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Research Report

An ERP study of passive creative conceptual expansion using a modified alternate uses task

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ABSTRACT

A novel ERP paradigm was employed to investigate conceptual expansion, a central component of creative thinking. Participants were presented with word pairs, consisting of everyday objects and uses for these objects, which had to be judged based on the two defining criteria of creative products: unusualness and appropriateness. Three subject-determined trial types resulted from this judgement: high unusual and low appropriate (nonsensical uses), low unusual and high appropriate (common uses), and high unusual and high appropriate (creative uses). Word pairs of the creative uses type are held to passively induce conceptual expansion. The N400 component was not specifically modulated by conceptual expansion but was, instead, generally responsive as a function of unusualness or novelty of the stimuli (nonsense = creative > common). Explorative analyses in a later time window (500–900 ms) revealed that ERP activity in this phase indexes appropriateness (nonsense > creative = common). In the discussion of these findings with reference to the literature on semantic cognition, both components are proposed as indexing processes relevant to conceptual expansion as they are selectively involved in the encoding and integration of a newly established semantic connection between two previously unrelated concepts.

1. Introduction

1.1. *Current state of creativity research*

Ever since brain based investigations of creative thinking emerged around two decades after Joy Paul Guilford gave his Presidential Address about creativity to the American Psychological Association in 1950 (Arden et al., 2010; Guilford, 1950), many efforts have been made to investigate our ability to think creatively. While neuroscientific investigations of creativity primarily employed EEG based methodologies, the past 10–15 years have also witnessed a great surge of neuroimaging studies on creative thinking. However, we are still far from understanding the specific neural

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underpinnings of creative cognition as what has emerged after four decades of creativity research are a multitude of scattered results and few consistent conclusions (Arden et al., 2010; Dietrich and Kanso, 2010). This is due to many factors such as a great deal of diversity in how creative thinking is measured, as well as a high variance regarding appropriate control tasks. In addition, the neuroscientific study of creativity is also challenging as it is often difficult to determine the exact time point of the process of interest, as well as to obtain enough trials to reach sufficient statistical power, or, for instance, to prevent movement inducing responses which could lead to artefacts (Abraham et al., 2012b; Abraham, 2012).

One further challenging problem is that there is a tendency to investigate creativity as though it is a unitary construct (Dietrich and Kanso, 2010). In an effort to go against such trends, new paradigms have been adopted in recent neuroimaging studies where select operations of creativity, such as conceptual expansion, have been targeted (Abraham et al., 2012a, 2012b; Rutter et al., 2012b; Kröger et al., 2012) Conceptual expansion describes the ability to broaden the defining boundaries of semantic concepts beyond their usual characteristics (Smith et al., 1995; Ward, 1994) This is a process that is vital in the generation of novel ideas and it has been investigated in fMRI studies using paradigms that call for active generation (Abraham et al., 2012b) or passive induction (Rutter et al., 2012b; Kröger et al., 2012) of conceptual expansion. Few ERP studies, however, have been conducted thus far to assess conceptual expansion or indeed any other aspect of creativity.

1.2. *Previous ERP research on creativity*

Traditionally, EEG studies in the field of creativity research have focused on either amplitude or synchronization changes associated with creative performance, but seldom have ERP components been explored in relation to creative cognition (Arden et al., 2010; Dietrich and Kanso, 2010). Until recently, the only exception to this case were a handful of investigations on insight problem solving (Lang et al., 2006; Lavric et al., 2000; Luo et al., 2011; Qiu et al., 2008).

In a recent study conducted by Rutter et al. (2012a), a novel and promising way to investigate creative thinking using ERP methods was established. In this study, conceptual expansion was successfully linked to the well-known N400 component. Rutter et al. (2012a) used metaphorical statements as stimuli and compared creative (unusual and appropriate), nonsensical (unusual and inappropriate) and literal phrases (usual and appropriate) which were classified as such by subjects on a trial-by-trial basis. One of their findings was that the N400 and a late ERP component were modulated as a function of the unusualness of the stimuli.

The N400 component is a well-documented ERP component which is characterized as a negative-going waveform between 200 and 600 ms, which peaks around 400 ms after the critical event. It usually shows a centro-parietal distribution and a slight right-hemisphere bias (Kutas and Federmeier, 2011). This ERP component was first reported as a brain response to semantically incongruent sentence endings, such as "He took a sip from the *transmitter* (Kutas and Hillyard, 1980). The authors proposed that a higher N400 signalled an interruption of on-going sentence processing and a search for meaning in the sentence. Following the original discovery, several studies have investigated the N400 using a variety of paradigms. This ERP component is held to be highly relevant for indexing lexical and semantic aspects of language processing as well as semantic memory and recognition memory(Kutas and Federmeier, 2011; Lau et al., 2008).

1.3. *The present study*

To investigate the link between conceptual expansion to the N400 component, this present study adapted a paradigm used in an fMRI study by Kröger et al. (2012) where conceptual expansion was induced using a modified version of the alternate uses task (Wallach and Kogan, 1965). The original alternate uses task requires the generation of 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) to include novel dimensions (e.g., plant pot, ashtray). The responses in the classic alternate uses task are not differentiated in terms of the degree to which they encompass the two defining components of creativity, which are Originality (novel, unique) and Appropriateness (relevant, meaningful) (Runco and Jaeger, 2012). The current modification of original paradigm, however, enables the concurrent consideration of both these components separately (originality OR appropriateness) as well as together (originality AND appropriateness).

In this experimental task (Fig. 1), subjects were shown word pairs consisting of an everyday object and a potential use for this object. Subjects had to decide on a trial-by-trial basis whether they found the use for the given object to be unusual, appropriate or both. Three different trial outcomes

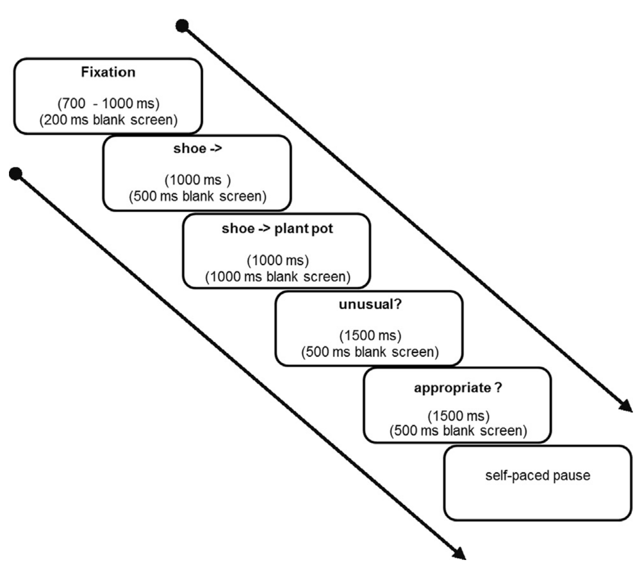

Fig. 1 – Experimental trial overview: The fixation period lasted between 700 and 1000 ms (steps of 100 ms). Total trial length from fixation cross to onset of the break thus varied between 8400 and 8700 ms.

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

Conditions	Unusual (Question 1)		Appropriate (Question 2)	
	Mean	SD	Mean	SD
Creative uses	712	180	601	183
Nonsensical uses	751	156	571	167
Common uses	655	153	546	143

were possible: object use combinations rated as highly unusual and highly appropriate (creative uses), or highly unusual and low appropriate (nonsensical uses) or low unusual and highly appropriate (common uses). Subjects were informed that the fourth trial outcome of a no–no response (low unusual and low appropriate) was not possible and would not make sense because a low appropriate object-use combination is always highly unusual. This experimental design therefore allowed each trial to be individually validated by each participant as belonging to one of the three conditions (creative uses, nonsensical uses, common uses). Trials in which subjects judged a particular object use combination to be highly unusual and highly appropriate (creative uses) are trials in which conceptual expansion was passively induced. This is because subjects needed to loosen and expand the conceptual boundaries of the object in order to make a new semantic connection between the previously unrelated object-use concepts.

In line with the literature, we expect a modulation of the N400 as a function of the semantic congruence of the given object-use combination. Trials judged as low unusual and high appropriate (common uses) should result in a reduced N400 amplitude as no violation of prior world knowledge occurred (Hagoort et al., 2004). This would be in contrast to trials judged as high unusual and low appropriate (nonsensical uses), which should show a strong N400 amplitude. The interesting case would be the N400 pattern associated with the trials judged as highly unusual and highly appropriate (creative uses), where conceptual expansion was induced as novel but fitting associations were made. On the one hand, a semantic mismatch or incongruence occurs as the subject is exposed to a wholly novel semantic association. Thus, just as in the case of the nonsensical uses, the N400 associated with the creative uses is expected to be significantly higher than that of the common uses. On the other hand, unlike the nonsensical uses, creative object use combinations can be successfully integrated into existing semantic networks. Rutter et al. (2012a) reported a graded effect in the N400 time window with the highest amplitude for nonsensical metaphors and more positive amplitudes for creative metaphors, followed by literal phrases (N400: nonsense > creative > common).

If the N400 reflects solely semantic or world knowledge violations, we expect the N400 to be undifferentiated between the creative uses and nonsensical uses. However, if the N400 is also responsive to the successful integration of novel semantic association into existing knowledge structures, we expect the N400 amplitude to be smaller in the case of creative uses compared to nonsensical uses, in line with the findings of Rutter et al. (2012a).

2. Results

2.1. *Behavioral findings*

The mean concordance between experimenter-determined conditions and subject-determined conditions was highest for common uses (92.8%) followed by nonsensical uses (88.3%) and creative uses (80.2%), showing that, as expected, the creative uses were judged more subjectively than the other uses ($p < .05$).

Table 1 shows the mean reaction times and standard deviations across all conditions to both questions. The repeated measures ANOVA with the factors condition (creative uses, nonsensical uses, common uses) and question (first question = unusual, second question = appropriate) revealed significant main effects for both the factors: condition ($F(2, 38) = 11.1$; $p < .001$; partial eta squared $\eta^2 = .37$) and question ($F(1, 19) = 71.4$; $p < .001$; partial $\eta^2 = .79$). These main effects indicate that responses to creative uses and nonsense uses were associated with longer reaction times than in the case of common uses and that responses to the first question (Unusual?) were significantly slower than responses to the second question (Appropriate?). A significant interaction effect (condition × question) between both the factors was also found ($F(2, 38) = 8.5$; $p = .001$; partial $\eta^2 = .31$).

Bonferroni-corrected ($p < .05$) post hoc *t*-tests which were conducted to explore the interaction effect revealed that subjects responded significantly faster to the first question in the common uses condition compared to the first question in the creative uses ($p = .015$; Cohen's $d = .34$) and nonsensical uses conditions ($p < .001$; $d = .62$). Additionally, subjects responded significantly faster to the second question in the common uses condition compared to the second question in the creative uses condition ($p = .027$; $d = .34$).To further explore this interaction effect, a 2 × 2 repeated measures ANOVA with the factors condition (creative uses, nonsensical uses) and question revealed that even after removing the common uses from the analysis a significant interaction effect remained ($F(1, 19) = 21.2$; $p < .001$; partial $\eta^2 = .53$). This indicates that the resulting interaction is due to the fact that responses to the first question (unusual) were slower in nonsensical uses trials than in the creative uses trials, but were faster in nonsensical uses trials following the second question (appropriate)[1].

2.2. *ERP findings: General*

Grand average waveforms of 36 electrode sites covering the entire scalp are shown in Fig. 2. The waveforms of single electrode sites Cz and C2 are depicted in Fig. 3 for a closer

[1]Please note that the RT data was derived from the time taken to respond to the question prompts, and not the time taken to respond to the stimuli. However, as information related to the question prompt is assessed prior to the prompt itself, we cannot make any clear claims about how the RT measurements directly relate to the cognitive processes in question. We nonetheless include the RT-related findings in the paper as it may be of interest to researchers in order to understand all the peripheral factors that relate to the implementation of this novel ERP paradigm in the study of creative cognition.

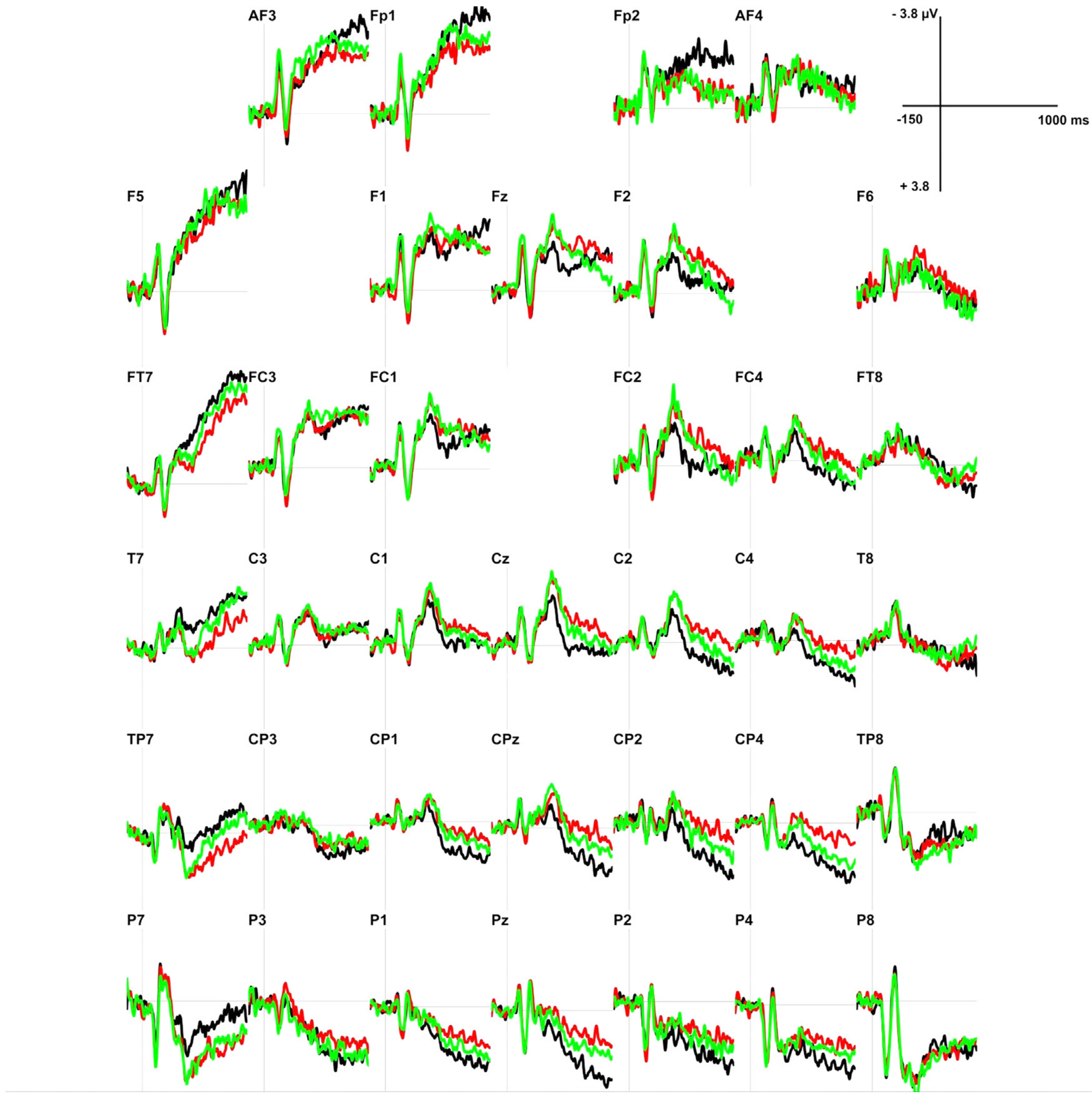

Fig. 2 – Grand-average ERPs for creative uses (green line), nonsensical uses (red line) and common uses (black line) on 36 electrodes. Vertical line marks onset of the critical word. Negativity is plotted upward. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

illustration of the negative going peak around 400 ms (N400) after onset of the critical word. Starting at around 500 ms a positive-shift can be seen in all three conditions which is smaller for nonsensical uses trials compared with creative and common uses trials.

2.3. ERP findings: N400 (time window 300–500 ms)

The repeated measures ANOVA showed significant main effects for the factor electrode ($F(8, 152)=33.9$; $p<.001$; partial $\eta^2=.64$) and condition ($F(2, 38)=5.9$; $p=.007$; partial $\eta^2=.24$) and no significant interaction of electrode × condition ($F(16, 304)=1.2$; $p=.3$; partial $\eta^2=.06$).

The N400 differences between the conditions were such that creative uses ($p=.038$; $d=2.48$) and nonsensical uses ($p=.027$; $d=2.61$) elicited a significantly greater negative mean amplitude in this time window than the common uses. However, the N400 elicited during the processing of creative uses and nonsensical uses did not differ significantly from one another ($p=1$; $d=.18$) (Fig. 4).

2.4. ERP findings: Post-N400 late component (time window 500–900 ms)

To assess potential differences between the three conditions beyond the N400 time window, an explorative analysis was conducted in the late time window between 500 and 900 ms. As shown at electrode sites Cz and C2 in Figs. 2 and 3, waveforms associated with nonsensical and creative uses begin to diverge after 500 ms, with a greater sustained negativity for nonsensical uses but a more positive shift in case of creative uses.

The repeated measures ANOVA revealed significant main effects for the factor electrode ($F(8, 152)=31.6$; $p<.001$; partial $\eta^2=.62$) and condition ($F(2, 38)=10.8$; $p=.001$; partial $\eta^2=.36$)

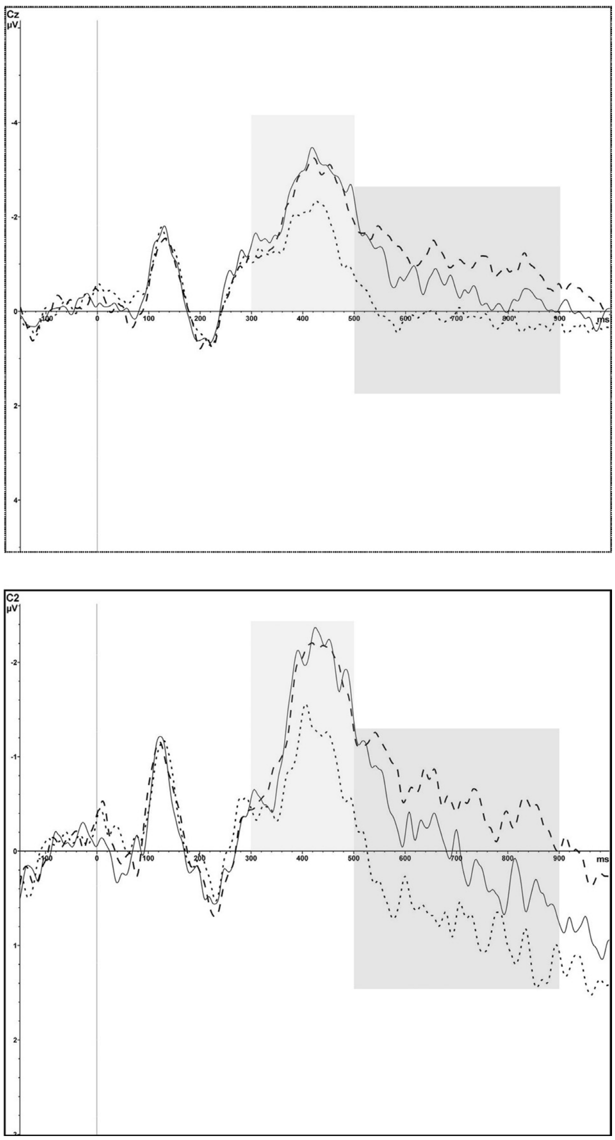

Fig. 3 – Grand average ERPs on electrode sides Cz and C2 for creative uses (solid line), nonsensical uses (dashed line) and common uses (dotted line). Light-gray box marks early time window (300–500 ms, N400 analysis). Dark gray box marks late time window (500–900 ms, post-N400). Vertical line marks onset of the critical word. Negativity is plotted upward. Timeline in milliseconds.

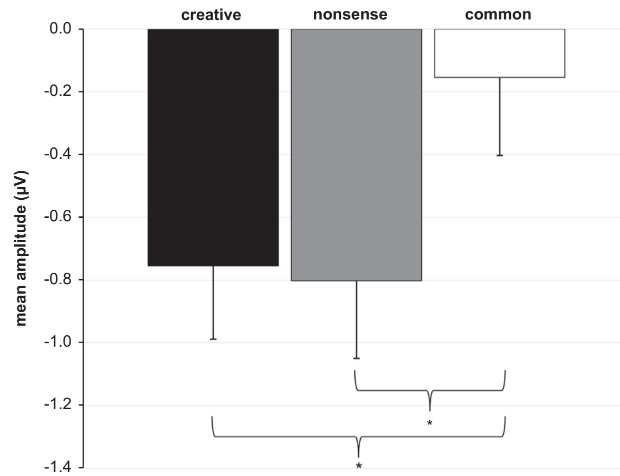

Fig. 4 – Mean amplitudes from nine electrodes (C1, Cz, C2, CP1, CPz, CP2, P1, Pz and P2) of all three conditions (creative uses, nonsensical uses, common uses) in early time window (300–500 ms, N400 effect). Error bars shown represent standard error of the mean. Significant differences ($p<.05$) are marked with an asterisk.

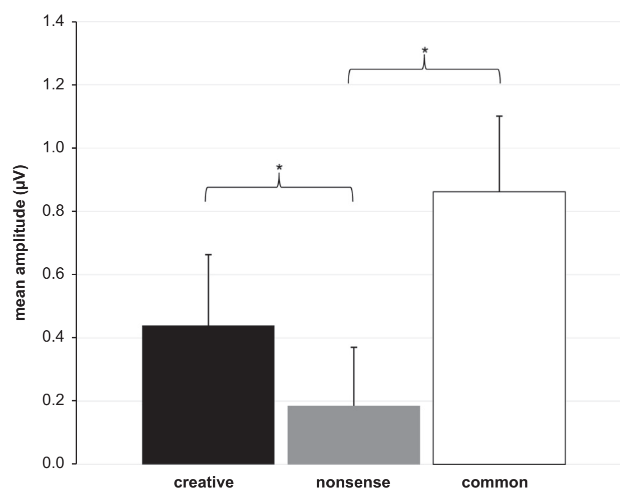

Fig. 5 – Mean amplitudes from nine electrodes (C1, Cz, C2, CP1, CPz, CP2, P1, Pz and P2) of all three conditions (creative uses, nonsensical uses, common uses) in later time window (500–900 ms). Error bars shown represent standard error of the mean. Significant differences ($p<.05$) are marked with an asterisk.

and again no significant interaction of electrodes × condition ($F(16, 304)=1.2$; $p=.3$; partial $\eta^2=.06$).

Moreover, just as in the case of the N400, the difference between waves elicited by the nonsensical uses and common uses in the later time window continued to be significant ($p<.001$; $d=4.32$). However, unlike in the case of the N400, the waves elicited during processing of creative uses did not differ significantly from common uses in the late time window ($p=.3$; $d=1.83$). While creative uses and nonsensical uses were undifferentiated in their N400 response, in the post-N400 late time window, the processing of creative uses led to a more positive amplitude shift compared to nonsensical uses ($p=.011$; $d=2.44$) (see Fig. 5).

3. Discussion

The aim of the current study was to investigate possible modulations of the well-established N400 ERP component alongside later potential ERP components by the creative cognitive process of conceptual expansion when compared to the information processing of mere novelty or appropriateness. A recent ERP study conducted by Rutter et al. (2012a) was also conducted to this end. However, in contrast to that study, the employed stimuli in the present study were not metaphors but word pairs consisting of everyday objects and of a described use for this object within a modified alternate uses task paradigm.

In doing so, we implemented several innovations in the investigation of creative thinking using EEG methods. First of all, we chose not to focus on creativity as a unitary entity and instead targeted one crucial mental operation of creative thinking, namely conceptual expansion. We also did not analyze EEG amplitude or synchronization changes but assessed the process of conceptual expansion with reference to specific time-locked ERP components. The experimental paradigm was designed such that each trial of the experiment had to be individually validated by each subject as belonging to a particular condition. Individual differences in the process of conceptual expansion were thus taken into account. This approach also allowed for the assessment of the separable effects of originality and appropriateness from that of creative conceptual expansion which arises from a combination of these factors (Kröger et al., 2012).

3.1. *Modulation of the N400*

The results clearly demonstrate that object-use pairs that were classified by the participants to be high unusual and low appropriate (nonsensical uses) or high unusual and high appropriate (creative uses) associations elicited significantly higher N400 amplitudes than those classified as low unusual and high appropriate (common uses). This fits perfectly with the N400 literature which suggests that the N400 is particularly responsive to semantic deviance. Moreover, the N400 amplitude difference between the nonsensical uses and creative uses was not significant which indicates that the N400 is sensitive to the levels of novelty or unusualness associated with the stimuli but not to differing levels of associated appropriateness of the conceptual combinations. This finding suggests that the mental operations in relation to conceptual expansion are not solely reflected in the N400 component. After all, the pattern of the N400 was not differentiated by the fact that although the creative object-use combination is semantically incongruent at first, unlike the case of the nonsensical object-use combination, the novel semantic association evoked by the creative uses can eventually be successfully integrated into one′s knowledge structures.

Defining what the N400 indexes is a matter of on-going debate (Kutas and Federmeier, 2011). While some classify the N400 as a correlate of an early prelexical stage of the comprehension processing stream (Deacon et al., 2000) others associate the N400 with a later postlexical stage (Hagoort et al., 2004). The fact that the N400 is influenced by top-down processes as well as bottom-up processes, led to the recent proposal by Lotze et al. (2011), that the degree of matching between top-down processes and bottom-up information is reflected in the N400 modulation, with a mismatch resulting in a higher N400 amplitude. In their study they were able to show, for example, that pure form-based information (upper-case letters) could attenuate the N400 effect of a critical word (Lotze et al., 2011).

Given that the current study was not designed to test the validity of these competing theories, the findings of our study cannot be taken as direct support to any one of these theoretical formulations over another. As the N400 amplitudes were higher upon exposure to both the creative and nonsensical object-use combinations relative to the common object-use combinations in the current study, we postulate that the modulation seen here is likely to reflect a mismatch between expectations or world knowledge and the critical word. This mismatch led to comparable N400 amplitudes in both the nonsensical uses and creative uses condition relative to the common uses condition (nonsensical uses = creative uses > common uses).

The N400 pattern shown in the current study is only partially comparable to the reported N400 pattern in the study of Rutter et al. (2012a). Although the reported main effects were comparable in both studies, a linear trend was also discovered in the Rutter et al. (2012a, 2012b) study which suggested a graded effect in the N400 time window, with the highest negative mean amplitude for nonsensical metaphors and less negative amplitudes for creative metaphors, both relative to literal phrases (N400: nonsensical > creative > common). Apart from the many differences in the methodological approach (stimulus material, analysed electrodes, subjects, statistical analysis, etc.) between the two studies, there are also critical differences between the cognitive demands of the two tasks used. When faced with the task employed in the current study, there is a higher need for inference generation to be able to judge whether a given object use combination is unusual and appropriate (e.g. creative uses: shoe → plant pot). In the study of Rutter et al. (2012a) the manner in which the presented concepts could be related to one another was far more obvious as the connection and direction of the association was explicitly stated within the sentence (e.g. creative phrases: The clouds wept over the fields).

We can thus conclude that the manner in which the N400 is modulated in semantically incongruent contexts may be dependent on one or more of these subtle factors, which could in turn lead to discrepancies across studies in this early ERP time window.

3.2. *Late ERP components (post-N400: 500–900 ms)*

As no significant difference was found between the amplitudes elicited by creative uses (conceptual expansion) and nonsensical object-use combinations in the N400 time window, an explorative analysis was run in a post-N400 time window to evaluate whether any differences between these conditions would emerge, as also reported by Rutter et al. (2012a). Significant differences between the amplitudes of the three conditions were found in that greater positive mean amplitudes were associated with the processing of creative uses and common uses compared to nonsensical uses. Just as in the case of the N400, the nonsensical object-use combinations continued to elicit a stronger relative negativity in the late window compared to the common object-use combinations. But there was a fascinating switch in the amplitude pattern associated with the creative object-use combinations as the brain activity associated with the processing of creative uses was no longer significantly differentiable from that of the common uses, whereas the difference between the mean amplitude of creative and nonsensical uses was highly significant (nonsensical > creative = common).

These findings also only partially fit with the results reported by Rutter et al. (2012a) in the later time window. They reported a linear trend which showed a graded effect (nonsensical > creative > common) with the lowest mean amplitude for nonsensical metaphors followed by creative metaphors, both relative to literal phrases. However, unlike in the present findings, the ERP waveform differences between the creative phrases and literal phrases was still significant (Rutter et al., 2012a).

On the basis of the pattern of findings in the current study, we postulate that the relative negativity in the nonsensical uses condition results from the continued failure to integrate the nonsensical object-use combination into existing semantic networks, whereas the positive shift found in the creative uses condition (and the common uses condition) could be indicative of a successful semantic integration process. As few ERP studies have been conducted to investigate creative thinking, we refer to findings from other related cognitive domains to aid our interpretation of this post-N400 effect.

Post-N400 slow wave effects have been previously described in studies on joke comprehension (Coulson and Williams, 2005; Coulson and Wu, 2005), as well as language comprehension tasks (Baggio et al., 2008, 2010; Davenport and Coulson, 2011, 2013; Pijnacker et al., 2009; Rhodes and Donaldson, 2008). However, such slow wave effects were often observed as sustained negativities (Baggio et al., 2008; Coulson and Williams, 2005; Nieuwland and Van Berkum, 2008; van Berkum, 2009) or as late positivities (Davenport and Coulson, 2011, 2013) over frontal electrode sites. Studies that report slow wave effects over centro-parietal electrodes sites therefore offer a better comparison to the results found in the present study.

For example, Baggio et al. (2010) reported a similar centro-parietal slow wave effect following the reading of sentences like: "The journalist began the article before his coffee break". These sentences necessitate the reader to infer that the journalist started to write the article. This "silent semantic element" therefore requires additional cognitive computations, which were reflected in a post-N400 time window (500–1000 ms) in form of a sustained negative shift (Baggio et al., 2010).

In a study by Pijnacker et al. (2010), participants had to decide whether a presented conditional inference was correctly drawn from a given modus ponens which was either preceded by a congruent or a disabling context (Pijnacker et al., 2010). A disabling context led to more rejections of the drawn conclusion and elicited a slow negative wave starting at around 250 ms after onset of the critical word and lasting until 1000 ms over central electrodes. The authors interpreted this slow wave negativity as a correlate of a "complex, inference-driven interpretive process" (Pijnacker et al., 2010).

Both studies thus reported a post-N400 sustained negativity possibly reflecting higher cognitive demands, which is not entirely in line with the present findings as the post-N400 sustained negativity was found for nonsensical uses which were not necessarily more cognitively demanding or involved complex inference processing.

The findings of Rhodes and Donaldson (2008) offer a better fit to the current results regarding the sustained negativity effect for nonsensical trials. In their experiment, unrelated word pairs elicited a comparable sustained negativity in a time window between 500 and 900 ms over left parietal electrode sites compared to word pairs which were either associatively or semantically related (Rhodes and Donaldson, 2008). The more positive amplitudes for related word pairs compared to unrelated word pairs were interpreted as recollection from long-term memory, possibly reflecting the well-known parietal old/new effect (Rugg and Curran, 2007). However, the effect in their study followed a left parietal distribution, whereas the effect in the present study showed a more right-lateralized centro-parietal distribution.

In summary, although there are many findings regarding post-N400 slow wave effects, it is still difficult to draw clear conclusions about the function of such late ERP components. This is because each of these studies have targeted different cognitive processes with different paradigms, and therefore cannot be readily aligned with one another. While the studies could be partly related to one another with reference to the nonsensical uses condition and the findings of associated sustained negativity, there is little comparability between the paradigms in the context of the creative uses condition and the underlying process of conceptual expansion. So the hypothesis that the post-N400 late ERP component reflects the success associated with the semantic integration process is one that begs further exploration.

3.3. *Conclusions and implications*

In summary, this study successfully adapted a novel experimental fMRI paradigm within an EEG setting (Kröger et al., 2012) to carry out one of the first ERP experiments to investigate conceptual expansion as one critical aspect of creative thinking. In doing so we have demonstrated that well-established ERP components can be used to investigate the neural correlates of creative thinking when suitable paradigms are developed that focus on specific creative cognitive processes.

The results of the current study, where a modified alternate uses task was used to assess passively induced creative conceptual expansion relative to novelty and appropriateness, found two ERP components to be instrumentally implicated in these operations: the N400 and a post-N400 late component. By relating these findings to those of related fields in the literature, it appears that the N400 acts like a semantic novelty or mismatch indicator whereas the successful integration of relevantly associated concepts within one′s conceptual knowledge is reflected within a later post-N400 time window.

With regard to implications of the findings for the field of creative cognition, the N400 was found to reflect the processing of novelty or unusualness as it was insensitive to the distinction between novelty that is contextually inappropriate (nonsensical uses) and novelty that is contextually appropriate (creative uses). The post-N400 late component, in contrast, reflected the process of appropriateness as it was insensitive to the distinction between appropriateness that is contextually familiar (common uses) and appropriateness that is contextually unfamiliar (creative uses). The discovery that the cognitive operations relevant to conceptual expansion are best captured by taking into account the influence of both the N400 time window (novelty or originality) AND the post-N400 late time window (reflecting appropriateness or fit) is a valuable one for the field of creative neurocognition. This is especially significant as originality (novelty/unusualness) and appropriateness (relevance/fit) are the two defining elements of creativity (Stein, 1953).

Investigating the information processing of novel yet appropriate conceptual combinations that induce conceptual expansion in real-time within neuroscientific settings provide a unique avenue by which one can not only uncover the dynamics underlying select aspects of creative thinking, but also attain a broader understanding of the neurocognitive mechanisms underlying semantic cognition.

4. Experimental procedures

4.1. *Participants*

Twenty-four right-handed students either received a 15 Euro payment or course credit for their participation in the experiment. Handedness was assessed using the German version of the Edinburgh Inventory of Handedness (Oldfield, 1971). Four subjects had to be excluded from further analysis because they did not reach the minimum inclusion criterion of at least 30 trials per condition (see Data Analyses section for further details). The final sample therefore comprised 20 native German-speaking subjects (11 women; age *range*= 20–27 years, *mean*=22.55, *SD*=2.1) with normal or corrected-to-normal vision. None of the participants had a history of neurological or psychiatric illness, and none were taking drugs according to self-report. All gave written informed consent before participation. The experimental standards were approved by the ethics committee of the German Society of Psychology (Deutsche Gesellschaft für Psychologie).

4.2. *Task design/procedure*

Participants were seated in front of a computer monitor in a separate room that was isolated from that of the experimenter and the computers. After applying the electrodes the participants were given task instructions and performed a 10-min practice session on a computer with another set of stimuli. Stimuli were presented using Presentation software (Neurobehavioral Systems, Inc., Albany, CA) and consisted of black letters (size=28) on a grey background. During each trial, subjects viewed two consecutive words consisting of a common object (first word) and a described use for this object (second word).

Each trial (see Fig. 1) started with a fixation cross presented in the middle of the screen, lasting between 700 and 1000 ms, which was jittered in steps of 100 ms. After a 200 ms blank screen, the first word (common object) was shown for 1000 ms followed by a 500 ms blank screen and the second word (described use, further referred to as critical word) lasting for another 1000 ms. We chose to present the two words one after another to prevent any overlap between ERP components. Following a 1000 ms blank screen, the questions “Unusual” and “Appropriate” each appeared for 1500 ms, separated by a 500 ms blank screen. Subjects were asked to give a yes/no answer to each of these questions by pressing either the left or the right arrow key of a computer keyboard with the index finger and the ring finger of their right hand.

Participants were instructed to decide whether they found a given object use combination to be unusual and/or appropriate. To prevent misunderstandings with what was meant with the words “unusual” and “appropriate”, they were told that a use was to be classified as “unusual” if it was novel or unfamiliar to them 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 (creative uses, yes–yes response), high-unusual and low-appropriate (nonsensical uses, yes–no response) and low-unusual and high-appropriate (common uses, no–yes response). Subjects were also informed that a no–no response (low unusual and low appropriate) would not make sense as a low appropriate object-use combination is always highly unusual.

After each trial, participants had the opportunity to take a break and start the next trial at their own pace, via button press of the up arrow key, to prevent extensive blinking and exhaustion. With a trial length of 10 s and a total of 135 trials, presented in a pseudo-randomized order, the experimental session lasted approximately 25 min (pauses taken by the participants not included).

4.3. *Materials*

The study used a stimulus-set created for a previous fMRI study (Kröger et al., 2012) which was adapted to meet ERP criteria for investigating the N400 component. 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 experimenter-determined conditions (creative uses, nonsensical uses and common uses) in combination with a described use for this object (for examples see Table 2). Words were checked for word length and frequency of occurrence in the German language. A one-way ANOVA revealed that there were no significant differences in word length between the three experimenter-determined conditions ($F(2, 132)=1.37$; $p=.26$). Frequency of occurrence in the

Table 2 – Example stimuli for all three conditions (creative uses, nonsensical uses, common uses) in German. English translation is added below the original stimulus.

Condition	Stimulus
Highly unusual and highly appropriate (*creative associations*)	Schuh→Blumentopf *shoe→plant pot*
Highly unusual and low appropriate (*nonsensical associations*)	Schuh→Osterhase *shoe→Easter bunny*
Low unusual and highly appropriate (*common associations*)	Schuh→Kleidungsstück *shoe→piece of clothing*

German language was computed using the online Vocabulary Database of the University of Leipzig in Germany (http://www.wortschatz.uni-leipzig.de/). The frequency classes of this database indicate the frequency of the target word in relation to the German definite article "der" ("the"). For example the word "der" ("the") is 2\widehat9 times more frequent than the word "Ball" ("ball"). A median test compar ing the three conditions confirmed that they did not differ significantly regarding the frequency of occurrence ($md=19$ for creative uses and nonsensical uses, $md=18$ for common uses; $p=.7$).

4.4. *ERP recording*

The electroencephalogram (EEG) was recorded from 64 Ag/AgCl electrodes using an actiCAP system (Brain Products GmbH, Gilching, Germany) and BrainVision recorder software. Data was recorded using an average-reference on-line. The EEG signal was amplified by a QuickAmp amplifier (Brain Products GmbH, Gilching, Germany) and sampled at 500 Hz by a 24 bit analogue-to-digital converter. Impedances were kept below 5 kΩ. Eye blinks and movements were recorded by bipolar EOG electrodes that were placed above and below the right eye, as well as in horizontal position next to both eyes.

4.5. *Data analysis*

As the subjects determined which trials should be allotted to each condition (creative uses, nonsensical uses, common uses) with their responses, it was important to establish sample homogeneity using a priori inclusion criterion that ensured a minimum number of trials per condition across all subjects in the final sample. Behavioral pilot studies indicated that some variability was unavoidable when using subject-determined trial classifications as participants vary from one another on the evaluation of whether a particular object-use combination should be considered as unusual and appropriate. While the subject-determined trial classification is certainly the major strength of the current paradigm as it ensures the individual validation of the experimental design, it also necessitates the exclusion of all participants who did not meet the strict inclusion criterion of having at least 30 trials per condition.

In order to detect significant differences in reaction times (RTs), a 3×2 repeated measures ANOVA was carried out, with the factors Condition (creative uses, nonsensical uses, common uses) and Question (Unusual, Appropriate).

EEG data were analyzed using the Vision Analyzer 2.0 software (Brain Products GmbH, Gilching, Germany). Raw data were initially filtered with a 50 Hz notch and a 0.01 Hz high-pass filter and afterwards segmented into epochs of 1150 ms duration. Each segment started at 150 ms before the onset of the critical word and belonged to one of the three possible conditions (creative uses, nonsensical uses or common uses) based on the participants′ responses. Segments were baseline-corrected using the 150 ms time window before onset of the critical word. Eye blinks were removed using an ocular correction procedure based on the Gratton and Coles algorithm (Gratton et al., 1983). A 30 Hz low-pass filter with a slope of 24 dB/Oct was applied and artefacts with amplitude exceeding +/−50 μV were removed. ERP waveforms were averaged for each participant and each condition. Subsequently grand-averaged ERPs of all participants were calculated in time windows of interest. An early time window (300–500 ms) and a late window (500–900 ms) were used to capture the N400 effect as well as any late components. This latter time window was chosen on the basis of a former study conducted by Rhodes and Donaldson (2008), who tried to capture any continuation of an observed N400 effect.

For each time window, a repeated measures ANOVA was computed using the CPz electrode and its eight neighbouring electrodes (C1, Cz, C2, CP1, CP2, P1, Pz, P2) as one factor (electrodes) and the three conditions (creative uses, nonsensical uses, common uses) as another factor (conditions). The electrode sites were chosen on the background of the known centro-parietal distribution of the N400 effect (Kutas and Federmeier, 2011) and in order to explore later ERP components following the N400, after visual inspection of the data.

Pairwise Bonferroni-corrected comparisons were carried out within the repeated measures analysis to assess possible main and interaction effects. In all cases, effects sizes (Cohen′s d and partial eta squared η^2) are reported along with significance levels.

The Greenhouse–Geisser correction (Greenhouse and Geisser, 1959) was applied to all ERP repeated measures analyses with more than one degree of freedom because the assumption of sphericity was violated. Corrected p-values with the original degrees of freedom are reported for both ERP time windows.

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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 HH provided theoretical and methodological expertise at several stages of the project. CH provided methodological expertise and laboratory settings to carry out the study.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.brainres.2013.07.007.

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