Differences in Cognitive Processes Between Gifted, Intelligent, Creative, and Average Individuals While Solving Complex Problems: An EEG Study

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This study investigated the differences in cognitive processes related to creativity and intelligence using EEG coherence and power measures in the lower ($\alpha_1 = 7.9 – 10.0$ Hz) and upper alpha band ($\alpha_2 = 10.1 – 12.9$ Hz). In two experiments, gifted, creative, intelligent subjects, and individuals of average ability solved closed and open problems while their EEG was recorded. The analysis of EEG measures in Experiment 1 indicated that highly intelligent individuals (HIQ—gifted and intelligent) showed higher alpha power (less mental activity) and more cooperation between brain areas when solving closed problems than did average intelligent individuals (AIQ—creative and average). Much more pronounced were the differences in EEG patterns obtained in Experiment 2. Highly creative individuals (HC—gifted and creative) displayed less mental activity than did average creative individuals (AC—intelligent and average) when engaged in the solution of different creative problems. Creative individuals also showed more cooperation between brain areas than did gifted ones, who showed greater decoupling of brain areas when solving ill-defined problems. The results of both experiments suggest that creativity and intelligence are different abilities that also differ in the neurological activity displayed by individuals while solving open or closed problems. The results further suggest that a selective involvement of cortical zones that are relevant for the solution of a problem could be an explanation for the observed differences in problem solving.

Several studies have reported negative associations between brain activity under cognitive load and intelligence (Anokhin, Birbaumer, Lutzenberger, Nikolaev, & Vogel, 1996; Haier et al., 1988; Haier, Siegel, Tang, Abel, & Buchsbaum, 1992; Jausovec, 1996, 1997a, 1998; Krause, 1992; Lutzenberger, Birbaumer, Flor, Rockstroh, & Elbert, 1992; Neubauer, Freudenthaler, & Pfurtscheller, 1995). The reported results suggest that intellectually competent individuals during problem solving were less mentally active than individuals...
with average intellectual abilities. The interpretation of these findings was an efficiency theory: “Intelligence is not a function of how hard the brain works but rather how efficiently it works. This efficiency may derive from the disuse of many brain areas irrelevant for good task performance as well as the more focused use of specific task relevant areas. (Haier et al. 1992, p. 415)” A similar explanation was put forward by O’Boyle, Benbow and Alexander (1995). They hypothesized that enhanced right hemispheric involvement during basic information processing, as well as superior coordination and allocation of cortical resources within and between hemispheres, are unique characteristics of the gifted brain. A possible explanation being prenatal exposure to high levels of the hormone testosterone that might influence brain organization by enhancing the development of the right-hemisphere (Geschwind & Behan, 1982; Geschwind & Galaburda, 1987). In a series of experiments, Benbow (1986, 1988) established a link between extreme intellectual precocity and left-handedness, immune disorders, and myopia; each of which may be considered by-products of advantaged right-hemispheric development. In an EEG study, these findings could be only partly replicated (O’Boyle, Alexander, & Benbow, 1991). In another a study using PET, Haier and Benbow (1995) found no differences in the involvement of the right and left hemispheres related to mathematical ability.

The cited studies have two characteristics in common: First, individuals were classified into the high ability groups mainly based on intelligence test scores. Some of the studies (Jausovec, 1996, 1997a, 1998) have noted that individuals were gifted regarding creativity and other talents, however, these abilities were neither controlled, nor were they further investigated. Second, the problems used to stimulate cognitive processes were rather simple. Haier et al. (1988, 1992) used the computer game Tetris and RAPM (Raven, Court, & Raven, 1983). Jausovec (1997a, 1998) used different memory, computational, and classification tasks. All these problems can be classified as well defined. There are at least two distinctive features of well-defined problems that set them apart from ill-defined ones (Howard, 1983). First, the criteria that should be used when deciding whether or not the goal has been attained are specified clearly in the case of well-defined problems. With ill-defined problems, the goal is often vague. Second, the information necessary to solve a well-defined problem is usually specified precisely in the statement of the problem itself. In the case of ill-defined problems, it is often unclear what kind of information exactly is relevant to the problem at hand.

A major question is whether individuals use similar processes when they solve problems of different types. A powerful strategy for finding the right paths in the problem space of well-defined problems is means–end analysis (Ernst & Newell, 1969). For Anderson (1993), means–end analysis is the main process that humans use when they solve problems. This process is determined by two key features: difference reduction and subgoaling. Difference reduction is the tendency to select operators that produce states more similar to the goal state. The interim states in this reduction process are subgoals. Chi and Glaser (1985) and Simon (1979) argued that even in dealing with ill-defined problems, solvers use heuristics not unlike those that they use for well-defined problems, such as subgoaling. The generalization that can be drawn from their discussion is that creative problem solving is only a special case of the general problem solving strategy of means–end analysis. A contrary assumption was put forward by Dörner (1983) and Voss, Sherman, Tyler, and Yengo (1983). They concluded that creative problem solving has a
broader field of application than means–end analysis, which is a useful strategy only with problems that have a known solution.

A central difficulty related to this kind of research is to find a method that would make invisible thinking processes observable. In a recent study, Jausovec and Bakracevic (1995) used heart rate (HR) as a moderating variable. Their study showed a continuous increase in HR during the respondents’ solution of well-defined problems and a sudden increase in HR when respondents solved insight problems. These results suggest a more incremental solution approach to well-defined problems and a more sudden solution, described as illumination, to insight problems. The subjects’ HR during the solution of Dialectic and Divergent production problems, which are also classified as ill-defined problems, was less regular and was interrupted by several decreases/increases in HR, which could indicate the strategy of hypothesis testing. In another study, using alpha power measures, Jausovec (1997b) was able to show that ill-defined problems seem to be more demanding in the preparation phase than closed problems. More mental effort is needed to understand and plan the solution of ill-defined problems. A second finding of the study was that during the solution of well-defined problems, the respondents displayed less alpha power (higher mental activity) than during the solution of ill-defined problems. A similar finding, namely that creativity caused lower brain activity, was also reported by Beisteiner, Altemuller, Lang, Lindinger, and Deecke (1994). In this study, analytic, creative, and memory processes for different music tasks were compared. The explanation for the differences observed was task difficulty. The creative tasks were rated by the subjects as being the easiest ones.

The aim of the present study was to further investigate the relationship between ability and processes involved in problem-solving using EEG methodology. It was expected that respondents with different levels of intelligence and creativity would differ in the way in which they solved closed and open problems, and that these differences would be reflected in EEG patterns.

A second issue of the study was a methodological one. Most of the EEG studies reported had used alpha power measures for exploring differences in intelligence. Evidence indicates that alpha power is inversely related to mental effort (Adrian & Matthews, 1934). Amplitude decrease in the alpha rhythm—called “alpha blocking,” or “alpha desynchronization”—has been reported for several cognitive tasks such as mental arithmetic, tasks taken from IQ tests, and creative problems (Butler & Glass, 1976; Donchin, Kutas, & McCarthy, 1977; Glass, 1964; Gutierrez & Corsi-Cabrera, 1988; Martindale, 1999; Martindale, Hines, Mitchell, & Covello, 1984; Nunez, 1995). An interesting description of alpha blocking was provided in an early study by Penfield and Jasper (1954) for Einstein, who showed continuous alpha rhythm while carrying out complex but for him fairly automatic mathematical operations. Suddenly, his alpha waves dropped out. He reported that he has found a mistake in the calculation he had made the day before.

Recently, Klimesch, Doppelmayr, Pachinger, and Ripper (1997a) and Klimesch, Doppelmayr, Schimke, and Ripper (1997b) could show that dividing the alpha band into an upper (10.3–12.3 Hz) and a lower band (8.3–10.3 Hz) could provide additional information with regard to mental functioning. In several studies using the event-related desynchronization (ERD) method, Klimesch et al. (1997a,b) found that theta synchronization and desynchronization in the lower alpha band where associated with episodic
memory tasks and attentional demands of the tasks. On the other hand, semantic memory
tasks showed significant alpha desynchronization only in the upper alpha band (Klimesch,
Schimke, & Pfurtscheller, 1993). The conclusion drawn from these experiments was that
the lower alpha band was primarily associated with attentional processes, whereas the
upper alpha band was primarily associated with semantic memory processes.

A second measure used in the present study was coherence, the normalized
cross-correlation that provides information about the cooperation between various brain
areas. It has been shown that electrical relatedness in some way reflects the functional
relationship among brain areas (Petsche, Pockberger, & Rappelsberger, 1986; Sheppard &
Boyer, 1990). Nunez (1995) argued that decreased overall coherence obtained when a
cognitive task is performed could indicate that cognitive processing involves a general shift
from more global to local operation. On the other hand, Petsche (1996) suggested that
increases of coherence may indicate a closer cooperation of the brain areas in question,
whereas coherence decrease shows that brain regions become functionally more separate. In
both cases, the number of coherence changes centered on an electrode could be an indicator
of the functional importance of this region for the task. Thatcher and Walker (1985)
demonstrated a negative correlation between coherence increase and IQ. A similar finding
was reported by Kaplan (1995), who obtained negative correlations between coherence
measures and memory test scores of creative individuals. In contrast, Marosi et al. (1994)
established that a higher coherence in the alpha band was related to superior school
performance. Petsche (1997) who correlated coherence measures with scores on a text
composition task also found that most of the correlations obtained in males were positive
and related to the left hemisphere. In another study, Petsche (1996) further demonstrated
that acts of creative thinking were characterized by more coherence increase between
occipital and frontopolar electrode sites than in the solution of more closed problems.

The present study aimed to compare coherence and amplitude measures in the lower
and upper alpha band in relation to problem-solving processes employed by more or less
intelligent (highly intelligent [HIQ]/average intelligent [AIQ]) and creative individuals
(highly creative [HC]/average creative [AC]).

**Experiment 1**

In the first experiment, the EEG activity of gifted, creative, intelligent, and average
individuals was compared while they were solving problems with different complexity
levels. Two problems with two levels of complexity were used. Complexity was defined as
the number of elements given in the problem space. The problems could be classified as
well-defined calling for a stepwise solution approach. It was, therefore, expected that
patterns of EEG activity between individuals would mainly differ in relation to intelligence
and be less influenced by the level of creativity.

**Method**

**Subjects**

The sample included 49 right-handed student-teachers taking a course in Psychology.
Based on intelligence (WAIS) and creativity tests (Torrance, 1974), students were divided
into four groups: gifted (HIQ and HC), creative (HC and AIQ), intelligent (HIQ and AC),
and average (AIQ and AC). An ANOVA indicated significant between-group differences in intelligence test scores $[F(3,45) = 89.02, p < 0.000]$ and creativity test scores $[F(3,45) = 57.78, p < 0.000]$ (see Table 1).

### Procedure and Materials

The students’ EEG was recorded while students were solving two problems with two levels of complexity. According to Wakefield’s (1989) classification scheme, the problems could be classified as closed problems with closed solution situations—interpolation problems calling for convergent or logical thinking. The problems used were the Transportation problem (Dörner & Schaub, 1992) and the Plan-a-Day problem (Funke & Krüger, 1993). Both problems were presented on a computer monitor situated in front of the respondent.

The main task in the Transportation problem (T) was to achieve a desired number of free parking places in town and a desired number of bus passengers on local bus lines by changing the parking fee and frequency of bus departures. The answers (numbers between 1 and 40) had to be typed on the computer keyboard. In the easier version, only one element could be changed (parking fee or frequency of bus departures); in the complex version, both elements had to be changed to achieve the goal state. Each complexity level consisted of four problems. The easy version had an additional problem that was used to introduce the respondent to the problem features and requirements related to the input of data. The respondents had 10 min to complete each complexity level. The computer program gave feedback when the respondents achieved a correct solution and presented the next problem. The computer program kept a record of each respondent’s data input, number of correct solutions, time needed to achieve a solution, and number of steps taken in approaching to or digressing from the goal.

The aim of the Plan-a-Day (P) problem was to plan a day’s activities. For that purpose, the respondent was given a number of activities that had to be accomplished in one day. The problem simulated the working day of a businessman. The constraints of the problem were: number of tasks, time (in which each task had to be accomplished and how long it took to finish each task), time needed to reach the place in town where the task had to be accomplished (once a car could be used, the time needed to reach a place was reduced to one-third), and importance of the task (three levels: no information on the level of importance, important, very important). On the computer monitor, a schematic town map was presented with highlighted buildings showing where and when the tasks had to be accomplished. A display was also given of the times needed to reach each

### Table 1. Means and Standard Deviations for IQ and Creativity Test Scores (Z Scores) for the Four Ability Groups: Gifted, Creative, Intelligent, and Average

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>IQ test</th>
<th>Creativity test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Average</td>
<td>12</td>
<td>99.83</td>
<td>4.63</td>
</tr>
<tr>
<td>Gifted</td>
<td>11</td>
<td>129.82</td>
<td>4.60</td>
</tr>
<tr>
<td>Creative</td>
<td>11</td>
<td>106.18</td>
<td>8.60</td>
</tr>
<tr>
<td>Intelligent</td>
<td>15</td>
<td>127.33</td>
<td>3.75</td>
</tr>
</tbody>
</table>

and average (AIQ and AC). An ANOVA indicated significant between-group differences in intelligence test scores $[F(3,45) = 89.02, p < 0.000]$ and creativity test scores $[F(3,45) = 57.78, p < 0.000]$ (see Table 1).
building from the present location of the respondent (blinking cursor), the availability of the car and the current time, which changed according to the moves made by the respondent. The easier version consisted of five tasks. The correct solution was to accomplish all five tasks. The complex version consisted of nine tasks. The best solution was to accomplish seven tasks—those with the highest levels of importance. For each plan, the respondent was given 10 min. All answers were typed on the computer keyboard (nine different letters). Before starting with the two problems, the respondent was given a training problem that was used to introduce the problem and the commands needed to operate it. The computer program analyzed the correctness of each solution on a 10-point scale, the time needed to reach the solution, and the number of different plans constructed (strategy changes).

On their first arrival, at the laboratory the students were told that their EEG would be recorded while they solved four problems. After the EEG preparation was completed, students were presented with the Transportation problems, followed by the Plan-a-Day problems. Between each group of problems, a break lasting for approximately 5 min was given.

**EEG Recording and Quantification**

Brain wave activity was recorded using an ECI Electro-cap (Blom & Anneveldt, 1982). Using the Jasper (1958) 28-electrode placement system of the International Federation, EEG activity was monitored over 19 scalp locations (Fp1, Fp2, F3, F4, F7, F8, T3,T4, T5, T6, C3, C4, P3, P4, O1, O2, Fz, Cz, and Pz). All leads were referenced to linked ear lobes (A1 and A2) and a ground electrode was applied to the forehead. Additionally, vertical eye movements were recorded with electrodes placed above and below the left eye. Electrode impedance was maintained below 5 kΩ. The digital EEG data acquisition and analysis system (SynAmp and Scan 4.0) had a bandpass of 1.5–40.0 Hz. At cutoff frequencies, the voltage gain was approximately –6 dB. The 19 EEG traces were digitized online at 500 Hz with a gain of 1000 (resolution of 0.084 μV/bit) and stored on a hard disk. Prior to analysis, a correction for ocular artifacts was performed (Semlitsch, Anderer, Schuster, & Presslich, 1986). The correction was made only for vertical eye movements and not for horizontal ones, which might be a potential methodological problem. The data were divided into 2-s epochs (1024 data points) and automatically screened for artifacts. Excluded were all epochs showing amplitudes above ±85 μV. A fast Fourier transformation (FFT) was performed on artifact-free 2-s chunks of data in order to derive estimates of absolute spectral power (microvolts) in different frequency bands (\(\alpha_1 = 7.9–10.0\) Hz and \(\alpha_2 = 10.1–12.9\) Hz). For each problem and scalp position, a spectral power average (microvolts) was computed. Coherence values in the lower and upper alpha band were estimated for all electrode pairs. In that way, 171 coherence measures were computed for each problem.

**Results and Discussion**

The data were analyzed using the statistical package SPSS for Windows 9.0. All univariate repeated measures analyses of variance were corrected for violation of the sphericity assumption. The Results Sections include the corrected \(p\) (Huynh–Feldt) and the nominal degrees of freedom (Jennings, 1987).
Behavioral Measures

Differences in respondents’ problem solving efficiency were analyzed with two General Linear Models (GLM) for repeated measures—2 (complexity level) × 2 (intelligence—high/average) × 2 (creativity—high/average). The transportation problem showed significant between-group differences related to intelligence \([F(1,45) = 11.20, p < 0.008]\) and a significant intelligence by complexity interaction effect \([F(1,45) = 10.70, p < 0.002]\). The GLM for the Plan-a-Day problem indicated significant between-group differences for the level of intelligence \([F(1,45) = 17.62, p < 0.000]\) and significant intelligence by complexity interaction effects \([F(1,45) = 5.12, p < 0.029]\). As can be seen in Table 2, the HIQ individuals in comparison with the AIQ showed significantly higher scores for the Transportation as well as Plan-a-Day problems. These results were expected given the fact that both problems were classified as well-defined, calling for little or no creativity.

**Alpha Power Measures**

In order to determine differences in the lower alpha band (\(\alpha_1\)) between the four ability groups, a GLM for repeated measures—2 (hemisphere—left/right) × 2 (complexity high/low) × 8 (electrode location) × 2 (intelligence—high/average) × 2 (creativity—high/average)—was conducted for the Transportation and Plan-a-Day problems. The GLM conducted for the Transportation problem showed a significant interaction effect for the factors hemisphere, electrode location, and creativity \([F(7,315) = 3.12, p < 0.027]\) and complexity, location, and intelligence \([F(7,315) = 2.44, p < 0.039]\). For the Plan-a-Day problem, a significant interaction effect for the factors hemisphere, intelligence, and creativity were observed \([F(1,45) = 4.98, p < 0.031]\). Significant was also the interaction effect between the factors hemisphere, complexity, intelligence, and creativity \([F(1,45) = 4.52, p < 0.039]\). To obtain a more detailed picture of the differences related to the level of intelligence and creativity, a GLM for repeated measures—2 (complexity—high/low) × 2 (intelligence—high/average) × 2 (creativity—high/average)—for each electrode location and problem was calculated. As can be seen in the upper part of Table 3, significant differences for the level of intelligence in the frontal (Fp1, Fp2, F8) and central (C3) sites were observed. The HIQ group showed higher alpha power when confronted with the Transportation problems. For the Plan-a-

### Table 2. Means and Standard Deviation for the Efficiency Scores for the Transportation and Plan-a-Day Problems—Easy and Complex Versions

<table>
<thead>
<tr>
<th>Problem</th>
<th>HIQ M</th>
<th>HIQ SD</th>
<th>AIQ M</th>
<th>AIQ SD</th>
<th>HC M</th>
<th>HC SD</th>
<th>AC M</th>
<th>AC SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>3.77</td>
<td>0.59</td>
<td>3.69</td>
<td>0.70</td>
<td>3.64</td>
<td>0.73</td>
<td>3.81</td>
<td>0.56</td>
</tr>
<tr>
<td>C</td>
<td>1.92</td>
<td>1.62</td>
<td>0.70</td>
<td>0.97</td>
<td>1.50</td>
<td>1.63</td>
<td>1.22</td>
<td>1.37</td>
</tr>
<tr>
<td>Plan-a-Day</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>5.92</td>
<td>3.65</td>
<td>4.30</td>
<td>3.65</td>
<td>5.86</td>
<td>3.72</td>
<td>4.59</td>
<td>3.66</td>
</tr>
<tr>
<td>C</td>
<td>7.31</td>
<td>3.02</td>
<td>2.83</td>
<td>3.64</td>
<td>6.05</td>
<td>3.86</td>
<td>4.52</td>
<td>4.03</td>
</tr>
</tbody>
</table>
Day problems, a significant difference for the level of creativity in the T6 location was observed. The HC individuals showed less alpha power than did the AC individuals.

The same analysis as for the lower alpha band was performed for the upper alpha band ($\alpha_2$). The GLM conducted for the Transportation problem revealed significant interaction effects between the hemisphere, location, and creativity [$F(7,315) = 3.27, p < 0.018$] and the interaction of complexity, location, and intelligence [$F(7,315) = 3.26, p < 0.010$]. The GLM conducted for the Plan-a-Day problem showed a significant interaction between the level of creativity and hemisphere [$F(1,45) = 4.41, p < 0.041$] and the level of creativity, hemisphere, and location [$F(7,315) = 3.97, p < 0.009$]. Also significant was the interaction between the level of intelligence, complexity, and location [$F(7,315) = 4.09, p < 0.010$]. Subsequent GLMs conducted for each location and problem showed six significant group-related differences for both problems. As can be seen in the lower part of Table 3, for the Transportation problems significant differences were observed in the parietal sites (P3, P4, Pz), whereas for the Plan-a-Day problem, differences were observed in the temporal site (T6) and midline parietal site (Pz). The differences showed a similar trend to those observed in the lower alpha band.

Altogether, the results obtained support the hypothesis that EEG patterns to a greater extent differ in relation to the level of respondents’ intelligence and are less influenced by the level of creativity. Two trends could be observed. First, gifted and intelligent individuals (HIQ) displayed slightly higher alpha power measure than did average and creative ones (AIQ). These differences were statistically significant for both alpha bands and problem types. This finding is similar to the observed difference in the number of solved problems that were also significant only in relation to the level of intelligence. Second, for the Plan-a-Day problem the HC individuals displayed less alpha power in both bands in the T6 site. This finding

### Table 3. Means, Standard Deviation, and F-test for Between-Group Effects of Intelligence (HIQ/AIQ) and Creativity (HC/AC) for the Lower ($\alpha_1$) and Upper Alpha Band ($\alpha_2$) for the Transportation (T) and Plan-a-Day (P) Problems

<table>
<thead>
<tr>
<th>Location</th>
<th>Problem</th>
<th>HIQ M</th>
<th>HIQ SD</th>
<th>AIQ M</th>
<th>AIQ SD</th>
<th>HC M</th>
<th>HC SD</th>
<th>AC M</th>
<th>AC SD</th>
<th>F-IQ (1,45)</th>
<th>F-C</th>
</tr>
</thead>
<tbody>
<tr>
<td>fP1-c1</td>
<td>T</td>
<td>2.86</td>
<td>0.66</td>
<td>2.46</td>
<td>0.68</td>
<td>2.69</td>
<td>0.68</td>
<td>2.63</td>
<td>0.68</td>
<td>4.23*</td>
<td>N.S.</td>
</tr>
<tr>
<td>fP2-c1</td>
<td>T</td>
<td>2.75</td>
<td>0.64</td>
<td>2.38</td>
<td>0.63</td>
<td>2.60</td>
<td>0.63</td>
<td>2.53</td>
<td>0.63</td>
<td>4.35*</td>
<td>N.S.</td>
</tr>
<tr>
<td>C3-\alpha1</td>
<td>T</td>
<td>4.04</td>
<td>1.47</td>
<td>3.17</td>
<td>1.45</td>
<td>3.65</td>
<td>1.45</td>
<td>3.56</td>
<td>1.46</td>
<td>4.28*</td>
<td>N.S.</td>
</tr>
<tr>
<td>F8-\alpha1</td>
<td>T</td>
<td>2.65</td>
<td>0.69</td>
<td>2.24</td>
<td>0.68</td>
<td>2.42</td>
<td>0.68</td>
<td>2.47</td>
<td>0.69</td>
<td>4.38*</td>
<td>N.S.</td>
</tr>
<tr>
<td>T6-\alpha1</td>
<td>P</td>
<td>3.28</td>
<td>0.86</td>
<td>2.94</td>
<td>0.84</td>
<td>2.83</td>
<td>0.84</td>
<td>3.43</td>
<td>0.85</td>
<td>5.13*</td>
<td>N.S.</td>
</tr>
<tr>
<td>P3-\alpha2</td>
<td>T</td>
<td>3.51</td>
<td>0.92</td>
<td>2.98</td>
<td>0.93</td>
<td>3.36</td>
<td>0.93</td>
<td>3.13</td>
<td>0.94</td>
<td>4.04*</td>
<td>N.S.</td>
</tr>
<tr>
<td>P4-\alpha2</td>
<td>T</td>
<td>3.63</td>
<td>0.91</td>
<td>3.04</td>
<td>0.96</td>
<td>3.41</td>
<td>1.00</td>
<td>3.25</td>
<td>0.82</td>
<td>5.06*</td>
<td>N.S.</td>
</tr>
<tr>
<td>Cz-\alpha2</td>
<td>T</td>
<td>3.42</td>
<td>0.97</td>
<td>2.78</td>
<td>0.96</td>
<td>3.28</td>
<td>0.96</td>
<td>2.96</td>
<td>0.97</td>
<td>5.38*</td>
<td>N.S.</td>
</tr>
<tr>
<td>Pz-\alpha2</td>
<td>T</td>
<td>3.99</td>
<td>1.06</td>
<td>3.11</td>
<td>1.05</td>
<td>3.76</td>
<td>1.05</td>
<td>3.34</td>
<td>1.05</td>
<td>8.67**</td>
<td>N.S.</td>
</tr>
<tr>
<td>T6-\alpha2</td>
<td>P</td>
<td>3.03</td>
<td>0.88</td>
<td>2.59</td>
<td>0.87</td>
<td>2.52</td>
<td>0.87</td>
<td>3.09</td>
<td>0.87</td>
<td>5.19*</td>
<td>N.S.</td>
</tr>
<tr>
<td>Pz-\alpha2</td>
<td>P</td>
<td>3.63</td>
<td>0.81</td>
<td>3.14</td>
<td>0.81</td>
<td>3.42</td>
<td>0.80</td>
<td>3.35</td>
<td>0.81</td>
<td>4.40*</td>
<td>N.S.</td>
</tr>
</tbody>
</table>

**Notes:**
- Reported are only electrodes showing significant differences. No significant interaction effects were observed.
- N.S. = not significant.
- *p < 0.05.
- **p < 0.01.
might well point to the fact that HIQ individuals try to cope with more complex interpolation problems by employing a more broad range of brain areas than do AIQ ones. However, the differences in EEG patterns were not as pronounced as one would expect, given the highly significant between-group differences related to intelligence and creativity (see Table 1). A reason for that might well be because the problems used in the first experiment resembled tasks used in IQ tests only at a general level. Based on previous research (Jausovec, 1994), one could expect that a stepwise strategy would be appropriate for the solution of the Transportation and Plan-a-Day problems as well as for some problems used in the IQ tests that were the base for the assignment of individuals to the four groups.

Coherence Measures

Between-group differences were analyzed with a GLM for repeated measures—2 (complexity level) \times 2 (intelligence—high/average) \times 2 (creativity—high/average). Because of the number of separate tests computed (171 per problem), the risk of a type I error is high. Therefore, the probability maps show only those differences where at least 5 percent of GLMs conducted for each problem and band were significant (Tremblay et al., 1994).

As can be seen in Fig. 1a and b, the general trend was that HIQ individuals in comparison with AIQ displayed higher cooperation between brain sites mainly located in the right hemisphere, showing rather short distance cooperation between brain areas in the right frontal (Fz, Fp2, F4, F8), temporal (T4, T6) and central (Cz, C4) sites. A decoupling between the left frontopolar and temporal sites could be also observed for the Transportation problem. Much less pronounced were the differences for the HC individuals who showed higher cooperation between brain areas mainly in the frontal areas.

EXPERIMENT 2

In this experiment, a comparison was made of EEG activity between gifted, creative, intelligent, and average individuals while solving creative problems. The creativity problems were chosen in such a way that some resembled tasks on creativity tests, while some were more related to problems students have to solve in their every day life. It was expected that, in comparison with the HC individuals, the AC ones would show lower alpha activity while solving creative problems.

Method

Subjects

The sample included 48 right-handed student-teachers taking a course in Psychology. Students were divided into the four ability groups in the same way as in Experiment 1. An ANOVA indicated significant between-group differences for intelligence test scores \([F(3,44) = 75.49, p < 0.000]\) and creativity test scores \([F(3,44) = 50.65, p < 0.000]\) (see Table 4).
Figure 1. Significant differences in $\alpha_1$ coherence measures between the four ability groups HIQ/AIQ and HC/AC for the Transportation and Plan-a-Day problems.
Procedure and Materials

The students’ EEG was recorded while they were solving four problems that were classified according to Wakefield’s (1989) classification scheme into two problem types, each containing two problems.

1. Open problem and solution situations (Dialectic problem). These problems do not evoke a “correct” solution but call for the discovery of a problem. For that purpose, a modified version of the Livian war problem (Ladbeater & Kuhn, 1989) was designed. The students first received a 1,400-word-long text describing the reasons for a fictive war between two states. The text was written in the form of newspaper articles, published in newspapers of the two states involved in the conflict and by others being more or less directly involved. Students were instructed to carefully read the text and try to devise their own picture of the reasons for the conflict (Reading problem). When finished reading, they were asked to think about writing an essay about the Livian war (Writing problem). No time limits were given for the reading and essay writing parts of the problem.

2. Closed problem and open solution situations (Divergent production problem). These problems resemble creative thinking problems in the open-endedness of their solution, but are more specific with regard to the operators and knowledge needed to solve them. Six problems adapted from creativity tests were used (Wallach & Kogan, 1965). Three problems were verbal: Name all the things you can think of that will make noise; tell me all the different ways you could use an automobile tire; and tell me all the ways in which a radio and a telephone are alike. The other three problems were figural. Students were shown three different unfinished pictures and asked to think about all the things each completed drawing could be. All six problems were presented on a computer monitor situated in front of the respondents. Students were asked just to think about the answers and not to verbalize them aloud. Each question, or picture, was displayed for a period of 2 min. In this period, students had to produce as many answers as possible. Each problem was followed by a 1-min pause in which the computer screen turned green and music was played. Ten seconds before the new problem was presented the music stopped. In that way, students could prepare for EEG recording: relax and reduce eye blinks.
Students were first presented with the three verbal problems, followed by the figural problems, reading the text, and the essay writing problem. Between each group of problems a break lasting for approximately 5 min was given.

**EEG Recording and Quantification**

EEG recording in Experiment 2 was the same as in Experiment 1. For each problem (Verbal and Figural, Divergent production problem, the Reading, and Essay writing problems) a spectral power average and coherence measures were computed.

**Results and Discussion**

The statistical methods and considerations in Experiment 2 were the same as in Experiment 1.

**Alpha Power Measures**

In order to determine differences in the lower alpha band (\(\alpha_1\)) between the four ability groups, a GLM for repeated measures—2 (hemisphere) \(\times\) 4 (problems) \(\times\) 8 (electrode location) \(\times\) 2 (intelligence) \(\times\) 2 (creativity)—was conducted. The analysis revealed a significant group effect for the level of creativity \([F(1,44) = 25.23, \ p < 0.000]\). Also significant were the interaction effects between the level of creativity and the problem type \([F(3,132) = 3.00, \ p < 0.044]\), level of creativity and location \([F(7,308) = 9.54, \ p < 0.000]\), and level of creativity, task, and location \([F(21,924) = 3.59, \ p < 0.006]\). The between-group factor level of intelligence showed significant interaction effects with the factors hemisphere \([F(1,44) = 5.02, \ p < 0.030]\) and hemisphere and level of creativity \([F(1,44) = 7.10, \ p < 0.011]\). To obtain a more detailed picture of the differences revealed, for each problem and electrode location a GLM for repeated measures—2 (problem type) \(\times\) 2 (intelligence) \(\times\) 2 (creativity) was conducted.

As can be seen in Table 5 and Fig. 2, HC (gifted and creative individuals solving creative problems showed higher \(\alpha_1\) power measures than did the AC (average and intelligent) students. Highly significant differences were obtained for all 19 electrode locations for both problems. In the right frontal site, F8, an additional interaction effect between the factors, creativity and intelligence, was observed. A subsequent Scheffe post-hoc test indicated that the gifted group in comparison with all other three groups displayed the highest levels of alpha power.

The same analysis as for the lower alpha band was performed for the upper alpha band (\(\alpha_2\)). A GLM for repeated measures revealed a significant group effect for the level of creativity \([F(1,44) = 24.25, \ p < 0.000]\). The between-group factor level of creativity showed significant interaction effects with the factors problem type \([F(3,132) = 3.41, \ p < 0.032]\), location \([F(7,308) = 10.20, \ p < 0.000]\), problem type and location \([F(21,924) = 2.82, \ p < 0.009]\). The level of intelligence showed significant interaction effects with the factors hemisphere \([F(1,44) = 5.09, \ p < 0.030]\) and hemisphere and level of creativity \([F(1,44) = 7.29, \ p < 0.010]\).

As can be gathered from Table 6 and Fig. 3, HC individuals, while solving creative problems, showed higher \(\alpha_2\) power measures than did the AC individuals. These differences showed a similar trend to those observed in the lower alpha band. For the Divergent production problems in location T3, a significant interaction between the level
of creativity and intelligence was observed. A subsequent Scheffe post-hoc test showed significant higher alpha power for the gifted individuals than for the other three groups (average, creative, and intelligent).

Coherence Measures

Between-group differences were analyzed with a GLM for each electrode pair, problem, and alpha band. As can be seen in Fig. 4, significant between-group differences in the lower alpha band were observed for the Divergent production problems (13%) and Dialectic problems (39%). A general trend was that HC individuals, by comparison with the AC ones, showed greater inter- and intrahemispheric cooperation between brain areas. This was especially pronounced for the Dialectic problems in the frontal areas and between both frontopolar sites and parietal, temporal, and occipital areas. On the other hand, HIQ individuals showed greater decoupling of brain areas than AIQ individuals. These differences were extremely pronounced between the midline parietal (Pz), frontal (Fz), and central site (Cz), and both central sites (C3, C4). Scheffe tests—conducted for significant interaction effects between the level of creativity and intelligence—further indicated that the gifted individuals showed the highest level of decoupling between brain areas mainly in the left hemisphere (F3, P3, C3), whereas the creative individuals displayed most pronounced cooperation between brain areas between the midline parietal site and both frontopolar sites.
Figure 2. Topographic maps of EEG power measures in the lower alpha band (α) for the four ability groups while solving Divergent production and Dialectic problems.
A similar pattern of coherence measure was observed in the upper alpha band only for the Dialectic problems showing 33 percent significant differences. As revealed in Fig. 5c and d, creative individuals showed more cooperation between brain areas, whereas HIQ individuals showed an even more intense decoupling of brain areas. For the Divergent production problems, 23 percent significant differences were determined. Less cooperation between brain areas for the HC individuals was observed. Differences were pronounced mainly between the creative and average individuals (Fig. 5b). On the other hand, HC individuals showed more decoupling between brain areas in the occipital and temporal sites, whereas the HIQ individuals showed more cooperation between brain areas mostly in the right hemisphere (O2, P4, T6, T4, C4, F8).

In general, the Dialectic problems, which required the highest levels of creativity, in both alpha bands proved to be the most significant between-group differences. The HC individuals displayed higher cooperation between the far distant brain regions (frontopolar, parietal, occipital, and temporal electrode sites) in both alpha bands. HC individuals also displayed greater cooperation in the frontal areas. Similar results were reported by Petsche (1990) for the task of creating texts. A second characteristic was that gifted individuals most often displayed the lowest coherence measures indicating a decoupling of brain areas. This decoupling was most pronounced in the frontal areas but also between the far distant brain regions. Two reasons could underlay the decreases in coherence: First, more cooperation occurred in areas smaller than the electrode distance, and second, an increase in the activity with subcortical sites may occur. Probably, both events contribute to the

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**Table 6.** F-Tests for Significant Between-Group Effects: Level of Intelligence (HIQ/AIQ) and Creativity (HC/AC) in the Lower Alpha Band (α2) for the Divergent Production and Dialectic Problems

<table>
<thead>
<tr>
<th>Location</th>
<th>Divergent production problems</th>
<th></th>
<th>Dialectic problems</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F^2-IQ</td>
<td>F-C</td>
<td>F-IQ/C</td>
<td>F^2-IQ</td>
<td>F-C</td>
</tr>
<tr>
<td>Fp1</td>
<td>0.63</td>
<td>13.99**</td>
<td>0.89</td>
<td>3.90</td>
<td>15.82**</td>
</tr>
<tr>
<td>Fp2</td>
<td>0.02</td>
<td>14.66**</td>
<td>0.27</td>
<td>0.19</td>
<td>20.80**</td>
</tr>
<tr>
<td>F3</td>
<td>0.42</td>
<td>21.46**</td>
<td>1.25</td>
<td>1.76</td>
<td>21.14**</td>
</tr>
<tr>
<td>F4</td>
<td>0.01</td>
<td>22.11**</td>
<td>0.68</td>
<td>0.12</td>
<td>24.13**</td>
</tr>
<tr>
<td>F7</td>
<td>1.06</td>
<td>14.06**</td>
<td>1.53</td>
<td>4.42*</td>
<td>10.39*</td>
</tr>
<tr>
<td>F8</td>
<td>0.36</td>
<td>7.40*</td>
<td>2.18</td>
<td>0.35</td>
<td>17.42**</td>
</tr>
<tr>
<td>Fz</td>
<td>0.08</td>
<td>20.98**</td>
<td>1.34</td>
<td>0.77</td>
<td>22.03**</td>
</tr>
<tr>
<td>T3</td>
<td>1.87</td>
<td>8.58*</td>
<td>4.67</td>
<td>0.77</td>
<td>2.23</td>
</tr>
<tr>
<td>T4</td>
<td>0.01</td>
<td>8.39*</td>
<td>0.06</td>
<td>0.12</td>
<td>4.66*</td>
</tr>
<tr>
<td>T5</td>
<td>0.06</td>
<td>16.98**</td>
<td>2.04</td>
<td>2.06</td>
<td>12.07**</td>
</tr>
<tr>
<td>T6</td>
<td>1.01</td>
<td>11.16</td>
<td>0.12</td>
<td>0.05</td>
<td>6.21*</td>
</tr>
<tr>
<td>C3</td>
<td>0.40</td>
<td>25.16**</td>
<td>2.35</td>
<td>0.23</td>
<td>17.42**</td>
</tr>
<tr>
<td>C4</td>
<td>0.14</td>
<td>21.31**</td>
<td>0.03</td>
<td>0.08</td>
<td>22.02**</td>
</tr>
<tr>
<td>Cz</td>
<td>0.00</td>
<td>23.70**</td>
<td>1.10</td>
<td>0.71</td>
<td>17.78**</td>
</tr>
<tr>
<td>P3</td>
<td>0.05</td>
<td>23.45**</td>
<td>0.40</td>
<td>0.76</td>
<td>11.74**</td>
</tr>
<tr>
<td>P4</td>
<td>0.51</td>
<td>19.69**</td>
<td>0.02</td>
<td>0.00</td>
<td>12.94**</td>
</tr>
<tr>
<td>Pz</td>
<td>1.01</td>
<td>20.48**</td>
<td>0.00</td>
<td>0.09</td>
<td>11.16*</td>
</tr>
<tr>
<td>O1</td>
<td>1.88</td>
<td>16.88**</td>
<td>1.31</td>
<td>0.65</td>
<td>8.16*</td>
</tr>
<tr>
<td>O2</td>
<td>2.84</td>
<td>20.17**</td>
<td>2.85</td>
<td>0.13</td>
<td>12.94**</td>
</tr>
</tbody>
</table>

**Notes:**

\( df \) for F-test = (1,44).

\*p < 0.05.

\**p < 0.001.
Figure 3. Topographic maps of EEG power measures in the upper alpha band ($\alpha_2$) for the four ability groups while solving Divergent production and Dialectic problems.
Figure 4. Significant differences in $\alpha_1$ coherence measures: (a) and (c) differences between the HIQ/AIQ and HC/AC individuals; (b) and (d) differences between the average (A), creative (C), intelligent (I), and gifted (G) individuals.
c.) Dialectic problems - $\alpha_1$

- HIQ < AIQ
- HC > AC
- HC < AC

d.) Dialectic problems - $\alpha_1$

- C > A
- C > G
- C > A, G
- C > A, L, G

Figure 4. Continued.
Figure 5. Significant differences in $\alpha_2$ coherence measures: (a) and (c) differences between the HIQ/AIQ and HC/AC individuals; (b) and (d) differences between the average (A), creative (C), intelligent (I), and gifted (G) individuals.
c.) Dialectic problems - $\alpha_2$

- $\text{HIQ} < \text{AIQ}$
- $\text{HC} > \text{AC}$
- $\text{HC} < \text{AC}$

d.) Dialectic problems - $\alpha_2$

- $\text{C} > \text{A}$
- $\text{C} > \text{G}$
- $\text{C} > \text{A, G}$

Figure 5. Continued.
observed decrease and suggest that gifted individuals, while contemplating about the essay, activated fewer mental areas than the other three ability groups. This explanation supports the efficiency hypothesis put forward by Haier et al. (1988) and corresponds with Ojemann’s (1982) finding that in multilinguals, the poorer language is distributed over a larger area than the better one.

Fewer significant differences were observed for the Divergent production problems. The differences also markedly differed between the lower and upper alpha band. HC individuals showed more cooperation between brain areas only in the lower alpha band. In the upper alpha band, an almost reverse pattern was observed. HC individuals displayed more decoupling of brain areas, while HIQ individuals showed more cooperation between brain areas in the right hemisphere. The pattern of cooperation between brain areas was similar to the one observed in HIQ individuals while solving the Plan-a-Day problem (see Fig. 1b). The explanation for this similarity might be the characteristic of the Divergent production problems. From a theoretical viewpoint, the solution of these problems required less creativity than solving the Dialectic problems. A second, mutually not exclusive explanation could be the functional diversity of both alpha bands. One could speculate that the HIQ individuals solved the Divergent production problems more relying on semantic memory processes, whereas the HC individuals solved the same problems with a greater attentional effort and the involvement of episodic memory.

**DISCUSSION**

The major finding of this study was that between-group differences in creativity and intelligence were related to different EEG patterns obtained while individuals were engaged in solving closed and creative problems. The analysis of power measures in Experiment 1 indicated that HIQ individuals displayed less mental activity when solving closed problems than did AIQ individuals. The level of creativity had only a minor impact on the EEG patterns displayed in both alpha bands. Much more pronounced were the differences in EEG patterns obtained in Experiment 2. HC individuals displayed less mental activity than did AC individuals when engaged in the solution of different creative problems. The reason why differences were more pronounced for the open problems than for the closed ones could lie in the fact that the creative problems, to a greater extent, resembled tasks used in creativity tests, while, on the other hand, closed problems used in the first experiment differed significantly from tasks used in intelligence tests. This would further point to a rather task-specific relationship between intelligence and brain activity, being more influenced by surface task characteristics, such as form of presentation, than their deep structure, such as processes involved in the solution. A similar explanation was put forward by Detterman (1994). In Detterman’s theory, intelligence is a complex system of independent parts. In the light of his theory, it is probable to expect that several measures of brain functioning will relate to intelligence and that it is unlikely that a single biological measure will account for a large portion of the variance of intelligence.

The results of both experiments suggest that creativity and intelligence are different abilities that also differ in the neurological activity displayed by individuals while solving open or closed problems. In both cases, less mental activity is related to higher creativity and/or higher intelligence. In the light of the efficiency theory, it is
likely that HIQ individuals have fewer difficulties with closed problems because they use specific brain areas relevant for the solution of such tasks. However, when confronted with open problems they probably activated brain areas that are not relevant for the solution of the tasks at hand, and therefore, have less creative answers. The same explanation could be given for the HC individuals when solving creative or closed problems.

A second finding of the study was that differences in EEG patterns related to intelligence (Experiment 1) were not so numerous and were much more clear-cut than those related to creativity (Experiment 2). In the first experiment, alpha power as well as coherence measures in both alpha bands followed a general trend mainly showing between-group differences related to respondents’ intelligence. In the second experiment, only alpha power measures in both bands showed a clear-cut relationship with creativity. On the other hand, differences in coherence were much more diverse. HC individuals displayed more cooperation between brain areas in the lower alpha band and more decoupling of brain areas in the upper alpha band. HIQ individuals, while solving the Divergent production problems, showed more decoupling of brain areas in the lower alpha band and more cooperation between brain areas in the upper alpha band, whereas for the Dialectic problems, an intensified decoupling of brain areas in the upper alpha band was observed. This might suggest that HIQ solved creative problems more by relying on semantic memory processes, whereas creative individuals to a greater extent relied on processes related to attention and episodic memory. One might further speculate that this could point to more primary processes being less consciously controlled in creative individuals when confronted with ill-defined problems.

The coherence measures also showed many significant interaction effects related to the level of creativity and intelligence. Creative individuals displayed more cooperation between brain areas than did gifted ones, who by contrast showed less cooperation between brain areas when solving creative problems. This might point to a greater specialization of brain functions in gifted individuals. Creative individuals displayed inter- and intrahemispheric cooperation between the far distant brain regions, while for adjacent electrode pairs, mainly in the upper alpha band, a decoupling of brain areas was observed. Such results suggest that generally decreased coherence, together with more selective involvement of cortical zones with increased coherence, reflects the specificity of function among areas of the brain, which, in turn, is related to intelligence and creativity.

The results further suggest that creativity has a less pronounced influence on the solution of closed problems than has intelligence on creative problem solving. It is possible that creative performance can be achieved in different ways involving also different brain activity. Creativity is rather diverse, covering fields such as science on the one hand, and art on the other (Runco, 1994). Conversely, the solution of closed problems mainly requires the process of means–end analysis. This process is determined by two key features: difference reduction and subgoaling. Such a process is fairly uniform, and therefore, could explain the much lower impact of creativity on the solution of closed problems, which was also reflected in EEG patterns.

The results of the present study suggest that a selective involvement of cortical zones that are relevant for the solution of a problem could be an explanation for the observed differences in problem solving. Further, it seems reasonable that future
research relating ability with different measures of brain activity should not exclusively focus on measures of intelligence, but also on creativity.

The study has also shown that coherence measures provided additional information about the involvement of brain areas in problem solving. Although the physiological and cognitive significance of an increase, as opposed to a decrease, of coherence has yet to be fully determined, it does give insight into the brain areas involved in task performance. One may agree with Petsche’s (1996, 1997) conclusion that coherence is highly task-specific, and therefore, most suitable for the study of mental processes. Looking for functional relations between brain regions rather than for localized power measures is useful because of the basic structure of the cortex, which is a device for the most widespread diffusion and mixing of signals (Braitenberg & Schutz, 1991). Nearly every pyramidal cell sends an axon into the white matter and most of these re-enter the cortex at some distant location in the same hemisphere, or opposite hemisphere. In addition, multiple branches of the axon provide input to regions within of 3-mm radius. Thus, no cortical neuron seems to be separated by more than two or three synapses from any other neuron. An essential function of such a system must be the maximal possible convergence/divergence of signals. Therefore, when studying the brain more information can be provided by measures that determine electrical relations between different areas than just the level of activity in different areas. This was confirmed also by the present study.

REFERENCES


