Affective Creativity Meets Classic Creativity in the Scanner

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Abstract: The investigation of neurocognitive processes underlying more real-life creative behavior is among the greatest challenges in creativity research. In this fMRI study, we addressed this issue by investigating functional patterns of brain activity while participants were required to be creative in an affective context. Affective creativity was assessed in terms of individual's inventiveness in generating alternative appraisals for anger-evoking events, which has recently emerged as a new ability concept in cognitive reappraisal research. In addition, a classic divergent thinking task was administered. Both creativity tasks yielded strong activation in left prefrontal regions, indicating their shared cognitive processing demands like the inhibition of prepotent responses, shifting between different perspectives and controlled memory retrieval. Regarding task-specific differences, classic creative ideation activated a characteristic divergent thinking network comprising the left supramarginal, inferior temporal, and inferior frontal gyri. Affective creativity on the other hand specifically recruited the right superior frontal gyrus, presumably involved in the postretrieval monitoring of reappraisal success, and core hubs of the default-mode network, which are also implicated in social cognition. As a whole, by taking creativity research to the realm of emotion, this study advances our understanding of how more real-life creativity is rooted in the brain. *Hum Brain Mapp 39:393–406, 2018.* © 2017 Wiley Periodicals, Inc.

Key words: creative ideation; fMRI; cognitive reappraisal; emotion; divergent thinking

INTRODUCTION

Neuroscientific investigations have revealed important insights into potential mechanisms of how creative inventiveness is rooted in the brain [Fink and Benedek, 2014; Gonen-Yaacovi et al., 2013]. Despite its progress, however, creativity research has often been criticized due to its strong focus on verbal divergent thinking (such as the generation of alternative uses of everyday objects in the Alternative Uses task), and it is seldom concerned with spontaneous, real-life creative ideation [Abraham, 2013; Tanggaard, 2013]. Indubitably, assessing creativity as a part of life itself is an intricate matter. As a result, only few researchers investigated functional patterns of brain activity during more natural creative behaviors like visual divergent thinking [Aziz-Zadeh et al., 2013], artistic design [Kowatari et al., 2009], imagining dancing [Fink et al., 2009], or musical improvisation [Berkowitz and Ansari, 2010; also see Beaty, 2015 for review]. Another type of creative behavior which we encounter in many areas of our everyday life is creativity in dealing with emotions. More

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precisely, what we call affective creativity hereinafter refers to creativity-related processes in the context of cognitive reappraisal, an emotion regulation strategy considered to be highly effective in coping with adverse events [Augustine and Hemenover, 2009; Webb et al., 2012].

Cognitive reappraisal refers to the process of deliberately reinterpreting the subjective meaning of an emotionally evocative event and thereby changing its emotional impact [Lazarus and Alfert, 1964; Lazarus and Folkman, 1984]. Given that emotions are reappraised on a daily basis which ensures psychological well-being and adequate interpersonal functioning [Garnefski et al., 2002; Gross and John, 2003], focusing on creativity in an affective context in terms of cognitive reappraisal constitutes a novel, innovative approach to investigate creative behavior in more real-life settings [Hasson and Honey, 2012]. It has already been empirically substantiated that generation of cognitive reappraisals and creative ideation display a considerable overlap in their cognitive demands [Weber et al., 2014], as both warrant the generation of multiple and alternative, preferably original but still practicable solutions to an open-ended problem. These parallels, however, are not immediately obvious and only hold if cognitive reappraisal is investigated as an actual capacity and not as self-reported, habitual response tendency of individuals [Gross and John, 2003]. Along these lines, Weber et al. [2014] shaped the concept of reappraisal inventiveness, the ability to spontaneously invent manifold reappraisals for emotionally aversive situations. Accordingly, this constitutes a novel way of applying creative potential to problem solving in ecologically valid everyday scenarios. Embedded in this reappraisal inventiveness concept is the potential to flexibly adopt new thought patterns that exceed routines, which perfectly corresponds to the common conception of creative thinking [Fink et al., 2017b]. This overlap also becomes evident in considering the crucial role executive processes play in both classic creativity and divergent thinking in an emotional context. Cognitive reappraisal, for instance, requires high cognitive flexibility to shift between various contextual perspectives and to exercise novel strategies. This can among others be attributed to basic executive functions such as the inhibition of prepotent associations, memory updating, and cognitive switching [Joormann and Gotlib, 2010; Malooly et al., 2013; Weber et al., 2014], which likely determine the effectiveness of cognitive reappraisal in reducing negative affect [Papousek et al., 2017; Pe et al., 2013]. Executive processes have also been established as important prerequisites of creative thoughts in general [Beaty and Silvia, 2012; Fink and Benedek, 2014; Gonen-Yaacovi et al., 2013], with the growing consensus that it is their close interaction with default network processes (mind-wandering, loose associations) [Beaty et al., 2015, 2016; Jung et al., 2013] that yields truly original ideas. Consequently, it is reasonable to assume that flexible generation of new perspectives and high internal processing demands are a hallmark of both classic creativity and creative thinking in an affective context [Fink et al., 2017a; Weber et al., 2014].

Despite this obvious overlap of processes involved in cognitive reappraisal and creative ideation, hardly any attempts have been made to link these two research traditions. Such an approach would have great potential to assess creativity-related brain mechanisms in response to more ecologically valid, real-life creativity demands. One notable exception is a recent study of Fink et al. [2017a], which found similar functional patterns of EEG alpha activity for conventional creative ideation (Alternative Uses Test) and the generation of cognitive reappraisals to self-relevant anger-eliciting events. Both tasks yielded strong alpha power increases at prefrontal sites, hinting at their shared executive processing demands. However, the study also revealed important differences, as cognitive reappraisal elicited significantly stronger alpha power increases at frontopolar sites, along with lower alpha increases at more posterior sites, possibly suggesting more cognitive control and less spontaneous imagination processes when creative ideation operates in an affective context.

The aim of this study was to compare functional patterns of brain activity during creativity in an affective context with classic creative ideation by means of fMRI to determine the neural networks associated with these different types of creativity tasks more precisely. Recent meta-analyses of functional imaging studies of creative ideation revealed a core creativity network involving frontal and parieto-temporal regions, specifically the lateral prefrontal cortex, and also the precuneus, the supramarginal gyrus, and left temporal regions [Gonen-Yaacovi et al., 2013; but see Boccia et al., 2015]. Increased activation of the lateral prefrontal cortex also consistently emerged in imaging studies on the neural basis of cognitive reappraisal [Dörfel et al., 2014; Johnstone et al., 2007; Price et al., 2013], along with activation in left posterior regions (for meta-analysis, see Buhle et al. [2014]). It needs to be emphasized that most functional imaging studies on reappraisal typically examined brain activity while participants were asked to use cognitive reappraisal to reduce the impact of negative affective pictures (compared to just-watch conditions). This study took an entirely different approach by investigating cognitive reappraisal as a type of creativity in an affective context. As in Fink et al. [2017a], we used modified items of the Reappraisal Inventiveness Test (RIT) [Weber et al., 2014] to measure individuals' brain activation during spontaneous generation of alternative appraisals for self-relevant, anger-eliciting situations. What renders the RIT unique in affective research is that it was deliberately designed as a divergent thinking task, aimed at reflecting individuals' potential for cognitive flexibility and creative ideation. In the RIT, individuals are required to generate manifold cognitive reinterpretations for an emotional problem, constituting a performance-oriented approach involving creativity-related demands in an affective context. This notion is empirically substantiated by the finding that the ideational fluency and flexibility subscales of the RIT correlated up to $r = 0.61$ with classic divergent thinking measures [Weber et al., 2014]. Accordingly, using a similar reappraisal generation task allowed for an objective monitoring of participant's compliance with the reappraisal instructions [Demaree et al., 2006], and the presentation of this task during fMRI assessment could be realized in a manner that is highly comparable to the Alternative Uses Test (AUT) we administered to stimulate classic creative ideation. In addition, another advantage of the used reappraisal task is that it depicts everyday hassles of individuals in personally relevant situations, which in turn, very likely increases motivation for proper task engagement.

The objective of this study was to uncover potential overlapping mechanisms between classic creative ideation and creativity in an affective context (e.g., inhibition of typical responses, effective memory retrieval), and also to determine potential unique demands of creative ideation in an affective context (e.g., updating of affective value, switching between negative and neutral mental sets) [Malooly et al., 2013]. We expect both creativity tasks to activate brain regions supporting executive functions (e.g., lateral prefrontal cortex) [Badre and Wagner, 2007; Derrfuss et al., 2005; Kim et al., 2012]. This prefrontal activation however might be stronger and possibly more left-lateralized in cognitive reappraisal, as here, executive functions need to operate in an emotional context, which might create additional demands and accordingly enhance activity in left frontal areas [Fink et al., 2017a; Papousek et al., 2017]. Additionally, we expect the AUT to produce stronger activation in left parieto-temporal regions, which have been shown to be particularly sensitive to the originality facet of creativity [Abraham et al., 2012; Fink et al., 2010, 2012; Kleibeuker et al., 2013].

MATERIALS AND METHODS

Participants

Initially, 51 university students were recruited to participate in this study. Six participants had to be excluded from data analysis, three due to technical problems during fMRI assessment and three because they reported feeling partially irritated by the loud scanner noise during the experimental tasks. The final study sample consisted of 45 students (31 female, 14 male) in the age range between 18 and 34 years ($M = 23.0$; $SD = 3.48$). All participants were right-handed, had no previous experience with the experimental tasks, and reported no psychoactive drug intake or history of mental or neurological diseases. They gave written informed consent and were either paid or received course credit for participation in the fMRI study. The study was approved by the local ethics committee of the University of Graz, Austria.

Experimental Tasks and Procedure

To stimulate classic creative ideation in the brain, the Alternative Uses Test (AUT) was administered, a widely used divergent thinking task assessing creative potential (Benedek et al. 2014a; Fink and Benedek, 2014; Fink et al., 2017a]. The AUT requires participants to generate alternative, original uses for conventional everyday objects (e.g., "brick"). Affective creativity was stimulated by means of a reappraisal generation task (RGT), which closely resembled the Reappraisal Inventiveness Test (RIT) [Weber et al., 2014]. Similar to the RIT, participants were asked to put themselves in anger-eliciting situations and to think of different ways to reappraise these upsetting events to downregulate their anger. In line with cognitive emotion theories, the RIT situations depict the behavior of another person who willingly or carelessly induces harm. In the *kitchen* item of the RIT, for instance, participants are confronted with the following situation: *"You invite friends over for a meal, but when you step into the kitchen of your flat, the entire kitchen is a mess. Yesterday, your flatmate had promised to clean up the kitchen by today. When you go to talk to your flatmate, he tells you that he was watching TV and then didn't feel like cleaning up anymore."* [Weber et al., 2014, p. 360]. This study's reappraisal generation task (RGT) was specifically designed for an fMRI environment and consisted of eight RIT vignettes already applied in previous EEG studies [Fink et al., 2017a; Papousek et al., 2017; four original vignettes by Weber et al., 2014; four additional vignettes created by Papousek et al., 2017] Additionally, we constructed 12 more anger-eliciting vignettes for the purpose of this study, matching the main characteristics of the existing vignettes to the best possible extent. The applied RGT provides several advantages over other reappraisal approaches, not only because of the increased self-relevance and the relation to reality of its vignettes, but also because it allows controlling for actual adherence to reappraisal instructions, which is rarely seen in emotion regulation research [Demaree et al., 2006].

The AUT was adapted for optimal incorporation into the fMRI environment in a similar fashion. As such, both the AUT and the RGT were presented in an identical manner, only differing with respect to the key experimental variation that required participants to invent original uses for conventional objects in the AUT, while in the RGT, they had to come up with reappraisals for anger-eliciting scenarios. RGT and AUT were presented in separate blocks and in counterbalanced order, with a fixed item sequence within each block. As seen in Figure 1, each RGT trial started with a jittered fixation interval of 4–8 s. Then, participants listened to an audio description of an everyday, anger-eliciting situation lasting about 20 s and imagined the situation happening to them. Next, a matching photograph was presented for 3 s to more clearly frame the negative content of the situation. After this picture presentation, a white-colored interrogation mark was displayed and remained on the screen for 15 s, indicting the

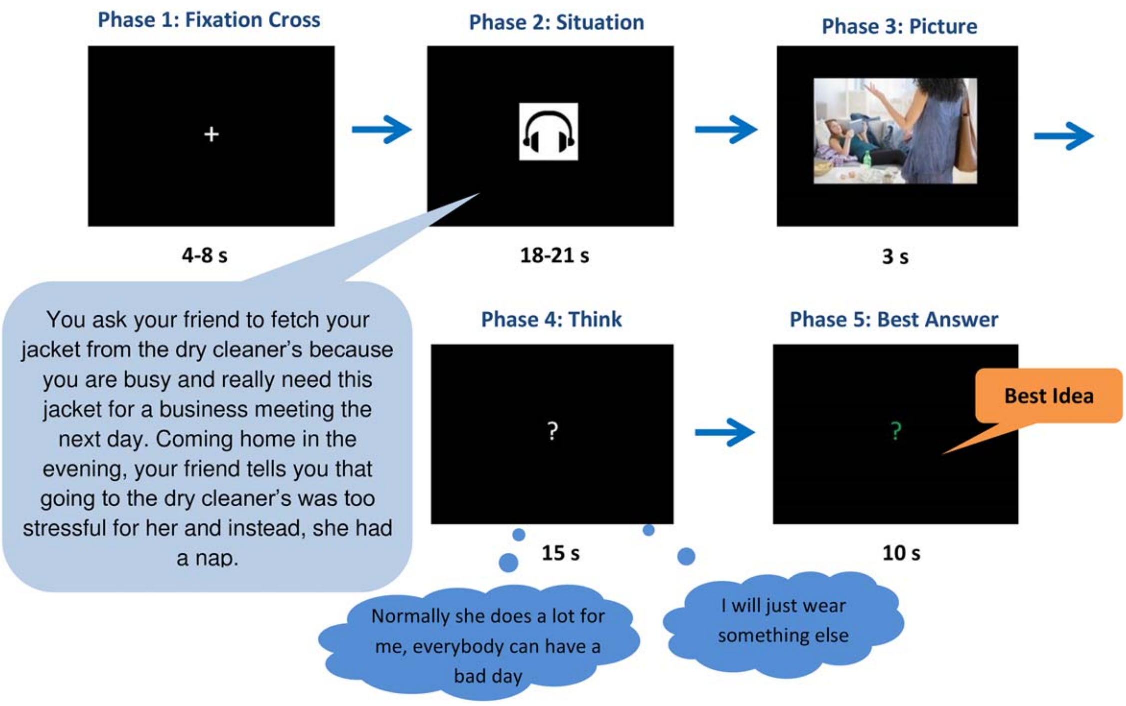

Figure 1.

Schematic sequence of an RGT item. A jittered fixation phase (4–8 s) is followed by an audio story of an anger-eliciting event (18–21 s), which is subsequently illustrated by a matching photograph (3 s). This is followed by a thinking phase (15 s), indicated by a white interrogation mark. When the interrogation mark changes its color into green, participants were requested to vocalize their best idea (10 s). [Color figure can be viewed at wileyonlinelibrary.com]

creative ideation phase. During this time, participants had to think of possible ways to reappraise the situation in a way that diminishes anger. When the allotted time of 15 s had elapsed, the interrogation mark changed its color to green and participants had to articulate their best reappraisal idea within a time period of 10 s.

As can be seen in Figure 2, the procedure for the AUT was almost identical to the RGT, with the only critical difference that participants listened to audio descriptions of emotionally neutral situations that contained various conventional everyday objects (20 s). The "target" object, for which original uses had to be generated later in the trial, was disclosed only after the acoustic stimulus presentation via the photograph, presented for 3 s. After a 15 s ideation phase, in which participants were required to think of creative uses for the depicted object, they again had 10 s to vocalize their most original idea.

Both the RGT and the AUT comprised a total of 20 situations, resulting in a task presentation time of 40 min. The items of both tasks were presented in two blocks, which were randomized across participants. Participants listened to the RGT and AUT audio stories via in-ear headphones. Implementing an acoustic item presentation in this fMRI study had several advantages over a written item format. Confounding effects of reading speed and visual processing differences due to text length or letter characteristics could be excluded and as participants could become more deeply immersed and picture the respective stories more vividly, the situations may also involve higher ecological validity. Another great advantage of this procedure is the fact that all given responses were recorded and transcribed for further analysis.

Behavioral Assessment

For scoring originality of ideas generated in the AUT during fMRI assessment, we applied an external rating procedure often used in previous creativity studies [Fink et al., 2010, 2012; Schwab et al., 2014]. Four independent raters evaluated each of the 20 ideas of a participant on a four-point rating scale, ranging from 1 ("not original at all") to 4 ("highly original). Subsequently, the ratings were averaged over all items, resulting in one originality measure per participant. The raters showed excellent inter-rater-reliability (ICC AUT-originality = 0.88). In a similar fashion, four independent raters evaluated the effectivity of the 20 reappraisal ideas generated during fMRI, in terms of how effective they deemed each reappraisal in reducing experienced anger with the respective situations.

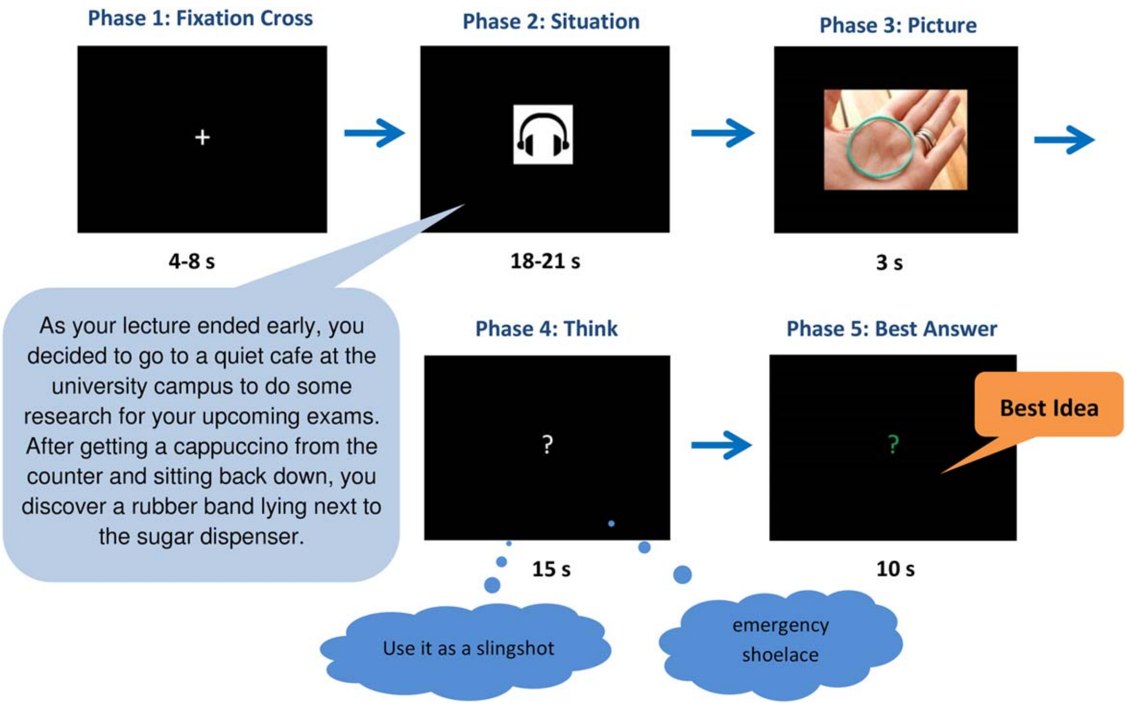

Figure 2.
Schematic sequence of an AUT item. A jittered fixation phase (4–8 s) is followed by an audio story including various objects (18–21 s), where the target object is subsequently indicated by a photograph (3 s). This is followed by a thinking phase (15 s), indicated by a white interrogation mark. When the interrogation mark changes to green, participants vocalize their best idea (10 s). [Color figure can be viewed at wileyonlinelibrary.com]

The applied scale ranged from 1 ("not effective at all") to 4 ("highly effective), inter-rater-reliability was satisfactory (ICC RGT-effectivity = 0.75).

To obtain more comprehensive measures of reappraisal inventiveness and creative ideation, we additionally administered the original Reappraisal Inventiveness Test (RIT) [Weber et al., 2014] and four items of the AUT outside the scanner. In line with the scoring procedure of the RIT [Weber et al., 2014], two scales were used for the RIT items administered outside the scanner: RIT-fluency refers to the total number of generated, nonidentical reappraisals, while RIT-flexibility refers to the number of categorically different reappraisals. As the RIT is a maximum performance test, measuring what people can do at their best when faced with upsetting scenarios, these scales are a crucial indicator of reappraisal success. Subjective anger ratings of the imagined anger-eliciting scenarios were assessed as well (7-point scale from 0 "not angry at all" to 6 "extremely angry"). The AUT items administered outside the scanner were similarly scored for ideational fluency and ideational flexibility (number of categorically different creative ideas). Ideational flexibility is rarely assessed in the context of the AUT, yet it is one of the most relevant indicators of divergent thinking ability, as it conveys pivotal information that is not contained in fluency or originality [Runco et al., 2010]. Originality was also scored for the AUT items administered outside the scanner (AUT-originality-out), which was highly correlated with AUT originality inside the scanner ($r = 0.64$, $P < 0.001$). Ideas generated for the RIT and the AUT outside the scanner were independently rated by two experimenters. For evaluating AUT-flexibility, a category scheme similar to the verbal imaginations subscales of the BIS test [Jäger et al., 1997] was used, which is a widely used and proven psychometric measure of divergent thinking ability. Inter-rater agreement was again excellent (ICC-AUT fluency = 0.98; ICC AUT-flexibility = 0.81, ICC RIT-fluency = 0.93, ICC AUT-originality = 0.82; ICC RIT-flexibility = 0.90). Descriptive statistics for all performance measures can be found in Table I.

fMRI Data Acquisition

Imaging was performed on a 3 T MRI scanner MAGNETOM Skyra (Siemens Medical Systems, Erlangen, Germany) using a 32-channel head coil. Structural images were acquired using an MPRAGE T1-weighted sequence (TR = 1,950 ms, TE = 2.89 ms, inversion time = 950 ms, flip

TABLE I. Descriptive statistics of the performance parameters of the AUT and the RGT outside the scanner and during fMRI assessment

	Min	Max	*M*	SD	α
Outside the scanner					
RIT-flu	3.00	8.80	5.10	1.28	.88
RIT-flex	1.80	6.00	3.74	0.93	.89
AUT-flu	3.00	10.00	6.26	1.54	.94
AUT-flex	2.63	6.00	4.05	0.84	.84
AUT-or	1.64	2.86	2.28	0.26	.77
fMRI assessment					
RGT-eff	1.44	2.91	2.11	0.46	.72
AUT-or	1.36	2.63	2.04	0.35	.82

Note. RIT-flu = RIT-fluency; RIT-flex = RIT-flexibility; RGT-eff = rated effectivity of RGT ideas; AUT-flu = AUT-fluency; AUT-flex = AUT-flexibility; AUT-or = AUT-originality; Min = minimum; Max = Maximum; *M* = mean value; SD = standard deviation; α = Cronbach Alpha; *N* = 45.

angle = 12°, 176 sagittal slices, FOV = 256 × 256 mm). BOLD-sensitive T2*-weighted functional images were acquired using a single-shot gradient-echo EPI pulse sequence (TR = 2,520 ms, TE = 30 ms, flip angle = 90°, slice thickness = 3.3 mm, 10% distance factor, matrix size = 66 × 66, FoV = 218 mm, 38 axial slices per volume, order descending). The first two volumes were discarded to allow for T1 equilibration effects. In addition to structural and functional images, a dual-echo gradient echo field map (TR = 403 ms, deltaTE = 2.46 ms) was recorded for distortion correction of the acquired EPI images. Head motion was restricted using firm padding that surrounded the head. To record the verbal responses of the participants, an MR-compatible microphone was used (FOMRI-III, Optoacoustics Ltd., Moshav Mazor, Israel). Stimuli were presented using the Software Presentation (Neurobehavioral Systems, Albany, CA).

fMRI Data Analysis

Functional MRI data analysis was performed using SPM 12 software (v6906; Wellcome Department of Imaging Neuroscience, London, UK), which ran in an MATLAB 2015b environment (Mathworks Inc., Natick MA). For each participant ∼875 images were obtained, with the variation being due to individually randomized jittering of fixation events. Functional images were corrected for geometric distortions by the use of the FieldMap toolbox [Hutton et al., 2002]. All fMRI data were preprocessed using Data Processing Assistant for Resting-State fMRI (DPARSF, v4.1_160415), which is part of DPABI [Yan et al., 2016]. Functional images were realigned and unwarped, slice-timed corrected, and then co-registered to the high-resolution structural image, which was segmented with the DARTEL toolbox of SPM. All functional datasets were then spatially normalized into the standard Montreal Neurological Institute (MNI) space and smoothed using a 9 mm FWHM Gaussian spatial kernel.

First-level analyses were performed by computing linear *t*-contrasts (experimental conditions vs fixation period and between experimental conditions) for the idea generation interval (15 s) for each participant individually, which were then entered into random effects one-sample *t* tests. In light of the research questions, the overlap in brain activation elicited by classic creativity and creativity in an affective context was examined by means of a conjunction analysis, by computing a repeated measures ANOVA (flexible factorial design) without the subject factor [Hervé et al., 2013]. Both input conditions were contrasted to baseline and the group conjunction was voxel-wise corrected for multiple comparisons by means of the conservative FWE (1%) procedure implemented in SPM 12. In addition, *t* contrasts between both tasks were calculated to reveal specific differences in brain activation between classic creativity and affective creativity demands. For the contrasts between RGT and AUT, a voxel-wise FWE correction of 5% was used for corrections for multiple comparisons. Only activation clusters exceeding a spatial extent threshold of 80 voxels (3 × 3 × 3 mm) are reported.

RESULTS

fMRI Results

Overall activation patterns of the experimental tasks: Conjunction analysis

To assess the general activation patterns of both tasks, a conjunction analysis was computed to identify voxels that were significantly activated in both the RGT and the AUT [Nichols et al., 2005]. Here, we used a more stringent significance level in correcting for multiple comparison (voxel-wise FWE $P < 0.01$). Brain regions both activated by the RGT and the AUT were found in the left inferior (IFG), left superior (SFG), and left middle frontal gyri (MFG), along with activation in the left precentral and postcentral gyri and supplemental motor areas (SMAs) and the anterior cingulate cortex (ACC). Additionally, both tasks yielded significant activation clusters in the right cerebellum. In Figure 3, the overlap of activation between both experimental tasks (RGT and AUT conjunction) is shown. Both the RGT and the AUT were associated with activation in a widespread, predominantly left-hemispheric prefrontal network, involving the left SFG, IFG, and MFG and SMAs. Overlapping activation of both tasks can be further seen in the right cerebellum, the precentral and postcentral gyri, and the ACC (Table II).

Differences in brain activation of classic and affective creativity

Contrasting the RGT against the AUT (RGT > AUT) resulted in five significant activation clusters, the strongest

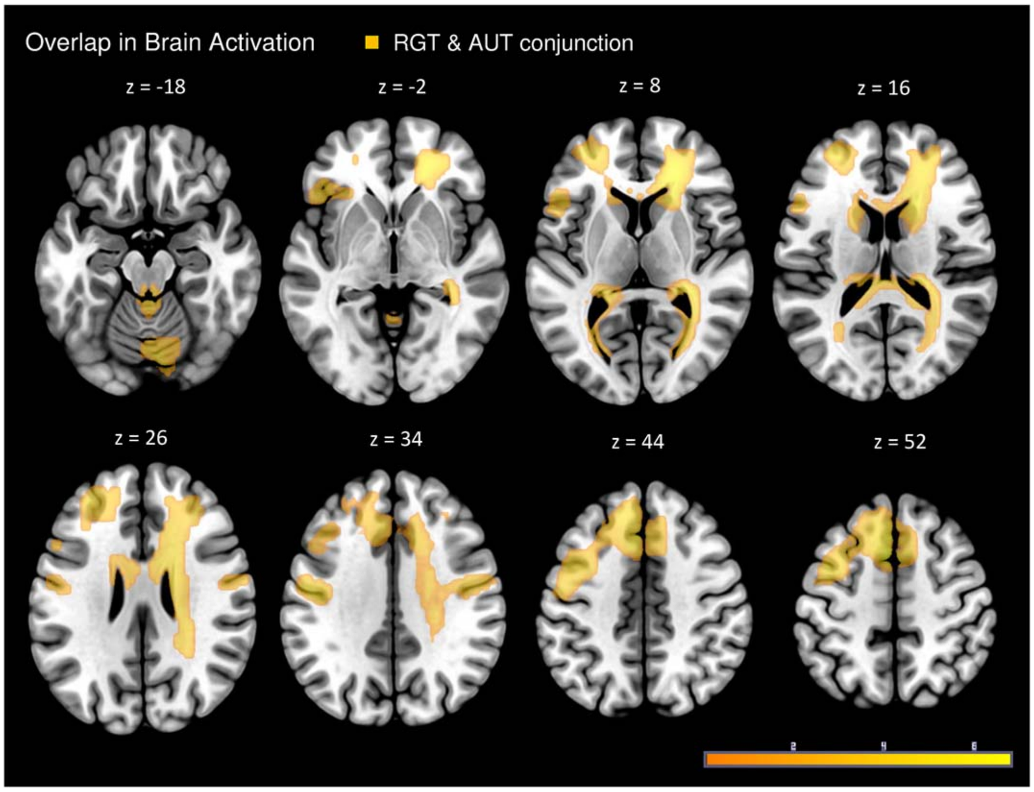

Figure 3.

Whole-brain analysis (*T* maps) of active voxels during both RGT and AUT by means of conjunction analysis (all effects at voxel-wise $P < 0.01$ FWE corrected, $k > 80$). Both the RGT and the AUT (yellow colors) are associated with a rather large rather left-lateralized frontal network including the superior, middle, and inferior frontal gyri and supplemental motor areas, pre- and postcentral gyri, and the anterior cingulate cortex. [Color figure can be viewed at wileyonlinelibrary.com]

was found in the right precuneus and in middle cingulate cortex. The remaining activation clusters comprised the right superior and middle frontal gyri, the right middle temporal gyrus (MTG), and the left and right angular gyri (AG). For the reverse contrast (AUT > RGT), four significant activation clusters were found, the strongest in the left supramarginal gyrus (SMG). Additionally, the AUT was accompanied by significantly stronger activation than the RGT in the left IFG and the left MFG and the left inferior and middle temporal gyri. Taken together, the AUT engaged a clearly left-lateralized network involving frontal and parieto-temporal regions, whereas RGT activation was more right lateralized and more pronounced in posterior brain areas (Fig. 4).

Correlations of Functionally Defined ROIs With Creativity Performance Measures

To assess the association between brain activity patterns and task performance measures, we performed correlational analyses between RGT and AUT performance measures and functionally defined regions of interest (ROIs) that were more strongly activated in the RGT than the AUT and vice versa. RGT and AUT performance was quantified during fMRI assessment (AUT-originality, RGT-effectivity) and outside the scanning environment (RIT fluency, flexibility; AUT fluency, flexibility, originality). ROI extraction was performed using the SPM 12 REX toolbox [Whitfield-Gabrieli, 2009]. For the RGT, findings revealed a significant ($P < 0.01$) positive correlation with the right superior frontal gyrus ($t = 2.90$, $P(\text{FDR}) = 0.010$; RIT-fluency: $r = 0.47$, RIT-flexibility: $r = 0.45$, RGT-effectivity: $r = 0.37$) and the right precuneus ($t = -2.29$, $P(\text{FDR}) = 0.010$; RIT-flexibility: $r = 0.32$). With respect to the AUT, we found a negative correlation with the left IFG ($t = 2.46$, $P(\text{FDR}) = 0.055$; AUT-fluency: $r = -0.36$, AUT-flexibility: $r = -0.33$, AUT-originality: $r = -0.31$), indicating that better AUT performance was associated with lower activation of the left IFG. Originality of ideas generated outside the scanner also showed a trend toward a negative relationship with left IFG activation; however, this

TABLE II. Overview of significant activation clusters for the conjunction analysis of RGT & AUT (voxelwise $P < 0.01$ FWE corrected, $k > 80$), and for the contrasts between the experimental tasks (voxelwise $P < 0.05$ FWE corrected, $k > 80$)

Location	MNI peak coordinate	k	t-max
Conjunction RGT and AUT			
L sup frontal G, L mid frontal G, L inf frontal G	−6, 9, 57	4,514	10.44
L/R SMA, L/R mid cingulate			
L precentral and postcentral G, ACC			
R cerebellum	39, −60, −30	1,312	9.94
RGT > AUT			
R mid cingulate cortex, L/R precuneus	9, −48, 33	414	7.14
R angular G	54, −57, 30	212	7.42
R mid temporal G	60, −15, −18	202	7.08
R sup frontal G, R mid frontal G	9, 48, 45	186	6.92
L angular G	−51, −60, 30	113	6.53
AUT > RGT			
L supramarginal G, L inf parietal G	−60, −27, 36	379	7.53
L inf temporal G, L mid temporal G	−51, −57, −6	172	9.12
L mid frontal G	−45, 39, 15	124	7.75
L inf frontal G	−45, 6, 27	87	6.33

Note. Coordinates are reported in MNI space as given by SPM 12 and correspond only approximately to the Talairach and Tournoux [1988] space. Anatomical labels are based on the AAL (automated anatomical labeling) atlas [Tzourio-Mazoyer et al., 2002]. Location, MNI peak coordinates, cluster size k, and maximum t value of the significantly activated clusters. The first label represents the location of the peak activation; additional labels denote further brain areas covered to at least 20% by the activation cluster. Abbreviations: L = left hemisphere; R = right hemisphere; inf = inferior; mid = middle; med = medial; G = gyrus; SMA = supplemental motor areas; ACC = anterior cingulate cortex.

correlation did not reach statistical significance (AUT-originality: $r = -0.24$, $P = 0.110$) (Figs. 5 and 6).

DISCUSSION

This study was designed to examine similarities and differences in brain activation between classic creative ideation and creative behavior in an affective context. Both types of creativity tasks yielded considerable overlap of brain activation, as evident in a widespread, left-lateralized prefrontal network comprising regions of the IFG, SFG, and MFG that was active during both the generation of alternative objects uses (AUT) and the cognitive reappraisal of anger-eliciting events (RGT).The association of prefrontal brain activity with these two different types of creativity tasks was expected, as numerous studies have emphasized the role of executive functions in creative thought [Beaty and Silvia, 2012; Benedek et al., 2014ab; Fink et al., 2009; Zabelina and Robinson, 2010]. Executive processes in creativity include cognitive flexibility, the inhibition of dominant response tendencies, and effective memory retrieval [Beaty and Silvia, 2012; Benedek et al., 2012; Gonen-Yaacovi et al., 2013], all of which have been typically observed in left lateral prefrontal regions [Badre and Wagner, 2007; Hirshorn and Thompson-Schill, 2006; Jonides and Nee, 2006; Oztekin et al., 2009]. This has been found in a plethora of creativity domains (verbal, figural, musical, artistic) and tasks (combinatorial vs unusual generation, verbal vs nonverbal), revealing flexible cognitive control as a critical facet of creative cognition [Boccia et al., 2015; Gonen-Yaacovi et al., 2013]. Similarly, fMRI studies on cognitive reappraisal have consistently observed activation in left lateral prefrontal regions [Jensen et al. 2012; Ochsner et al., 2002; Phan et al., 2005], or an attenuation of that activation in samples characterized by a marked decline in executive functions [depressed patients: Johnstone et al., 2007; older people: Opitz et al., 2012]. The prominent overlap of left prefrontal brain activation during the RGT and the AUT in our study strongly supports the notion of shared cognitive processes such as cognitive control implicated in both classic creativity and creativity in an affective context.

Findings also revealed important differences between both experimental tasks. AUT-specific activation (AUT > RGT) was found in a network of left prefrontal and left temporo-parietal regions, most prominently the left SMG, the left inferior temporal gyrus (ITG) and the left IFG. Remarkably, this activation pattern almost perfectly resembles the classic divergent thinking brain network revealed in previous creativity studies [Fink et al., 2010, 2012, 2015; Gonen-Yaacovi et al., 2013]. The left IFG, implicated in response inhibition and verbal information processing [Costafreda et al., 2006; Swick et al., 2008] is known to be a key region involved in creative ideation, as it facilitates the controlled retrieval and selection of relevant remote associations to enable the generation of novel creative ideas [Abraham et al., 2012; Benedek et al., 2014a;

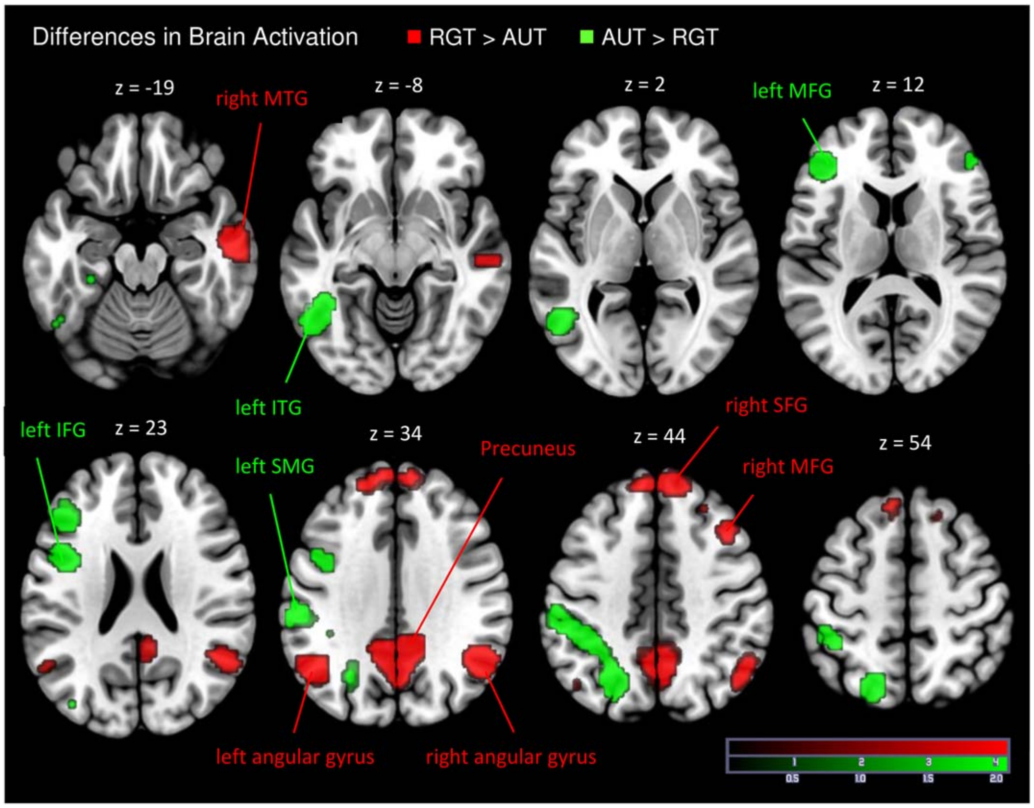

Figure 4.

Significant activation clusters in the contrasts RGT > AUT (red colors) and AUT > RGT (green colors). All effects at voxelwise $P < 0.05$ FWE corrected, $k > 80$. MTG = middle temporal gyrus; MFG = middle frontal gyrus; IFG = inferior frontal gyrus; SMG = supramarginal gyrus; SFG = superior frontal gyrus. [Color figure can be viewed at wileyonlinelibrary.com]

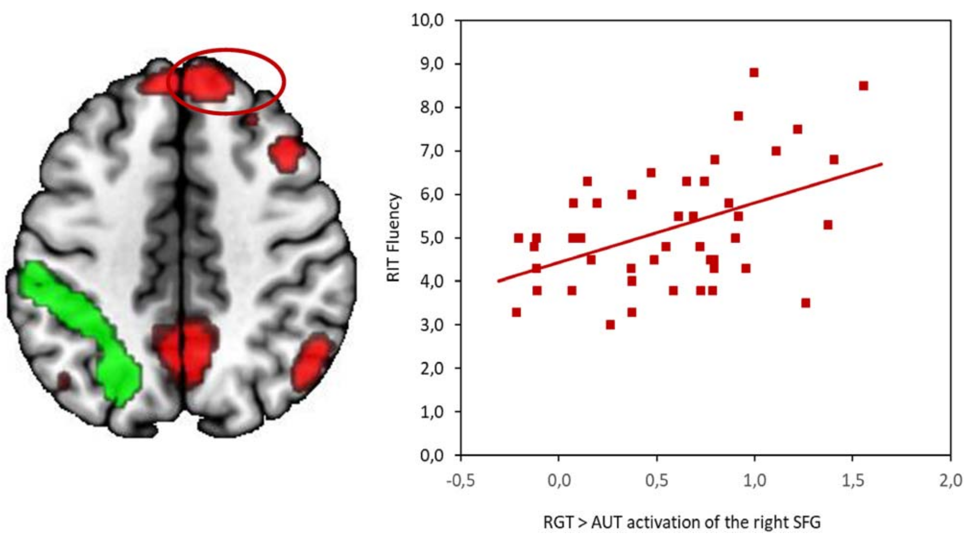

Figure 5.

Correlation between performance on the Reappraisal Inventiveness Test (RIT) and stronger activation of the right superior frontal gyrus (SFG) in the RGT > AUT contrast. Higher RIT fluency was associated with stronger activation in the right SFG. [Color figure can be viewed at wileyonlinelibrary.com]

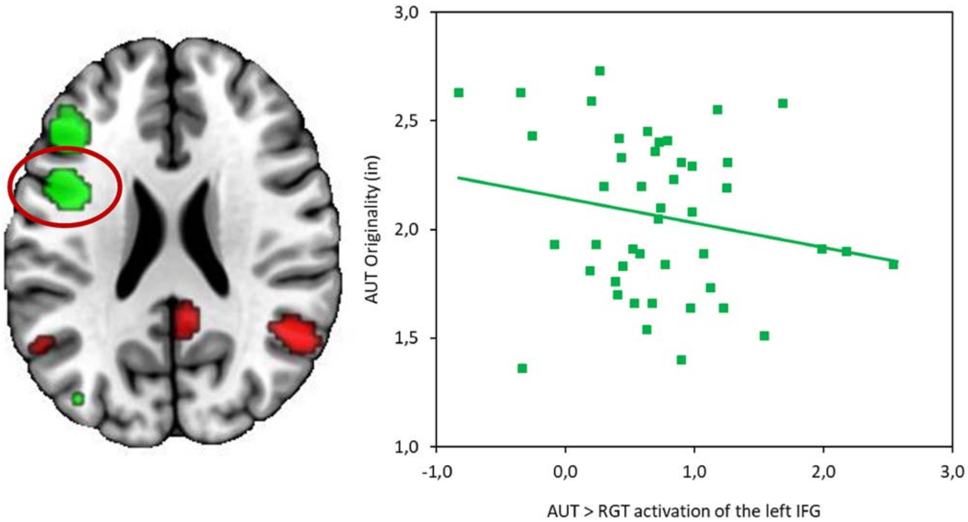

Figure 6.
Correlation between performance on the Alternate Uses Test (AUT) and stronger activation of the left inferior frontal gyrus (IFG) in the AUT > RGT contrast. Lower AUT originality was associated with stronger activation in the left IFG. [Color figure can be viewed at wileyonlinelibrary.com]

2014b; Fink et al., 2009; Gonen-Yaacovi et al., 2013]. Somewhat surprising in this study was the small but significant negative correlation between AUT performance and activation of the left IFG, suggesting that better performance in the AUT was associated with lower AUT activation relative to the RGT. This seems to indicate that higher creativity was associated with less controlled memory retrieval or lower response inhibition. In line with similar research findings [Park et al., 2015; Saggar et al., 2015], this finding may also hint at the possibility that individuals with more creative potential show higher neural efficiency (less brain activation) while solving the task. However, this finding needs replication. The left SMG on the other hand has been found to be particularly sensitive to the originality facet of creativity [Benedek et al., 2014a,b; Fink et al., 2015; Kleibeuker et al., 2013] and along with the left MTG these brain circuits constitute the core regions of the semantic system of the brain [Binder et al., 2009], which has reliably been associated with different creativity-related task demands [Gonen-Yaacovi et al., 2013]. Altogether, the fact that the identified AUT brain network is almost identical to literature does not only corroborate that the modification of the AUT in this study was successful, but also demonstrates the high reliability and replicability of brain activity patterns elicited by classic divergent thinking task demands.

Interestingly, relative to the AUT, RGT-specific activation (RGT > AUT) was found in a rather right-lateralized network, including the right SFG and MFG, the right MTG and the right precuneus, and bilateral angular gyri. Numerous studies emphasized the relevance of prefrontal regions and associated executive functions for successful reappraisal generation, implying both the left [Choi et al., 2016; Dörfel et al., 2014; Johnstone et al., 2007; Papousek et al., 2017; Price et al., 2013], and the right lateral PFC in the top–down regulation of negative affect [Falquez et al., 2014; Ochsner et al., 2004, 2012; Phan et al., 2005; Veit et al., 2012]. In our study, RGT-specific activation of the right SFG was also positively correlated with RIT performance outside the scanner (RIT-fluency, RIT-flexibility). This could point to necessary interference resolution between dominant affective responses and top–down implementation of creative reappraisal ideas [Champod and Petrides, 2007; Ochsner et al., 2004]. Kalisch [2009] further claimed that early reappraisal stages were dominated by efforts to implement a reappraisal strategy, whereas in later periods, maintenance processes prevailed. In terms of neural substrates, this corresponds to a left-to-right shift in prefrontal activity as reappraisal time progresses [Kalisch, 2009]. Considering that during fMRI, participants vocalized their best reappraisal idea only, this could have required comparatively stronger evaluations of reappraisal quality, as individuals had to judge the discrepancy between the affective response initially elicited by the situation and that after reappraising the situation. As this process of comparing one's pre- and postreappraisal affective responses includes emotional judgment and updating of affective value, this might provide an additional explanation for the observed frontal activity pattern during the RGT [Grimm et al., 2008; Ochsner et al., 2004]. This interpretation is also supported by the positive correlation of right SFG activation with the RGT-effectivity ratings. Looking at this result from the creativity domain offers another intriguing perspective. Although the right prefrontal cortex is not commonly associated with creative ideation, activation of the right IFG has been observed in creativity tasks requiring set-shifting and combination of remote elements [Goel and Vartanian, 2004; also see Boccia et al., 2015; Gonen-Yaacovi et al., 2013]. As the RGT requires a complex combination of cognitive and affective information to generate suitable reappraisals for a critical situation, it is possible that the accompanying right-lateralized PFC activation is linked to these high combinatorial demands of creativity in an affective context.

Cognitive reappraisal also frequently modulates activity in temporal regions seemingly involved in semantic memory and the representation of emotion regulation goals [Messina et al., 2015; Morawetz et al., 2016]. While the general right-lateralized activity pattern in the RGT coincides with the idea that emotional arousal, particularly in terms of negative affect, is associated with the right hemisphere [Craig, 2005], in this study, the RGT specifically activated the right MTG. Note that this region has been associated with the retrieval of emotional autobiographic memories [Levine, 2004; Piefke et al., 2003]. In this respect, the right MTG could enable a more controlled access to unpleasant past experiences to better incorporate past problem solutions into current anger reappraisals [Markowitsch et al., 2003]. In creativity research, Asari et al. [2008] found the right temporopolar region as being significantly associated with unique responses to Rorschach figures, suggesting that it might be connected to emotionally charged representations and thus, an emotional linkage to creative ideas. Moreover, recent meta-analyses on neural correlates of moral cognition [Bzdok et al., 2012; Schurz et al., 2014] found the right MTG as being implicated in empathy and theory of mind, which figure prominently in the creative process of reappraising negative social situations. Such social inferences are also closely related to the concept of self-projection (the mental simulation of alternative situations) [Buckner and Carroll, 2007] and are as such, linked to activity of the default mode network [Spreng and Grady, 2010]. Interestingly, this might explain the finding that the RGT elicited stronger activation in the AG and precuneus, both of which are usually strongly affiliated with classic creativity [Beaty et al., 2015; Jung et al., 2013]. Discussing potential task differences in terms of cognitive load, one might assume that classic creativity, due to its high internal processing demands and focus on originality of ideas, simply elicited a higher cognitive task load compared to affective creativity, which in turn was reflected in higher default-mode activity during the RGT [Beaty et al., 2016; Raichle, 2015]. This global interpretation is difficult to maintain however. While the precuneus has been identified as a crucial region of the default-mode network [Raichle, 2001], other critical default mode regions like the posterior cingulate cortex and the dorsal and ventral medial prefrontal cortex were not more strongly activated during the RGT. An alternative and perhaps more straightforward interpretation is that both the precuneus and AG also play a major role in social cognition [Cavanna and Trimble, 2006; Seghier, 2013]. Accordingly, the AG is activated by tasks involving theory of mind and inferences about human intentions [Mar, 2011; Mason and Just, 2011]. As part of the ventral attention network, however, the AG also contributes to automatic knowledge retrieval and shifting of attention [Binder et al., 2009; Corbetta et al., 2008]. The precuneus is strongly associated with mental and visuospatial imagery (for review, see Cavanna and Trimble [2006]) and various self-referential processes, encompassing empathic judgements, third person perspective taking and future simulations [Banissy et al., 2012; Dosch et al., 2010; Van Overwalle and Baetens, 2009]. Given that the precuneus is regularly activated during cognitive reappraisal [Goldin et al., 2008; Phan et al., 2005; Urry et al., 2006, Xie et al., 2016], it can be assumed that next to social reasoning, individuals also draw on mental imagery to more flexibly invent alternative perspectives for negative scenarios. This notion is supported by the observed positive correlations with RIT-flexibility. Taken together, it appears that affective creativity, compared to classic creativity, requires a more complex mental exploration of different social, emotional, and memory perspectives to be integrated into effective anger reappraisals.

This study was the first fMRI study to compare functional brain activity patterns during classic creative ideation with more real-world creative behavior in an affective context. As the findings of this study suggest, both types of tasks display strong overlap of brain activation, hinting at their shared cognitive processing demands. At the same time, they also exhibit important differences, especially in brain networks implicated in the processing of affective information. A few limitations need to be addressed in this regard. Our study took an innovative, yet deliberately exploratory approach to compare brain activation in classic and affective creativity. Despite the well-known, general activation patterns of creativity and cognitive reappraisal (as obtained in different research contexts, for respective meta-analyses, see Buhle et al. [2014] and Gonen-Yaacovi et al. [2013]), future studies would benefit from the inclusion of another control task to more precisely tackle the issue of specificity and generality of neural processes implicated in both tasks, especially regarding the prefrontal cortex. Such an approach would, for instance, allow for the assessment of the extent to which the stronger activation in the RGT than the AUT simply stems from processes that are more specific to general affective processing or alternatively, whether this activation pattern indeed reflects creative ideation in an emotional context. Until then, all interpretations of greater RGT than AUT activation in the context of creativity in an affective context should be regarded with caution. Additionally, further investigations are warranted using a full reappraisal inventiveness paradigm [Fink et al., 2017a; Weber et al., 2014] in the scanner. Having participants generate as many alternative and effective cognitive reappraisals as possible within a given amount of time might even more strongly accentuate activation differences between affective and classic creativity, when both tasks demand high fluency and high quality of generated ideas. Notwithstanding these limitations, this study represents an important step toward extending creativity research on more real-world creative behavior, and moreover, by specifically putting creativity into an affective context, it reveals that cognition and emotion interact in a closely intertwined manner.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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