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## Research Report

## Using a shoe as a plant pot: Neural correlates of passive conceptual expansion

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## ABSTRACT

Conceptual expansion is a key process that underlies our ability to think creatively. In the present event-related fMRI study, a modified Alternate Uses Task was used to identify brain regions involved during passive conceptual expansion and thereby separately assess the effects of the two defining elements of creative output: Originality (unusualness) and Relevance (appropriateness). Participants viewed word pairs consisting of an object and a use and indicated whether the given use was unusual and/or appropriate for the given object. Trials with object-use combinations judged as unusual and appropriate (HUHA) were contrasted against trials judged as just unusual but inappropriate (HULA) or just appropriate but not unusual (LUHA). As hypothesized, conceptual expansion related activation (HUHA) was found in the bilateral inferior frontal gyrus (BA 45, 47), left temporal pole (BA 38) and left frontopolar cortex (BA 10). We discuss the specific contributions of these regions with reference to semantic cognition.

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## 1. Introduction

Although the study of creative thinking has a long scientific tradition, little is known about the underlying neurocognitive mechanisms. This lack of knowledge is due to conceptual problems as well as technical limitations and suboptimal experimental paradigms for the neuroscientific investigation of creative thinking (Dietrich, 2004; Dietrich & Kanso, 2010). One of the more critical problems is that creative thinking has mainly been examined as a unitary construct but with a

range of tasks that are not comparable to one another. This has led to a multitude of scattered findings. A recent review summarized that the only reliable conclusion to date from neuroimaging studies is that creative thinking leads to changes in prefrontal brain activation (Dietrich & Kanso, 2010). Unfortunately, this is also a very unspecific claim given that the prefrontal cortex is a large structure which is known to underlie a wide range of functions from cognitive control to mental state reasoning (Amodio & Frith, 2006; Badre, 2008). The lack of consistency in neuroscientific

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findings related to creative thinking highlights the necessity to develop new paradigms where the construct of creativity is investigated in terms of its component processes.

In comparison to the neuroscience of creative thinking, there is a substantial agreement about the definition of creativity from the psychological domain. Creativity is typically defined from the product perspective in that a creative product has to be original or unusual as well as relevant or appropriate in a certain context (Hennessey & Amabile, 2010; Runco, 2004). The first theoretical approach which stressed the multifaceted nature of creativity was the creative cognition approach (Finke et al., 1992). Unlike the tradition of early cognitive models of creativity (Mednick, 1962; Mendelsohn, 1976), which focused on individual differences in creative ability, this approach examined normal cognitive processes which underlie our ability to think creatively. Several types of mental operations are held to be involved in creative thinking that are not qualitatively different from normative cognitive processes (Smith et al., 1995).

The aim of the current study was to disentangle the multifaceted construct of creativity by identifying brain regions involved in the processing of one critical facet of creative thinking, namely the process of conceptual expansion. This process is one of the core features of creative thinking in that it involves broadening the existing definitions or boundaries of a concept beyond its usual characteristics and therefore aids the development of new ideas (Smith et al., 1995; Ward, 1994). In the original conceptual expansion task, subjects were asked to imagine and draw an animal living on another planet which is very different from Earth (Ward, 1994). In other words what was required in this task was to expand the original concept of what an animal can look like while still be definable as an animal. The drawings were evaluated with respect to deviations from ordinary Earth animals in terms of fundamental features like bilateral symmetry and the presence of sense organs. Interestingly, subjects revealed a tendency to rely on generic exemplars of animals, even when instructed not to do so. This “path-of-least-resistance” strategy or the tendency to adopt the least cognitive demanding approach that is possible in a given situation is commonly observed when performing generative tasks (Finke, 1990; Ward, 1994). Despite its significance, no neuroimaging studies have so far explicitly assessed conceptual expansion.

The original conceptual expansion task cannot be directly implemented in an fMRI setup due to problems that would arise from technical difficulties such as drawing responses and inadequate number of trials. To overcome some of the difficulties which are typically encountered when trying to combine neuroimaging with active engagement in creativity tasks, a novel paradigm was developed in the current study to induce conceptual expansion. For this purpose we used a modified version of the alternate uses task (AUT, Wallach & Kogan, 1965), a classic creative thinking task in which conceptual expansion is assessed (Abraham & Windmann, 2007). The AUT tests the ability to generate as many uses as possible for common objects (e.g., a shoe) and thereby necessitates that the subject expands the usual conceptual boundaries in which the object is customarily used (e.g., foot protection). While the classic AUT does not dissociate the originality (or unusualness) component from the relevance (or appropriateness)

component of creativity, the current modification of the paradigm enables the concurrent consideration of both these components separately (originality OR relevance) as well as together (originality AND relevance).

In this modified version of the AUT, subjects view word pairs of a common object together with a described use for this object and have to decide on a trial-by-trial basis whether they find the use for the given object unusual (U), appropriate (A) or both. Trials in which subjects judge a particular object use combination to be highly unusual and highly appropriate (HUHA) or unfamiliar but fitting are trials in which the subjects were induced to loosen the classic boundaries of the presented concepts thereby allowing for the conceptual expansion and conceptual integration of the previously unrelated concepts. This is in contrast to trials in which subjects decide that a particular object use combination is only unusual but not appropriate (high unusual and low appropriate — HULA) or only appropriate but not unusual (low unusual and high appropriate — LUHA). In this manner, a creative object use combination that is unusual and relevant (HUHA) can be separated from a purely unusual but irrelevant combination (HULA) as well as from purely relevant but common combination (LUHA). This allows for the assessment of the separable effects of originality and relevance from that of creative conceptual expansion. Instead of simply relying on pre-determined conditions, the great advantage of this procedure is that the experimental design is individually validated by each participant on a trial by trial basis.

Unlike in the classic AUT, participants in the current study do not have to generate a creative (unusual AND appropriate) use for a given object by themselves, but are instead presented with a solution to a problem that they judge as being creative. The fact that they recognize the bringing together of the two concepts (the object and its use) as being unusual but appropriate is proof of passive conceptual expansion taking place as they passed such a judgment only when an object-use combination was unfamiliar but fitting. Although we expect quantitative as well as qualitative differences in brain activation between an active and a passive conceptual expansion paradigm due to factors like volition and a stronger directed memory search process in case of the passive conceptual expansion, we assume that the type of conceptual expansion induction (volitionally induced in the AUT versus externally induced in the current modified AUT), would not affect the general manner in which conceptual structures are expanded upon in the human brain. After all, the conceptual structures being expanded within either scenario would be one and the same. By doing away with the volitional side though, we are able to systematically assess the neural underpinnings of passive conceptual expansion without the added confounds of increased cognitive difficulty during creative thinking, unpredictability in generating creative responses upon cue, and so on.

We expect to find passive conceptual expansion related activation in three brain areas namely the frontopolar cortex (BA 10), the anterior and middle inferior frontal gyrus (IFG: BA 45, 47), and the temporal pole (BA 38). This is because bringing two concepts together which were previously only weakly or not at all related to one another necessitates the activation of these concepts and searching for their associative links,

both of which require controlled semantic retrieval and selection mechanisms. Such processes are known to involve the IFG (Badre et al., 2005; Thompson-Schill, 2003). The temporal pole which has also been referred to as the “semantic hub” of the brain (Patterson et al., 2007) has been implicated in the extraction of amodal conceptual information and may therefore also play a role in search processes in semantic networks. With regard to the separable factors of originality (or unusualness) and relevance (or appropriateness), the IFG and temporal pole regions would also be expected to be responsive as a function of unusualness given the higher demands on semantic selection and retrieval during novelty processing.

One further process that is also needed when expanding an existing concept by linking it with another previously unrelated concept is the integration of the detected relations between the two previously weakly related or unrelated concepts to form an expanded new concept. We hypothesize that this aspect of the conceptual expansion processing should engage the lateral frontopolar cortex (BA 10). Although the exact function of this brain area is a matter of ongoing debate (Ramnani & Owen, 2004), there is substantial evidence that it is involved in relational integration processing (Bunge et al., 2005; Green et al., 2010; Kroger et al., 2002), where multiple relations have to be considered simultaneously in order to infer the correct solution of a problem as, for instance, in the Raven's Progressive Matrices test (Christoff et al., 2001). This makes it a candidate region for the integration processes during passive conceptual expansion.

## 2. Results

### 2.1. Behavioral findings

We carried out a 3×2 repeated measures ANOVA to check for differences in reaction times between the three types of conditions (HUHA, HULA, LUHA) and two types of questions (Question 1: unusual, Question 2: appropriate). We found significant main effects for the condition type ( $F(2,38)=8.173$ ,  $p=.001$ ) and question type ( $F(1,19)=40.576$ ,  $p<.001$ ) as well as a significant interaction ( $F(2,38)=6.684$ ,  $p=.003$ ). Bonferroni corrected ( $p<.05$ ) post hoc T-tests revealed that subjects took significantly longer to respond to the second question (appropriate) in the HUHA condition compared to the second question in the HULA ( $p=.001$ ) and the LUHA condition ( $p=.004$ ). Additionally subjects responded significantly faster to the second question compared to the first question,

independent of type of condition. See Table 1 for mean reaction times and standard deviation.

### 2.2. fMRI findings

Whole brain and region of interest analysis for a priori defined regions BA 10, BA 47, BA 45 and BA 38 were carried out. We also did exploratory analysis to reveal additional activated regions. All activations reported were FWE-corrected for multiple comparisons ( $p<.05$ ).

#### 2.2.1. Passive conceptual expansion

To determine which brain regions were activated during passive conceptual expansion (HUHA), a conjunction analysis was conducted ( $HUHA>HULA \cap HUHA>LUHA$ ) (Results in Table 2). Consistent with our prediction, passive conceptual expansion related activation was found in left inferior frontal gyrus (IFG) with activation peaks in BA 47 and BA 44 while also extending into BA 45. Although no peak activations were found in the frontopolar cortex or temporal pole in the whole brain analysis, the results of the region of interest analysis showed passive conceptual expansion related activation in the left frontopolar cortex (BA 10) and the left temporal pole (BA 38), as well as in the bilateral IFG (BA 45, 47). The whole brain analysis also revealed the involvement of the left rostral cingulate zone (BA 32, 8, 6) (see Fig. 2).

#### 2.2.2. Unusualness and appropriateness

The conjunction analysis for unusualness ( $HUHA>LUHA \cap HULA>LUHA$ ) did not reveal the predicted involvement of the IFG or the temporal poles. Brain regions that were instead found to be activated for the unusualness conjunction included the left supramarginal gyrus (BA 2/40) (Table 3). The appropriateness conjunction ( $HUHA>HULA \cap LUHA>HULA$ ) resulted in significant activations mainly in posterior and anterior cingulate gyrus (BA 31, 24, 32) and in parts of the frontomedian wall (BA 9, 32) (Table 4).

## 3. Discussion

Using a novel paradigm, the aim of this study was to disentangle the multifaceted construct of creative cognition by investigating our capacity to engage in passive conceptual expansion which involves the bringing together of original and relevant semantic connections. The paradigm enabled us to dissociate the brain responses associated with passive conceptual expansion (unusual and appropriate) compared to the processing of purely unusual (only original) or purely appropriate (only relevant) responses and was individually validated by each subject on a trial by trial basis.

### 3.1. Passive conceptual expansion

In order to identify brain regions selectively involved in the process of passive conceptual expansion, we compared trials judged as high unusual and high appropriate (HUHA) against trials rated as high unusual but low appropriate (HULA) as well as low unusual and high appropriate trials (LUHA). In line with our predictions, passive conceptual expansion

**Table 1 – Reaction times (mean and standard deviation in milliseconds) for all three conditions.**

Conditions	Unusual (question 1)		Appropriate (question 2)	
	Mean	SD	Mean	SD
HUHA	688.68	115.06	622.53	123.97
HULA	691.12	120.82	544.81	91.35
LUHA	653.09	96.30	546.09	93.70

**Table 2 – Passive conceptual expansion: whole brain analysis and region of interest analysis. Anatomical Specification, MNI coordinates, number of voxels (l.m.: another local maxima in the cluster above), maximum T-value of the significantly activated areas in the HUHA>HULA  $\cap$  HUHA>LUHA conjunction analysis. All results were corrected for multiple comparisons (FWE) at  $p < .05$ .**

Area	BA	Side	x	y	z	Cluster size	T-value	p
<i>Passive conceptual expansion: whole brain analysis</i>								
Inferior frontal gyrus	47/45/10	L	-36	35	4	56	12.43	.000
Inferior frontal gyrus	44/45	L	-45	11	16	76	10.76	.000
Inferior frontal gyrus	46/45	R	51	38	4	12	9.82	.000
Inferior frontal gyrus	47	R	27	29	-11	5	9.52	.000
Inferior frontal gyrus	47	L	-27	23	-14	3	7.33	.021
Inferior frontal gyrus	45	R	51	26	1	1	6.86	.046
Superior frontal gyrus (med)	32/8	L	-9	23	46	27	9.58	.000
Superior frontal gyrus	8	L	-21	14	52	l.m.	7.30	.022
Anterior cingulate cortex	32	L	-9	26	22	1	7.29	.023
Anterior cingulate cortex	32	L	-9	29	28	1	7.19	.027
Anterior cingulate cortex	32	L	-6	32	31	1	6.82	.048
Subthalamic nucleus		R	9	-13	-8	14	9.95	.000
Hypothalamus		L	-9	-5	-1	23	9.15	.001
Subthalamic nucleus		L	-6	-10	-8	l.m.	8.01	.005
<i>Passive conceptual expansion: region of interest analysis</i>								
Lateral frontopolar cortex	10	L	-36	38	13	7	6.02	.003
Inferior frontal gyrus	47	L	-27	26	-14	48	6.95	.000
		L	-36	29	-2	l.m.	6.28	.001
		L	-42	20	-11	l.m.	5.43	.005
		L	-33	14	-20	1	4.71	.022
		L	-39	26	-17	1	4.71	.022
		L	-42	41	-8	1	4.60	.028
		L	30	23	-8	1	4.46	.038
		R	51	26	1	2	6.86	.000
		R	54	26	-5	1	6.59	.000
		R	27	32	-8	7	6.19	.001
		R	51	23	-8	5	5.26	.007
		R	48	35	-2	1	5.10	.009
Inferior frontal gyrus	45	L	-51	17	16	24	7.06	.000
		L	-54	11	19	2	5.79	.001
		L	-36	26	7	4	5.50	.002
		R	51	35	4	2	9.81	.000
		R	51	26	1	2	6.86	.000
		R	51	26	22	4	4.69	.011
Temporal poles	38	L	-48	20	-11	2	4.72	.017
		L	-45	17	-14	1	4.39	.036

related activation was found in the frontopolar cortex (BA 10), inferior frontal gyrus (IFG: BA 45, 47) and temporal pole (BA 38).

The IFG activity is likely to reflect higher semantic retrieval and selection demands due to the effort incurred by searching for the link between the weakly associated concepts presented in the object-use combination. This region is known to be involved in semantic processing (Binder et al., 2009; Bookheimer, 2002), exhibits stronger BOLD responses to concepts with low associative strengths, and is sensitive to semantic distance between concepts during analogical reasoning (Bunge et al., 2005; Green et al., 2010). More specifically, it has been proposed that the anterior portion of the IFG (BA 47) plays a major role in controlled semantic retrieval, whereas the middle IFG (BA 45) is more involved in the selection of retrieved semantic representation (Badre & Wagner, 2007).

Stronger passive conceptual expansion related activation was also expected to be found in the so-called “semantic hub” region of the brain in the temporal poles (BA 38) given

its role in the storage of amodal conceptual knowledge. This has been shown in experiments using rTMS that disrupted neural processing in this area as well as in semantic dementia patients with atrophy of this region (Lambon Ralph & Patterson, 2008; Lambon Ralph et al., 2009).

The lateral frontopolar cortex was expected to play a key role in the integrational processing demands that arise during passive conceptual expansion. This brain area is engaged during relational reasoning on the most abstract level (Badre, 2008) as well as in monitoring and integration of subgoals during working memory tasks (Braver & Bongiolatti, 2002), and during active processing of self-generated or inferred information (Christoff et al., 2003; Christoff et al., 2004). Activity in the frontopolar cortex has also been shown to co-vary parametrically with increasing semantic distance between items in an analogical reasoning task (Green et al., 2010) as well as with relational complexity, which corresponds to the number of relations simultaneously kept in mind while inferring conclusions (Kroger et al., 2002). In an effort to bring together the

**Table 3 – Unusualness: whole brain analysis and region of interest analysis. Anatomical Specification, MNI coordinates, number of voxels (l.m.: another local maxima in the cluster above), maximum T-value of the significantly activated areas in the HUHA>LUHA  $\cap$  HULA>LUHA conjunction analysis. All results were corrected for multiple comparisons (FWE) at  $p < .05$ .**

Area	BA	Side	x	y	z	Cluster size	T-value	p
<i>Unusualness: whole brain analysis</i>								
Supramarginal gyrus	2/40	L	-63	-31	40	12	8.58	.000
<i>Unusualness: region of interest analysis</i>								
Lateral frontopolar cortex	10	L	-39	38	16	2	5.31	.012
Inferior frontal gyrus	47	No activation found						
Inferior frontal gyrus	45	No activation found						
Temporal poles	38	No activation found						

diverse task-related findings in this region into a more task-independent general description, Ramnani and Owen (2004) argued that the frontopolar cortex is required for integration of output results from multiple cognitive operations while following a higher behavioral goal. Taken together the data fit very well with the idea that the lateral frontopolar cortex is involved in passive conceptual expansion as this process demands the integration of two previously weakly related or unrelated concepts.

### 3.2. Active versus passive conceptual expansion

It must be noted that our study investigated the processing of passive conceptual expansion which we expect to differ from a situation in which a person has to actively expand an

existing concept on a generative basis. We assume that beside other relevant factors such as a stronger convergent memory search process during a passive conceptual expansion task, the most obvious difference between a passive and an active approach would lie in the volitional side of bringing about the expansion. Nevertheless we would postulate that the actual expansion of the concept would be expected to involve similar structures related to semantic cognition in the brain regardless of whether it was initiated volitionally or induced automatically. This is because information processing demands on the access, selection, retrieval and integration of semantic information would be necessary regardless of whether the conceptual expansion was actively or passively induced. It would be expected that volitionally induced or active conceptual expansion will engage similar brain areas to a greater extent

**Table 4 – Appropriateness: whole brain analysis and region of interest analysis. Anatomical Specification, MNI coordinates, number of voxels (l.m.: another local maxima in the cluster above), maximum T-value of the significantly activated areas in the HUHA>HULA  $\cap$  LUHA>HULA conjunction analysis. All results were corrected for multiple comparisons (FWE) at  $p < .05$ .**

Area	BA	Side	x	y	z	Cluster size	T-value	p
<i>Appropriateness: whole brain analysis</i>								
Posterior cingulate gyrus	31	L	-6	-55	22	29	9.84	.000
Medial frontal gyrus	9	L	-6	44	34	21	8.54	.002
Medial frontal gyrus	9	L	-9	53	31	l.m.	7.99	.006
Anterior cingulate gyrus	24	R	3	35	7	38	8.31	.004
Anterior cingulate gyrus	32	L	-3	44	10	l.m.	8.15	.005
Middle temporal gyrus	21	L	-60	-7	-20	3	7.71	.010
Middle temporal gyrus	21	L	-60	-16	-11	3	7.52	.015
Middle temporal gyrus	21	L	-63	-10	-14	1	7.51	.015
Middle temporal gyrus	21	L	-54	-16	-20	1	7.03	.037
Angular gyrus	39	R	57	-58	28	5	7.82	.009
Angular gyrus	39	L	-54	-64	28	2	7.25	.024
<i>Appropriateness: region of interest analysis</i>								
Lateral frontopolar cortex	10	L	-9	47	10	71	7.64	.000
		L	-3	59	28	l.m.	6.46	.001
		L	-3	53	-2	l.m.	5.96	.003
		R	3	53	10	41	5.99	.003
		R	6	53	-2	l.m.	5.98	.003
		R	3	47	-8	1	4.90	.030
Inferior frontal gyrus	47	No activation found						
Inferior frontal gyrus	45	No activation found						
Temporal poles	38	L	-48	17	-17	6	5.67	.002
		L	-42	8	-29	1	4.44	.032
		L	-51	14	-20	1	4.31	.042

compared to passively-evoked conceptual expansion (quantitative changes). Several further structures (such as hypothetical reasoning, inhibitory control and extended cognitive control related brain regions) would also be expected to be involved during active conceptual expansion (qualitative differences).

Some studies have inadvertently investigated active conceptual expansion without explicitly referring to such a process (Chrysikou & Thompson-Schill, 2011; Fink et al., 2010). For example in a fMRI study from Chrysikou and Thompson-Schill (2011) one group of participants were required to actively retrieve the common use of an everyday object while another group were required to generate a creative use. Common use generation activated the lateral prefrontal cortex, whereas the creative use generation led to activations in occipito-temporal cortex. Unfortunately these results are not directly comparable to the results derived from the paradigm used in the current study due to critical differences in the paradigms such as not distinguishing between unusual and appropriate uses (as creative uses are defined) from merely unusual but inappropriate uses. The same limitation in integrating the current results with those in the literature applies to the study by Fink et al. (2010) in which the active generation of original ideas was associated with higher activation in the anterior supramarginal gyrus. We found a similar region (almost the same MNI coordinates) to be significantly activated during unusualness processing in general, but not during passive conceptual expansion. The fact that we accounted for both originality and appropriateness of the association might explain the divergence between the findings.

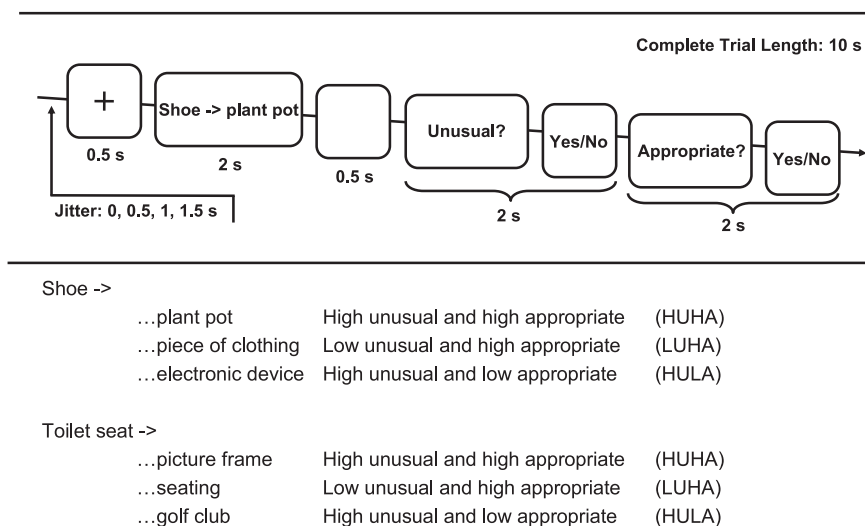
### 3.3. Unusualness and appropriateness

The processing of unusual object use combinations was also expected to lead to activations in the IFG and the temporal pole given the literature on semantic memory retrieval and storage processing, as well as the responsiveness of this region with reference to semantic associative strength (Bunge et al., 2005). The results of the current study however did not

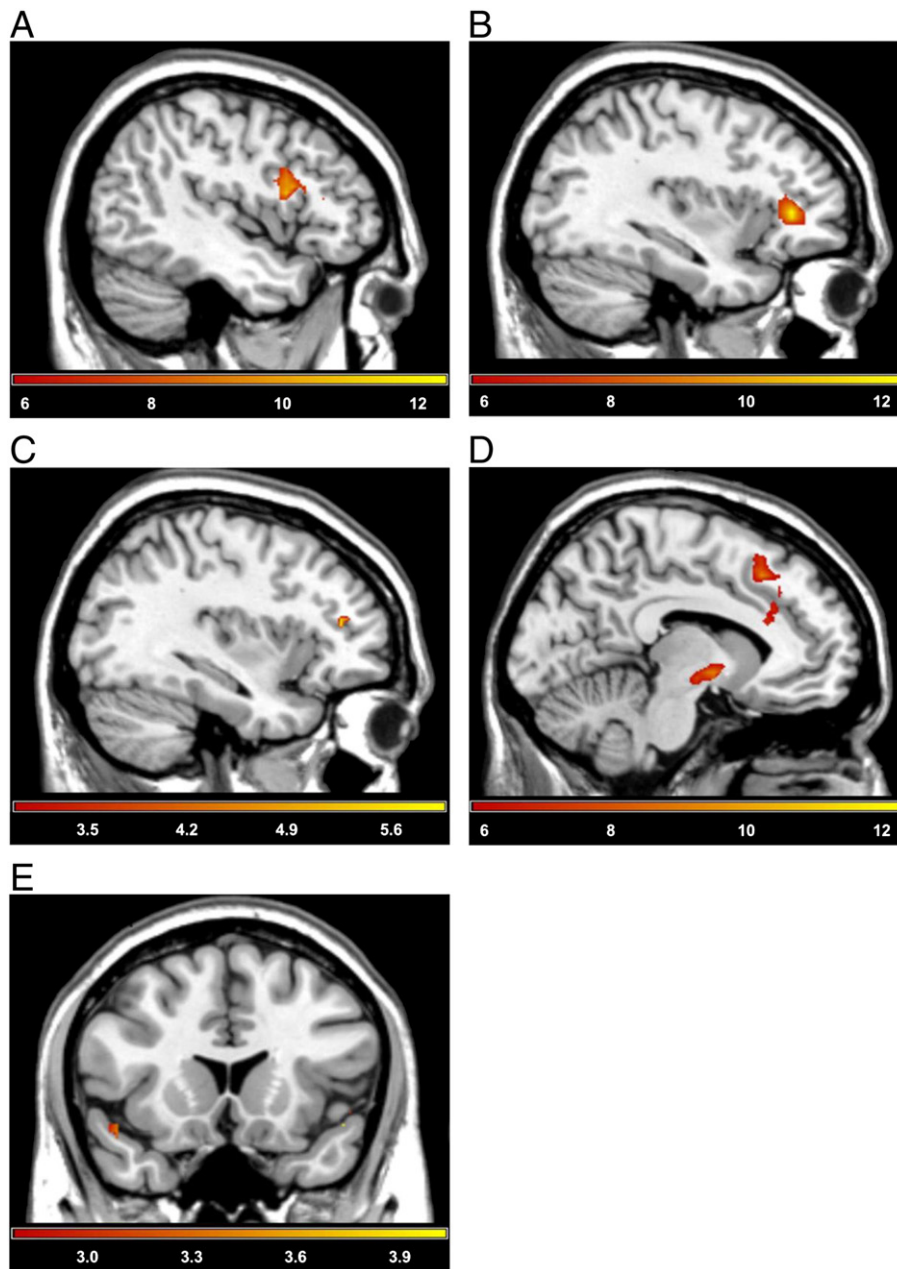
support these hypotheses. One possible interpretation of the results is to align it to what is known about semantic processing with regard to spreading activation in semantic networks (Collins & Loftus, 1975). In the HUHA and LUHA trials, a semantic connection between the concepts could be forged because of a strong (LUHA) or weak (HUHA) overlap of the activated associated semantic nodes. However, because the stimuli cannot be related to one another in the HULA trials, there would be no overlaps in the associated activated semantic nodes in the network that would enable the linkage of the two concepts. The semantic search process in the case of HULA could therefore be readily aborted because of the speed of the spontaneous spreading activation in semantic networks. The current behavioral data lends some support to this interpretation as the subjects responded “No” to the appropriateness question in the HULA condition with comparable speed as they did “Yes” to the appropriateness question in the LUHA condition. This indicates an equally prompt processing of the stimuli in both the HULA and LUHA condition with respect to the appropriateness question. The reported activation of the supramarginal gyrus in the HULA condition is in line with results from other studies investigating the active generation of unusual object uses (Fink et al., 2010).

The appropriateness conjunction yielded activation in posterior cingulate (BA 31) and parts of the frontomedian wall (BA 9/32), regions that are known to be involved in declarative memory retrieval (Abraham et al., 2008). In a more recent fMRI study, medial prefrontal cortex activation was shown to be associated with enhanced memory retrieval of information congruent with prior knowledge (van Kesteren et al., 2010). This corresponds partially with the current observations of appropriateness-related activations in medial prefrontal regions as information judged to be appropriate was either congruent with prior knowledge (LUHA) or could be added to existing knowledge (HUHA).

All in all the evidence suggests that the information processing of sheer unusualness or novelty recruits posterior brain regions, whereas appropriateness and conceptual



**Fig. 1 – Trial overview (above) and Examples of the stimuli used in each condition (below). The temporal jitter at the start of each trial led to a variable inter stimulus interval of 1.5 to 4.5 s (steps of 500 ms) due to the constant trial length of 10 s. The 0.5 s fixation period consisted of 300 ms fixation cross and 200 ms blank screen.**



**Fig. 2 – Passive conceptual expansion related activation in A: IFG (BA 44/45), B: anterior IFG (BA 47), C: Frontopolar Cortex (BA 10, ROI analysis,  $p < .005$  uncorrected), D: dorsal ACC (BA 32/BA 8), E: Temporal Poles (BA 38, ROI analysis,  $p < .005$  uncorrected). Color bars represent T-values.**

expansion related information processing necessitates the involvement of frontal regions in the brain.

### 3.4. Other relevant findings

Our exploratory analysis revealed that apart from the IFG activation, the second main frontal activation cluster found during passive conceptual expansion comprised the dorsal ACC (BA 32) and parts of BA 8 and BA 6 (rostral cingulate zone). These areas are customarily thought to be involved in detection of errors or conflicts between competing representations as a form of action monitoring during decision making

and the consequent recruitment of cognitive control mechanisms and adjustments in motor behavior (Botvinick et al., 2004; Carter & van, 2007; Mars et al., 2005; Rushworth et al., 2004; Ullsperger & von Cramon, 2004). This fits well with the considerations about what subjects actually had to do during the HUHA condition. We presume that the decision conflict was higher in the HUHA condition compared to the other two conditions (HULA, LUHA) given that the subjects had to initiate controlled search in semantic networks, select between competing representations and to adjust their decision outcome as a consequence of the successfully retrieved conceptual links between the presented object-use pair. Such demands could

render the engagement of the rostral cingulate zone necessary. This region has indeed been reported in other neuroimaging studies of creative thinking, especially in insight problem solving experiments (Aziz-Zadeh et al., 2009; Jung-Beeman et al., 2004).

### 3.5. Summary and conclusions

In summary, a novel neuroscientific paradigm was successfully developed to investigate one mental operation underlying our ability to think creatively, namely passive conceptual expansion. In doing so, we overcame traditional approaches in the field of creativity research which dealt with the creativity construct as a unitary entity. This study is also the first to dissociate the brain activity relating to the conjoined and separable effects of originality versus relevance, the two defining components of creativity. The next step in investigating operations underlying creative conceptual expansion would be to compare the current findings with those ensuing from an active conceptual expansion paradigm in terms of both qualitative and quantitative differences. Future neuroimaging research on creative thinking should also consider the role played by other relevant mental operations, such as creative imagery and the constraining influence of examples (Abraham & Windmann, 2007).

The findings of the present study show that a better understanding of the neural correlates of creative thinking is enabled when paradigms are developed that are optimized for neuroscientific investigations and where the construct of creative thinking is broken down into its underlying processes. Moreover, the findings highlight the need to integrate the literature on the neuroscience of creative thinking with that of “normative” cognition and to generally do away with the conviction that creative operations are qualitative different from other mental processes.

## 4. Experimental procedures

### 4.1. Participants

Twenty-six right-handed native German-speaking subjects either received a 15 Euro payment or a course credit for their participation in the experiment. Six subjects had to be excluded from further analysis because they did not meet the minimum inclusion criterion of at least 30 trials per condition. One additional subject had to be removed due to extensive movement during data acquisition. The final sample therefore comprised 19 subjects (10 women; age range = 19–31 years, mean = 22.68) with normal or corrected-to-normal vision. None of the participants had a history of neurological or psychiatric illness or was taking drugs. All gave informed consent before participation. The experimental standards were approved by the ethics committee of the German Society of Psychology (Deutsche Gesellschaft für Psychologie, DGPs).

### 4.2. Task design

We employed an event-related fMRI design. During each trial (Fig. 1), subjects viewed a pair of words for 2 s consisting of a

common object and a described use for this object in each trial. After the presentation of a blank screen for 500 ms, subjects were asked to evaluate whether in their opinion the described use for the object was unusual or not (Unusual?) and whether it was appropriate or not (Appropriate?). This was done by giving a yes/no answer to each of these questions by pressing either the left or the right button of a response box. Participants were instructed that a use was to be classified as “Unusual” if it was novel or unfamiliar and “Not Unusual” if it was known or familiar. They were also instructed that a use was to be classified as “Appropriate” if it was fitting or relevant and “Not Appropriate” if it was unfitting or irrelevant. Each stimulus was categorized as belonging to one of three possible conditions based on the participant’s response. The three possible conditions were: high-unusual and high-appropriate (HUHA, yes-yes response), high-unusual and low-appropriate (HULA, yes-no response) and low-unusual and high-appropriate (LUHA, no-yes response). Subjects were told that a no-no response (low unusual and low appropriate) would not make sense as a low appropriate response is always highly unusual. Each question was shown for 1.5 s followed by a 500 ms blank period so that subjects had 2 s per question to respond. Each trial started with a jittered blank screen (0–1.5 s, jittered in steps of 500 ms) followed by a 500 ms fixation period consisting of the presentation of a fixation cross for 300 ms and a 200 ms blank screen. With a trial length of 10 s and a total of 149 trials (including 14 null events), the experimental session lasted 24.83 min.

### 4.3. Materials

Stimuli were pretested in behavioral experiments with another set of subjects. 45 experimenter-determined word pairs per condition were used to ensure the high likelihood of there being a minimum of 30 subject-determined trials in each condition. Each object was used in all three conditions (HUHA, HULA and LUHA) in combination with a described use for this object. Objects and uses were all single words.

The behavioral pilot studies indicated that some variability was unavoidable when using subject-determined trial classifications as, for instance, what one participant considers to be an unusual and appropriate object-use combination (HUHA) may be classified by another subject to be unusual but inappropriate (HULA). A minimum inclusion criterion of 30 trials per condition for each subject was therefore set as it was imperative that the fMRI analyses were not unduly influenced by widely varying trial-condition distributions across subjects. While the subject-determined trial classification is a major strength of the current paradigm, it comes with a cost of having to exclude all participants who did not meet the strict inclusion criterion. Please refer to the supplementary data for an overview of the classifications of each stimulus across participants.

### 4.4. Imaging session

Participants were placed on the scanner bed in a supine position. A two-button response box was placed under the right hand, so that the right index and middle fingers were positioned on the appropriate response buttons. Stimuli were presented under computer control using Presentation® software (Version 0.70, [www.neurobs.com](http://www.neurobs.com)), in black font



(size=28) on gray background and projected with an LCD projector onto a screen in a resolution of 800×600 pixel. Subjects viewed this screen through a mirror that was mounted onto the head coil. Prior to the imaging session, participants were given written instructions and performed a 5-minute practice session on a computer outside the scanner. After the imaging session, subjects received a post-experimental survey as well as a list of stimuli which they had just seen in the experiment and were asked to rate on a 5-point scale (1 = completely unknown, 5 = well known) whether they had already known the object use combinations prior to the experiment.<sup>1</sup>

#### 4.5. Data acquisition

Functional MRI was acquired via whole-body 1.5 T Siemens Symphony scanner (Siemens, Erlangen, Germany) with a standard head coil at the Bender Institute of Neuroimaging. A single-shot gradient echo planar imaging (EPI) sequence was used with the following parameters: 25 axial slices; repetition time (TR), 2500 ms; echo time (TE), 55 ms; flip angle (FA), 90°; field of view (FOV), 192 mm; voxel size, 3×3×3 mm; slice thickness, 5 mm; gap, 1 mm; volumes: 614. A detailed T1-weighted anatomical MP-RAGE (magnetized prepared rapidly acquired gradient echo) sequence consisting of 160 volumes (1 mm slice thickness) was conducted with the same spatial image orientation as the functional data.

#### 4.6. fMRI data analysis

Data were preprocessed and analyzed using SPM 8 routines (Wellcome Department of Cognitive Neurology, London, UK). The preprocessing procedure consisted of a realignment to the first image, slice time correction, coregistration of functional and anatomical data, segmentation and normalization to the standard brain of the Montreal Neurological Institute and smoothing with a Gaussian kernel with a full width at half maximum (FWHM) of 9 mm. Low-frequency signal changes and baseline drifts were removed using a high-pass filter set at 150 s.

Event-related BOLD responses were analyzed using the general linear model with a canonical hemodynamic response

function combined with time and dispersion derivatives time-locked to the onset of the event. The design matrix included one regressor for each condition (HUHA, HULA, LUHA, null events), one regressor for each question (Question 1: unusual, Question 2: appropriate, together with the reaction time of the button press as a parametric modulation parameter), and the six movement parameters from the realignment procedure. The regressors for each condition were determined individually according to the individual responses of each participant. Pair-wise T-contrasts between the three conditions were computed and the resulting contrast images were used for second level analysis.

The main focus centered on three second-level conjunctions which were computed for whole brain analysis as well as a priori defined regions of interest via paired T-Test routines. These revealed which brain regions were commonly activated across contrasts as a function of a particular process of interest. First Conjunction (conceptual expansion):  $HUHA > HULA \cap HUHA > LUHA$ . Second Conjunction (Unusualness):  $HUHA > LUHA \cap HULA > LUHA$ . Third Conjunction (Appropriateness):  $HUHA > HULA \cap LUHA > HULA$ .

For both the whole brain and the ROI analysis a family-wise error (FWE) of  $p < .05$  was applied to correct for multiple comparisons. Additionally for the whole brain analysis a cluster threshold of 3 voxels was adopted for single peaks. The ROI analyses were performed for a priori predicted regions (BAS 10, 45, 47, 38, 21) using the WFU Pickatlas toolbox version 2.5.2 for SPM (Maldjian et al., 2003; Maldjian et al., 2004).

#### Author contributions

SK and AA wrote the paper. AA conceived of the study. SK carried out the study and the analyses. SK, BR and AA developed the final experimental design. SW and BR provided theoretical and methodological expertise at several stages of the project. RS and CH provided methodological expertise and laboratory settings to carry out the study.

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#### Appendix A. Supplementary data

Supplementary data to this article can be found online at [doi:10.1016/j.brainres.2011.10.031](https://doi.org/10.1016/j.brainres.2011.10.031).

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<sup>1</sup> Results of the post-experimental survey are not explored in detail because of evidence of an unexpected memory bias which is likely to have occurred due to prior exposure to HUHA stimuli in the fMRI experiment. Participants who were confronted with the stimuli during the fMRI session tended to rate the object-use combinations in the HUHA condition as more familiar in the post-fMRI feedback session compared to another control group of participants ( $n=14$ ) who did not participate in the main fMRI experiment and had no prior exposure to the stimuli used in the experiment (mean novelty rating for HUHA in the experimental group=2.23,  $sd=0.58$ ; mean novelty rating for HUHA in the control group=1.90,  $sd=0.65$ ;  $cohen's\ d=0.54$ ). As this difference between the experimental and control groups was only specific to the HUHA ratings and not to the HULA (mean experimental group=1.09 vs. mean control group=1.08) or LUHA ratings (mean experimental group=4.89 vs. mean control group=4.91), we postulate that the engagement with the HUHA stimuli during the fMRI session and the successful integration of unusual but appropriate object-use combinations into existing semantic networks thereafter is likely to have given rise to this memory bias.

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