However, in the current study, it was only activated in creative reappraisal, which may be because we used guided reappraisals instead of self-generated reappraisals. Less cognitive effort is required when reading guided reappraisals than generating reappraisals independently. In addition, ordinary reappraisals are commonly used reappraisal tactics that can be easily predicted and thus lead to fewer response conflicts than insightful creative reappraisals. Hence, the activation of the dlPFC may indicate that only creative reappraisals underwent in-depth cognitive processing when perceived passively.

In addition to PFC activation, the temporal pole (TP) and TPJ were activated more in the processing of creative reappraisals. The functions of these two areas could be associated with semantic processing and social cognition, such as theory of mind (Olson et al., 2007; Saxe, 2006; Siegal and Varley, 2002). In the present study, the TP and TPJ may participate in the semantic processing of reappraisal materials and the understanding of their social significance.

5. Conclusion and future studies

As an important strategy for emotion regulation, cognitive reappraisal is widely used in psychotherapy such as cognitive behavior therapy (CBT), and its effects in regulating emotion have been verified in both psychological experiments and consultation practice. However, the key psychological factor that contributes to producing and increasing the regulatory effects of reappraisal is still unknown. In the present study, we indicate the key role of creativity or insight in reappraisal and find that the regulatory effects of reappraisal can be greatly enhanced by increasing the level of creativeness or insightfulness of the reappraisal. We found that highly creative reappraisal not only resulted in better regulatory effects and a longer regulatory period but also could produce true cognitive restructuring and turn an unpleasant emotion toward negative pictures to a positive one through compound cognitive brain processes of representational change accompanied by positive emotional arousal, feelings of mental reward, and the consolidation of new episodic memories. Given that it is difficult, if not impossible, for people to generate truly creative or insightful cognitive reappraisals toward adverse situations by themselves, external help is critical for fostering such creative reappraisals. Further studies on this issue may investigate how to develop an efficient approach to trigger insightful understanding and reappraisals of unfavorable situations.

6. Limitations

The greatest disadvantage of this study is that the participants did not self-generate cognitive reappraisals but rather passively processed those generated by other people, which seems to embodies the process of creative reappraisal "comprehension". Further research should use some more appropriate negative stimuli enable people to generate creative reappraisals on their own, such as micro-counseling dialogues (Yu et al., 2016, 2019) and adverse events (Fink et al., 2017), to investigate the effect of creative in emotional regulations. And we should also compare the differences of cognitive and neural basis between passive viewing and self-generating reappraisal strategies to identify the differences between these two approaches. Moreover, it is possible that some creative reappraisals may contained some "humorous components". Although the humorous components could also be closely related to or theoretically belong to the category of "creative reappraisals", further studies should also seek to distinguish the effects of the regulation of emotions through creative reappraisal and humorous reappraisal.

Acknowledgments and Disclosures

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Appendix A. Supplementary data

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