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On the neurobiology of creativity. Differences in frontal activity between highly and low creative subjects

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Running head: Frontal differences in highly and low creative subjects

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Abstract—The aim was to investigate the relationship between creativity and hemispheric asymmetry, as measured by regional cerebral blood flow (rCBF). Two groups, each consisting of twelve healthy male subjects, who got either very high or low scores on a creativity test, were pre-selected for the rCBF investigation. rCBF was measured during rest and three verbal tasks: automatic speech (Auto), word fluency (FAS) and uses of objects (Brick). State and trait anxiety inventories were answered after the rCBF measurements. Intelligence tests were also administered. It was predicted that highly creative subjects would show a bilateral frontal activation on the divergent thinking task (Brick), while low creative subjects were expected to have a unilateral increase. Calculations were made of differences in blood flow levels between the FAS and the Brick measurements in the anterior prefrontal, frontotemporal, and superior frontal regions. In accordance with our prediction, repeated measure-ANOVAS showed that the creativity groups differed significantly in all three regions. The highly creative group had increases, or unchanged activity, while the low creative group had mainly decreases. The highly creative group had higher trait anxiety than the low creative group. On the intelligence tests the low creative group was superior both on logical-inductive ability and on perceptual speed, while the groups were equal on verbal and spatial tests. The results are discussed in terms of complementary functions of the hemispheres.

Key Words: cerebral laterality; frontal function; flexibility; divergent thinking; logical thinking; trait anxiety.

Introduction

The classical four stages of preparation, incubation, illumination and verification in the creative process were described early on [8], as was the view of our imaginative ability as the basis for all forms of creativity [76]. Fundamental also are cognitive functions such as divergent thinking, which implies finding many solutions to an open-ended problem, in contrast to convergent thinking where the (logically) right answer to a question is found [22]. Important for creativity is as well an intentional, emotional involvement in one´s work [37, 58], and features such as autonomy, independence of judgement, and metacognitive, evaluative skills [13, 26, 59].

Creativity was placed in a neuropsychological frame of reference already when Bogen and Bogen [5] claimed that a major obstacle to high creativity was the left hemisphere inhibition on right hemisphere functions. Others [1, 12, 36, 41, 43] thought that the hemispheres complemented each other in higher psychological functions such as creativity. In contrast, Kinsbourne [31] suggested that creation may advance by drawing on the specialized processing of one hemisphere only.

Experimental studies of the creative functioning of the hemispheres have been performed by a number of researchers [11, 27, 30, 39]. Martindale et al. [39] found that creative subjects had significantly more right- than left-hemisphere activity (pariety-temporal EEG), as opposed to low creative people on a creative task, but not on a non-creative task. Katz [30] found hemisphericity (i.e. the quotient between two tests, supposedly tapping functions localized in either hemisphere) to be related to objective indices of creativity. Hoppe and Kyle [27] examined patients with commissurotomy (“split-brain“) as well as normal subjects and concluded that creativity depends on whether the “presentational symbolization and imagery in the right hemisphere are available to the left hemisphere via the corpus callosum“ (p.153). In a series of studies, Carlsson [9, 10, 11] established qualitative hemispheric differences on a perceptual personality test of defence mechanisms. The right visual half-field group (left hemisphere) responded with more repression and isolation, while the left half-field group (right hemisphere) had more of regressive answers. Furthermore, the hemispheric differences were found to be very pronounced in low creative subjects. In contrast, the highly creative subjects in both visual half-field groups showed a bilateral response, i.e. they more often responded with defensive strategies typical of the not directly stimulated hemisphere [11]. The results supported the view, succinctly stated by Lezak [33], that “the bilateral integration of cerebral function is most clearly exhibited by creative artists who typically enjoy intact brains“ (p. 69).

Not only are complementary functions in the two hemispheres likely to contribute to creativity, but in addition the controlling and executive functions of the frontal lobes probably are essential as well. Although Goldstein [21] did not explicitly mention creativity, his wording appears crucial: “[Frontal lobe patients] lack initiative, foresight, activity, and ability to handle new tasks….[They are] impaired in voluntary shifting and choice“ (p. 192). Zangwill [83] had the notion that a frontal lesion would disrupt divergent, rather than convergent thinking. Also, Perecman [50] suggested that the creative process is connected with the manipulation of representational systems, while Shallice [64] proposed a ‘supervisory attentional system’, responding both with routine stimulus analysis and response production mechanisms in novel combinations [as reported in 19]. Recently, Liotti et al. [34] reviewed work about the different representational systems in the frontal lobes. They found it conceivable that the right prefrontal cortex was specialized in generating associations of a non-verbal or visuo-spatial nature.

Based on the above theoretical and experimental work we assume creativity in the neuropsychological frame of reference to be a *functional system*, as conceptualized by Vygotskij [77]. This system depends on the interaction between multiple nodes, comprising both the sequential, analytical functions of the left hemisphere, and the visuo-spatial, analogical functions of the right hemisphere [for a thorough review of the functions in the two hemispheres, see 25]. Furthermore, the directive and executive functions of the frontal lobes play a paramount role. The functional systems in the brain [35] can be studied by methods that map simultaneously activated cortical areas. The use of regional cerebral blood flow (rCBF) measurements to study the functional organization of the cortex was pionered by Risberg and coworkers [28, 53, 54, 56].

In the present study creativity was operationalized within an empirically validated model of the creative process [68]. This model implies that the person can use his or her imaginative ability in a generative and autonomous way with regard to the objective reality. These aspects have been operationalized in a test developed especially to study the creative person´s visual perception, namely the Creative Functioning Test (CFT) [69]. The CFT measures the ability of the subject to generate own imaginative interpretations of a stimulus picture. In the present study the CFT was used to pre-select two groups, one with minimal, and the other with maximal creativity. Thereafter the selected subjects went through a comprehensive test battery. This report will give an account of the rCBF measurements, anxiety inventories, as well as intelligence tests. (The entire investigation included personality tests, blood samples for hormone analysis, and an interview. These results will be described elsewhere.) During the rCBF measurements three verbal activation tasks were given with the intention to accomplish a step-wise increase of blood flow in the brain. The least complex task, namely automatic speech, was assumed to activate functions in the right hemisphere, in line with earlier results [60]. The next step, a word fluency task, was supposed to result in a left-hemispheric asymmetry in the dorsolateral prefrontal cortex (DLPFC) [46, 78]. No differences between the creativity groups were predicted in these two tasks. In contrast, a third task, (divergent) “uses of objects“, was supposed to activate visuo-spatial right-hemispheric functions, inherent in creativity. Thus, our first hypothesis was that when the verbal fluency and the uses of objects measurements were being compared, the highly creative group would show a more bilateral frontal activation pattern on the latter task while the low creative group was supposed to use predominantly left-hemispheric frontal functions on both tasks. A *second hypothesis* was that the highly creative subjects would get higher scores on the uses of objects task than the low creative subjects. Regarding the intelligence battery, our *third hypothesis* was that the highly creative group would perform better on spatial tests (due to their greater involvement of the right hemisphere), whereas (*fourth hypothesis*) the low creative group should do better on the verbal and logical tests (due to their reliance on left-hemispheric functions). To control for anxiety, such inventories were answered after the rCBF. In line with earlier research [2, 68], a certain amount of distress and worry was expected to characterize the highly creative person (*fifth hypothesis*).

Methods

Subjects

A cohort of 60 male right-handed undergraduate students were recruited by personal information or posters. On the introductory testing day the subject underwent several personality tests, starting with the CFT. If the subject got either a very high or a low score on the CFT, he was asked to participate in the full investigation and gave a signed informed consent. Only one student did not want to participate. Thus, a *highly creative group* (n = 12) and a *low creative group* (n = 12) were formed. Both groups had a mean age of 23 years (range: 20 - 27) and consisted of subjects from several faculties. All subjects were healthy, according to a standardized medical questionnaire. On the Edinburgh Handedness Inventory [47] the mean for the right-left quotient was 0.93 in both groups (decile 8 in Oldfield´s sample). The complete investigation was conducted on three separate days for each selected subject, who got a fee of 600 Swedish kronor. The study was approved by the ethical committee at the Medical Faculty of Lund University and the Radiation Safety Committee of the University Hospital in Lund.

The Creative Functioning Test

The teoretical background of the Creative Functioning Test (CFT) implies that our perception of reality is the end-product of a brief (feed-back) construction process in the mind/brain. The (hypothetical) initial stages of such a process take place completely outside the realm of mental awareness (i.e., they are of a neuronal rather than psychological character), while later stages in the construction of a percept involve networks in the brain of a greater width and complexity. The final steps form a stabilized (interpersonal) perception of the objective world. [For thorough theoretical and empirical surveys of the so called percept-genetic theory and the related microgenetic theory the reader is referred to 7, 24, 32, 81.] Since the process leading to a stable visual percept is almost instantaneous, it is difficult to study under normal circumstances. To circumvent this problem, a *tachistoscopic* method is used, which causes an artificial prolongation of the perceptual process. By using meaningful pictures of sufficient complexity it becomes possible to trace subjective associations derived from personal veins. The tachistoscopic presentation enables a certain loosening up of the “weave of objectivity“.

The CFT stimulus. The tachistoscopically presented stimulus in the CFT is a still-life drawing depicting two common objects. The picture, drawn by a professional artist is built up by shadings and diffuse contours, making it fairly easy to see other things in it. When presented on short exposure times the objects in the CFT picture can be seen as for instance the body or the face of a person, but the possible meanings are manifold and sometimes idiosyncratic. [The manual contains a description of the illumination values in the testing room and other experimental specifications; see 69.]

The instruction was that pictures would be shown very briefly on the screen in front of the subject, who was asked to describe after each exposure what he thought he saw on the screen. The subject was not told that it was one and the same picture all the time.

The increasing series started with 0.02 sec., and the exposure times were increased according to a fixed procedure. The longest possible exposure was 3.62 sec. When the subject had reported the correct motif, the time increase was halted.

The decreasing series. There was no interruption from the increasing series. Thus the picture presentation continued with successively decreasing times, down to a level when the subject could no longer discern anything at all on the screen.

The dimension of ideational flexibility. The ability to form mental representations of the indistinct contours and shapes glimpsed on the screen was tried in the increasing series. Number of different interpretations (ideational flexibility) in the increasing series has been found to correlate moderately with independent criteria of creativity. But it is difficult in this part of the test to distinguish between associating fluency on the one hand, and the ability to shift from rational thought to more primary process oriented cognition, on the other. This distinction is put to test in the inverted portion of the CFT.

The dimension of creative strength. The second part of the testing implied a series of abbreviated exposure times with the effect that the perceptual support for correct recognition diminished step by step. Since the objective perception, i.e. what the stimulus really depicted, exerts a considerable influence on the viewer, a crucial question of relevance for creativity was if the person tended to be *stimulus-bound*. Such a (low creative) subject would regard subjective interpretations that he gave in the increasing series as mistakes. He would in the decreasing series accordingly comply with the objective reality of “facts“. In Lezak´s [33] words such a person would have difficulty to shift “..from a strong stimulus-source to a weak or subtle or complex one“ (p.92)*. From a more cognitivistic perspective, a formulation like ”creativity (…) produced by an absence of cognitive inhibition” (p. 253) [17] might be feasible. Thus, when correct recognition had been attained, a low creative person would inhibit, or not consciously attend to, any subjective interpretation from the increasing series, during the decreasing part. The highly creative individual, on the other hand, is able to accept reality at sufficiently long picture presentations, and to give a correct interpretation of the stimulus. But when the ambiguity in the test stimulus increases anew, he is apt to diverge from objectivity, and assign higher priority for his subjective representational world. The inverted part of the CFT thus reflects a person´s preferences in the choice between “facts“ and “fantasy“.

Scoring of the increasing series (ideational flexibility). Number of themes was estimated. Each different subjective interpretation was alotted one point. A partially new theme rendered one-half point.

Scoring of the decreasing series (creative strength). The manual describes a scale with six steps. In the present study they were compressed into three steps, as described in [11]: *High creativity* (scale-steps 5 - 6): During the decreasing series the the correct perception was wholly abandoned, and on one or several exposures the whole picture was seen as something completely different. *Medium creativity* (steps 2 - 4): Only a part of the picture was given a subjective interpretation, or the interpretation was rather vague or only implied plastic changes of the contents in the picture. *Low creativity* (step 1): The subject did not report any changes in the perception of the stimulus or at the most that the picture got foggy, darker, or disappeared piece by piece.

Validity and reliability of the CFT. In an extensive series of investigations high correlations have been shown between the CFT and, for instance, richness of ideas, expressiveness, originality, creative interests, and predictions of creative achievement. These

* One would think that some people did indeed infer that the same picture was shown. However, in view of the

aspects have been judged by external raters in for example studies of researchers (G = .67), professional artists (r = .72), children and youngsters (r = .83), and advanced students of architecture (r = .46) [63, 65, 66, 67, 70, 72]. Recently, creativity in the CFT was associated (in university teachers) with the university being regarded as a place of openness and diversity [61, 62]. Two trained scorers of the CFT often agree in more than 90 % of the cases. In the present study all protocols were scored by the first author and by an independent judge. If any disagreement occurred, a third, trained judge was called in.

The rCBF measurements

On the second day of investigation four measurements of rCBF were made. The 133-xenon inhalation technique was applied. A mixture of 133Xe and air (70 - 100 MBq/l) was inhaled by the subject for one minute via a face mask and a rebreathing spirometer system, followed by 10 minutes of normal air breathing according to the standard procedure [45]. Either 30 s of background (first measurement) or 5 min of remaining activity (repeated measurements within 1 h) was recorded before administration of the isotope [53]. The inert gamma-emitting tracer diffuses into brain tissue from arterial blood and is cleared by venous blood. The gamma radiation emitted by the tracer was continuously monitored by 254 stationary scintillation detectors mounted in a pneumatically controlled helmet (Cortexplorer 256 HR; Ceretronix Inc., Randers, Denmark). The system adjusts for differences in head sizes and shapes, and the positioning of the head was standardized in relation to bony landmarks (nasion and ear channels) by means of light crosses [56]. This makes it possible to reposition the subject correctly after a break. The rate of isotope washout recorded formed the basis for calculations of flow values. The Initial Slope Index (ISI), a predominantly grey matter flow parameter [57], was chosen as a measure of cortical blood flow due to its high stability and

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decreasing exposure times in the inverted series, such an inference becomes more and more difficult to uphold.

reliability [47]. Regional distribution values (percentage of total mean) were clustered into seven predefined regions (anterior prefrontal, superior frontal, frontotemporal, posterior temporal, central, parietal, occipital) in each hemisphere, according to a previously established classification [44]. Arterial PCO_2 was estimated from recordings of end-tidal CO_2 concentrations (Omeda gas analyzer). Absolute mean hemispheric blood flow values were corrected for differences in arterial PCO_2 to a standard level of 40 mm Hg [42]. Heart rate and respiratory rate were monitored during each measurement. Systolic and diastolic blood pressures were measured after each rCBF measurement. During the verbal tasks the subject had a small microphone placed on the throat close to the larynx enabling tape-recording of the verbal report.

Design of the rCBF measurements: Four measurements of rCBF were made with the subject in a supine position. The subject went up for a 15 min break between the second and third measurements. The eyes were closed and covered during all measurements. The first measurement was always made during resting wakefulness. The other three measurements were made during different verbal activation tasks, presented in a randomized order: (1) *Automatic speech (Auto)*. The subject was instructed to count aloud, increasing numbers, starting with one. The task continued during the entire measurement; (2) *Verbal fluency task (FAS)* [4], in which the subject was instructed to say all words (except proper nouns) one could think of that begun with a specified letter (f, a, s...). A new letter was given each minute; (3) *Uses of objects test (Brick)* [23]. The instruction was to report as many different uses of bricks that he could think of, both ordinary uses and more uncommon ones. The task continued during the entire measurement.

*Scoring of the FAS and Brick tasks***.** Test score on the FAS was the mean number of words produced per minute. (The words produced during the first and last minute were omitted.) On the Brick task the number of categories was calculated. An independent rater with no knowledge of the subjects did the categorizing.

Assessment of anxiety

Spielberger state and trait anxiety inventories (STAI) were administered immediately after the last rCBF activation. Each form consists of twenty anxiety-related statements, which the subject assessed on a four-graded scale. For the *state* form the subject was instructed to think about how he had felt during the rCBF measurements. The *trait* form concerned the subject´s mood in general. [Reliability and validity data of the STAI are found in 73.]

The cognitive testing

On the third day of investigation the subject was evaluated by psychometric testing. Three *verbal tests* were administered: Vocabulary (from WAIS-revised; in a Swedish standardized version) [3, 79]; Synonyms and Opposites (both from a Swedish standardized test battery; the Delta battery) [8]. Four *performance tests* were administered: Block Design (measuring construction ability and visuospatial organisation); Digit Symbol (measures visual attention and perceptual speed); a logical-inductive (Matrices) test, as well as a surface development test (measures spatial visualization ability). (The first and second performance tests came from WAIS-R and the latter two from the Delta battery.)

Statistical analyses

rCBF data were transformed into colour coded maps combined with a statistical mapping system, displaying only groups of detectors where the difference in relative distribution values between measurements was significant at the $P < 0.001$ level. This procedure was used only as an exploratory and illustrative tool, not as a basis for statistical inference [80]. For statistical inferences a priori designed repeated-measures analyses of variance (ANOVAs) were considered the most appropriate [49]. To investigate the effect of task on hemispheric activation, ISI hemispheric means (corrected for arterial PCO_2) were subjected to a 2 groups (highly creative and low creative) x 2 hemispheres x 4 tasks (Rest, Auto, FAS and Brick) ANOVA. The same analysis was performed for each of the three prefrontal regions of interest (anterior prefrontal, frontotemporal and superior frontal; covering the DLPFC). To investigate the specific effect of the Brick condition, calculations were made of the differences in activation levels between the FAS and the Brick measurements in each prefrontal area. This data was analysed in ANOVAs with a 2 groups x 2 hemispheres design. Other analyses of the data were performed with unpaired *t*-tests, with linear regression analysis, Pearson's *r*, and $\chi 2$ (all two-sided.)

Results

The Creative Functioning Test

When the independent judge had made her scoring, disagreements occurred in three cases. A third trained judge scored these protocols and a final majority decision was reached. Thus, the *low creative group* came to consist of ten low and two medium cases (due to an oversight in the selection procedure, conducted by the first author before the co-judges were engaged). All subjects in the *highly creative group* belonged to the high category.

Ideational flexibility ranged from 0 – 5 interpretations with a median of 2. The creativity groups differed significantly in number of interpretations of the stimulus. Nine low creative persons scored below the median cut, in contrast to only one in the highly creative group ($\chi 2 = 10.9$; df = 1; $P < 0.001$).

The rCBF measurements

Overall distribution differences from Rest to FAS and from Rest to Brick. Figure 1 and 2 show the significant differences between the resting condition and the FAS activation (fig 1) and from Rest to the Brick measurement (fig. 2). The *highly creative group* had bilateral frontal increases from Rest to Brick, while the *low creative group* had a unilateral, left-sided, increase on both comparisons.

Hemispheric absolute blood flow values during all measurements. For the total group a significant effect of hemisphere was found ($F(1, 22) = 19.1$; $P = 0.0002$). Thus, the mean blood flow was higher in the left than in the right hemisphere over all measurements.

Furthermore, a significant task x hemisphere interaction was found ($F(3, 66) = 4.7$; $P < 0.005$), implying that a high level was coupled with less asymmetry to the left. Thus the Auto measurement showed the highest hemisphere activation levels and no asymmetry, whereas the FAS had the lowest levels and a left-sided asymmetry. The creativity groups tended to differ ($F(1, 22) = 3.6$; $P = 0.07$), implying that the *highly creative group* had higher hemisphere means on all measurements. This difference was most accentuated in the resting condition. Thus, the *highly creative group* had higher hemisphere means during Rest than during the three activations, while in contrast the *low creative group* had the lowest activity in the resting condition. An ANOVA especially for Rest resulted in, for the left hemisphere, $P = 0.007$ ($F(1, 22) = 9.026$); and for the right hemisphere, $P = 0.005$ ($F(1,22) = 9.92$).

rCBF distribution values for all tasks in the prefrontal regions. The frontal regions of interest had somewhat differing patterns of activation. In the *anterior prefrontal regions* a significant effect of task was established ($F(3, 66) = 3.44$; $P = 0.02$), implying a step-wise increase from Rest, via Auto, to FAS, and with the highest level for Brick. Also a significant task x hemisphere interaction was found ($F(3, 66) = 2.80$; $P < 0.05$). Thus, there was a right-sided asymmetry during Auto and a left-sided asymmetry during the other measurements [*]. In the *fronto-temporal regions* a main effect of task was found ($F(3, 66) = 8.49$; $P = 0.0001$), indicating a low level during Rest, and high levels for the three verbal tasks. Also, a task x

[*] Automatic speech resulted in a right-sided frontal activation, which is in line with earlier results [60]. It is intriguing that the task of counting from one upwards gave rise to higher absolute blood-flow in the hemispheres than both the generation of words or uses for an object. Possibly, mental processes involving other networks in the brain have a share in the high level for automatic speech. During more complex tasks (i.e. FAS and Brick), other networks than those involved in the task may be inhibited to a greater extent.

hemisphere interaction was found ($F(3, 66) = 4.56$; $P < 0.006$). This was due mainly to the Auto measurement, having a strong asymmetry to the right. In the *superior frontal regions* a main effect of task was found ($F(3, 66) = 6.97$; $P = 0.0004$). The pattern was approximately the same as for the frontotemporal area. Further, a main effect of hemisphere was established ($F(1, 22) = 17.07$; $p = 0.0004$), implying a left-sided asymmetry. Also the hemisphere x creativity group interaction was significant ($F(1, 22) = 8.56$; $P < 0.008$), which meant that, in the superior frontal region, the *highly creative group* had a marked left-sided asymmetry over all tasks, whereas the *low creative group* showed a symmetrical pattern.

Differences in rCBF between the FAS and the Brick measurements. For each subject the mean blood flow for the FAS was subtracted from the mean flow for the Brick in each prefrontal region. This difference was analyzed by ANOVAS. The analyses resulted in significant differences between the creativity groups in all three regions. Thus, in the *anterior prefrontal regions* the means for the *highly creative group* increased bilaterally from FAS to Brick, while the *low creative group* showed a right-sided decrease, and an unchanged mean on the left side $F(1, 22) = 4.39$; $P < 0.05$). In the *frontotemporal regions* the *highly creative group* had unchanged levels bilaterally, while the levels decreased bilaterally for the *low creative group*, especially on the right side ($F(1, 22) = 4.19$; $P = 0.05$). In the *superior frontal regions* the level for the *highly creative group* increased from FAS to Brick on the right side and was unchanged to the left, while the *low creative group* had bilateral decreases ($F(1, 22) = 8.63$; $P < 0.008$). (Figures 3 - 5)

Performance on the FAS and the Brick related to the CFT

The FAS. The performance means for the two creativity groups were practically alike (*highly creative:* 13.5 words per min; *low creative:* 13.9 words). The result on ideational flexibility was not significantly related to FAS.

The Brick. The mean number of categories did not differ significantly between the creativity groups (*highly creative:* 13.2 categories; *low creative:* 11.3). *Ideational flexibility* was significantly positively related to Brick (median cuts yielded: $\chi 2 = 4.6$, df = 1; $P < 0.05$).

The FAS versus Brick. A positive correlation between the performances on the FAS and the Brick was established ($r = 0.50$; $P = 0.01$).

Performance on the Brick task related to the frontal activation during Brick

Correlations between number of categories on the Brick task and the flow level during the Brick activation in the three prefrontal regions were calculated. In the superior frontal regions, left and right, significant negative linear relations were established ($R = -0.44$; $P < 0.03$ versus $R = -0.57$; $P < 0.004$).

Anxiety and the Creative Functioning Test

For the total group the state anxiety mean was 35.1, and trait anxiety 31.1. Compared with the means for American male college students (36.5 versus 38.3) the present sample thus was fairly low in anxiety, particularly trait anxiety. (Swedish norms are not available.) State and trait anxiety were not significantly intercorrelated. The *highly creative group* had higher trait anxiety than the *low creative group* (means: 33.1 versus 29.2; $t = 2.036$; $P = 0.05$). The means for state anxiety were 37.4 versus 32.8. This difference did not reach significance.

Anxiety and the rCBF

Neither state nor trait anxiety was significantly related to the hemispheric means during the resting condition, nor to the means in the prefrontal areas. We also analyzed the relationship between the flow difference from FAS to Brick in the prefrontal areas, and the state and trait results. There were no significant correlations for the entire cohort. The same analyses were made for each creativity group. One significant correlation was found, namely for state anxiety in the *highly creative group*. Thus, in the *left anterior prefrontal area*, state anxiety was positively related to the flow difference from FAS to Brick ($r = 0.57$; $P = 0.05$).

The cognitive tests and the Creative Functioning Test

The three verbal tests taken together yielded a standardized total verbal score, and the two visuo-spatial tests gave a total spatial score. The creativity groups did not differ on the verbal or spatial total scores. On the other two tests significant differences between the creativity groups were found, however. The *low creative group* was superior on the Matrices (7.7. versus 5.7 stanine; $t = 3.866$; $P < 0.001$) as well as on the Digit Symbol (12.3 versus 9.7 standardized points; $t = 3.105$; $P < 0.01$). For *ideational flexibility* approximately the same results were found. Furthermore, the Matrices and the Digit Symbol results were positively intercorrelated ($r = 0.43$, $P < 0.05$).

The cognitive tests versus the FAS and Brick performances

The cognitive tests were also compared with the FAS and the Brick scores. Both the FAS and the Brick correlated positively with the total verbal score although only the Brick comparison reached significance (FAS: $r = 0.39$; $P = 0.06$; Brick: $r = 0.41$; $P < 0.05$).

The cognitive tests and anxiety

Finally, we compared the cognitive results with state and trait anxiety. A negative correlation was found between the Matrices and trait anxiety ($r = -0.51$; $P = 0.01$).

Discussion

The beforehand selected differently creative subjects differed as predicted on the regional blood flow activation patterns. Our *first hypothesis* was confirmed. Thus, the *highly creative* group utilized bilateral prefrontal regions when doing the Brick task, while the *low* *creative group* used functions predominantly on the left side. When the activation response during the fluency (FAS) task was compared with that of the Brick task, the *highly creative group* showed increases, or unchanged activity, in all three bilateral prefrontal areas. The *low creative group* showed mainly decreases and had an unchanged level only in the left anterior prefrontal region.

Our *second hypothesis* was partly confirmed. The *highly creative group* had a higher mean score on the Brick task than the *low group*, but not significantly so. However, *ideational flexibility* in the CFT was significantly related to the Brick task. That is, persons with few picture interpretations in the CFT also had a low number of categories of brick uses. It seems reasonable that the flexibility score in the CFT would be related to number of categories in the Brick task, which is actually a flexibility measure. The Brick task also seemed to contain a substantial verbal component, since it correlated both with the verbal cognitive tests and with the performance on the FAS. It is possible that the *low creative group* mostly used verbal reasoning when figuring out ways to use bricks. We did not ask the subjects in a systematic way how they went about to solve the task. A comparison can be made with recent findings of differing patterns of frontal cortical activity associated with different cognitive strategies [14]. When comparing a design fluency task to copying of abstract drawings, bilateral prefrontal increases were associated with a visuo-spatial strategy, while a mixed verbal and visuo-spatial strategy led to a left-sided prefrontal activation.

Our *third and fourth hypotheses* regarding the cognitive tests were partly confirmed. Contrary to the hypothesis, the *highly creative group* was not better on the spatial tests. It is probable that our conception of creativity, namely the aptness to form (and have confidence in) subjective visual representations, does not coincide with the ability to spatially manipulate three-dimensional objects. An additional hypothetical explanation could be that the *low creative subjects* took help of analytical reasoning to solve the spatial tasks, since they, as predicted, were superior on a test of logical reasoning (Matrices). This latter result is understandable, since a creative answer on the CFT implies that the subject does not think predominantly in a rational or analytical manner. Another reason why this group was better on logical induction may have to do with the fact that they had significantly less anxiety (which was in accordance with the *fifth hypothesis*). A relatively low level of distress may well facilitate logical reasoning, especially on a time-limited test. This assumption was supported by the negative correlation between trait anxiety and the Matrices test. Also, the *low creative group* did better on Digit Symbol, which, according to Lezak [33], may be affected by many different performance components. The better result here might be associated with selective attention skill or skill to encode the symbol verbally [15].

The *highly creative group* had higher means on both state and trait anxiety, although only the latter reached significance. Furthermore, the overall blood flow during the resting condition was significantly higher for this group than for the low creatives. These findings agree with the view that creative people may habitually feel somewhat more anxious than noncreative people and have slightly higher levels of basic arousal on physiological measures [38, as reviewed in 17]. Furthermore, creative inspiration may depend on the subject´s ability to put him/herself in a low-arousal state [38]. This is due to the fact that an increase in arousal raises the likelihood that the more dominant responses will be performed [16]. In the present study it may well have been the case that the highly creative subjects had difficulties to put themselves in a low-arousal state during the (somewhat stressful) CBF measurements, which may be part of the explanation why some of them did not perform well on the Brick task. Since the state anxiety questionnaire covered all four measurements, the specific anxiety level during Brick was unfortunately not available.

Earlier research [29] has implicated the frontal lobes in anxiety; we accordingly examined this but found no correlations between anxiety and the measurement during rest, regionally or in the hemispheres. However, on the FAS to Brick flow comparison there was a significant correlation with state anxiety in the left anterior prefrontal region, for the *highly* *creative group* only. The validity of this finding is uncertain. If valid, it might reflect a stronger motivation in the creative subject when confronted with a creative task. It is conceivable that the higher activation during Brick for the *highly creative group* was caused by a combination of anxiety and creative ideation. However, the right-sided frontal involvement for the highly creative group was not related to anxiety.*

The present results are in line with the view that the right frontal lobe is more involved in spontaneous production of non-verbal representations, whereas the left lobe may exert control and secondary evaluative and verbal analysis [cf 20]. Furthermore, the *superior frontal regions* seemed to play a special part in this investigation. Good performance on the Brick task was *negatively* correlated with a high activity in both the left and the right regions. Also, the *highly creative group* showed a left-sided asymmetry over all tasks in this region (although the FAS-Brick comparison revealed a rise in the right superior frontal area). Speculatively, the retrieval of and mental scanning of memories containing objects might be involved [56]. Cognitive efficiency, with high scores on the Brick task, may result in less activation [cf. 6, 48]. Further studies focussing on these unexpected results are warranted.

Admittedly, the subtraction design in our study had certain flaws. An improvement would have been for the Brick task to contain a new object each minute, or that the FAS had been restricted to only objects. Moreover, the two tasks have inbuilt differences which limits the interpretation of the rCBF maps. The FAS concerns the retrieval of stored words from the long.term memory, while in the Brick one could both find stored uses and ”invent” own, idiosyncratic uses of bricks. These limitations considered, it is nevertheless likely that the prerequisites for the subtraction procedure were approximately equal for both groups, and that the differences that we have found reflect functional differences between the highly and low creative groups.

* Compare with a study where seemingly contradictory results were found, namely that low trait anxious subjects tended to be more global and high trait anxious subjects to process a (visual) stimulus analytically [75].

Finally, the argument could be made that logical reasoning and a good hold on reality is necessary if one is to succeed as for instance a creative scientist or inventor. This objection is very much to the point. In a study of scientists and humanists, participants who were judged by their supervisors to have many original ideas often did not reach the highest (sixth) scale step on the Creative Functioning Test [71]. This extreme level was more frequent in certain other groups, for instance painting artists, or amateur painters and poets [70, 72]. It was concluded that "while amateurs are inclined to indulge in subjective fancies, researchers were anxious not to lose sight of the world of facts" [68] (p. 199). According to Katz [30], creative performance is reflected in those who can also access and are efficient in using the cognitive mode supported by the complementary cerebral hemisphere. Put in other words, an overemphasis on convergent thinking may hamper the development of divergent thinking [50], or, indeed, the reverse. Since we excluded the *medium creative group* from our investigation, it is a question for further research if these subjects would have been more efficient in utilizing both verbal and visuo-spatial functions when solving the Brick task, which might have resulted in high performance.

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However, in our study only one subject had a trait anxiety score that would have sufficed for inclusion in the high group of that study.

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Figure legends

Fig. 1. Colour flow maps showing the rCBF patterns (ISI, 2-3 minutes; % of total mean) in all parts of the superficial cerebral cortex from the vertex view, by a projection of the spheric shape into a two-dimensional plane (right hemisphere = right half; frontal = up). The upper two maps show changes in distribution values (% of total mean) from rest to verbal fluency (FAS) for highly creatives (n=12) and low creatives (n=12), respectively. Yellow colour indicates no changes, while red colour scale denotes increases and green colour scale decreases. The lower two maps represents a statistical mapping procedure (t-test, two-tailed) displaying only groups of detectors (labelled "cluster") where the difference in distribution values between tasks was significant at the $P < 0.001$ level (increases = orange; decreases = green). Note the more pronounced left frontal activation response for low creatives.

Fig. 2. Colour flow maps illustrating the ISI changes in distribution values (% of total mean) from rest to the Brick test for highly creatives (n=12) and low creatives (n=12),

respectively (for explanations see fig. 1). Note the highly creatives' bilateral frontal activation response and the low creatives' frontal activation response exclusively to the left.

Fig. 3. Illustration of the difference in ISI distribution values (% of total means) from verbal fluency (FAS) to the Brick test for highly creatives (n=12) and low creatives (n=12), respectively, in the anterior prefrontal regions. Repeated-measures ANOVA group difference ($P < 0.05$) was found.

Fig. 4. Illustration of the difference in ISI distribution values (% of total means) from verbal fluency (FAS) to the Brick test for highly creatives (n=12) and low creatives (n=12), respectively, in the frontotemporal regions. Repeated-measures ANOVA group difference ($P < 0.05$) was found.

Fig. 5. Illustration of the difference in ISI distribution values (% of total means) from verbal fluency (FAS) to the Brick test for highly creatives (n=12) and low creatives (n=12), respectively, in the superior frontal regions. Repeated-measures ANOVA group difference ($P < 0.008$) was found.