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# Can clouds dance? Neural correlates of passive conceptual expansion using a metaphor processing task: Implications for creative cognition

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ABSTRACT

Creativity has emerged in the focus of neurocognitive research in the past decade. However, a heterogeneous pattern of brain areas has been implicated as underpinning the neural correlates of creativity. One explanation for these divergent findings lies in the fact that creativity is not usually investigated in terms of its many underlying cognitive processes. The present fMRI study focuses on the neural correlates of conceptual expansion, a central component of all creative processes. The study aims to avoid pitfalls of previous fMRI studies on creativity by employing a novel paradigm. Participants were presented with phrases and made judgments regarding both the unusualness and the appropriateness of the stimuli, corresponding to the two defining criteria of creativity. According to their respective evaluation, three subject-determined experimental conditions were obtained. Phrases judged as both unusual and appropriate were classified as indicating conceptual expansion in participants. The findings reveal the involvement of frontal and temporal regions when engaging in passive conceptual expansion as opposed to the information processing of mere unusualness (novelty) or appropriateness (relevance). Taking this new experimental approach to uncover specific processes involved in creative cognition revealed that frontal and temporal regions known to be involved in semantic cognition and relational reasoning play a role in passive conceptual expansion. Adopting a different vantage point on the investigation of creativity would allow for critical advances in future research on this topic.



## 1. Introduction

Creativity is one of the most complex cognitive abilities in human adaptive behaviour. Despite many discrepancies between experts on what makes an idea or product creative and the more naïve concept of creativity prevalent in the general population, a widely accepted working definition of creativity has emerged among researchers (e.g., Amabile, 1990; Boden, 2003; Dietrich, 2004; Finke, Ward, & Smith, 1992; Hennessey & Amabile, 2010; Runco, 2004; Sternberg & Lubart, 1999; Ward, Smith, & Finke, 1999). According to this definition, an idea, concept, or solution needs to meet two important requirements to be classified as creative. The first requirement refers to the originality or uniqueness of the concept, the second one concerns its appropriateness or relevance. An outcome has to be both novel and fitting for the task at hand to be considered creative (e.g., Ward, 2007). Creative processes are thought to involve different stages, each of which requires the recruitment of many cognitive processes to solve any given task (Ward, 2007; Ward et al., 1999). However, their investigation, especially in the light of possibilities given through the rapid rise of neuroimaging techniques, has not advanced very far. Many reasons account for this impasse in creativity research.

First of all, most creativity tasks require verbal responses from participants, or heavily rely on their self-reports, as is the case for the insight tasks where participants have to report whether or not they found the solution by insight (Aziz-Zadeh, Kaplan, & Iacoboni, 2009; Jung-Beeman et al., 2004). Using functional magnetic resonance imaging (fMRI) as a mode of examination makes it difficult to record participants' verbal responses during scanning due to the susceptibility to movement artefacts. Most studies avoid this pitfall by logging participants' verbal accounts after completion of the scanning session (Howard-Jones, Blakemore, Samuel, Summers, & Claxton, 2005). This method, however, is associated with uncontrollable biases in participants' recall or the forgetting of earlier ideas (Healy, Havas, & Parkar, 2000; Wixted, 2004), which can lead one to question the reliability of the findings. Additionally, several neuroimaging designs have long trial durations (e.g., 20 s in Chavez-Eakle, Graff-Guerrero, Garcia-Reyna, Vaugier, & Cruz-Fuentes, 2007), or the processes in question are not time-locked

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to a defined stimulus or response (e.g., Fink et al., 2009), thereby making it harder to relate brain activations to the actual time point at which a creative process occurred. Furthermore, the conditions with which the creative tasks are contrasted often differ not only with regard to the creative processes involved, but, in various other aspects as well, such as task difficulty or task requirements (e.g., Bechtereva, Korotkov, Pakhomov, Roudas, & Starchenko, 2004; Bechtereva et al., 2000; Howard-Jones et al., 2005). For instance, Bechtereva and colleagues (2000) had participants create stories from semantically distant words and contrasted them with a word remembering task as a control condition. Not only do the two tasks differ in difficulty, as it is harder to create stories from unrelated words, the modes of the tasks themselves are not comparable as the mere remembering of words recruits a whole host of different processes when compared to the active generation of a novel story. Such circumstances render it challenging to interpret findings as creativity-specific.

Most importantly, however, the investigation of creativity has conceptualized creativity not as a complex construct involving a multitude of cognitive processes, but has rather treated it as a singular entity (for criticism of this view, see Dietrich, 2004; Dietrich & Kanso, 2010). Apart from the cognitive process of insight which is defined by the sudden experience of the right solution during problem solving (e.g., Aziz-Zadeh et al., 2009; Jung-Beeman et al., 2004), no other specific creative operation has been the target of concerted neuroscientific investigation. The common approach to the investigation of creativity is to employ divergent thinking tasks which require the production of multiple solutions for a problem. The specific cognitive processes recruited by these tasks, however, are impossible to determine because of the many differences between tasks and designs. The result is a number of very heterogeneous findings that attempt to pin down the neural correlates of creativity as a whole without specifying the distinct processes involved in any given task. The various brain regions identified across these studies span almost the entire prefrontal cortex with only little overlap between studies (e.g., Bechtereva et al., 2004; Chavez-Eakle et al., 2007; Fink et al., 2009; Howard-Jones et al., 2005; for a detailed review, see Dietrich & Kanso, 2010).

One possibility to avoid many of the drawbacks of previous neuroimaging studies would be to target specific operations of creativity individually. Conceptual expansion is, hereby, of particular interest for the investigation of creative cognition. It describes the extension of existing concepts to include new features and attributes, thereby widening its original definition (Abraham & Windmann, 2007; Abraham, Windmann, Daum, & Gunturkun, 2005; Abraham, Windmann, Siefen, Daum, & Gunturkun, 2006; Ward, Patterson, Sifonis, Dodds, & Saunders, 2002), and thus plays a crucial role in generating new ideas. As the behavioral tasks to assess conceptual expansion involve drawing and have no time constraints (e.g., Ward, 1994), they are not suitable for fMRI designs. An indirect approach would therefore be better suited to examine this process in an fMRI setting. The domain of metaphor processing offers an ideal opportunity for such a venture (e.g., Hillert & Buracas, 2009; Mashal, Faust, Hendler, & Jung-Beeman, 2007, 2009; Rapp, Leube, Erb, Grodd, & Kircher, 2004; Stringaris, Medford, Giampietro, Brammer, & David, 2007). Paradigms that assess novel metaphor processing where different and often semantically distant domains have to be integrated mentally in order to derive meaning are particularly relevant as they can be modified to investigate conceptual expansion in creative cognition. For instance, Mashal and colleagues (2007) used novel metaphoric, conventional metaphoric, literal and unrelated word pairs and asked participants to indicate the nature of relatedness for each pair. The authors were able to show stronger activation in the anterior inferior frontal gyrus (IFG; Brodmann's areas (BAs) 44/45) for novel compared to conventional metaphors, as well as activation in frontopolar areas (BA 10) when contrasting metaphors and literal phrases with senseless phrases. Although these studies can partially contribute to shed light on the neural correlates of creative cognition, there are several factors that limit such generalizations. For instance, previous studies either fall short of ensuring the novelty and appropriateness of the material used or only control one of these features necessary to match the definition of creativity (e.g., Rapp et al., 2004; Stringaris et al., 2007). This criticism does not invalidate the conclusion of the cited studies as in neither case the main goal was to investigate creativity *per se*. Mashal and colleagues (2007), however, did claim in their study that findings associated with novel metaphoric expressions were relevant for understanding creative operations. Their stimulus material, though, was pre-categorized by the experimenter as being novel and appropriate. Considering the high inter-individual variability of the organization of semantic networks, a semantic connection that might be deemed as creative (i.e., both novel and appropriate) by one subject, might not be classified as such by another subject. To warrant the conclusions regarding creative thought, it would be important to optimize the experimental design in a manner that accounts for this inter-individual variability.

The present study introduces a new paradigm to investigate conceptual expansion in creative cognition that is suitable to avoid common problems associated with neuroimaging studies of creativity. The study's aim is to investigate singular processes that are involved when engaging in creative thinking. The experimental approach adopted in this new paradigm is based on the assumption that conceptual expansion can be achieved not only through an active cognitive effort to broaden a concept, but can also be induced passively through the perception and the resulting integration of two semantically distant concepts. The difference between active and passive conceptual expansion would be expected to lie in the volitional or self-driven aspect of expanding concepts. It cannot be assumed that the cognitive processes involved when generating something novel and those involved when understanding something novel are exactly the same. However, a substantial overlap between processes involved in the active and the passive task can be expected due to the fact that the conceptual structures that are being expanded are the very same. Expanding existing concepts would therefore engage similar structures related to semantic cognition regardless of the manner in which the expansion was evoked. Engaging in active conceptual expansion would likely result in greater activation of theses areas and incorporate areas not involved during the passive task, such as structures associated with inhibitory control processes or imagery-related operations. Nonetheless, because passive conceptual expansion partially draws on the same neural structures, it allows one to investigate select aspects of creative thinking while avoiding common problems of fMRI investigations of creativity.

Conceptual expansion will be passively induced in the present study by having participants read three different types of phrases derived from the variation of creativity's two main features, namely novelty (or unusualness) and appropriateness (or relevance). By having subjects process stimuli that are either highly unusual and highly appropriate (HUHA: conceptual expansion), highly unusual but low appropriate (HULA: unusual/novel), or low unusual but highly appropriate (LUHA: common/appropriate), the study aims to take a more specific look on the neural correlates of conceptual expansion, novelty and appropriateness. Conceptual expansion is held to be achieved through phrases represented in the HUHA category given that in this case two formerly unrelated or weakly related concepts are directly linked together in an appropriate but novel manner for the first time. This requires the boundaries of both concepts to be expanded beyond their established limits. By basing the condition-specific categorization of the stimuli phrases entirely on participants' dichotomous ratings of the phrases on the response dimensions of unusualness and appropriateness, inter-individual differences in the organization of their conceptual networks are also accounted for within the experimental design. This approach therefore allows for the nonverbal and time-specific investigation of a creative process determined on a subject-by-subject basis while, at the same time, providing appropriate conditions for comparisons.

It is hypothesized that conceptual expansion (HUHA) will involve areas in the anterior IFG (BA 45 and BA 47) because this area has been linked to semantic retrieval and the resolution of semantic uncertainties (e.g., Badre, Poldrack, Pare-Blagoev, Insler, & Wagner, 2005; Poldrack et al., 1999; Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997). Additionally, conceptual expansion is expected to lead to activation in the frontopolar region (BA 10) due to greater demands on relational information integration for this condition compared to the other two. The frontopolar region has been shown to be especially involved in the integration of self-generated or inferred information and multiple relations (e.g., Bunge, Wendelken, Badre, & Wagner, 2005; Christoff et al., 2001; Green, Fugelsang, Kraemer, Shamosh, & Dunbar, 2006; Green, Kraemer, Fugelsang, Gray, & Dunbar, 2010; Kroger et al., 2002). Conceptual expansion is also expected to lead to activation in the temporal lobe in the middle and inferior temporal gyri (especially, BA 20 and 21), as well as the temporal pole (BA 38), areas known to be involved in semantic processing and storage (e.g., Binder, Desai, Graves, & Conant, 2009; Lambon Ralph, Cipolotti, Manes, & Patterson, 2010; Lambon Ralph, Pobric, & Jefferies, 2009; Patterson, Nestor, & Rogers, 2007).

While the investigation of appropriateness will be explorative in the current study, novelty processing is also expected to lead to greater demands on semantic retrieval and semantic selection which should result in activation in the anterior IFG (BA 45 and BA 47) and activation of temporal areas (BA 20, 21 and 38).

## 2. Materials and methods

### 2.1. Participants

The original sample included 27 healthy, right-handed students of the University of Giessen that participated in the fMRI study in exchange for course credit or monetary compensation (€ 17.50). All participants were native German speakers. A total of nine participants had to be excluded from data analyses due to excessive movement during scanning ($n = 2$), insufficient number of HUHA judgements ($n = 3$), and too many wrong answers in the control condition ($n = 4$), thereby possibly defeating the purpose of the control condition, namely to control effects of difficulty. All reported analyses and results are based on the final sample of 18 participants (9 females). Mean age was 22.78 years ($SD = 3.26$). The experimental standards of the study were approved by the Ethics Commission of the German Psychological Society (DGPs).

### 2.2. Materials

Fifty-four experimenter-determined stimuli sentence triplets were initially created. Each sentence consisted of subject, verb and object in present perfect tense (for examples, see Table 1). Three different verbs were chosen for each triplet that r rendered the sentence to be either literal (corresponding to LUHA), senseless (corresponding to HULA) or metaphorical (corresponding to HUHA). It is important to note that a combination where both unusualness and appropriateness are judged as low (LULA) is not possible as the two defining characteristics of creativity, unusualness and appropriateness, are not independent from each other. Something that is judged to be usual or common is by definition appropriate at the same time. Low unusualness or low novelty entails that the object, idea or, in this case, combination of semantic instances is known or has been encountered before and is therefore immediately appropriate as well. An association that is inappropriate or irrelevant would not be established in everyday life to also be common or usual. Behavioral pilot studies were conducted to arrive at the final set of 132 stimuli used in the fMRI study. Inclusion criteria for the metaphorical sentences were determined as follows: More than 60% of participants in the pilot study had to judge the phrase as highly unusual and highly appropriate. Additionally, at least 60% of participants had to agree on the unfamiliarity of the phrase.

**Table 1**
Examples for stimuli phrases. Example phrases for the three experimental conditions. Critical word is printed in bold.

| Condition | Sentence |
|---|---|
| Highly unusual – highly appropriate (HUHA) | The clouds have **danced** over the city. |
| Highly unusual – low appropriate (HULA) | The clouds have **read** over the city. |
| Lowly unusual – highly appropriate (LUHA) | The clouds have **moved** over the city. |

A one-way ANOVA showed that the three experimental conditions differed significantly ($p = .047$) from each other in regard of word length of the verb. Bonferroni-corrected post-hoc tests did reveal, however, that this effect was primarily carried by marginally significant differences in verb word length between the senseless and the literal verbs ($m = 8.45$ and $m = 9.39$, respectively, $p = .051$). Additionally, the verbs were checked for their frequency of occurrence in the German language. Using an online tool (http://wortschatz.uni-leipzig.de/), frequency of occurrence for each verb was computed. A median test comparing the three conditions showed that the conditions did not differ significantly regarding the frequency of occurrence of the verb.

In order to ensure that possible differences in activation between the conditions are not merely an effect of varying reaction times (RTs) associated with the answers given to the conditions (as was indicated by the behavioral pilot studies) a control condition was included in the experiment. To keep the control condition as similar as possible to the experimental conditions and only increase difficulty of the task, control sentences consisted of phrases written backwards. Participants' task was to decide whether or not the phrases contained an animal and whether or not they contained a spelling error. Another pretest confirmed that the control condition was at least as difficult as the most difficult experimental condition as could be seen in reaction times. Forty-four control phrases were included in the experiment, containing either an animal and a spelling error, an animal and no spelling error, no animal and a spelling error, or neither an animal nor a spelling error.

### 2.3. Experimental procedure

After giving their written consent to participate in the study and following some practice trials outside the scanner, participants completed the experimental task during fMRI. Participants were placed on the scanner bed in a supine position. Each trial began with a jittered blank screen (0–1500 ms), then the presentation of a fixation cross for 300 ms, followed by a 200 ms blank screen. Subsequently, a stimulus phrase was presented for 3000 ms, followed by the questions “Unusual?” and “Appropriate?” for 1500 ms, respectively, separated by a 500 ms blank screen. Participants pressed a “yes” or a “no” button on a response box with their right index or middle finger, respectively, to indicate their judgements. Participants were instructed that they should respond

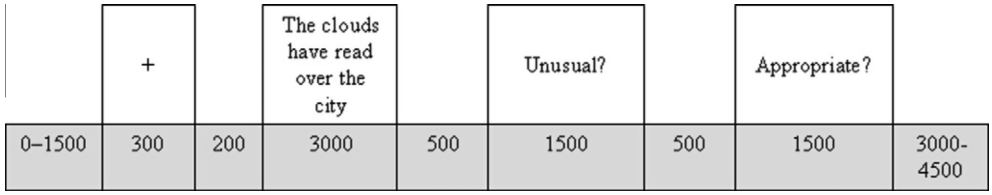


**Fig. 1.** Experimental trial. Example of the experimental trial timeline. Durations are displayed in the bottom line in milliseconds.

"yes" to the Unusual-question if the presented information was novel or unfamiliar and "no" if it was known or familiar. They were also instructed that they should respond "yes" to the Appropriateness-question if the presented information was fitting or relevant and "no" if it was unfitting or irrelevant. Following the last question, another jittered blank screen was presented (3000–4500 ms), resulting in a total trial time of 12 s (see Fig. 1). The experiment included 17 null trials consisting in the presentation of a blank screen for the length of a regular trial.

The stimuli phrases were presented in a pseudo-randomized order and projected onto a screen at the end of the scanner (visual field = 18°) using an LCD projector (EPSON EMP-7250) and were viewed through a mirror mounted on the head coil. Upon completion of the scanning session, participants rated each stimulus phrase in regard to whether or not they had already known the phrase prior to reading it in the experiment on a 5-point Likert scale.[1] Additionally, participants were asked to complete the vocabulary scale of the Hamburg Wechsler Intelligence Test for Adults (HAWIE, Tewes, 1994).[2] The HAWIE vocabulary scale is assessed by reading 32 words with increasing difficulty to the participants and asking them to give a brief definition of each word. The resulting number of correctly defined words is transformed into a standardized value, while taking the participants' age into consideration.

### 2.4. Data acquisition

Functional and anatomical scans were obtained using a 1.5 T whole-body tomography system (Siemens Symphony) with a standard head coil. Structural image acquisition consisted of 160 T1-weighted sagittal images (MPRage, 1 mm slice thickness). A gradient echo field map sequence was acquired before the functional image acquisition to obtain information for unwarping $B_0$ distortions. For functional imaging, one run with a total of 950 volumes was recorded using a T2*-weighted gradient echo-planar imaging sequence (EPI) with 25 slices covering the whole brain (slice thickness = 5 mm; gap = 1 mm; descending slice order; TA = 100 ms; TE = 55 ms; TR = 2.5 s; flip angle = 90°; field of view = 192 mm × 192 mm; matrix size = 64 × 64). The orientation of the axial slices was tilted to parallel the OFC tissue–bone transition to keep susceptibility artefacts to a minimum.

### 2.5. Data analysis

For each participant, stimulus phrases were grouped into the three experimental conditions based on the participant's responses. This resulted in a differing number of phrases per condition for each subject. To avoid underrepresentation of any one experimental condition, subjects with a disproportionate distribution of stimulus phrases between the three experimental conditions were excluded from data analysis. Cut-off criterion for exclusion of participants was determined at less than 28 instances in any one condition.

Functional data processing and analyses were done using SPM8 package (Wellcome Department of Cognitive Neurology, London, UK; see http://www.fil.ion.ucl.ac.uk/spm). Preprocessing routines included realignment, slice timing, normalization, and smoothing procedures. Each subject's functional images were corrected for motion and unwarped using the first volume as a reference, as well as a voxel displacement map (vdm5), constructed using the fieldmap toolbox of SPM8. Realigned and unwarped images were corrected for time differences in acquisition. T1 anatomical images were coregistered to the mean functional image. Functional images were then normalized with a voxel size of 3 mm to the anatomical image and spatially smoothed using a 9 mm full-width, half-maximum (FWHM) Gaussian filter.

First and second level analyses were computed using a general linear model approach (Friston et al., 1994). For each subject, three experimental conditions, the control condition and the null trials were modelled as regressors and convolved with the standard hemodynamic response function combined with time and dispersion derivatives. Regressor onsets were equal to stimulus onsets and were modelled in an epoch-related design with an epoch duration of 7 s (from the stimulus phrase onset till the end of presentation time for the second question). Additionally, the six movement parameters obtained by the realignment procedure were included into the model to account for possible residual movement artefacts after realignment and a high-pass filter of 1/150 s was employed. One-sample *t*-tests were computed to obtain the relevant contrast images for each single subject. The contrast images were entered into group statistics analyses.

Conjunction analyses were carried out to uncover which brain regions are commonly activated across contrasts as a function of a particular process of interest. Conjunction analyses allow for the investigation of activation that is conjointly present in two contrasts. Contrasts of interest obtained on first level were entered into paired *t*-tests on second level using the conjunction null hypothesis (Nichols, Brett, Andersson, Wager, & Poline, 2005). Tests using the conjunction null hypothesis are more conservative in that they test for an AND conjunction that only dismisses the null hypothesis if all subjects show activation in the tested voxel in both contrasts. Using conjunction analyses allows for the investigation of activation that is specific to conceptual expansion separated as opposed to activations caused solely by novelty or appropriateness. In order to investigate activity related to the novelty of the stimulus phrase, a conjunction analysis of the contrasts that compared the two highly unusual conditions to the low unusual condition, respectively, (Novelty = **HU**HA > LUHA

[1] In an initial analysis, only HUHA phrases with a familiarity rating of less than 4 were included for each participant. This, however, resulted in a drastic cut in the number of phrases judged as unusual and appropriate. When taking into consideration that these types of phrases had been selected based on a strict cut-off criterion for familiarity in the behavioural pilot studies, the suspicion arose that participants' familiarity judgments might be biased by the recent encounter of the very same phrases in the experiment. To test this assumption, a group of participants that had not taken part in any of the pilot studies or the main study ($n = 20$) filled out the familiarity ratings independent from the main study. Results from an independent t-test confirmed the existence of a memory bias that was likely to have been caused by the prior presentation of the stimuli. Participants that saw the stimuli prior to the familiarity rating evaluated them as more familiar than participants that did not see the stimuli prior to the rating ($m = 2.60$ and $m = 2.35$, respectively; $t(86) = -2.31$, $p = .024$). Therefore, the familiarity ratings were dismissed in the analyses of the main study due to unreliability.

[2] Analyses that included HAWIE values as a covariate did not lead to differing results and are therefore not reported.

**Table 2**
Reaction times. Mean reaction times in milliseconds across the four conditions for each question. Standard deviations are given in brackets.

| Condition | Question | |
|---|---|---|
| | Unusual | Appropriate |
| HUHA | 701.6 (208.3) | 605.0 (200.3) |
| HULA | 692.1 (172.6) | 593.3 (140.8) |
| LUHA | 677.8 (175.7) | 539.3 (151.0) |
| Control | 801.0 (115.3) | 533.9 (151.1) |

∩ **HU**LA > LUHA) was computed. For activity specific to the appropriateness dimension of the stimulus phrases, we looked at the conjunction of contrasts comparing the two highly appropriate conditions with the low appropriate condition, respectively (Appropriateness = HU**HA** > HULA ∩ LU**HA** > HULA). Finally, specific activation caused by conceptual expansion was assessed through a conjunction analysis involving the contrasts between the highly unusual and highly appropriate phrases and the remaining two experimental conditions, respectively (conceptual expansion = **HUHA** > HULA ∩ **HUHA** > LUHA).

Based on the a priori expectations, five Regions-of-Interest (ROI) were designed using the WFU Pick Atlas toolbox available for SPM8 (Maldjian, Laurienti, & Burdette, 2004; Maldjian, Laurienti, Kraft, & Burdette, 2003). ROIs were created for Brodmann's areas 10, 45, 47, 21, 22 and 38.[3] Unless specified otherwise, all reported data have been FWE – corrected for multiple comparisons at $p < .05$. As the cognitive effects under investigation in the present study are complex, clusters consisting of three or more voxels (minimum cluster size: 81 cubic mm) are reported in order to reduce the risk of type II errors (Lieberman & Cunningham, 2009).

## 3. Results

### 3.1. Behavioral data

Table 2 shows means and standard deviations for the four conditions for each question. A repeated measures 4 × 2 ANOVA with factors condition (HUHA, HULA, LUHA, control) and question type (unusual, appropriate) was conducted to determine possible differences in RTs. The analysis showed significant main effects of condition ($F(3,51) = 3{,}47$, $p = .023$) and question type ($F(1,17) = 137{,}47$, $p < .001$), as well as a significant interaction between condition and question type ($F(3,51) = 15.01$, $p < .001$). Further analyses showed that RTs for the "unusual/animal" question were slower than for the "appropriate/error" question ($m = 718.1$ ms and $m = 567.9$ ms for unusual/animal and appropriate/error, respectively; $p = <.001$). Reaction times were also significantly longer for the control condition compared to every experimental condition for the "unusual/animal" question only ($p = .038$, $p = .01$, and $p = .001$ for control vs. HUHA, HULA, and LUHA, respectively; see Table 2 for corresponding means). For the "appropriate/error" question, HUHA showed a slightly longer RT compared to the control condition ($p = .025$). As no behavioral differences were found between the three experimental conditions, the control condition will not be discussed further.

**Table 3**
Overview of brain activations. Activation peaks for the different conjunction analyses. Peak coordinates of each cluster are given in standard MNI space. Structure, Brodmann's area (BA), Hemisphere (Hem), cluster size and peak $t$-value ($t$) are presented, as well. Significance threshold for the analyses is $p < .05$ (FWE-corrected) and extent threshold is $k \geqslant 3$ (minimum cluster size: 81 cubic mm). Asterisk marks significance threshold of $p < .001$ (uncorrected). ROIs: bilateral Brodmann's areas 10, 20, 21, 45, 47 and 38; IFG: inferior frontal gyrus; MFG: middle frontal gyrus; MTG: middle temporal gyrus; STG: superior temporal gyrus.

| Area | BA | Hem | Cluster size | MNI peak coordinate | | | t |
|---|---|---|---|---|---|---|---|
| | | | | x | y | z | |
| *Conceptual expansion (HUHA > HULA ∩ HUHA > LUHA)* | | | | | | | |
| IFG | 45 | L | 16 | −48 | 17 | 4 | 5.12 |
| IFG | 45 | R | 5 | 60 | 17 | 4 | 4.80 |
| IFG | 47 | L | 9 | −42 | 20 | 1 | 5.05 |
| IFG/MFG | 47/11 | L | 44 | −36 | 29 | −8 | 8.14 |
| MFG | 10 | L | 3 | −33 | 50 | 13 | 4.67* |
| MFG | 10 | L | 4 | −30 | 53 | 19 | 3.77* |
| STG | 38 | L | 5 | −48 | 20 | −14 | 4.91 |
| *Appropriateness (HUHA > HULA ∩ LUHA > HULA)* | | | | | | | |
| MTG | 21 | L | 6 | −63 | −22 | −14 | 6.22 |
| *Novelty (HUHA > LUHA ∩ HULA > LUHA)* | | | | | | | |
| IFG | 45 | R | 4 | 54 | 29 | 7 | 3.94* |

### 3.2. Neuroimaging data

Table 3 shows the regions of significant activation for all three conjunction analyses in the ROIs BA 10, 20, 21, 38, 45 and 47. For the conjunction analysis aimed at revealing activation associated with conceptual expansion (**HUHA** > HULA ∩ **HUHA** > LUHA) it was hypothesized that there would be significant activation in the anterior IFG (BA 45 and 47), the middle temporal gyrus (BA 20 and 21), as well as the frontopolar cortex (BA 10). The findings partially confirm the hypotheses as a significant increase in BOLD signal was found in the left IFG (BA 45 and BA 47) for HUHA compared to HULA and LUHA: Additionally, there was significant activation in the right IFG (BA 45) and the left temporal pole (BA 38). Activations were also found in the left middle frontal and superior frontal gyri corresponding to the frontopolar cortex (BA 10), albeit only uncorrected at a threshold of $p < .001$.

It was expected that the processing of novel or unusual information would lead to activations in the anterior IFG (BA 45 and 47) as well as the middle temporal gyrus and temporal pole (BA 20, 21 and 38). These hypotheses were only partially confirmed as the conjunction analysis which assessed activations associated with novelty processing (**HU**HA > LUHA ∩ **HU**LA > LUHA) only showed activation in the right inferior frontal gyrus (BA 45), also at an uncorrected threshold of $p < .001$.

Finally, an explorative conjunction analysis was carried out to uncover which brain areas are associated with the processing of appropriateness (HU**HA** > HULA ∩ LU**HA** > HULA). The findings revealed the significant involvement of the left middle temporal gyrus (BA 21) (see Fig. 2).

## 4. Discussion

This study employs a new approach to investigate creative cognition by breaking down the concept of creativity into single processes and focusing on one cognitive operation playing a central role in creative cognition, namely conceptual expansion. Here, passively inducing conceptual expansion in participants and letting them determine the nature of the respective stimulus phrase rendered it

[3] We also conducted whole-brain voxel-wise analyses. Alongside other areas of activation, the whole-brain analyses revealed greater activation in bilateral IFG (BA 45 and BA 47) and left MTG (BA 22) for conceptual expansion, in bilateral SFG and MFG (BA 10/11) and left MTG (BA 21) for appropriateness, as well as in right IFG (BA 45) for novelty. Due to a priori hypotheses about the involvement of these areas and overlapping findings for whole-brain and ROI analyses, only the ROI results are reported. Tables with whole-brain results and a color-coded map depicting overlap between conceptual expansion and novelty in the prefrontal cortex can be found in Supplementary material. Additional contrasts were computed using the control condition as an inclusive mask. Given that masking the contrasts did not change the results and the fact that RTs as an indicator of task difficulty did not differ significantly between experimental conditions, all analyses reported in the paper disregard the control condition. Results of the direct contrast between the HUHA condition compared to the control condition are included in Supplementary material.

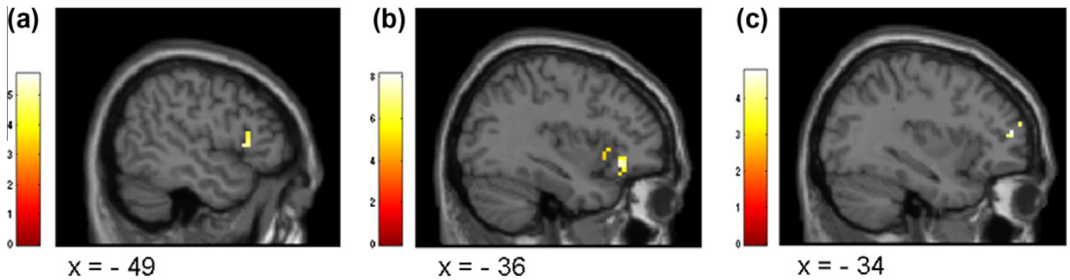


**Fig. 2.** Activations as a function of conceptual expansion. Conceptual expansion: activations as a function of conceptual expansion in the Regions-of-Interest: (a) left mid-inferior frontal gyrus (IFG: BA 45), (b) left anterior IFG (BA 47) and (c) left frontopolar cortex (BA10). Color bars represent Z-value at an FWE-corrected $p < .05$ for BA 45 and BA 47, at an uncorrected $p < .001$ for BA 10.

possible to obtain a clearer picture on the brain activations that are associated with conceptual expansion, novelty and appropriateness.

### 4.1. Conceptual expansion

The results confirm the hypotheses concerning the aspects of information processing involved in conceptual expansion. As expected, we were able to show bilateral anterior IFG (BA 45/47) involvement in the processing of conceptual expansion. The findings reveal several clusters especially within the left lateral anterior IFG for phrases judged as unusual and appropriate (HUHA). Activations in these areas, albeit to a smaller extent, were also found in analogous regions in the right hemisphere. Recent studies have linked this region to an increased effort to retrieve semantic information and greater semantic selection demands (Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997; Wagner, Pare-Blagoev, Clark, & Poldrack, 2001; Wig, Miller, Kingstone, & Kelley, 2004) as well as increasing semantic distance (Green et al., 2010). In the present study, these regions were more strongly recruited during conceptual expansion, i.e. when a phrase was judged by the participant as being both novel and appropriate in a given context. Deciding on the novelty and appropriateness of the phrases seems to call for an increased demand on controlled retrieval and selection of semantic knowledge that is not as necessary when faced with stimuli that are only novel (HULA) or only appropriate (LUHA). Unusual and appropriate phrases require the recovery of semantic knowledge about the two semantically distant concepts that need to be brought into relation.

While the role of the IFG appears indisputable in semantic processing, there is some debate as to the precise role of this region. Wagner and colleagues (2001), for instance, have claimed that the left anterior IFG is associated with controlled retrieval of semantic knowledge, whereas Thompson-Schill and colleagues (1997) argue for the role of the left anterior IFG in semantic selection rather than retrieval processes. A more recent account by Badre and colleagues (2005) incorporates both possible functions of the anterior IFG, such that the left anterior ventrolateral prefrontal cortex (BA 47) is held to be more strongly recruited when a task necessitates top-down retrieval of semantic knowledge, whereas the left mid-ventrolateral prefrontal cortex (BA 45) is more strongly associated with the mediation of semantic selection. Both of these postulations can be applied to the current results as phrases judged to be both unusual and appropriate require the controlled retrieval of concepts and their distinct features, as well as the selection of an appropriate manner in which the concepts can be linked with each other.

In line with several previous studies that have identified the left middle temporal cortex (BA 21/22) and the temporal poles as areas linked with semantic knowledge (Badre et al., 2005; Bokde, Tagamets, Friedman, & Horwitz, 2001; Lambon Ralph et al., 2010), the present study also found activations along the left temporal pole as a function of conceptual expansion. In an attempt to bring together these two facets of semantic processing, Badre and colleagues (2005) proposed a two-step model of semantic memory in which semantic knowledge is stored within the temporal cortex. Retrieval of information from temporal regions emerges via automatic or controlled processes (Badre et al., 2005). Semantic selection processes as subserved by the mid-ventrolateral prefrontal cortex run parallel in both cases whereas controlled retrieval is held to be mediated by the left anterior ventrolateral prefrontal cortex. Results of the present study fit well within this model as both IFG (BA 45/47) as well as temporal pole (BA 38) activations resulted as a function of conceptual expansion (HUHA) implicating semantic selection, controlled semantic retrieval and semantic storage related processes. Automatic semantic retrieval is unlikely to have resulted within HUHA trials due to the uncommonness of the phrase.

The hypothesis concerning greater frontopolar activation (BA 10) when processing conceptual expansion could also be confirmed, albeit only at an uncorrected threshold of $p < .001$. This region has been implicated as playing a role in integrating the output of multiple cognitive operations (Ramnani & Owen, 2004) which was required in the present study due to the processing demands of the HUHA stimuli. Conceptual expansion was expected to result in greater relational information integration efforts in the frontopolar region as the connection of two previously unrelated or weakly related concepts in a novel and appropriate way necessitates the recovery of knowledge about the two distant concepts that need to be brought into relation to one another. Previous studies have shown the recruitment of frontopolar areas when processing highly complex stimuli in a reasoning task (Kroger et al., 2002), as well as when integrating relations across semantic distance in an analogy task (Green et al., 2010). Some studies have extended the role of the left frontopolar region even further by proposing that relational integration is achieved through the manipulation of self-inferred or self-generated information (Christoff, Ream, Geddes, & Gabrieli, 2003; Christoff et al., 2001). Notably, the involvement of this region as a function of conceptual expansion using the present paradigm could be also seen as an indicator for the suitability of an indirect approach to investigate conceptual expansion. After all, even though participants in the present study did not have to actively or volitionally expand concepts and thereby self-generate the information, the decision as to whether or not a phrase was unusual and appropriate had to be self-inferred by the participants.

In sum, the passive expansion of existing concepts seems to be associated with a network of processes associated with different structures in frontal and temporal areas.

### 4.2. Novelty

In the case of activity caused by the novelty of the phrases, the obtained results partially deviate from what was predicted. Both categories of unusual phrases were expected to elicit activation in the anterior IFG (BA 45/47) due to greater semantic retrieval and selection demands. The results revealed only a small area of IFG activation (BA 45) in the right hemisphere, albeit only at an uncorrected threshold of $p < .001$. One possible explanation for this finding might lie in the nature of the unusual and inappropriate phrases. HULA phrases might have been easily dismissed as senseless. This view is shared by Mashal and colleagues (2009) in their interpretation of the lack of activation for nonsensical sentences compared to literal or metaphorical ones. This would imply that the phrases judged as unusual and senseless by the participants were easily disregarded as such and did not recruit increased retrieval effort to reach a conclusion and to find a link between the two concepts implied through the stimulus. This obvious senselessness seems to, in turn, deem semantic retrieval under the control of the anterior IFG (BA 47) unnecessary. Here, our findings deviate from those of Stringaris and colleagues (2007) who showed anterior IFG activation not only for metaphoric but also for nonmeaningful sentences compared to literal ones. However, these differences in the pattern of findings may be due to the different nature of the stimulus phrases used in both studies. While Stringaris and colleagues (2007) presented participants with phrases in the form of "Some X are Y", our stimulus material was not as abstract and therefore closer to everyday language in content and in structure. This might have made it easier to dismiss senseless phrases as such in our study.

The obvious senselessness of the HULA phrases can also account for the lack of expected activation in the MTG and temporal pole regions (BA 20, 21 and 38) in relation to novelty processing. The senselessness of HULA stimuli might have been too obvious to initiate an extensive search in and retrieval from semantic networks in the temporal lobe. These are only post-hoc theoretical postulations. Yet, this is a previously unconsidered yet fascinating issue in the domain of semantic novelty processing that requires further research in order to comprehend its precise ramifications.

### 4.3. Appropriateness

Due to the explorative nature of the investigation into the neural processing of the appropriateness of the phrases, there were no predictions made in advance. The results nevertheless hold surprising findings that seem counterintuitive at first. Appropriateness in the present study led to activation in the left middle temporal gyrus (BA 21). Initially, greater activation in this area was expected for conceptual expansion as well as for the novelty aspect of the phrases due to greater efforts to retrieve semantic knowledge. For conceptual expansion, these expectations were met, whereas this was not the case for novelty, most likely due to the nature of the HULA phrases. Finding activation in the middle temporal gyrus as a function of appropriateness therefore appears counterintuitive at first. This result can, however, be explained with Badre and colleagues' (2005) proposal on semantic memory retrieval with the temporal areas functioning as knowledge storage that can be drawn upon through automatic or IFG-controlled processes. For phrases rated as LUHA, it can assumed that the retrieval of information about the commonness and appropriateness of the phrases happens through a more shallow processing without the need to elaborate deeper on semantic knowledge due to their literal nature. Common and appropriate phrases occur in everyday language and are therefore likely to be processed highly automatically, whereas the nature of phrases judged to be unusual and appropriate (HUHA) requires prefrontal executive control to retrieve the relevant semantic knowledge.

### 4.4. Limitations of the study

Even though the results of the present study contribute to the investigation of creative thinking, there are some limitations that have to be kept in mind when interpreting the findings. One of the fortes of the present study is the fact that creativity is not treated as a single entity but rather as a construct involving different cognitive processes. The present study focused on conceptual expansion as one of theses processes involved in creative thinking. However, this approach also brings forth certain limitations to the interpretation of the results. Findings from the present study are related to conceptual expansion as one cognitive operation relevant to creativity, but cannot claim to reflect activation caused by creativity in general. Interpretations of the findings are limited to the process of passively induced conceptual expansion in a verbal task which, nevertheless, plays an important role in creative thought. It must be noted, however, that studies using non-verbal semantic cognition tasks have implicated some of the same regions found in our research (e.g., Lambon Ralph et al., 2010; Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997) hinting at the possible involvement of these regions in nonverbal creative tasks, as well. Additionally, the areas found to be associated with conceptual expansion are not exclusive to creative thinking but rather are involved in other cognitive operations, as well. This fact, however, is in line with the creative cognition approach which postulates fundamental cognitive processes that are shared by all humans as forming the core of operations that enable creative thinking (Ward et al., 1999).

Another limitation of the study stems from the application of a conceptual expansion task that involves semantic relations. The resulting involvement of the IFG and related regions is not surprising when considering that the conceptual expansion task used in the present study is of semantic content. The current findings regarding the IFG are therefore only applicable to creative operations involving semantic relations. Whether or not the IFG would also be activated during creativity tasks that primarily involve other operations such as creative imagery remains an open question.

The most significant limitation of the present study is that creative thinking was not explicitly assessed within the experimental design. Previous functional neuroimaging and electrophysiological studies on creativity have required that subjects attempt to generate original responses while their brain responses are being recorded. The approach adopted in the current study was very different in that (1) only one specific aspect of creative cognition, namely conceptual expansion, was targeted, and (2) conceptual expansion was passively induced (as opposed to actively generated) during the experiment. This raises the critical question of how well the insights gained from the present study can be integrated with the literature on the neurocognition of creativity when the self-generation of creative ideas was not assessed. When considering this question, it is important to keep two critical issues in mind.

First, one of the endemic problems of creativity research is that creative thinking is an inherently unpredictable phenomenon (Dietrich & Kanso, 2011). Despite our best efforts, it is not possible to reliably or predictably prompt creativity within an experimental setting. Previous functional neuroimaging studies on creative thinking have not been immune to this problem because, even if they have assessed the brain's response when participants carry out creative tasks in an fMRI or PET scanner, "trying to be creative" is certainly not equivalent to "being creative". Moreover, it is not possible to guarantee the "creativeness" of the response as participants are likely to also generate uncreative responses despite being told to be creative, and vice versa. These are the limitations of investigating the creative process, as it is, almost by definition, a singular event that is extremely difficult to study in laboratory conditions. Additionally, studying creative thinking within functional neuroimaging settings inherently involves severe methodological problems, such as those that have been outlined in the

Introduction that are extremely difficult to overcome in an optimal manner. The field of creativity research has therefore used proxy procedures and measures in order to unravel this fascinating ability and the present study is one such attempt to do so. Even though these proxy procedures to investigate creativity remain imperfect solutions, they can still contribute to enhancing our knowledge of the information processing mechanisms involved in creative thinking.

Secondly, the approach adopted in this study was motivated in part by recent calls in the field for the need to approach the neurocognitive study of creativity in a systematic and creative manner as a necessary next step (Dietrich, 2007). One of the more obvious paths that can be adopted in order to systematically investigate creativity is to assess its component cognitive operations. While the experimental design of the present study is admittedly unconventional, it was tailored to assess conceptual expansion, which is a core facet of creative thinking. We believe that such attempts (also see Kröger et al., 2012) will enable us to get closer to the overarching goal of the field which is to understand the neurocognitive mechanisms underlying creative thinking.

### *4.5. Implications for laterality of language processing*

Though not specifically planned as a study on the laterality of language processing, the results of the present study can contribute to this discussion. According to the graded salience hypothesis (Giora, 1999) and Jung-Beeman et al. (2004), Jung-Beeman (2005) coarse semantic coding theory, novel metaphoric expressions are primarily processed in areas in the right hemisphere, either due to their non-salience (Giora, 1999) or due to a more coarse semantic network that allows for large semantic fields and in turn includes more distant concepts (Jung-Beeman, 2005; Jung-Beeman et al., 2004). The results of our study do not confirm these right hemispheric processing theories. For phrases eliciting conceptual expansion which were non-salient and recruit the activation of semantically distant concepts, we found activations that were more strongly lateralized to the left hemisphere. Such findings also go against the generic idea of a stronger involvement of the right hemisphere during creative processes (Dietrich, 2004; Dietrich and Kanso, 2010).

## 5. Conclusion

In sum, the present study took a step towards untangling the complex concept of creativity. By using a new experimental approach, we were able to show the involvement of frontal and temporal regions known to be associated with semantic cognition and relational reasoning in the processing of novel metaphoric phrases thought to elicit passive conceptual expansion. This was done by assessing the stimuli based on the fundamental features of creativity, i.e., novelty and appropriateness. Our results especially stress the importance of the anterior IFG (BA 45/47), the temporal pole (BA 38) and, to a lesser extent, the lateral frontopolar cortex (BA 10) for conceptual expansion. These regions are known to be involved in semantic selection (IFG: BA 45), controlled semantic retrieval (IFG: BA 47), semantic knowledge storage (temporal poles: BA 38) and relational information integration (frontopolar cortex: BA 10). While the MTG was associated with the factor of appropriateness, only the mid-IFG (BA 45) was associated with the factor of novelty in that it was activated during the processing of novel metaphorical and nonsensical phrases. Even though certain areas of activation can be found for either conceptual expansion, novelty and appropriateness, the fact that the common activation of IFG, frontopolar cortex and temporal pole can only be found in the conceptual expansion conjunction points to the significance of these regions during creative thinking over and above novelty and appropriateness processing. Inducing conceptual expansion through indirect or passive means offers new possibilities that might expedite the research on creative cognition to great heights.

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## Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.bandc.2011.11.002.

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