Professional training in creative writing is associated with enhanced fronto-striatal activity in a literary text continuation task

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Abstract

The aim of the present study was to explore brain activities associated with creativity and expertise in literary writing. Using functional magnetic resonance imaging (fMRI), we applied a real-life neuroscientific setting that consisted of different writing phases (brainstorming and creative writing; reading and copying as control conditions) to well-selected expert writers, and to an inexperienced control group.

During creative writing, experts showed cerebral activation in a predominantly left-hemispheric fronto-parieto-temporal network. When compared to inexperienced writers, experts showed increased left caudate nucleus, left dorsolateral and superior medial prefrontal cortex activation. In contrast, less experienced participants recruited increasingly bilateral visual areas. During creative writing activation in the right cuneus showed positive association with the creativity index in expert writers.

High experience in creative writing seems to be associated with a network of prefrontal (mPFC and DLPFC) and basal ganglia (caudate) activation. In addition, our findings suggest that high verbal creativity specific to literary writing increases activation in the right cuneus associated with increased resources obtained for reading processes.
1. Introduction

Creativity research has its origin in the 1950s and its common standard definition requires originality or novelty and effectiveness or appropriateness (Stein, 1953, Runco and Jaeger, 2012). Although creativity can be studied from different perspectives, in a cognitive neuroscientific context it is considered a cognitive process (Ward et al., 1999). The results of research on creativity are not consistent, and its neural mechanisms are poorly understood. In a recent review, Dietrich and Kanso (2010) concluded that there is no single mental process or region in the brain associated with creativity, but rather that creative thinking can be conceptualized as involving a multitude of processes. Creative performance ability depends not only on innate and acquired skills, general intelligence, and talent, but also on training and task motivation (Amabile, 1996). Creative activities often require domain-specific knowledge acquired through preparation and practice over years, resulting in mastery of these complex skills. Then, this enables full capacity of creativity (Weisberg, 1999).

Regarding writing in a professional context, creative writing is considered the critically reflected and professionally supervised acquisition of literary writing techniques (Ortheil, 2005), enabling access to several creative processes that lead to literary achievements. Thus, this concept is the basis for training creative processes. Flower and Hayes (Flower, 1981) developed a cognitive process theory of writing based on behavioral observations. Analyzing the cognitive processes of text composition, they described three basic phases of the writing process: planning, translating, and reviewing (Flower and Hayes, 1981). With respect to writing techniques, poor writers used a predominantly free-associative writing style (i.e., “write it as it comes”), whereas experienced writers worked by generating goals and sub-goals arising from their well-trained, stored, and automatized repertory (Flower and Hayes, 1981). Later, in a revised model, the cognitive processes were reorganized (Hayes, 1996) by subsuming planning and translating under more general categories as reflection and text production, as well as reviewing under text interpretation. In addition, Hayes (1996) re-emphasized the central role of working memory and motivation in writing processes.

The cerebral representation of creative writing has not been studied sufficiently and none of the prior imaging research assessed creative writing in real time. Two imaging studies (Bechtereva et al., 2004; Howard-Jones et al., 2005) investigated creative story-generation task from predetermined sets of words. In both studies, story generation was limited to the mental process –without any physical writing inside the scanner. Bechtereva et al. (2004) associated increased verbal creative capabilities with left parieto-temporal regions (BAs 39/40). In a functional magnetic resonance imaging (fMRI) study, Howard-Jones et al. (2005), observed increased activity predominantly in the superior medial prefrontal cortex (BAs 9/10, mPFC) and the left anterior cingulate cortex (ACC) during creative story generation compared to similar uncreative conditions. In contrast, uncreative story generation was connected with activity in occipital areas and the right inferior parietal cortex.

Any kind of expertise is associated with particular brain networks or brain organization involving cortical, subcortical, and cerebellar cortices (Koziol et al., 2010). In particular, the basal ganglia and the cerebellum are related to instrumental, cognitive, and behavioral automatization. Several previous imaging studies investigating musicians (Doyon and Benali, 2005; Zarate and Zatorre, 2008) and singers (Kleber et al., 2010) found an economization of cortical representation and increased recruitment of the basal ganglia network with increasing levels of expertise. A recent fMRI study (Wan et al., 2011) on professional and amateur board game players emphasized the critical role of basal ganglia in
cognitive expertise, specifically the caudate nucleus for intuitive processing. Moreover, flow experience is associated with basal ganglia activity (Dietrich, 2004).

In the present study, we extended a previous study (Shah et al., 2013) and investigated the cerebral representation maps of expert writers comparing them to inexperienced writers. In contrast to former imaging studies (Bechtereva et al., 2004; Howard-Jones et al., 2005), we considered actual writing in real time during fMRI scanning crucial to the investigation of the process of creative writing and to the correct assessment of individual performance. Thus, we developed a new fMRI paradigm based on theoretical methodologies for assessing creativity (e.g., Amabile, 1996), behavioral observations of cognitive writing processes (e.g., Flower and Hayes, 1981), and brain mapping studies investigating creative story generation (e.g., Howard-Jones et al., 2005). Using a categorical design based on the different writing phases, as suggested by Flower and Hayes (1981), we isolated creative cognitive processes using the subtraction method (Fink et al., 2007). Our text-continuation task contained text material from contemporary German literature, and was based on a common training method of creative writing (i.e., working creatively with a given text). Our neuroscientific setting was designed according to the contemporary methodologies of creativity research (Fink et al., 2007) and ensured real-life creativity (Hasson and Honey, 2012). It also met the requirements of creativity according to Stein (1953): originality and novelty by composing an individual text version, and appropriateness by adapting to the predetermined start of the text and its literary context. The texts produced in the fMRI scanner enabled direct performance control during scanning and a creativity assessment of the text written in the scanner according to the blinded qualitative Consensual Assessment Technique (CAT; Amabile, 1996). Furthermore, to separate experience-induced and creativity-associated neural functions, we correlated brain activities with training evaluation and verbal creativity skills scored with a verbal creativity index (VCI) of a German verbal-productive creativity test (Schoppe, 1975). In our previous investigation on a non-expert sample group (Shah et al., 2013), we differentiated brain networks of the creative writing phases ‘brainstorming’ and actual ‘creative writing’ and their non-creative control conditions (‘reading’, ‘copying’). We found that both creative writing and non-creative copying showed a broad network of motor and visual brain areas for handwriting and in addition cognitive and linguistic areas. The contrast ‘creative writing – copying’ resulted in bilateral activations of the hippocampus associated with episodic memory, the posterior cingulate cortex (PCC) being connected to spontaneous cognition, and both temporal poles linked to semantic integration. In particular, brain activity in the left inferior frontal gyrus (BA 45) and the left temporal pole (BA 38) were positively associated with verbal creativity (Shah et al., 2013).

In the present study we expected that the experienced group would show higher verbal creativity skill scores (VCI) and achieve better creative performance, and that this would be accompanied by characteristic changes in functional activation during the creative writing phases. Due to more experience in writing, their representation maps should reflect economization and automatization of brain activities and increased activation in the basal ganglia in accordance with prior findings on expertise from other domains (Doyon and Benali, 2005; Wan et al., 2011; Zarate and Zatorre, 2008). Furthermore, we expected changes of brain activities in the prefrontal cortex (Howard-Jones et al., 2005; Bechtereva et al., 2004; Gonen-Yaacov et al., 2013, Benedek et al., 2014) and associations with verbal creativity which were predominantly located in left inferior frontal and anterior temporal lobe structures (Shah et al., 2013).
2. Methods

2.1 Participants

We analyzed the performance of 48 native German participants in a creative writing task with functional magnetic resonance imaging (fMRI). We examined 20 students (expert writers) of Creative Writing and Culture Journalism from the only two universities in Germany that offer academic courses in creative writing: the Universities of Hildesheim and Leipzig (8 female and 12 male; mean age: 25.2 standard deviation (±) 2.7; mean semester: 7.1 ±3.9). These students can be considered as well-selected and domain-specific talented people because the selection criteria for the programs are extremely competitive and only 6% percent of applications are accepted. We compared their brain activity to those of an inexperienced, non-expert control group (non-expert writers) consisting of 28 students from the University of Greifswald (14 female and 14 male; mean age: 24.0 ±1.9). This group was already investigated in our prior study (Shah et al, 2013) and we extended analyses here. All participants were healthy and right-handed as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971). Groups did not differ with regard to age (t(46) = 1.86, p > 0.05), sex (χ² = 0.47, p > 0.05), or handedness (t(46) = 0.93, p > 0.05). Written consent was obtained from all participants. The fMRI-study was approved by the Ethics Committee of the Medical Faculty of the University of Greifswald.

2.2 Experience of creative writing

All participants were asked about their experience and practice of creative writing. Experts reported writing experience of 11.7 ±4.8 years on average, including their studies of creative writing, whereas the non-experts claimed an average of 3.1 ±5.2 years. Weekly writing practice during the last three months before scanning comprised 21.0 ±10.2 h for the expert and 0.5 ±0.8 h for the non-expert group. In summary, expert writers engaged in more hours of practice during the last three months (t (19) = 9.0; p < 0.001) and had more years of experience (t (46) = 5.80; p < 0.001). Adapting a method commonly used in music research (e.g. Pau et al., 2013), we calculated an individual practice index (PI) by multiplication of creative writing experience with weekly writing practice [(semester + years of writing practice) x practice of writing per week].

2.3 Instructions

Before scanning, participants received written instructions about the sequence of tasks, and that head and body movements should be limited to hand and eye movements necessary for writing. In addition they were instructed to pause any kind of creative or other cognitive processes and to visually fixate on an indicated cross during rest. Each task in the MRI was described in a standardized way. Participants were asked to continue with a task as long as it was presented to them. Furthermore, for the tasks “brainstorming” and “creative writing” participants were instructed to compose a continuation of the literary texts, as creative as possible, with the restriction that stories should be appropriate to the presented text part. This explanation was derived from the most common definition of creativity, that of Participants were allowed to change their story line between “creative writing” as obtained during “brainstorming.”

2.4 Text material
The presented texts A and B were selected text passages from contemporary German literature, of different literary genres, and chosen by our coauthor from the University of Hildesheim. Text A was prose literature about a violinist who had lost his violin and hence remained unknown. It was extracted from “Two or Three Years Later: Forty-Nine Digressions,” a collection of strangely entertaining and condensed short stories about everyday occurrences written by Ror Wolf (translated from German 2013). Text B was a poem of contemporary literature about the horrible suicide of an elderly man, written by the German lyricist Durs Grünbein, in a collection of 33 epitaphs titled “Den teuren Toten” (Grünbein, 1995; i.e. Our Dear Dead, however, this book, unlike Text A, has not yet been translated into English. Excerpts of both texts, and examples of highly creative continuations, are attached (see Supplementary Material).

2.5 Experimental design

During task execution, participants were lying in a supine position on the scanner table (see Figure 1). The tasks were printed on sheets of paper (210×297 mm), which were successively placed by an assistant on the inclined surface of a plastic desk positioned over the participants’ hips. For examination, the moveable table was slid into the scanner until the desk for writing touched the front side of the scanner. The assistant was standing beside the desk at the front of the scanner during the whole fMRI investigation, changing the paper sheets between the different scanning tasks, triggered by timed visual signals on a video projector. The assistant also controlled the participants’ writing activities on the desk during “copying” and “creative writing” periods, and ensured that participants were not writing or moving during the other periods of creative thinking or baseline activities. The only way the assistant could indicate “writing” or “not writing” was with a hand gesture through a small gap of a few centimeters between the bore of the scanner and the desk. This setup gave the advantage of more direct control than other recent technical methods (e.g., Ellamil et al., 2011) with minimal social interactions. The participants’ right upper arms were cushioned to restrict arm movements during writing and the desk position was individually adjusted depending on the participant’s arm length. A double-mirror system attached to the head coil allowed the participants to maintain visual contact with the paper for reading and handwriting with a felt-tip pen.

The design of fMRI examination included two runs of tasks, each regarding a different literary text passage (text A written by Ror Wolf; text B written by Durs Grünbein). Thus, each participant took part in both runs of story continuation with texts A and B presented in random order to prevent methodological artifacts. Each run included four tasks in the following order:

The first task was quiet “reading” of the presented text (approximately 120 words) for 60 seconds. Secondly, “copying” a part of the given text (approximately 35 words), by writing with a felt-tip pen for a fixed period of 60 seconds, was performed. Both tasks served as control conditions. Participants were supposed to perform them continuously during the entire 60 second period. In case they reached the end of the presented text before termination of this period, they had to start the task again. The constant handwriting activities during the “copying” period were observed by the assistant standing next to the scanner. During the third task, “brainstorming”, the first 30 words of the previous text were presented for 60 seconds, during which time the participants had to think about the presented text, generating ideas for their own creative text continuation without being allowed to actually write. The fourth task was “creative writing”, i.e. actual writing of a new, creative continuation of the same presented text for 140 seconds. Before scanning, the participants were instructed to create a
written, new, original but appropriate continuation of the given text. However, with regards to content, they were not tied to their ideas from the prior “brainstorming” period, that is, if other new ideas came to mind. During this task, the assistant ensured that the participants were writing continuously.

Between tasks (except between “brainstorming” and “creative writing”) a fixation cross was presented for 20 seconds to assess baseline activities and to separate the various task-dependent brain activities.

2.6 Behavioral Evaluation

After scanning, we assessed the participants’ attention during the scanning tasks, and the appropriateness of the setting, with a feedback questionnaire comprising visual analogue scales (VAS; 10 cm in length; 0 = “poor” to 10 = “very good”). The participants also reported on spontaneous thinking (“yes” or “no”) and the resemblance of their ideas during “brainstorming” and “creative writing”.

2.7 Creativity Evaluation

To assess participants’ creativity, we applied two established methods: the rating of produced texts according to CAT (Amabile, 1996), and a German verbal-productive creativity test, the “Verbaler Kreativitäts-Test” (Schoppe, 1975; for more detailed information see Supplementary Material).

In accordance with the CAT (Amabile, 1996), all produced texts were typewritten, de-identified, and sent in a randomized order to four independent judges, who were familiar with the domain (two professors and two lecturers from the department of Creative Writing and Culture Journalism at the University of Hildesheim). Overall, the CAT is considered a qualitative measure of creative products assuming that these people recognize creativity by their own independent criteria. All judges rated the creativity of each text on a 10-cm-long visual analogue scale (from 0: not creative at all, to 10: extremely creative). The creative writing index (CWI) was calculated for every participant using the mean value of both texts A and B of the “creativity” rating from all judges. To examine the interjudge reliability, we computed Cronbach’s alpha using the Statistical Package for the Social Sciences (SPSS 19.0). The inter-judge reliability of the creative writing index was satisfactory (Cronbach’s alpha = 0.72). The verbal creativity test (Schoppe, 1975), yields a verbal creativity index (VCI), consisting of nine subtests analyzing the participants’ verbal fluency and verbal production skills, and two subtests addressing aspects of flexibility and originality. We evaluated these verbal creativity tests according to the standardized instructions of the scale. Statistical relationships between both groups were calculated with Pearson’s correlation in SPSS 19.0. For comparison of mean values between groups we used independent samples T-test, including Lavene’s Test for Equality of Variances, and reported statistical significance at p < 0.01.

2.8 Data acquisition
Data were acquired using a 3.0 Tesla Siemens MAGNETOM Verio MRI scanner (Erlangen, Germany) with a 32-channel head coil. In order to restrict head movements, foam padding was placed around the head. For each of our two runs, 2D Echo-Planar-Imaging (EPI) generated 275 T2*-weighted functional images parallel to the anterior commissure/posterior commissure line (repetition time (TR) = 2000 msec, echo time (TE) = 30 msec, flip angle (FA) = 90°, matrix size 64 x 64 and field-of-view (FOV) 192 mm). Each volume included 34 axial slices with 3 mm thickness and a 1 mm interslice gap. The first two volumes of each session were discarded to allow for T1 equilibration effects. After functional imaging, 176 T1-weighted anatomical images of the whole brain were acquired using a fast 3D gradient echo pulse sequence (MPRAGE; TR = 1900 msec, TE = 2.52 msec, FA = 90°, matrix size = 246 x 256, FOV = 250 mm, voxel size = 1×1×1 mm³).

2.9 Data analysis

Data were analyzed using SPM5 (Statistical Parametric Mapping, Wellcome Department of Cognitive Neuroscience, London, UK) running on Matlab version 7.4 (MathWorks Inc; Natick, MA, USA). If not indicated otherwise, we used default-settings and the steps of preprocessing in standardized order. Unwarping of geometrically-distorted EPIs was performed using Field mapping in SPM 5. Hence we generated 34 magnitude and phase images acquired by a 2D gradient echo sequence, with different echo times (short TE = 4.92 msec, long TE = 7.38 msec), in order to reduce the spatial distortion caused by magnetic field inhomogeneity. Realignment corrected for motion and transformed the data into the same anatomical space. After slice timing, which realigned the images temporally, the data were realigned spatially. Each individual time-series was realigned to the first scan as a reference point. The realigned and unwarped EPIs were coregistered to the T1-weighted anatomical image. For normalization, the coregistered T1 images were segmented, then spatially normalized to the Montreal Neurological Institute (MNI) template, and resliced to voxel size 3×3×3 mm³. The resulting images were smoothed with a 9-mm full-width at half maximum (FWHM) Gaussian Kernel filter, to increase the signal-to-noise ratio.

In order to evaluate the quality of imaging data, the absolute realignment parameters x, y, z, pitch, roll and yaw were analyzed for each individual sample in view of maximum values for both translations and rotations. In addition, this determined exclusion criteria before group analysis. Thus, maximal head movements during scanning were 3 mm translation and 3 degrees of rotation for each participant (mean values of the maximal head movement values over all participants for “creative writing”: translation 0.70 ±0.33 mm; rotation 0.01 ±0.01 radials). They did not differ significantly between both texts (translation: t = 1.01; rotation t = 0.32; n.s.) or both groups for our most important condition of “creative writing” (translation: t = 1.33; rotation: t = 2.57; n.s.).

Individual statistical maps of main effects (“brainstorming” and “creative writing”) and control conditions (“reading” and “copying”) were evaluated for each participant using the fixed effect analysis according to the general linear model (first level analysis; task conditions vs. baseline conditions). The movement parameters of each individual subject estimated during realignment were introduced as covariates of no-interest into the general linear model to function as additive regressors for calculation of first level statistics. This procedure should reduce the first-order effects of head movement, because they were not more than the voxel size of the acquired data. A temporal high-pass filter (128 s) was used to remove slow BOLD signal drifts. In order to reduce influences of changing the paper sheets placed on the writing
desk, we did not consider the first and the last scans of each condition for modeling one-sample t-tests of main effects. In order to subtract brain activation related to motion or task related processes, we contrasted each creative condition versus its control condition (“creative writing minus copying”; “brainstorming minus reading”) within each participant. At the second level, the first level contrast images of each participant were calculated with a random effects analysis for between group comparisons (multiple comparisons). Independent two-sample t-tests were then performed for main effects and their corresponding contrast conditions to investigate significant differences between expert and non-expert writers (experts > non-experts; non-experts > experts). In order to show associations between BOLD magnitude of writing processes and behavioral data of writing experience, individual verbal creativity and actual creative performance, we performed a multiple regression analysis in SPM 5 and introducing the corresponding PI, VCI or CWI as covariate (regressor) variables for each participant.

Spatial assignment of significant brain areas was conducted with the SPM Anatomy Toolbox Version 1.6 (Eickhoff et al., 2005) and, if regions were not defined by ANATOMY, using anatomical masks from the Automated Anatomical Labeling software (Tzourio-Mazoyer et al., 2002). Brain activations were superimposed on the MNI render brain and on the T1-weighted Collins single-participant brain. For the main effects of the expert group we applied a correction over the whole brain volume (p<0.05; FWE corrected; Table 1). Given the exploratory nature of the study and the typically lower power in between-subject designs, we conducted a whole-brain analysis for the subject group comparisons and report significant brain activations above an intensity threshold of p < 0.001 uncorrected combined with a cluster size threshold of 5. In addition we performed a multiple regression analysis for verbal creativity, as expressed by the VCI, and experience in writing, as expressed by the PI. For the multiple regression analysis we used the contrasts “creative writing” and again applied a statistical threshold uncorrected for multiple comparisons. The multiple regression analysis was restricted to the expert group since data on the non-expert writers have been reported previously (Shah et al., 2013).

3. Results

3.1 Behavioral results

Both groups rated the situation of writing in the scanner as acceptable (appropriateness of the setting: experts: 5.7 ±2.7; non-experts: 6.4 ±2.3) and did not differ significantly (t(46) = 0.95; n.s.). Mean attention during “brainstorming” (experts: 6.6 ±1.8; non-experts: 7.6 ±1.6) and “creative writing” (experts: 6.9 ±1.8; non-experts: 7.6 ±1.6) was rated moderately high and this did not differ between texts (“brainstorming”: t(94) = 0.77; n.s.; “creative writing”: t(94) = 1.05; n.s.) or groups (“brainstorming”: t(46) = 2.08; no group differences; “creative writing”: t(46) = 1.43; no group differences). During the creative phases, approximately 45% of the experts advanced in a spontaneous way, whereas 50% did not describe a spontaneous stream of thought. In contrast, approximately 57% of non-experts reported spontaneous thoughts, whereas approximately 32% denied they experienced it. The occurrence of spontaneous thoughts did not differ between groups (χ² = 1.73, p > 0.05). Furthermore, approximately 55% of the experts tended to write their text continuations similar to “brainstorming”, but only about 46 % of the inexperienced writers reported this.
The number of written words served as performance control during “creative writing” (experts: text A 55.9 ±15.9 and text B 49.3 ±15.3; non-experts: text A 48.8 ±12.6; text B 44.4 ±12.6), which did not differ between groups (t(46) = 1.55; n.s.) or between texts (t(46) = 1.85; n.s.).

3.2. Evaluation of creativity

The mean verbal creativity index (total score, VCI; Schoppe, 1975) was 116.5 ±9.9 for expert writers and 107.1 ±8.8 for non-experts. Thus, experts showed a significantly higher VCI (t(46) = 3.42; p < 0.01). Creative performance of experts was commonly judged higher than that of non-experts (t(46) = 3.36, p < 0.01). We confirmed a positive correlation between creative performance in the scanner and individual verbal creativity scores (CWI and VCI: r = 0.38, p < 0.01). Expert writers also had a much higher practice index (PI) than non-experts (t(19) = 6.24; p < 0.001). The PI correlated positively with scanning performance (PI and CWI: r = 0.46, p < 0.01) and individual verbal creativity (PI and VCI: r = 0.43, p < 0.01).

3.3 Functional imaging data

3.3.1 Effects for expert writers

The main effect for the expert group during brainstorming and creative writing and for the interactions is depicted in Table 1 and shown in Figure 2. During brainstorming, experts showed activation in frontal and occipital regions lateralized to the left hemisphere. A subtraction of activation maps obtained during “brainstorming” with those obtained during “reading” (brainstorming > reading) revealed no significant effect. During creative writing, sensorimotor and visual areas were active but also the bilateral dorsolateral prefrontal cortex (dIPFC), left inferior frontal gyrus, left thalamus and inferior temporal gyrus and left basal ganglia. A subtraction of activation maps obtained during “creative writing” with those obtained during “copying” (creative writing > copying) showed no significant results.

3.3.2 Effects between groups

The effects for the between subject group contrasts are presented in Table 2. During “copying”, experts (expert writers > non-expert writers) showed increased activation in left dorsal premotor cortex (dPMC), left pallidum, right pre-SMA and right superior temporal gyrus. During “brainstorming”, experts showed increased activation in right middle cingulate, right posterior insula and putamen. During creative writing, experts showed increased activation in left superior, inferior and middle frontal gyrus, right inferior frontal gyrus and left caudate (Figure 3A). “Brainstorming minus reading” revealed increased activation in the right putamen, the right posterior insula, the right primary motor cortex, and the left supplementary motor cortex in experts. “Creative writing minus copying” resulted in increased activation of the right middle cingulate.

In contrast, the non-experts (non-expert writers > expert writers) showed increased activation in areas processing visual information (during reading and creative writing;
bilateral middle occipital gyrus (BA 18); during copying: left calcarine). The interactions between “brainstorming minus reading” and “creative writing minus copying” showed no increased activation in the non-experts when compared to the expert group.

3.3.4 Multiple regression analysis

The association between the activation magnitude during the “creative writing” condition and the verbal creativity index (CI, Schoppe, 1975) showed a significant positive effect in the right cuneus (MNI-coordinates (x, y, z): 15, -84, 36; t = 3.96; cluster size: 14 voxel; Figure 3B).

The multiple regression analysis with the practice index (PI) did not show significant results.

4. Discussion

The goal of the present study was to explore brain activity associated with expert creative writing in a setting which is comparable to creative writing of a professional writer. Therefore, we designed an fMRI paradigm that separated different steps of writing and involved the actual creation of a literary text. We identified increased bilateral dorsolateral prefrontal, left superior medial prefrontal and left caudate activation in expert writers compared to non-experts during actual “creative writing”. When subtracting the control condition “copying” from creative writing, there was increased activation in the right middle cingulate in experts. In addition, the “verbal creativity index” (Schoppe, 1975) correlated with activation in the right cuneus. In contrast, non-experts showed an increase in occipital activation when compared to expert writers. When contrasting “brainstorming minus reading”, expert writers showed increased activation in the right putamen, the right posterior insula, the right primary motor cortex, and left SMA compared to non-experts.

4.1 Increased prefrontal activation during creative writing in experts

As expected, verbal creativity assessed with the verbal creativity index and the evaluation of the written texts was higher in the expert group. This was reflected by increased brain activation at prefrontal and left caudate sites during creative writing. Specifically, experts activated the left superior medial prefrontal cortex (mPFC, BA 8/9), the left middle frontal gyrus (BA 9/46), and bilateral inferior frontal gyri (left BA 45, right BA 47) more than non-experts. Two previous studies on story generation found increased activation in left middle frontal areas (Howard-Jones: BA 9/32; Bechtereva: BA 8) for the creative condition. Bechtereva et al. interpreted this activation as memory–related in line with studies that show BA 8 involved in working memory tasks (Rämä et al., 2001). On the other hand, the left mPFC is strongly interconnected with Broca’s area (Ford et al., 2010) and has been demonstrated to be part of a language network (Binder et al., 1997). Additionally, the mesial superior frontal cortex has been associated with selection and coordination of multiple subgoals (Koechlin, 2000). As writing implicates competition for the writer’s attention among goals, knowledge, and the current text (Flower and Hayes, 1981), increased involvement of mesial prefrontal regions may thus ensure the necessary cognitive flexibility, the ability to
focus on relevant information, and a high working memory load to maintain several lines of incoming information (Curtis and D’Esposito, 2003). Interestingly, the same structure has been found active during conceptual expansion (Abraham et al., 2012b) and other divergent thinking tasks (Abraham et al., 2008) as well as metaphor production (Benedek et al., 2014) and was considered highly relevant for some aspects of creative thinking in general (Abraham et al., 2012b).

Increased left inferior frontal activation (BA 45) has been consistently seen in verbal creativity tasks (e.g., Abraham, 2012b, see Gonen-Yaacovi, 2013) and has been related to semantic processing and working memory processes (Binder et al., 2009). Increased right inferior frontal activation (BA 47) in experts writers, on the other hand, has been less often described (see Gonen-Yaacovi, 2013). Bechtereva and coworkers (2004) found right BA 45 and 47 activation when comparing the difficult story composing task to the word memorizing control task. Activation of the right BA 47 has been observed during emotional language processing, such as the observation of expressive gestures (Lotze et al., 2006) and the comprehension of affective prosody (Wildgruber et al., 2005). Interestingly, a recent metaanalysis found that under certain conditions the right hemisphere is involved in metaphor comprehension (Yang, 2014), and that for example the right BA 47 was active during metaphorical sentence processing. Increased right BA 47 activation may be characteristic for demanding literary and verbally creative tasks and thus be particularly present in expert writers.

4.2 Experts automatize processes via the basal ganglia

Expert writers recruited the left caudate nucleus during the creative writing phases more than the non-expert writers did. As a subcortical structure, the caudate nucleus is thought to be responsible for effortless transfer of information and skill automatization, due to its involvement in procedural memory and implicit motor control (Kreitzer and Malenka, 2008). In particular the caudate nucleus is interconnected with prefrontal areas functionally related to various cognitive processes (Alexander et al., 1986; Lehericy et al., 2004). Consequently, the caudate nucleus has been found involved in the acquisition of different skills, such as in working memory training (Kühn et al, 2013). Our findings are comparable to other studies on automatized movements in musicians and singing performance (Kleber et al., 2010; Zarate and Zatorre, 2008). Consequently, expert training seemed to develop cognitive writing skills into an automatic, implicit, and efficient process. In addition, our findings might be in accordance with findings on intuitive processing associated with cognitive expertise (Wan et al., 2011) and flow experience in any art domains (e.g., writing and free-jazz improvisation) (Dietrich, 2004). This implies that the task demands of creative text production fitted the experts’ writing style better –executing many decisions, strategies, relevant and well-learned skills (e.g., writing performance, language skills, sentence construction), and attaining domain-specific goals (e.g., characteristics of literary genres, engaging the readers’ interest) in an automatic, unconscious and intuitive way. Previous behavioral observations have characterized experienced writers in a similar way (Flower and Hayes, 1981).

4.3. Right cuneus activation correlated with verbal creativity index
Surprisingly, the verbal creativity index as assessed with a standardized creativity test (Schoppe, 1975) was positively associated with activation of the right cuneus. Although commonly not considered part of the core creativity network, this region has been found active in previous creativity studies, e.g., in a word association task conducted with highly creative artists and scientists (Andreason & Ramachandran, 2012). Fink et al. (2013) found verbal creativity positively associated with gray matter density in the right cuneus and attributed this to higher imaginative abilities of creative individuals. Moreover, creativity-related alpha synchronization across posterior brain areas has been often observed in EEG studies (see Fink & Benedek, 2012). With regard to the present study, we suggest that the correlation of the verbal creativity index with the right cuneus may be related to the proficient reading capabilities of expert writers. It has been reported that silent reading activates extrastriate visual areas (Gates & Yoon, 2005), a process which might be increased in more creative experts also during story writing. Whether this increased resources in reading is associated with a more critical evaluation of the own test written remains an open question.

On the other hand, when directly contrasting the non-expert to the expert group, the non-expert group increasingly recruited lateral occipital areas (calcarine gyrus). It is possible that this group engaged in more perceptual and visual processing of text material (Gernsbacher and Kaschak, 2003) or applied visual mental imagery strategies, a finding similar to a previous report showing an association with uncreative story generation (Howard-Jones et al., 2005).

4.4 Brainstorming anticipates creative writing including the motor act

During the brainstorming period in contrast to the “reading” control condition, expert writers activated the right putamen, the right insula, the left SMA and the right primary motor cortex more than non-experts. The insula has been primarily described as a brain region for the integration of interoceptive information and emotional experience (see Duerden et al., 2013). However, there are some reports that link the insula to speech production, its posterior part possibly operating as a relay station for the transmission of speech-relevant information on respiration-related metabolic states. (Ackermann & Riecker, 2010). Together with the activation of the right putamen that has been suggested to participate in articulation-related aspects of sentence generation (Argyropoulos et al., 2013) and primary and supplementary motor activation, brainstorming in expert writers may automatically evoke speech production activation. A comparable phenomenon has been reported in musicians who, in contrast to non-musicians, anticipate the motor response already during reading the notation (Pau et al., 2013).

4.5 Conclusions and limitations of the study

Regarding the selected groups, both consisted of students with an academic background that ensured they had a comparable level of intelligence. However, as we pointed out, there were significant differences in experience and practice of writing between the groups, and only some of the experts attained very high CI scores (>130) in the verbal creativity test (Schoppe, 1975). In addition, our expert writers were still undertaking formal education. However, our study focused on advanced students and their average writing experience already exceeded 10 years, which has been defined as “master-level” in creative
fields (Weisberg, 1999). Their familiarity with text material and their superior verbal and literary creativity was important for the objectives of our study. The between group effects are rather small. This might be based on the long scanning period, which was due to a real life paradigm. In addition, the subject groups were both highly educated students which decreases the between group effect more than if we had compared a student group with a group of non-students. Finally, we cannot completely exclude the possibility that the unusual writing situation and noise inside the scanner may have reduced individual creativeness. Nevertheless, experts performed significantly higher, as demonstrated by their CWI according to CAT (Amabile, 1996).

Generally, we think that cognitive brain processes relevant for literary writing cannot be equally measured with standard objective creativity tests (i.e., Torrance Test of Creative Thinking) because of their complexity and multidimensionality. With respect to the literary cultured and well-educated expert participants and even the judges, we developed a task for writing inside the fMRI scanner that allowed artistic flow of literary creativity and regarded domain-specific performance appraisable by qualitative and domain-specific assessment according to CAT (Amabile, 1996). We followed recommendations of a recent review (Hasson and Honey, 2012) regarding necessary real-life settings in neuroimaging in order to generalize research findings of cognition. If this had resulted in individually different cognitive processes, the observed brain activations would have emphasized the findings of more complex and hierarchical strategies of text material processing. Our results do not disagree with this issue. We suggest that future studies may be useful to differentiate between individual writing skills (e.g. writing techniques, stylistic device, rhetorical genre, text coherency). In that case, more precise tasks during scanning will be required, too.

After all, we are convinced that our experimental design including written text production during scanning provides more evidence for actual creative brain activities than designs used in earlier story-generation studies were able to provide (Bechtereva et al., 2004; Howard-Jones et al., 2005). A possible disadvantage of our fMRI paradigm may be that we could not control processes during phases that did not involve writing, such as the "brainstorming" period. Moreover, the explorative design without more precise instructions for task execution complicated the assignment of brain activation to particular cognitive processes. On the other hand, since participants were instructed to develop creative ideas and produce an individual continuation of a text immediately thereafter, it seems very likely that they actually did what they were supposed to do. However, we concede that participants could execute that task using several cognitive strategies, e.g. idea generation, verbal fluency, visual imagination of the stories content, formulating sentences, constructing mind maps, evaluating from the reader’s perspective. Thus, we refrained from further data analysis of “brainstorming” and future studies will be needed to differentiate brain processes underlying the stages of writing in more detail.

Our main goal was to develop an acceptable fMRI-setting with respect to expert literary creativity, avoiding interference of motion with cognitive brain processes. We are aware of the limitations of “paper-and-pencil-tasks” inside an fMRI-scanner (Fink et al., 2007). For this reason, we employed a high standard of control of movement parameters as described (in particular scanning environment; strict instructions to participants; estimation and inclusion of remaining movement parameters in data analysis). Critical time periods such as page-turning by the assistant were subtracted from the data before analysis. In doing this we provided protection of our results against movements of the right hand, head or eyes, and further validate our results.
Although the time spent in the scanner was quite long for participants, the time periods we designed were the minimum duration necessary to conceptualize a recognizable story line that was acceptable for CAT (Amabile, 1996). During preliminary stages, we tested runs with shorter time periods but none of the people tested could perform the “creative writing” task successfully. The assistant in the room ensured that participants wrote constantly during the time periods. Similarity, the word count of the produced texts negates group differences. These factors support our findings, that our BOLD effects demonstrate a qualitative difference between groups in approach to creative writing abilities. Our real-life experimental setting was in line with the demands outlined by Hasson and Honey (2012) and as such did not reduce complex information processing over long periods, as is required when creative writing. Overall, the main objective of future studies will be to develop appropriate cognitive tasks which can explore literary creativity and can be executed in shorter time periods.

Summarizing, the present study firstly investigated brain activities of expertly trained writers during actual creative writing of literary texts inside an fMRI-scanner. The texts produced in the scanner highlighted participants’ cognitive processes and enabled domain-specific and qualitative assessment of creativity. Neuronal correlates of expert creative writing were associated with increased cognitive control located in prefrontal areas and with skill automatization processes involving the basal ganglia, in particular the left caudate nucleus. In contrast, the increased activation of occipital areas in non-expert writers represented more visual and perceptual information processing. Altogether, our study is an important step towards understanding the neural processes underlying creative writing and expert literary education.

6. Funding

This study was supported by an intramural grant of the University of Greifswald.

7. Acknowledgements

We thank Carolin Shah and Evangelia Kaza for their support in methods development, design of the fMRI paradigm, and help with the examination of participants. We thank Flavia DiPietro for English correction of the final manuscript.
References


Tables

Table 1: Main effects; Expert writers; FWE corrected for multiple comparisons (p<0.05)

**Brainstorming**

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<tr>
<th>Area</th>
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<th>y</th>
<th>z</th>
<th>t-value</th>
<th>cluster</th>
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**Creative Writing**

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<td>3.13</td>
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1 Anatomical description; ri: right; le: left; inf.: inferior; hem.: hemisphere
Table 2A: Between group comparisons (main effects) of the experts and the non-experts

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Non-experts writers > expert writers

<table>
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<sup>2</sup> Brodmann’s area (BA)
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**Table 2B: Group comparison (interactions) between expert and non-expert writers**

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<td>Creative writing minus Copying</td>
<td>Right middle cingulate</td>
<td>24</td>
<td>15</td>
<td>18</td>
<td>36</td>
</tr>
</tbody>
</table>

**Non-expert writers > expert writers**

| Contrast | Region | | | | |
|----------|--------|-----------------|---------|---------|
| Brainstorming minus Reading | no significant results | | | |
| Creative writing minus Copying | no significant results | | | |

<sup>3</sup> Brodmann’s area (BA)
**Figures**

**A**

Conditions per run:

<table>
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<tr>
<th></th>
<th>Reading 60 s</th>
<th>Copying 60 s</th>
<th>Brainstorming 60 s</th>
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<td>Rest 20 s</td>
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</table>

**B**

![Image of scanning environment]

**Figure 1: Experimental design (A) and scanning environment (B)**

**A**: Experimental design consisted of two runs presented in random order, each containing working with a different literary text passage. During “creative writing” (140 sec) participants were asked to actual write a novel and creative continuation of the presented literary text. During the prior “brainstorming” (60 sec) participants were asked to plan their text continuation without physically writing. “Copying” (60 sec) and quiet “reading” (60 sec) served as control tasks. Between tasks a fixation cross (20 sec) was presented and appeared as baseline activities.

**B**: Scanning environment demonstrating participants’ position during writing out of the scanner and the presented paper sheet with space for writing placed on the plastic desk. A double-mirror system enabled visual contact with the paper sheets for reading and handwriting. For examination, the moveable table was slid into the scanner until the desk touched the front side of the scanner.
Figure 2: Main effect corrected for multiple comparisons within the ROIs for the expert group during brainstorming (top) and creative writing (bottom).

During brainstorming experts recruited bilateral inferior frontal gyrus, left precentral gyrus, bilateral inferior occipital gyrus but also (not seen on the segmented reference brain here) the right cerebellar hemisphere, the medial superior prefrontal cortex and right calcarine.

During creative writing experts showed activation additionally in the left superior parietal cortex, the inferior left temporal gyrus and –not seen here- in the left thalamus and left hemispheric basal ganglia.
Figure 3: Creative Writing

A: Group comparison of the experts minus non-experts revealed increased activation during creative writing in the left caudate and mPFC.

B: Positive correlation of right cuneus activation (y-slice: 15) during creative writing of experts with their verbal creativity score.
Supplementary Material:

1. Presented text material and examples of written text continuations during scanning

Text A: Presented text beginning of “In the Mountains”, the first of a collection of prose miniature stories extracted from “Two or three years later: Forty-nine Digressions“, written by Ror Wolf (translated from the German by Marquart J., Open Letter Books, 2013):

An unknown violinist – a man whose name I wouldn’t be able to recall even if I tried – said he’d forgotten, or rather lost his violin, a fact he realized upon being asked to play in a tavern in Gletsch.

(Ein Mann, ein Geiger, ein unbekannter Geiger, dessen Name mir beim besten Willen nicht einfallen will, sagte, als man ihn in einem Wirtshaus in Gletsch bat, ein wenig zu geigen, dass er seine Geige vergessen oder vielmehr verloren habe...)

Text A: The following text was the continuation of the prose literature written by Ror Wolf:

He thought he might have lost it in Lax on his way through the mountains, where a thick layer of snow had covered the ground. Because of the snow he might not have noticed his violin fall out; it could’ve fallen out silently, he wouldn’t have heard it fall. When he stopped at a tavern that evening and was encouraged to play a little, he discovered in that moment that he no longer had a violin. And so he forever remained an unknown violinist.

(Er glaube, er habe sie in Lax verloren, auf seinem Weg ins Gebirge, auf dem der Schnee derart dick den Boden bedecke, dass er gar nicht gespürt habe, wie sie hinabgefallen sei, sie sei ohne Geräusch hinabgefallen, er habe dieses Hinabfallen gar nicht bemerkt. Er sei an diesem Abend noch in ein Wirtshaus gegangen, wo man ihn aufgefordert habe, ein wenig zu geigen, und habe erst in diesem Moment entdeckt, dass er gar keine Geige mehr hatte. Vor allem deshalb sei er ein unbekannter Geiger geblieben, und zwar sein Leben lang.)
Text A: Select example of a highly creative text continuation written during scanning by one of the professional writers:

As it is known, Gletsch is located to the Aletsch Glacier. And as he was climbing the glacier and pausing by a crevasse to play the violin, to pitch the notes inside and to let spring up grass at the bottom, the glacier, winding its tongue around the sounds, suddenly gulped the violin. The whole piece of music and thus you hear at the Aletsch

(Denn wie bekannt ist, liegt Gletsch am Aletschgletscher. Und wie er so den Gletscher bestieg, und an einer Gletscherspalte Halt machte, um zu geigen, die Töne hineinzuwerfen und Gras auf dem Grund sprießen zu lassen, da schlang der Gletscher, seine Zunge um die Töne legend, die Geige hinunter. Das ganze Stück und so hört man am Aletsch)

Text B: Presented text beginning of a poem of contemporary literature about the horrible suicide of an elderly man, written by the German lyricist Durs Grünbein in a collection of 33 epitaphs titled “Den teuren Toten” (i.e. our dear dead, however this book has not yet been translated into English):

Horrible suicide of an elderly man in Innsbruck … reason residual…Maybe out of loneliness, as an expert believes, or out of depressive hatred of women, a childless widower shocked the whole female staff of a laundry last Thursday.

(Grausamer Selbstmord eines alten Mannes in Innsbruck. …Ursache ungeklärt… Vielleicht aus Einsamkeit, wie ein Experte glaubt, aus depressivem Frauenhass, hat letzten Donnerstag ein kinderloser Witwer die weibliche Belegschaft einer Wäscherei schockiert.)

Text B: The following text was the real continuation of the poem written by Durs Grünbein:
The fact that old age barely protects from perversions is proven by the icy serenity of the man when he proceeded to action in the morning. With a limp bunch of roses in his arms he entered the store, shouted Good day! and asked for a glass of water for his heart pills. No sooner was he alone than he disappeared quietly into the next room and put his head between the rolls of a clothes wringer. A witness described the noise as the crunch of car compactor, penetrating all walls till the second floor.

(Dass Alter kaum vor Perversionen schützt, beweist die eisige Gelassenheit, mit der der Mann am Morgen zur Tat schritt. Einen welken Rosenstrauß im Arm, betrat er das Geschäft, rief noch „Grüß Gott“ und bat um ein Glas Wasser für die Herztabletten. Kaum allein, verschwand er still im Nebenraum und legte seinen Kopf zwischen die Rollen einer Wäschemangel. Das Geräusch beschrieb ein Zeuge als das Knirschen einer Autopresse, sämtliche Wände bis zum zweiten Stock durchdringend.)

Text B: A select example of a highly creative text continuation written during scanning by one of the professional writers:

As he entered the building. Maliciously, clumsily he proceeded to action: asked what had been washed and left after that. Having arrived at home, he killed himself. What this had to do with women? Settlements in both cases. Washing, bachelors’life. But neither was much. Unmade laundry, unlived days.

(Als er das Gebäude betrat. Bös, ungelenk schritt er zur Tat: Fragte, was gewaschen worden sei und ging dann wieder. Zuhause angekommen nahm er sich das Leben. Was das mit den Frauen zu tun hatte? Erledigungen in beiden Fällen: Waschen, Junggesellenleben. Aber viel war das Beides nicht. Ungemachte Wäsche, ungelebte Tage.)
2. More detailed description of the Verbal Creativity Test of Schoppe 1975

The Verbal Creativity Test (VCT) of Schoppe (1975) assesses two main principles of verbal production: I) the recall of words and sentences including letter and semantic fluency (i.e. recall of words with a similar word-ending, producing sentences according to given single letters, producing different words with a similar meaning) and II) the generation of creative ideas (i.e. unusual uses, utopian situations, invention of original verbal creations for a common object). Each of the tasks was time limited and the total test period was around 37 min.

According to standardized instructions inadequate solutions were discarded and raw scores were transformed into six standard-values obtained from a specified standard population (academic education: students, N=500, age: 20-35). The individual Verbal Creativity Index (VCI) equals the mean value of the six standard-values.