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# Can clouds dance? Part 2: An ERP investigation of passive conceptual expansion

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ABSTRACT

Conceptual expansion, one of the core operations in creative cognition, was investigated in the present ERP study. An experimental paradigm using novel metaphoric, nonsensical and literal phrases was employed where individual differences in conceptual knowledge organization were accounted for by using participants' responses to categorize the stimuli to each condition. The categorization was determined by their judgment of the stimuli on the two defining criteria of creativity: unusualness and appropriateness. Phrases judged as unusual and appropriate were of special interest as they are novel and unfamiliar phrases thought to passively induce conceptual expansion. The results showed a graded N400 modulation for phrases judged to be unusual and inappropriate (nonsense) or unusual and appropriate (conceptual expansion, novel metaphorical) relative to usual and appropriate (literal) phrases. The N400 is interpreted as indexing greater effort to retrieve semantic information and integrate the novel concepts presented through the phrases. Analyses of the later time-window showed an ongoing negativity that was graded in the same manner as the N400. The findings attest to the usefulness of investigating creative cognition using event-related electrophysiology.



## 1. Introduction

Creativity constitutes a fascinating ability in the repertoire of human adaptive behavior. Among the different theoretical frameworks concerning the definition of creativity and its underlying cognitive structures (e.g., Abraham & Windmann, 2007; Boden, 2003; Finke, Ward, & Smith, 1992; Mednick, 1962; Ward, 1994, 2007; Ward, Smith, & Finke, 1999), a working definition has resulted about what makes an idea or product creative. According to this definition, a creative thought or product is one that is both original and appropriate to the task at hand (e.g., Sternberg & Lubart, 1999).

### 1.1. Creativity as a complex of multiple cognitive processes

Despite the consensus-based definition of what creativity entails, neuroscientific research is far from drawing a coherent picture of creative processes with reference to brain functions. This is due to various problems, including methodological limitations, such as drawing or vocal responses and lengthy trial durations that render standard creativity tasks suboptimal when combined with neuroscientific techniques. One of the main conceptual problems, however, is the fact that creativity is rarely investigated in terms of the multitude of single cognitive operations that underlie creativity (Dietrich, 2004; Dietrich & Kanso, 2010). This is based in part on a widely held misconception of creativity with regard to the type of thinking that is believed to lead to a creative outcome. Divergent thinking which is evoked when multiple solutions can be generated to solve a problem, is often thought to be the only type of thinking to produce creativity. However, convergent thinking, which is evoked, when a problem has only one correct solution, can also contribute to creative thinking. Convergent processes in creativity are commonly targeted in the field of insight problem solving (Bowden, Jung-Beeman, Fleck, & Kounios, 2005). Conversely, divergent thinking can also occur during tasks that do not call for a creative solution, such as hypothetical or prospective reasoning (e.g., Abraham, Schubotz, & von Cramon, 2008) where the number of potential solutions is open ended. In studying creative cognition, we move beyond this classification of convergent vs. divergent thinking and instead focus on the cognitive operations involved in creative thinking (e.g., Finke et al., 1992). Just as in the case of other cognitive processes like working memory or semantic retrieval, creative operations like creative imagery or conceptual expansion could occur under conditions of divergent or convergent thought.

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One cognitive process that is of particular interest in the investigation of creativity is "conceptual expansion". As the term suggests, conceptual expansion describes the ability to broaden one's existing concepts beyond their conventional limits to include new features or exemplars (Ward, 1994; Ward, Smith, & Vaid, 1997) and requires divergent thinking. Widening one's concepts, especially over greater associative distances, is the basis for arriving at novel and applicable solutions for a problem at hand, thereby fulfilling the two requirements that render an outcome to be creative. In the framework of the creative cognition approach which postulates that creative thinking arises from ordinary fundamental cognitive processes present in all humans, conceptual expansion is discussed as being among the core cognitive operations that are recruited when arriving at a creative solution (Ward, 1994). The original task that assessed conceptual expansion as a creative process asked participants to draw animals from a planet that is different from earth (Ward, 1994; Ward, Patterson, Sifonis, Dodds, & Saunders, 2002). Participants' ability to expand existing concepts is measured by the degree to which the drawn animals deviate from earth creatures in terms of their basic features. While the original task assessing conceptual expansion cannot be suitably adapted to assess conceptual expansion in neuroscientific settings, the vital role played by conceptual expansion in creative cognition indicates that it is imperative to develop alternative paradigms that allow for a better understanding of the neurophysiological mechanisms underlying this creative cognitive operation.

### 1.2. Creativity and electrophysiological methods

While several studies have investigated creativity using electroencephalograms (EEG), as yet no study has attempted to link any component related to event-related potentials (ERP) with creative thinking (for a thorough review, see Dietrich & Kanso, 2010). One exception to this claim are studies on the phenomenon of insight during problem solving (e.g., Lang et al., 2006; Lavric, Forstmeier, & Rippon, 2000; Qiu et al., 2008). This is unfortunate given that ERPs offer significant advantages when investigating cognitive operations compared to other neurophysiological methods such as functional magnetic resonance imaging (fMRI). Apart from a high temporal resolution, specific ERP components are held to represent distinct cognitive processes so this method allows for the determination of the onset and temporal distribution of the cognitive process of interest.

The N400 ERP component, for instance, is certainly of great relevance with regard to processes involved during conceptual expansion. The N400 is a negative-going waveform with a centro-parietal distribution, typically appearing around 300–600 ms after onset of its activating event and peaking around 400 ms after stimulus onset. Modulation of the N400 amplitude has been reported for various factors, including semantically incongruous words (Kutas & Hillyard, 1980a, 1980b), cloze probability of the final word (Kutas & Hillyard, 1984), words violating the preceding discourse context or world knowledge (Hagoort, Hald, Bastiaansen, & Petersson, 2004; Hald, Steenbeek-Planting, & Hagoort, 2007; van Berkum, Brown, & Hagoort, 1999) and the difficulty of semantic integration (e.g., Kutas & Van Petten, 1994). The N400 is considered to be an index of the difficulty to retrieve conceptual knowledge from the memory stores in the brain (e.g., Kutas & Federmeier, 2000; Kutas, Van Petten, & Kluender, 2006). In semantic priming studies, the N400 has also been interpreted as an index for higher-level integrational processes (e.g., Brown & Hagoort, 1993).

As conceptual expansion requires the search for existing concepts and the integration of new semantic associations with these existing concepts, the N400 constitutes the candidate ERP component to indicate the occurrence of those cognitive operations. Moreover, results from fMRI studies investigating creative thinking have demonstrated that the brain structures that are known to be involved in semantic selection, retrieval and integration (e.g., Badre, Poldrack, Pare-Blagoev, Insler, & Wagner, 2005; Green, Fugelsang, Kraemer, Shamosh, & Dunbar, 2006; Green, Kraemer, Fugelsang, Gray, & Dunbar, 2010; Poldrack et al., 1999; Thompson-Schill, D'Esposito, Aguirre, & Farrah, 1997) are engaged during creative conceptual expansion, as well (Kröger et al., 2012; Rutter et al., 2012). It remains unclear, however, if such parallels can be transferred to ERPs in a similar manner. The present study is the first of its kind to investigate creative cognition using ERPs. The objective is to clarify the manner in which ERP components that index semantic cognitive operations are modulated by creative cognitive processes.

### 1.3. The present study

Conceptual expansion is investigated in the present ERP study with the concurrent aim of overcoming some of the aforementioned shortcomings in neurophysiological research on creativity. A new approach is adopted which is based on the assumption that conceptual expansion cannot only be brought about "actively" such as when one volitionally attempts to expand a concept to include novel and relevant facets relating to other concepts, but also "passively" through the presentation of two distantly associated items that need to be connected through the widening of concepts (Kröger et al., 2012; Rutter et al., 2012). The approach adopted in the current study takes the latter perspective. Participants are not provided with a task that actively requires them to engage in conceptual expansion. Instead, conceptual expansion is passively induced in participants. A suitable way to implement this approach is to draw from experimental paradigms used in metaphor processing studies.

The comprehension of novel metaphors heavily relies on the integration of two distant concepts to provide meaning. Psycholinguistic studies on novel metaphor processing have repeatedly shown an increased N400 amplitude for novel metaphors compared to conventional metaphors and literal expressions (e.g., Arzouan, Goldstein, & Faust, 2007; De Grauwe, Swain, Holcomb, Ditman, & Kuperberg, 2010; Lai, Curran, & Menn, 2009). While the main focus of metaphor studies is to investigate how language is processed under different syntactic or semantic constraints, the objective of the current study is to differentiate how the information processing involved during conceptual expansion differs from the processing of mere unusualness and appropriateness. Although the current study differs from investigations of metaphor processing in terms of the main goals, paradigms from the language comprehension field have been adapted in the current study to suit our ends.

Participants in the current study were presented with novel metaphoric, nonsensical and literal expressions. In order to account for individual differences in participants' conceptual knowledge structures and their abilities to expand existing concepts, the new paradigm does not rely on classic experimenter-determined experimental conditions. Instead, the current approach requires participants to make yes/no judgments on the presented phrases with regard to the originality (unusualness) and relevance (appropriateness). Originality and relevance, as mentioned earlier, are the two defining features of creativity. This procedure results in the subject-determined categorization of the stimuli phrases as belonging to one of the following conditions: highly unusual and highly appropriate (HUHA/novel metaphoric), highly unusual and low appropriate (HULA/nonsense) or low unusual and highly appropriate (LUHA/literal).

**Table 1**
Example phrases for the three experimental conditions. Critical word is printed in bold. The literal English translation of the example phrases is presented in brackets. A complete list of the stimuli is listed in the Supplementary material.

| Condition | Phrase |
|---|---|
| Highly unusual – highly appropriate (HUHA) | *Die Wolken haben über der Stadt* ***getanzt****.* (The clouds have **danced** over the city.) |
| Highly unusual – low appropriate (HULA) | *Die Wolken haben über der Stadt* ***gelesen.*** (The clouds have **read** over the city.) |
| Low unusual – highly appropriate (LUHA) | *Die Wolken sind über die Stadt* ***gezogen****.* (The clouds have **moved** over the city.) |

Examples for each of the conditions can be found in Table 1. Phrases from the HUHA category are those that induce conceptual expansion in participants as it contains instances where previously unrelated or weakly related concepts are associated with one another in a novel yet relevant manner. It has to be noted that a combination of low unusualness and low appropriateness is not possible, as an association which is low in appropriateness is automatically highly unusual.

Employing subject-determined conditions allows one to rule out variability caused by inter-individual differences as what one participant regards as unusual and appropriate might be deemed as not unusual at all by another participant. The subject-determined conditions based on participant's judgments of the unusualness and appropriateness of the phrases also sets the present study apart from conventional metaphor processing studies. The latter employ phrases or word pairs that are predetermined by the experimenter to be novel metaphoric, conventional metaphoric, nonsensical or literal (e.g., Arzouan et al., 2007; Balconi & Amenta, 2010; Coulson & Van Petten, 2002; Lai et al., 2009). Moreover, participants' tasks in metaphor processing studies either involve silently reading the presented material (Balconi & Amenta, 2010) or making a judgment about whether or not the stimuli are meaningful or appropriate (Arzouan et al., 2007; Lai et al., 2009). The present study, in contrast, asks participants for their judgment on both of the essential elements that characterize a creative response, namely unusualness and appropriateness.

In line with findings from studies on metaphor processing (e.g., Coulson & Van Petten, 2002; Lai et al., 2009), HULA (nonsense) and HUHA (novel metaphorical) phrases are expected to result in greater N400 amplitudes than LUHA (literal) phrases as a function of the higher degree of unusualness in case of the former conditions. Previous studies using novel metaphoric expressions and senseless expressions have reported a greater N400 amplitude for senseless expressions (e.g., Arzouan et al., 2007; De Grauwe et al., 2010). HULA (nonsense) phrases in the present experiment are comparable to senseless expressions as they are incoherent and meaningless phrases. HULA (nonsense) phrases are therefore expected to elicit the greatest N400 amplitude of the three conditions. HUHA (novel metaphorical) phrases would in turn be expected to elicit greater N400 amplitudes than LUHA (literal) phrases due to their unusualness, which is likely to lead to greater effort in semantic retrieval (e.g., Kutas, 1994). However, given that the eventual retrieval of the appropriate semantic information leads to novel associations being forged and integrated within the conceptual knowledge stores, it is expected that less semantic integration difficulty should be encountered for HUHA (novel metaphorical) compared to HULA (nonsense) phrases.

Research on semantic processing also focuses on later ERP components, such as the P600, or late positive component, which has been discussed in terms of sentence-level integration (Kaan, Harris, Gibson, & Holcomb, 2000), reanalysis (Friederici, 1995) and additional retrieval from semantic memory (e.g., Coulson & Van Petten, 2002; Paller & Kutas, 1992). The findings for this late component, however, are less consistent than for the N400 (e.g. Pynte, Besson, Robichon, & Poli, 1996). Due to the novelty of the current ERP paradigm as a tool to investigate creative processes, the analysis of later processing stages will be exploratory.

## 2. Materials and methods

### 2.1. Participants

The original sample included 27 healthy right-handed students from the University of Giessen that participated in the study in exchange for course credit or monetary compensation (15 €). All participants were native German-speakers and had normal or corrected-to-normal vision. Handedness was assessed using the German version of the Edinburgh Inventory of Handedness (Oldfield, 1971). Nine participants had to be excluded from data analyses due to excessive drifts in their EEG data ($n = 1$), admittance to the consumption of an illegal substance that might influence brain activity ($n = 1$) or an insufficient number of stimuli classified as unusual and appropriate ($n = 7$). This resulted in a final sample of 18 participants (10 females). Mean age was 23.39 years ($sd = 3.66$). In order to ensure the homogeneity of the sample in terms of verbal intelligence participants completed the vocabulary subscale of the Hamburg Wechsler Intelligence Test for Adults (HAWIE, Tewes, 1994). Mean standardized HAWIE score was 12.89 ($sd = 1.13$), with individual scores ranging from 11 to 14. The experimental standards of the study were approved by the Ethics Commission of the German Psychological Society (DGPs). Written informed consent was obtained from all participants prior to participation.

### 2.2. Materials

The study used a stimuli-set created for a previous fMRI study (Rutter et al., 2012). The stimulus set consisted of 44 experimenter-determined sentence triplets (132 phrases in total) in perfect tense. Each sentence was composed of a noun, verb and object (for examples, see Table 1 and Table S1 in the Supplementary material). The three sentences of each triplet only differed with regard to the verb which was chosen to make the meaning of the sentence novel metaphorical, nonsensical or literal corresponding to the three experimental conditions. Each participant was presented with all 132 phrases and the order of presentation of the stimuli was pseudo-randomized to ensure, for instance, that there were at least five trials presented between any two trials of a sentence-triplet.

Verbs were checked for word length and frequency of occurrence in the German language. A one-way ANOVA revealed significant differences in word length between the three experimental conditions ($F(2, 129) = 3.14$; $p = .047$; $\eta^2 = .05$). Bonferroni-corrected pairwise comparisons showed, however, that this effect was primarily driven by a trend in word length differences between the nonsensical verbs (HULA) and the literal verbs (LUHA) ($m = 8.45$, $sd = 1.42$ and $m = 9.39$, $sd = 2.24$, respectively; $p = .051$). Frequency of occurrence in the German language was computed using the online Vocabulary Database of the University of Leipzig in Germany (http://wortschatz.uni-leipzig.de/). This database classifies words into different frequency classes based on the frequency of their occurrence relative to the German definite article "der" ("the"). As the resulting frequency values are ordinal-scaled, a non-parametric median test was chosen. The median test comparing

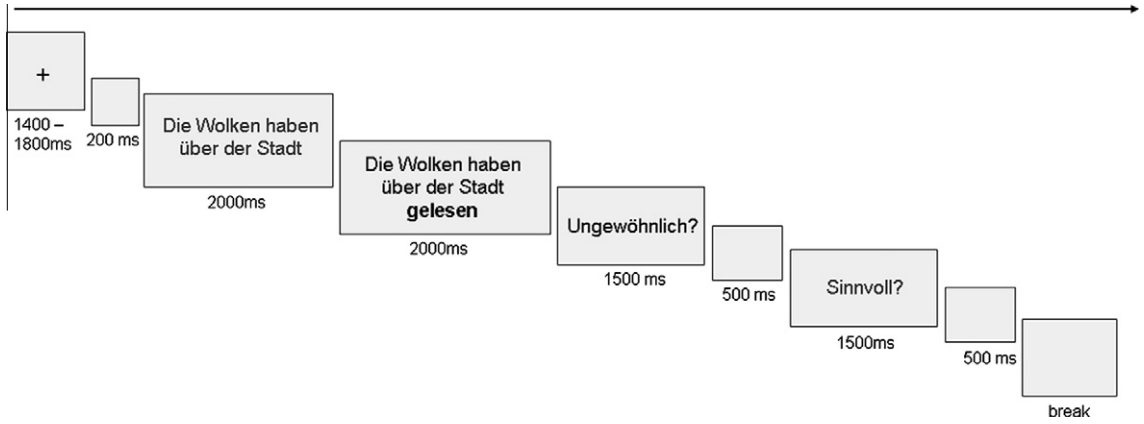


**Fig. 1.** Example of the experimental trial timeline. Total trial length from fixation cross to onset of the break was either 9600 ms, 9800 ms or 10000 ms. Stimuli phrases were presented in German where the critical word (verb) syntactically appears at the end of the phrase.

the three experimenter-determined conditions confirmed that they did not differ significantly regarding the frequency of occurrence of the verb (*md* = 15 for HUHA and HULA, respectively, *md* = 14 for LUHA; $p = .1$).

### 2.3. Procedure

Participants were tested individually in one session. After applying the electrodes, participants were seated in front of a computer screen and keyboard. Participants completed a few practice trials to become familiar with the task. Stimuli were presented in black print on a grey background using Presentation software (Neurobehavioral Systems, Inc., Albany, CA). Stimuli phrases were presented in the German language where the verb occupies the sentence-final position. Each trial (see Fig. 1) began with the presentation of a fixation cross on the left side of the screen. Presentation time of the fixation cross was randomized and ranged from 1400 ms to 1800 ms in 200 ms steps. After a blank screen lasting 200 ms, the stimulus phrase without the last word (being the verb) was presented for 2000 ms, after which the verb appeared at the end of the phrase for another 2000 ms. Following a 500 ms blank screen, the questions "Unusual?" (in German: "Ungewöhnlich?) and "Appropriate?" (in German: "Sinnvoll?") appeared for 1500 ms, respectively, separated by another 500 ms blank. During presentation of the respective questions, participants made "yes" or "no" judgments via button press with their right index or middle finger on the keyboard in front of them. To determine their response to the "Unusual"-question, participants were instructed to respond "yes" if the presented information was novel or unfamiliar to them and "no" if it was known or familiar. To determine their response to the "Appropriate"-question, they were also instructed to respond "yes" if the presented information was fitting or sensible and "no" if it was unfitting or nonsensical. After each trial, participants had the opportunity to take a break and start the next trial via button press at their own pace. Stimuli were presented in a pseudo-randomized order.

### 2.4. Electrophysiological recording

The electroencephalogram (EEG) was recorded continuously using the actiCAP system (Brain Products GmbH, Gilching, Germany) with 64 Ag/AgCl electrodes and monitored by the BrainVision recorder software. The EEG signal was amplified by the QuickAmp amplifier (Brain Products GmbH, Gilching, Germany) and digitized at a sampling rate of 500 Hz. Impedances were kept under 5 kΩ. Eye movements were monitored through bipolar electrodes that were placed above and below the right eye, as well as at the left and right canthi. Data was recorded using an average-reference on-line.

### 2.5. Data analysis

For each participant, stimulus phrases were assigned to the three conditions based on their individual evaluations concerning the usualness and appropriateness of the phrase. This resulted in a differing number of cases per condition for each participant. To avoid underrepresentation of any one condition, participants 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. Paired *t*-tests were carried out to detect possible differences in reaction times (RTs). As only RT differences between conditions that resulted in the same responses are of interest, RTs to the "unusual"-question were compared for the HUHA (metaphorical) and HULA (nonsense) conditions and RTs to the "appropriate"-question were compared for the HUHA (metaphorical) and LUHA (literal) conditions.

EEG data was analyzed using the Vision Analyzer 2.0 software (Brain Products GmbH, Gilching, Germany). Data was filtered with a 0.01 Hz high-pass and a 40 Hz low-pass filter. Ocular correction to remove eye movement artefacts was computed based on the method described by Gratton, Coles, and Donchin (1983). Data was further segmented into epochs of 1150 ms duration, starting at 150 ms before onset of the last word (further referred to as critical word). Segments were baseline-corrected using the 150 ms time window before onset of the critical word. Artefacts with amplitudes exceeding ±75 μV were removed from the data set. For each participant, ERP averages for each one of the three conditions were computed.[1] Grand Averages for each condition were used to derive the temporal intervals for the ERP components. A negative-going wave starting at about 350 ms with a peak at 420 ms was observed, thus the mean amplitude for the time interval 350 ms to 500 ms after onset of the critical word was computed (N400). In order to investigate possible late ERP components, the mean amplitude for the time interval of 500–900 ms after onset of the critical word was also calculated (late component).

For each of the ERP components of interest (N400; late component), a repeated measures ANOVA was computed with the factors Condition (HUHA, HULA, LUHA), Line (C-line, CP-line, P-line) and

[1] Information on the mean number of segments per condition per subject that were included in the final analyses can be found in Table S2 in the Supplementary material.

**Table 2**
Mean reaction times in milliseconds across all three conditions for each question. Standard deviations are given in brackets.

| Condition | Question | |
|---|---|---|
| | Unusual | Appropriate |
| HUHA (novel metaphoric) | 815.0 (112.8) | 666.9 (141.4) |
| HULA (senseless) | 775.6 (92.6) | 596.2 (125.7) |
| LUHA (literal) | 785.9(153.4) | 550.2 (106.8) |

Electrode position (3, 1, *z*, 2, 4). The Greenhouse–Geisser correction (Greenhouse & Geisser, 1959) was applied to all repeated measures with more than one degree of freedom. In these cases, corrected *p*-values with the original degrees of freedom are reported. In cases where main or interaction effects could be observed, additional planned pair-wise ANOVAs were carried out comparing each phrase category with one another. We focus on the main effects and interaction effects involving the factor Condition.

## 3. Results

### 3.1. Behavioral data

Table 2 shows means and standard deviations across the three conditions for each question. Comparing RTs to the "unusual"-question for HUHA (novel metaphorical) and HULA (nonsense) phrases revealed a significant difference between HUHA (novel metaphorical) and HULA (nonsense) phrases, such that participants responded slower to the "unusual"-question for novel metaphorical phrases relative to nonsensical phrases ($t_{17} = 2.25$; $p = .038$). For the "appropriate"-question, the analysis comparing RTs to HUHA (novel metaphorical) and LUHA (literal) phrases revealed that participants took significantly longer to respond when presented with novel metaphorical phrases compared to literal phrases ($t_{17} = 4.87$; $p < .001$).

### 3.2. ERP data

Grand averages elicited by the experimental conditions at selected electrode sites are depicted in Fig. 2. Figures for all 15 electrodes can be found in the Supplementary material. A N100/P200 complex can be observed starting at 100 ms after onset of the critical word. Around 350 ms after onset of the critical word a negative going component can be seen that peaks at around 420 ms and can thus be regarded as the N400 component. After the N400 peak, the waveform shows a late ERP component of sustained negativity, starting at about 500 ms.

#### 3.2.1. N400

The repeated measures ANOVA with factors Condition (HUHA, HULA, LUHA), Line (C, CP, P) and Electrode site (3, 1, *z*, 2, 4) revealed a significant main effect of Condition ($F(2,34) = 8.91$; $p = .001$; $\eta^2 = .34$) in the time window between 350 ms and 500 ms after critical word onset as well as a significant linear trend between the three conditions ($F(1,17) = 15.99$; $p = .001$; $\eta^2 = .49$). The linear trend (Fig. 3) indicates that the results can be best understood in terms of a linear function such that the N400 was largest in response HULA (nonsense) phrases, followed by HUHA (novel metaphoric) phrases, both relative to the LUHA (literal) phrases (N400: HULA > HUHA > LUHA).

Three planned pair-wise ANOVAs were carried out to compare each of the conditions individually with one another (HUHA vs. HULA, HUHA vs. LUHA and HULA vs. LUHA). The comparisons revealed that the waveforms elicited by HUHA (novel metaphorical) and HULA (nonsense) phrases for the N400 time-window were not significantly distinguishable from one another.[2] However, the waveforms elicited by both these phrase types were significantly differentiable from that of the LUHA (literal) phrases. HUHA (novel metaphorical) phrases resulted in a more negative N400 than LUHA (literal) phrases, as indicated by a significant main effect Condition ($F(1,17) = 7.50$; $p = .014$; $\eta^2 = .31$). A significant interaction effect between Condition and Line revealed that the differences in N400 amplitude are limited to central and centroparietal regions ($F(2,34) = 4.77$; $p = .033$; $\eta^2 = .22$). HULA (nonsense) phrases also produced a more negative N400 than LUHA (literal) phrases, as indicated by a significant main effect Condition ($F(1,17) = 15.99$; $p = .001$; $\eta^2 = .49$). A significant three-way interaction effect between factors Condition, Line and Electrode position ($F(8,136) = 2.61$; $p = .037$; $\eta^2 = .13$) showed that HULA phrases produced a more negative amplitude than LUHA phrases on 12 out of 15 electrodes (significant differences on electrodes C3, C1, Cz, C2, C4, CP1, CPz, CP2, CP4, P3, Pz, and P4, all $p < .05$). The lack of two-way interaction effects between the factors Condition and Line or Condition and Electrode position in this analysis indicates that the effects of the experimental conditions found for HULA and LUHA do not appear to be limited to a certain site or hemisphere.

#### 3.2.2. Sustained negativity

The findings of the sustained negativity late component closely parallel those of the N400. The repeated measures ANOVA between the factors Condition (HUHA, HULA, LUHA), Line (C, CP, P) and Electrode position (3, 1, *z*, 2, 4) revealed a significant main effect of Condition ($F(2,34) = 8.36$; $p = .001$; $\eta^2$=.33) in the time window between 500 ms and 900 ms after critical word onset, as well as a significant three-way interaction between the factors Condition, Line and Electrode position ($F(16,272) = 2.12$; $p = .042$; $\eta^2 = .11$). Additionally, the results showed a significant linear trend between the three conditions ($F(1,17) = 16.37$; $p = .001$; $\eta^2 = .49$). The linear trend (Fig. 3) indicates that the results can be best understood in terms of a linear function such that the sustained negativity was largest in response to HULA (nonsense) phrases, followed by HUHA (novel metaphorical) phrases, both relative to the LUHA (literal) phrases (sustained negativity: HULA > HUHA > LUHA). To fully explore the extent of these effects, three planned pair-wise ANOVAs were carried out to compare each of the conditions individually with one another (HUHA vs. HULA; HUHA vs. LUHA; HULA vs. LUHA).

Comparison between HUHA (novel metaphorical) and HULA (nonsense) showed a significant three-way interaction between the factors Condition, Line and Electrode position ($F(8,136) = 3.04$; $p = .013$; $\eta^2 = .15$). Pairwise comparisons showed that the mean amplitude of HUHA phrases (novel metaphorical) was less negative than the mean amplitude of HULA phrases (nonsense) on 3 out of 15 electrodes (significant differences on electrodes C2, CPz and P4, all $p < .05$). HUHA (novel metaphorical) continued to result in a more negative waveform than LUHA (literal) phrases, as indicated by the significant main effect of Condition ($F(1,17) = 5.82$; $p = .027$; $\eta^2 = .26$). Just as in the case of HUHA (novel metaphorical) phrases, HULA (nonsense) phrases also continued to remain more negative than LUHA (literal) phrases during this late time-window, as indicated by a significant main effect of Condition ($F(1,17) = 16.37$; $p = .001$; $\eta^2 = .49$).

The lack of interaction effects between factors Condition and Line or Condition and Electrode position on the sustained negativity indicate that the effects of experimental conditions do not appear to be limited to a certain site or hemisphere.

[2] No significant N400 differences were found between HUHA and HULA even in additional analyses where a wider set of electrodes (including frontal electrodes) were analyzed.

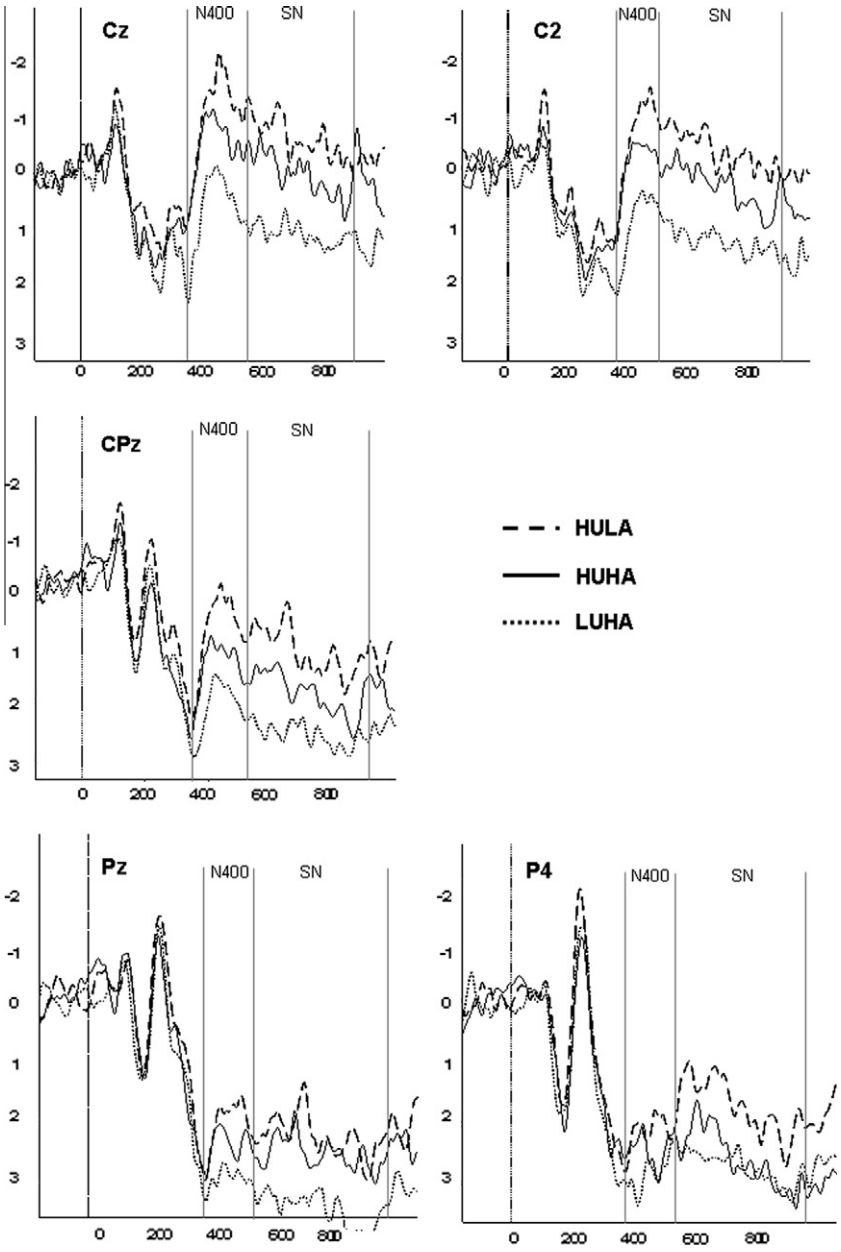


**Fig. 2.** Grand averages on central electrodes Cz, CPz and Pz, as well as on C2 and P4. Vertical line at time point 0 marks onset of the critical word (verb). Gray lines mark onset of N400 and sustained negativity (SN), respectively. Negative values are plotted upwards on *y*-axis in μV. Time is given in milliseconds. Figures for all 15 electrodes can be found in the Supplementary material.

## 4. Discussion

The main goal of the present study was to use ERPs to draw a clearer picture on how conceptual expansion as a creative cognitive process can be aligned with established aspects of brain function. Together with the advantage of having a high temporal resolution that made it possible to time-lock the creative process, the novel approach allowed for individual differences in the ability to expand existing concepts to be taken into consideration on a trial-by-trial basis. The short trial duration together with an adequate number of trials ensured a sufficient number of instances for each participant and consequently an optimal group average response. Another advantage of the novel approach lies in the possibility of clearly separating instances that are merely original (unusualness: HULA, nonsensical phrases) or relevant (appropriateness: LUHA, literal phrases) from instances that are creative in that they are both original and relevant (conceptual expansion: HUHA, novel metaphoric phrases).

### 4.1. N400

The findings for the early time-window between 350 and 500 ms showed a graded effect of the three experimental conditions on the N400 amplitude with LUHA (literal) phrases resulting in the least negative waveform, followed by HUHA (novel metaphorical) and then the HULA (nonsense) phrases. It is to be noted, however, that HUHA (novel metaphorical) and HULA (nonsense) phrases did not differ significantly in the direct comparisons. Instead, this subtle and graded effect could be gleaned from the linear trend of the main effect within the repeated measures analysis. A similar pattern has been reported in several studies from the field of language comprehension. For instance, Arzouan and col-

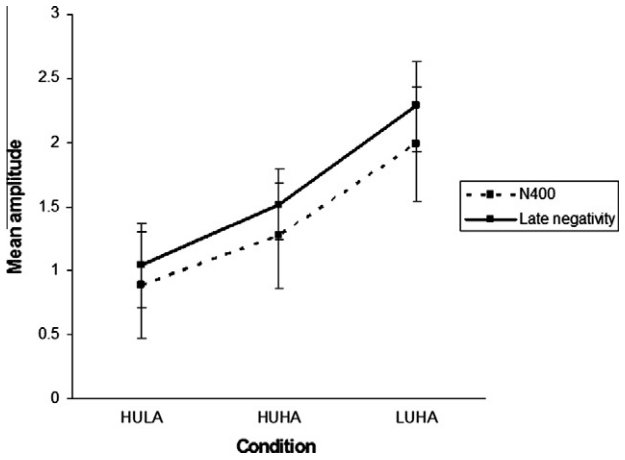


**Fig. 3.** Mean amplitude of the three conditions for the N400 and the sustained negativity. Plots are based on collapsed data over all 15 electrodes. Error bars indicate standard errors. The linear trend from the repeated measures ANOVAs for both components is significant.

leagues (2007) found such a graded N400 modification when investigating literal, conventional metaphoric, novel metaphoric and unrelated word pairs. More recently, De Grauwe, Swain, Holcomb, Ditman, and Kuperberg (2010) found this graded N400 modification for both mid-sentence and sentence-final words, which is in line with other studies on metaphor processing (e.g., Coulson & Van Petten, 2002, 2007; Lai et al., 2009; Pynte et al., 1996; Tartter, Gomes, Dubrovsky, Molholm, & Stewart, 2002).

Graded N400 amplitudes for different types of phrases have been interpreted in terms of conceptual blending theory (Fauconnier & Turner, 1998) in language processing. The conceptual blending theory postulates that the construction of multiple cognitive models and mappings between their components are the underlying processes for language comprehension. Greater N400 amplitudes for metaphorical or nonsensical expressions, for instance, are consequently interpreted as reflecting greater effort to construe mappings between distantly related domains and their components as well as the activation of background knowledge regarding the distant domains to derive meaning (Arzouan et al., 2007). The assumptions and interpretations of findings in this field can be extended and applied to the current results.

Taken together with the claim that the N400 component indexes higher-level integrative processes shown in semantic priming studies (e.g., Brown & Hagoort, 1993; Brown, Hagoort, & Chwilla, 2000; Holcomb, 1993), greater N400 amplitudes for HUHA (novel metaphorical) and HULA (nonsense) phrases compared to LUHA (literal) phrases in the current study can be seen as indexing greater efforts to establish a connection between the two semantically distant concepts conveyed through the stimuli. For LUHA (literal) phrases the derivation of meaning appears to be comparatively effortless since the phrases are literal in their nature (e.g., moving clouds) and represent established links between strongly associated concepts. In contrast, HUHA (novel metaphorical) and HULA (nonsense) phrases are both novel (e.g., dancing clouds; reading clouds) and require the integration of two unrelated concepts. The effort associated with this endeavor seems to be greatest for phrases that participants categorized as HULA (nonsense) due to their senselessness (e.g., reading clouds) and the inability to successfully integrate the two concepts to be associated with one another. Although the HUHA (novel metaphorical) phrases were unusual and unfamiliar to the participants, it was possible to successfully integrate the two presented concepts to give rise to a novel conceptual combination (e.g., dancing clouds). Even though the absolute difference in N400 amplitude triggered by HUHA (novel metaphorical) and HULA (nonsense) phrases did not reach significance, the linear trend findings support this interpretation.

Such a rationale is also in line with findings from a study by Rhodes and Donaldson (2008) where an N400 modulation was reported for word pairs with only an associative connection or for word pairs with a semantic and an associative connection, both relative to unrelated word pairs. In the current experiment, HUHA (novel metaphorical) phrases were not previously linked through association. A new semantic connection was established through the expansion of the existing concepts during the course of the experiment. The fact that this connection could be successfully established in the case of the HUHA (novel metaphorical) phrases but not the HULA (nonsense) phrases may account for the partially lower N400 amplitude accompanying the HUHA (novel metaphorical) compared to the HULA (nonsense) phrases. Further research is needed to confirm this interpretation. It is of note that the differing effort for integration observable in the graded N400 modulation is not apparent from the behavioral data. The behavioral data showed that RTs were highest for HUHA (novel metaphorical) phrases, whereas the ERP data revealed that the HULA (nonsense) phrases were accompanied by the most negative N400 amplitude. The N400 findings indicate the greater integrational effort involved in HULA (nonsense) relative to HUHA (novel metaphorical) and LUHA (literal) phrases (N400: HULA > HUHA > LUHA).

An alternative interpretation of the N400 treats this component as an index for the effort to retrieve semantic knowledge from memory stores in the brain (e.g., Kutas & Federmeier, 2000; Kutas, Van Petten, & Kluender, 2006). Both HUHA (novel metaphorical) and HULA (nonsense) phrases entail unusualness and it can be argued that the increased N400 amplitude for these conditions reflects an increased effort to search for semantic information regarding the novel concepts imparted through the phrases. The data provided through the present study does not suffice to fully clarify whether the greater N400 amplitude for HUHA (novel metaphorical) and HULA (nonsense) phrases reflects semantic memory retrieval or higher-order integrative processes. Further research will be needed to decide on the exact nature of the processes indexed by the N400 during a conceptual expansion task.

It could be argued that cloze probability might be a further explanation for greater N400 amplitudes for HUHA (novel metaphorical) and HULA (nonsense) compared to LUHA (literal) phrases as some studies have shown N400 modifications based on degree of expectedness associated with the sentences (Kutas & Hillyard, 1984). While HUHA (novel metaphorical) and HULA (nonsense) phrases are both unusual or novel and are therefore both unexpected in the given context, to solely base the interpretation of the N400 differences on the violation of semantic expectations does not suffice to explain the full extent of possible cognitive processing that can be reflected by this ERP component in the current study. The highly significant linear trend suggests the presence of processes exceeding merely expectation violations and it therefore appears to be more fitting to view these violations of semantic expectations as a catalyst that activates the enhanced retrieval and integration efforts discussed above.

### *4.2. Sustained negativity*

The analysis of the later time-window in the current study was exploratory and the results from the late component were found to closely correspond to the N400 findings. ERP studies on language comprehension have lead to heterogeneous findings concerning the late time-window. Some studies report the emergence of a P600 component after the N400 when processing ambiguous sentences (Friederici, 1995) and metaphors (Coulson & Van Petten, 2002; De Grauwe et al., 2010) whereas Pynte et al. (1996) did

not find a P600 component for metaphors compared to literal sentences.

HUHA (novel metaphorical) and HULA (nonsense) phrases in the present study did not elicit greater P600 components compared to literal phrases, but instead showed an ongoing negativity in the later time-window. Sustained negativities have been conceived as indexing different cognitive processes. Ruchkin and colleagues (Ruchkin, Johnson, Mahaffey, & Sutton, 1988) have linked slow negative waves to stimuli that are conceptually difficult to process, an interpretation that would be fitting for the stimuli at hand as well. However, the waveform described in their study differed in onset and latency from the waveform found in the present study.

Rhodes and Donaldson (2008) found a similar more negative going wave in a later time-window for unrelated word pairs relative to semantically or associatively connected pairs as in the current study. This was interpreted as recollection from long-term memory for the semantically and associatively linked pairs. This is in reference to old/new memory effects and episodic retrieval operations as described by Greve, van Rossum, and Donaldson (2007) and Donaldson and Rugg (1998) among others. However, the effect described in their work is limited to the left parietal areas and may therefore not suffice to be applicable to the interpretation of the effect found in the present study given that the discussed effect was not limited to a certain location.

The effect observable in the later time-window manifested itself as a continuation of the effects observed for the earlier time-window, namely a more negative-going waveform for both HUHA (novel metaphorical) and HULA (nonsense) phrases relative to LUHA (literal) phrases. In the case of the sustained negativity however, both the direct comparisons as well as the linear trend of the condition main effect demonstrated a graded effect of the three experimental conditions with LUHA (literal) phrases resulting in most pronounced negative waveform, followed by HUHA (novel metaphorical) and then the HULA (nonsense) phrases.

Recent ideas by Jiang, Tan, and Zhou (2009) on sustained negativity might be applicable to the current results in this light. In a series of studies on how violations of universal quantifiers in sentences are processed (e.g., the universal quantifier "all" was mismatched with a noun in singular object, as in "He threw away all that apple"), the authors found a sustained negativity, but no N400, on verb onset for violations of the quantifier (Jiang et al., 2009). The sustained negativity was conceived of as a reinterpretation of the verb after a mismatch between the phrase and the quantifier. The negativity was therefore proposed to index a reinterpretation process after an initial failure to reach meaning.

A similar underlying process is conceivable to explain the late negativity in the present study. Continuing the process indexed by the N400 associated with the establishment of a connection between two semantically distant concepts, the late negativity may mark the ongoing difficulty of integrating the two concepts. In the case of HUHA (novel metaphorical) phrases, the integration is eventually successful which could account for why the waveform becomes more positive in the later time-window and converges to the level of the LUHA (literal) phrases. The continued inability to bring together the concepts from the HULA (nonsense) phrases though is likely to have contributed to the continued negativity associated with this condition. It must be noted, however, that unlike in the present study, Jiang and colleagues (2009) did not report a preceding N400 for the sustained negativity and their primary focus lay on the processing of language comprehension.

Given the similarity of the N400 effects and the effects observed in the later time-window, it could be argued that the two components can be seen as one single sustained effect. When taking the linear trend and the direct comparisons into consideration which show a graded effect for the three conditions, it also seems plausible that two separate effects can be observed. Especially, the finding that waveform associated with the HUHA (metaphorical) phrases becomes significantly different from the waveform elicited by HULA (nonsense) phrases supports the existence of two distinguishable effects. However, the postulations on the significance behind the condition-based negativity and the question of whether or not the observed effects are indeed one single sustained effect in the present study on creative cognition are post hoc and therefore require further research to be fully clarified. Follow-up studies are necessary to fully understand the implications of this late ERP component together with the N400 in the context of creative cognition.

Taken together, the findings from the present study provide a first insight into which ERP components are important in indexing the operation of passive conceptual expansion as a creative cognitive process. As the paradigm of the present study used a passive conceptual expansion task, interpretation of the findings is certainly limited to this field and cannot be generalized to other creative processes, such as creative imagery. Conceptual expansion is only one among many cognitive operations that form the complex construct of creativity and cannot alone be held responsible for creative achievements. An important next step in the investigation of creative cognition will be to replicate the present findings in an active conceptual expansion task, as well as carrying out ERP investigations of other creative cognitive processes.

### 4.3. Conclusion

The present study was aimed at assessing conceptual expansion as a vital process of creative cognition using ERPs. The novelty of the employed paradigm was twofold. Unlike previous studies on metaphor processing for instance, participants were asked to judge not only the appropriateness but also the unusualness of the stimuli. The participants' judgments on these two defining aspects of creativity were then used to classify the stimuli into different conditions. This rendered it possible to incorporate individual differences in the organization and reorganization of existing conceptual knowledge within the paradigm. The results showed not only a clear difference within the N400 and the late sustained negativity components between nonsensical and creative phrases relative to literal phrases, but also a graded N400 and sustained negativity modulation for nonsensical, creative and literal phrases (in that order).

The N400 component was interpreted as reflecting the effort necessary to establish a connection between two unrelated concepts. The late negative component is postulated to be an indicator of a reanalysis process and ongoing effort. More research is needed, however, to clarify the cognitive operations underlying this late ERP component.

Taken together, the results support the notion of conceptual expansion as a continuous process involving different cognitive operations, such as semantic information retrieval, the formation of new associations between concepts and semantic integration processes. The current findings suggest that these different operations are not exclusively indexed by one specific ERP component, but are rather jointly represented by different ERP components. The results from the present study contribute greatly to the understanding of verbal creativity and parallel findings from fMRI investigations on verbal creativity that have demonstrated the involvement of similar brain regions during creative cognition as commonly found in semantic cognition such as the inferior frontal gyrus and the orbitofrontal cortex (e.g., Fink et al., 2009; Howard-Jones, Blakemore, Samuel, Summers, & Claxton, 2005; Kröger et al., 2012; Rutter et al., 2012). The current findings show that ERP components known to index semantic operations can be explored fur-

ther to understand the dynamics underlying creative cognitive processes as well.

The experimental paradigm employed in the current study is the first systematic investigation of creative cognition using ERPs. The findings of the present study attest to the fact that using an event-related electrophysiological approach provides a rich and novel avenue to explore further relevant questions that can provide genuine insights into the neurocognitive mechanisms underlying creative thinking.

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## Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.bandc.2012.08.003.

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