

THE EFFECTS OF EXPERIENCE DURING DESIGN PROBLEM SOLVING

Mehmet H. Göker

Technische Hochschule Darmstadt

Maschinenelemente und Konstruktionslehre

Magdalenenstr. 4, 64289 Darmstadt, Germany

goker@muk.maschinenbau.th-darmstadt.de

THE EFFECTS OF EXPERIENCE DURING DESIGN PROBLEM SOLVING

Mehmet H. Göker

Keywords: design cognition, design knowledge, design research, psychology of design, design experience

Abstract: Behavioral and physiological experiments to analyze the development, influence and application of experience during design problem solving are described. The results of the behavioral experiments show, that while novices try to solve assignments through deductive reasoning, experts prefer to apply their experience directly. The electrophysiological experiments indicate, that as a manifestation of this, the regions activated in the human brain during problem solving vary according to the experience a test person has. Novices show a longer activity in the frontal regions whereas the experts seem to have longer activity in the parietal regions of the brain.

To analyze the development, influence and application of experience during problem solving we conducted experiments in which test persons were asked to solve simple design assignments with the computer program “The Incredible Machine”¹. In the first, behavioral part of the project, the test persons were asked to “think aloud” while they worked on the assignments. The computer screen and the test persons were recorded with a video camera. The video and audio recordings were transcribed and analyzed. Our aim was to find out how new experiences in a domain are created and learned, how they are indexed and recalled, and how the problem solving experience in a domain affects the problem understanding, the approach used during problem solving and the created solution space. Details regarding these experiments can be found in [1, 2, 3].

In the second part of the project, we conducted experiments, in which the activity distribution in the human brain during problem solving was measured. The experiments were conducted in co-operation with Prof. Dr. W. Krause, Department of Psychology of the Friedrich-Schiller Universität Jena. Our main interest was to find out if the behavioral difference we observed between experts and novices does have a corollary in the activity distribution in the human brain, i.e. if there is a difference in the regions activated in the brain between experts and novices when they solve assignments.

1 The Computer Program “The Incredible Machine”

The computer program “The Incredible Machine” (TIM) simulates a design environment in which simple machines can be built by using the 45 provided elements (Table 1). Figure 1 shows the main screen of the program. The machine is built and started in the main window. The parts can be selected from the list on the right hand side of the screen. By clicking on the field in the upper right hand corner, the environment (gravity, air pressure) is activated and the machine started. The point and bonus display at the bottom of the screen was of no interest to us and deactivated. The program is operated using the mouse.

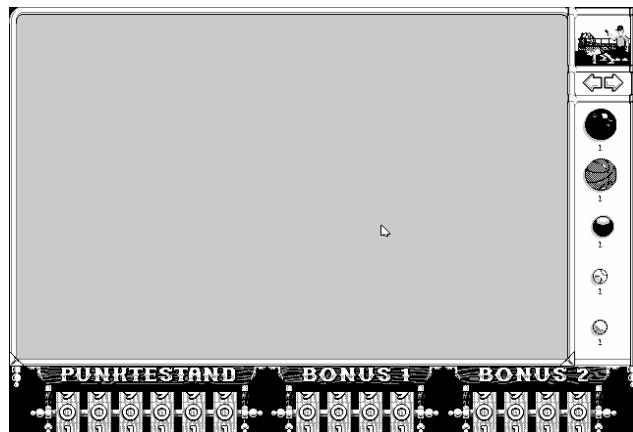


Figure 1: The Main Screen of “The Incredible Machine”

¹ “The Incredible Machine “ is a registered trademark of Sierra On-Line Inc., Coarsegold, CA.

























 Bowlingball	 Basketball	 Baseball	 Rope	 Conveyor belt	 Belt
 Wall	 Board	 Pipe	 Boxing-glove	 Pokey the Cat	 Trampoline
 Ape on a bike	 Rocket	 Colt	 Cannon	 Bucket	 Cage
 Balloon	 Pulley	 Switch / Outlet	 Generator	 Electromotor	 Ventilator

Table 1: Some of the Elements available in “The Incredible Machine”

2 The Behavioral Experiments

2.1 Setup of the Behavioral Experiments

During the behavioral experiments the test persons were asked to build machines to solve the given assignments and to “think aloud”. Their comments and the computer screen were recorded with a video camera.

After reading an introduction to the experiment and the computer program, the test persons had to solve four obligatory assignments in fixed order and to describe the elements they used in a description booklet. Following the first four assignments, they were asked to select two more assignments out of the eight we provided, give the reason why they selected these particular assignments, and solve them. To reduce the pressure, the test persons were told that their machines will not be evaluated in any way and that their time is not limited.

At the end of the experiment, the video and audio recordings were transcribed into a *protocol*, a *task list* and a *solution tree*. The *protocol* is a plain text transcription of the comments and actions of the test persons and the test administrator. The *task list* gives a chronological enumeration of the goals, the actions performed to achieve these goals, the results of these actions, and the new subgoals. The *solution trees* are graphical representations of the problem decomposition and solution space generated by the test person. The goals of the test person are shown in cursive capital, the hypothetical solutions in normal letters. Variants that have not achieved the posed goal are broken off with a horizontal line (e.g. Figure 2). The solution trees do not give a chronological account of the development of the solution but allow to analyze the reuse of elements.

During the behavioral experiments we observed 19 test persons of different backgrounds while they solved our assignments. None them was familiar with the program beforehand.

2.2 Summary of the Results of the Behavioral Experiments

Figure 2 shows the assignment 4 (“transport the basketball underneath the cage into the wooden box”) along with the solution and solution tree of Tp13. We can see that the test person split the assignment into the sub-goals “*FREE BALL*” and “*BALL TO THE LEFT*”. “*BALL TO THE LEFT*” was a situation with which the test person had experience and for which she employed the known solution directly. Sub-goals for which the test persons knew a solution can be identified through the deeper, straightforward branches of the solution tree. Test persons conceived assignments or sub-goals of this kind as tasks.

The solution to the sub-goal “*FREE BALL*” on the other hand was found only after various objects and arrangements were tested. No prior experience for this sub-goal was available. The solution tree branch for this sub-goal is shallow and has many spreading branches. It shows that the test person was trying various alternatives and was inexperienced. Test persons conceived assignments or sub-goals of this kind as problems.

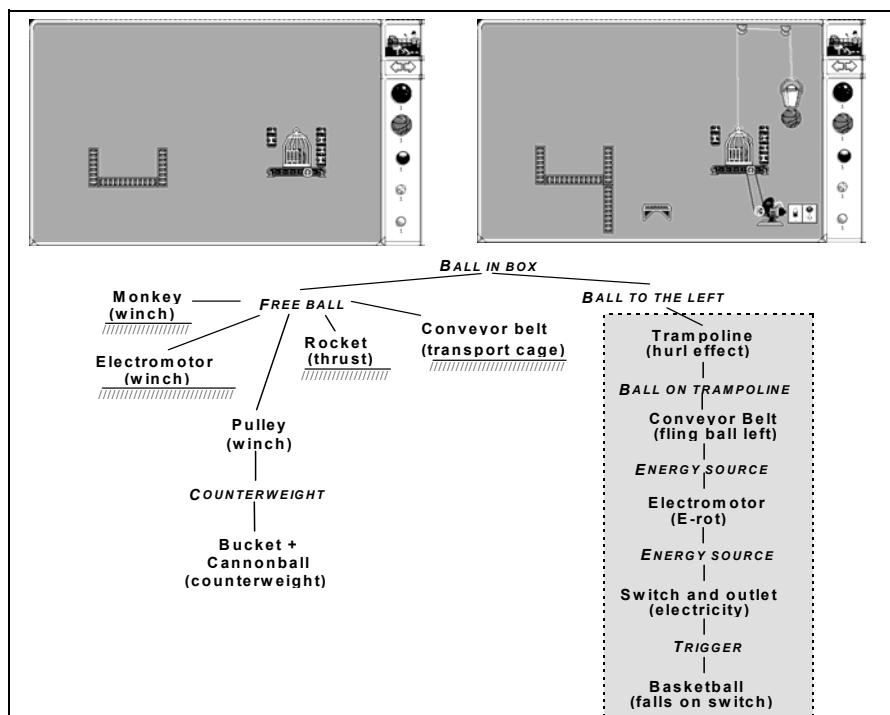


Figure 2: Tp13, Assignment 4, Solution, Solution Tree

The test persons memorized all functions they knew a part or assembly could fulfill and applied the object whenever a purpose that could be achieved by means of its function(s) was needed. The assemblies they built were indexed through the function these could fulfill and were treated as new, previously lacking, parts.

The experience of the test persons played a major role in their comprehension of the assignments. If they had experience with a similar assignment, the test persons solved it directly and perceived it as a task. If no experience was available the assignment posed a problem and deductive or trial-and-error approaches were

applied. Towards the end of the test, especially during the two assignments the test persons chose themselves, the assignments were solved by merely using the objects or assemblies learned during the course of the experiment.

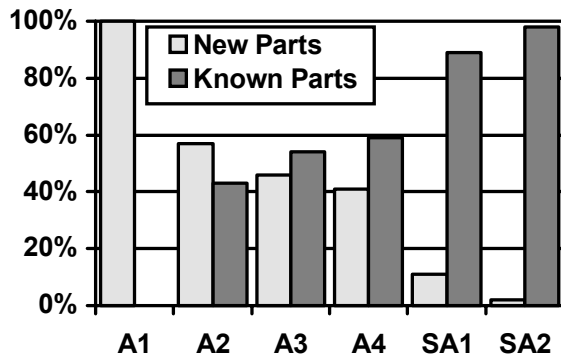


Figure 3: Development of the usage of known parts

Figure 3 shows the average percentage of new and previously known parts among the parts the test persons used to solve the assignments A1 to A4 and the two selected assignments SA1 and SA2.

One should note, that at the end of the experiment the test persons had in average used only 15 out of the 45 available parts (i.e. %33). Thus the reservoir of available new parts was by no means exhausted.

The sudden drop in the percentage of new parts from assignment 4 to the two selected assignments shows, that the test persons preferred assignments to which they could think of a solution in terms of their experience. However, the unreflected application of experience to solve the assignments did not necessarily result in the most efficient and effective solution. Details of these experiments can be found in [1, 2, 3].

3 Electrophysiological Experiments

3.1 The Coherence Analysis of Electroencephalography Data

During Electroencephalography (EEG) measurements electrodes are attached to fixed positions on the head of a test person (Figure 4) and the electrical potentials at these positions are recorded (Figure 5).

Based on these data, the normalized cross power spectra and the coherence between two EEG-Signals can be calculated [4, 5, 6]. Synchronous signals have a coherence of 1 (%100), and decoupled signals a coherence of 0 (%0). This measure of synchronicity is interpreted as a functional coupling between the signals and thus the respective regions in the brain [4, 7, 8, 9]. The higher the coherence between two regions is, the closer the co-operation is assumed to be. The coherence between two signals can be calculated for adjacent

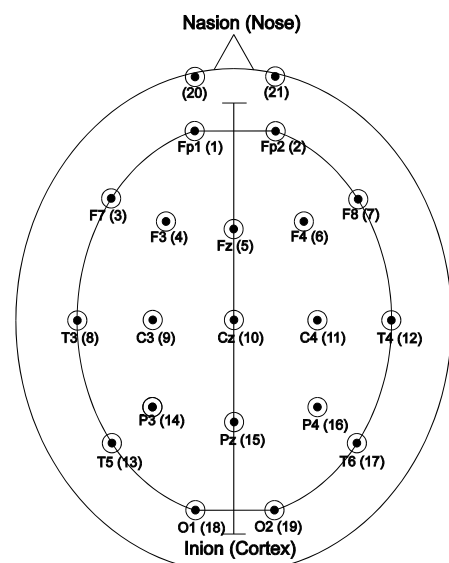


Figure 4: Positions and Channel numbers for EEG-measurements (10-20 System)

electrodes (local coherence) or for spatially separated electrodes (interregional coherence).

Due to the high spatial and temporal resolution that can be achieved, as well as the ability to investigate the coupling between various regions of the brain, we preferred coherence analysis over other electrophysiological approaches for the analysis of the effects of experience on the activity distribution in the human brain.

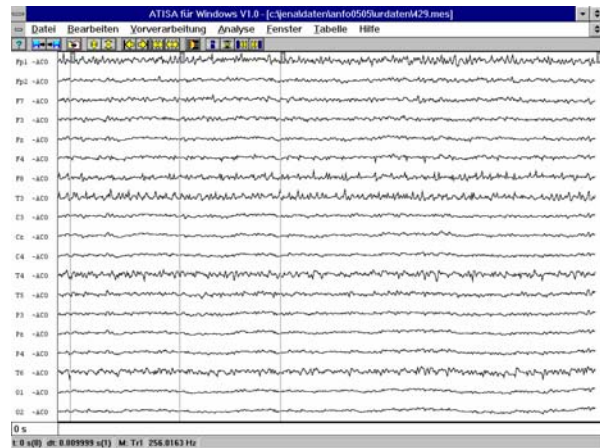


Figure 5: EEG-data of a test person

3.2 Assumptions regarding the Function of Regions in the Human Brain

Even if the functions of the regions of the human brain are not fully understood and the mapping of tasks to regions has not necessarily been decided upon, there are some basic assumptions that can be made based upon neurophysiological research [8, 10, 11, 12, 13, 14].

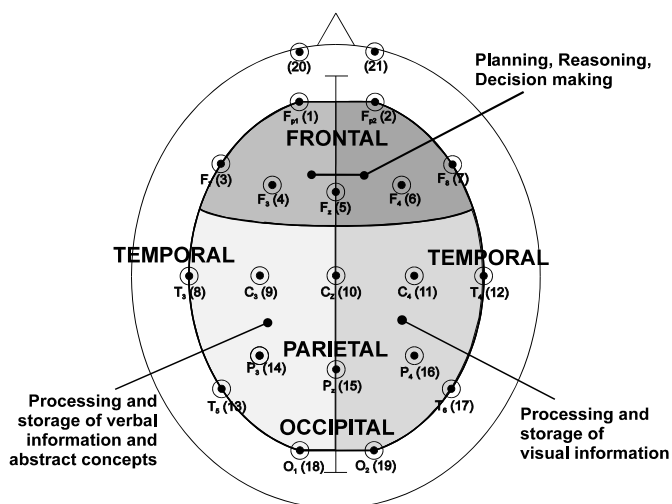


Figure 6: Assumptions regarding the function of regions of the brain

According to these assumptions, activity in the frontal regions is a sign of planning, reasoning and decision making. The left hemisphere is specialized on the processing of abstract concepts and language and contains our verbal memory. The right hemisphere is specialized on processing visual information and contains our visual memory (Figure 6). Due to

verbal and visual nature of most information both hemispheres are active most of the time.

3.3 Setup of the Electrophysiological Experiments

Similar to the behavioral experiments described above, test persons were asked to solve the assignments given on the computer screen. While the test persons solved the assignments, the computer screen and the utterances of the test person were recorded with a video camera. Additionally the test persons were connected to an EEG-device and the signals were recorded through a computer.

Two groups of test persons were observed in this experiment. The first group comprised of five experts that knew the assignments of the behavioral experiments and their solutions very well. They had excellent knowledge of all the parts available in TIM, as well as their functions and peculiarities. The second group were complete novices (six persons). They neither knew the program nor the assignments.

The test persons had to solve five different types of questions. First they were given some calculation tasks. These ranged from very simple (3+6) to very difficult or impossible (136/17 or “iki kere yedi” - two times seven in Turkish). These assignments served the purpose of acquainting the test persons with the experimental setup.

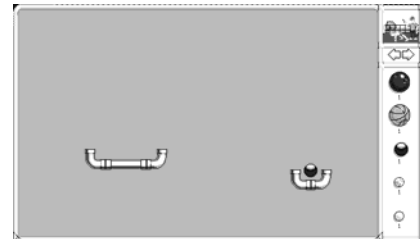


Figure 7: Cannonball into bowl (Assignment Jena4)

The second group of questions comprised of a range of TIM-design assignments of varying difficulty. Whereas some assignments were familiar to the expert group and very simple, other assignments posed unsolvable problems even to the experts (e.g. Figure 7).

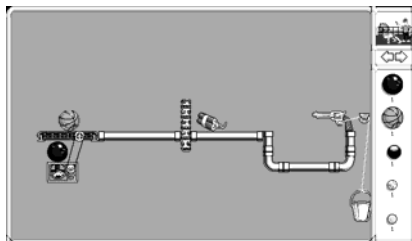


Figure 8: Solution understanding (Jena9)

In the third group of assignments the test persons were shown a solution to a familiar assignment and were asked to understand how it works (Figure 8).

The fourth group of assignments consisted of objects the test persons had to identify. The group started with objects which could be identified without prior knowledge (e.g. the “ape on a bike”) and ended with objects that could only be identified if the test person had used them during the design assignments (e.g. the “solar panel”).

In the last assignments group, the test persons were asked to classify or to compare objects. They had to decide which one of the objects would fall through a hole (Figure 9), which object was the heaviest or which object was alive.

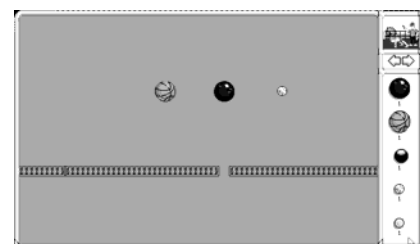


Figure 9: Which ball falls through the hole -A-

During the behavioral experiments the test persons had to think aloud.

However, this approach was unsuitable for EEG-measurements. Therefore we asked the test persons to signal us their readiness by clicking three times with the mouse, solve the assignment and signal us with the mouse again. Then they had to describe or tell their solution. The EEG data between the starting- and ending signals was used for the analysis. While this regions comprises the whole problem solving process for the identification,

classification and understanding assignments, it contains only the planning or conceptual design part of the design assignments.

3.4 Data Analysis

The recorded EEG data was analyzed using a program developed by Dr. Schack². We calculated the local coherences between each electrode and its four neighbors as well as the interregional coherence for the combinations between the frontal electrodes F_3 , F_z , F_4 and P_3 , P_z , P_4 for the frequency range from 13 to 20 Hz (Figure 10).

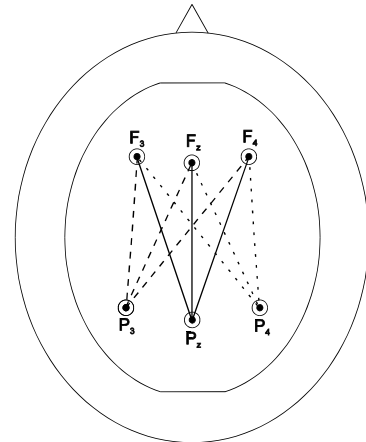


Figure 10: Electrode pairs for the calculation of interregional coherences

The selection of the electrodes for the interregional coherences is based on the assumption that a coupling between the frontal and the parietal regions is a sign of (or caused by) information acquisition and processing. Even if all channels of the calculated interregional coherences are shown in the graphs to follow, currently only the coherence between the frontal and parietal regions as a whole can be interpreted to some degree. Nevertheless the result for electrode to electrode interregional coherences have been included for the sake of completeness.

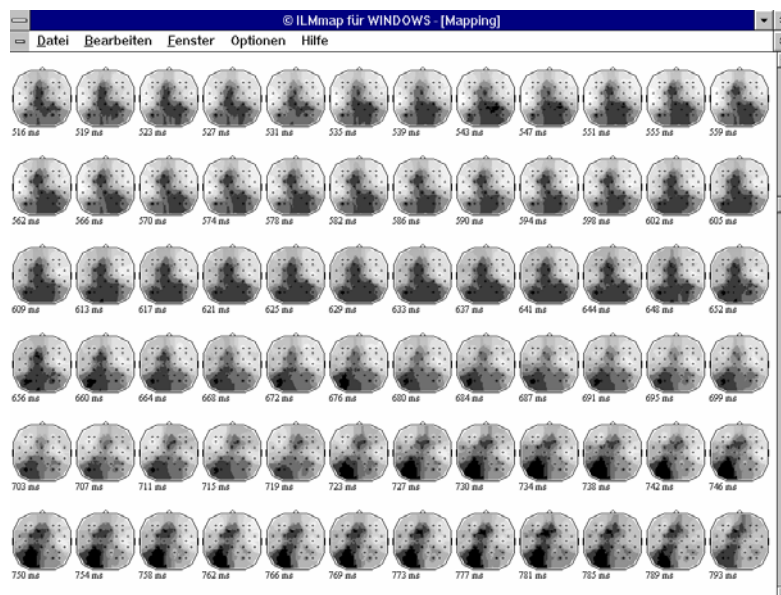


Figure 11: 277 msec of a problem solving process

The local coherence values can be mapped onto a graphical representation of the brain and displayed with a resolution of up to 256 Hz using the computer program IMap³ (Figure 11). This high resolution enabled us to observe processes that take place in the milliseconds-range [c.f. 8, 9, 15].

² The program “Adaptive Spektralanalyse” (Adaptive Spectral Analysis) is a research software and has been kindly provided to us by Dr. Schack (Institut für Medizinische Statistik, Information und Dokumentation, Klinikum der FSU Jena) for these experiments.

³ Imap is a research programm that has been developed at the Technical University Ilmenau and has been kindly provided to us for these experiments by Prof. Griebach (Technische Universität Ilmenau, Institut für Biomedizintechnik und Informatik).

Nevertheless, in order to be able to understand the effects of various factors on the problem solving process as a whole, a way to summarize this information is needed. Taking the average of the data levels out extrema and thus hides high coherences of short duration between electrodes (Figure 12).

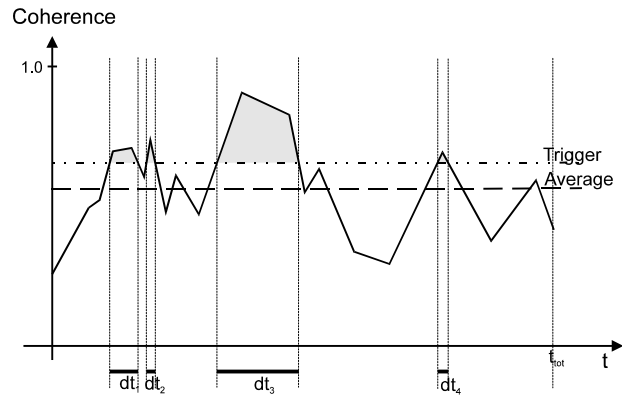


Figure 12: Leveling effect of average calculation

In order to circumvent this problem we implemented a computer program which calculates the percentage of high coherences (i.e. coherences above a selected trigger) with respect to the total problem solving time.

$$K = \frac{t_{coh}}{t_{tot}} \times 100 = \frac{\sum_{i=1}^n dt_i}{t_{tot}} \times 100$$

In this formula t_{coh} is the duration of high coherences and K the relative duration of high coherences with respect to the total time t_{tot} . The measure K has the advantage, that high coherences of short duration are not leveled out but expressed in terms of a percentage. Because the duration of high coherences is set into relation to the total time needed to solve the assignment, K is indifferent to the time differences between novices and experts.

The selection of a trigger to “high” coherences is somewhat arbitrary. We therefore decided to use three different triggers (0.85, 0.8 and 0.65) and also calculate the average coherence values for all data. Due to the fact that we are only interested in tendencies and comparisons between experts and novices, what matters is to select the same trigger for the same experiment for experts and novices.

The results of the calculations for the interregional coherences are shown in column diagrams. The first three columns on the left show the relative duration of high interregional coherences (RDHirC) between the frontal region and P_3 , the three columns in the middle between the frontal region and P_z , and the last three columns between the frontal region and P_4 . The trigger for these diagrams was selected to be 0,80.

The results for the local-coherence calculations can be visualized using IIMap. The picture, that is created in this way, shows the distribution of the relative duration of high local coherences (RDHLoC) for the complete problem solving process. For visibility reasons the trigger 0,65 was selected for these pictures. The pictures for all trigger values as well as for the average distribution can be found in [3].

3.5 Results of the Electrophysiological Experiments

3.5.1 TIM Design Assignments

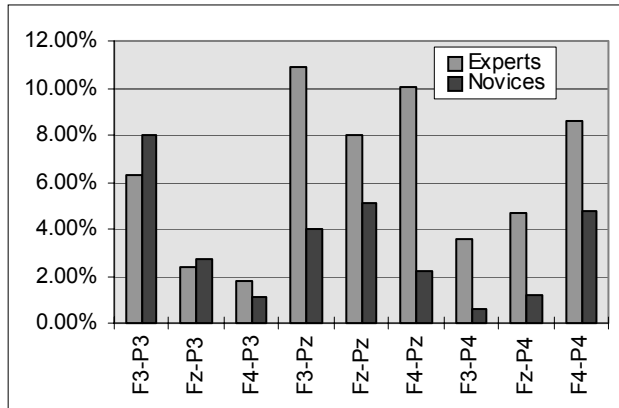


Figure 13: RDHirC for Experts and Novices for all TIM-Design assignments

Figure 13 shows the relative duration of high interregional coherences (RDHirC) for experts and novices for all TIM-Design assignments. For novices, a longer RDHirC between the frontal regions and P₃ (parietal-left, verbal-abstract) can be seen. The experts, on the other hand, have longer RDHirCs between the frontal electrodes and the regions around P_z and P₄. The average time needed

for the TIM-Design assignments was 8,91 sec for the experts and 17,23 sec for the novices

Figure 14 shows the distribution of the relative duration of high local coherences (RDHLoCs) for novices and experts for all TIM-Design assignments. Darker regions depict longer duration

	0% - 10 %		51% - 60%
	11% - 20%		61% - 70%
	21% - 30%		71% - 80%
	31% - 40%		81% - 90%
	41% - 50%		91% - 100%

Table 2: Color coding for the RDHLoC pictures

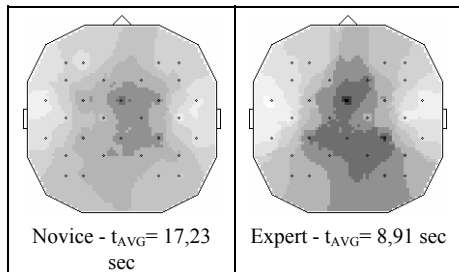


Figure 14: Distribution of the RDHLoC for Novices and Experts, all TIM-Design assignments

of high local

coherences, i.e. longer activation (Table 2). The average time needed by the test persons is shown under each picture. The longer activation in the right parietal region (visual information) for experts can also be observed in these pictures.

Based on the assumptions stated in 3.2 this causes the impression, that the expert utilizes his visual experience (parietal - right and middle, P₄ and P_z). The shorter RDHirC values for novices can be explained through the assumption that the novice does not have information of this kind available. The only RDHirC value, which is longer for the novice than for the expert, is the RDHirC between F₃ and P₃. This may be caused through an activation of the speech center and the utilization of abstract concepts.

To be able to take the planning effort necessary to solve an assignment into consideration, we split the TIM-Design assignments into two groups (no planning effort needed / planning effort needed) for the novices and into three groups (no planning effort needed / simple planning needed / planning effort needed) for the experts. The planning effort necessary reflects the amount of subgoals the test persons have to consider to solve an assignment. Whereas some assignments could be solved with a small number of subgoals i.e. at first glance,

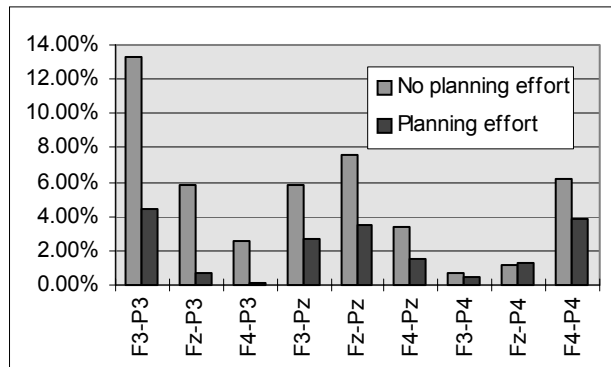


Figure 15: RDHirCs during TIM-Design assignments, Novices

some assignments were more complex and required more elaborate subgoals. The more precise distinction for the experts was necessary to distinguish between the assignments the experts were familiar with and assignments for which a small amount of planning work was really needed.

Figure 15 shows the RDHirCs during TIM-Design assignments for novices. The average time needed to

solve these assignments was 10,39 sec for assignments without planning effort and 21,79 sec for assignments with planning effort. It can be seen, that for assignments with planning effort the RDHirCs decrease.

Figure 16 shows that, for the novices, the left parietal (verbal-abstract) region is activated slightly longer during the assignments with no planning effort than during the assignments with planning effort.

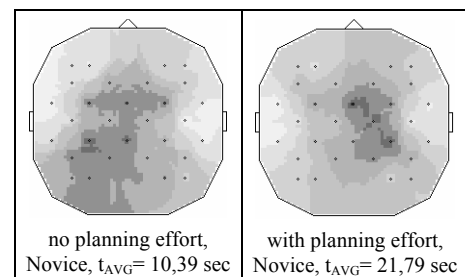


Figure 16: RDHLoC distribution for TIM-Design assignments with and without planning effort, Novices

Figure 17 shows the change in RDHirCs with respect to the planning effort needed, for the experts. The assignments with no planning effort and their solutions are well known to the experts. Thus the cognitive effort needed to solve these assignments is expected to be low. The RDHirCs for these assignments are short compared to the values for the novices.

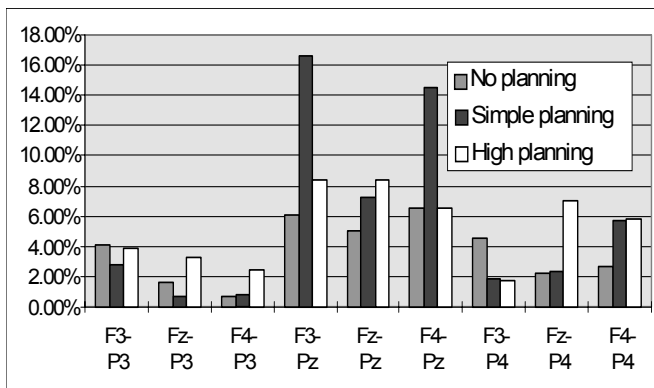


Figure 17: RDHrCs with respect to planning effort during TIM-Design assignments, Experts

The assignments with simple planning effort were usually solved by means of pre-built entities. For these assignments the RDHrCs are long. This could be interpreted as a sign of the retrieval of pre-build solutions. On the other hand, similar to the novices, a decrease in the RDHrCs can be observed for the assignments for which a high planning effort is necessary

even for the expert. It looks as if the experts becomes a novice in this situation.

The average time needed by the experts to solve the assignments without planning effort was 2,55 sec, for the assignments with simple planning effort 5,42 sec and for the assignments with high planning effort (problems) 25,87 sec.

Figure 18 shows that the areas involved in the processing of these assignments are almost identical, but show small differences in the relative duration. For assignments for which high planning effort is necessary there is a slightly longer activity in the frontal, parietal and occipital regions.

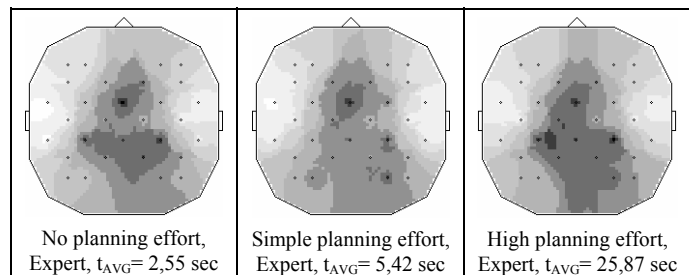


Figure 18: RDHLoC distribution with respect to planning effort, TIM-Design assignments, Experts

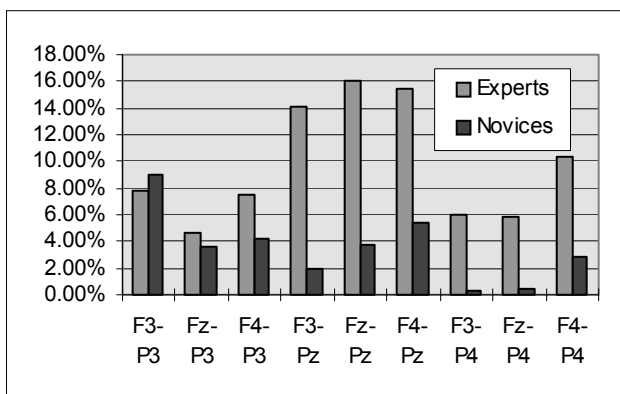


Figure 19: RDHrC during the identification of TIM-Objects, Experts and Novices

3.5.2 Identification of TIM-Objects

The effects that were observed for the TIM-Design assignments can also be recognized during the identification of TIM-Objects.

As can be seen from Figure 19 the RDHrCs between the frontal and the parietal regions during the identification assignments are longer for the

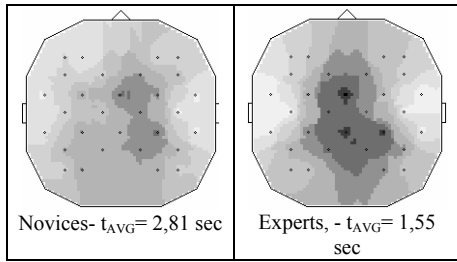


Figure 20: RDHLoC distribution during the identification of TIM-Objects, Experts and Novices

expert than they are for the novice. This might be caused by the utilization of previous experience by the expert. The average time needed for the identification assignments was 1,55 sec for the experts and 2,81 sec for the novices.

The longer activity in the parietal regions of the expert can also be discerned in the distribution of the RDHLoCs (Figure 20).

3.5.3 Classification and Comparison of TIM-Objects

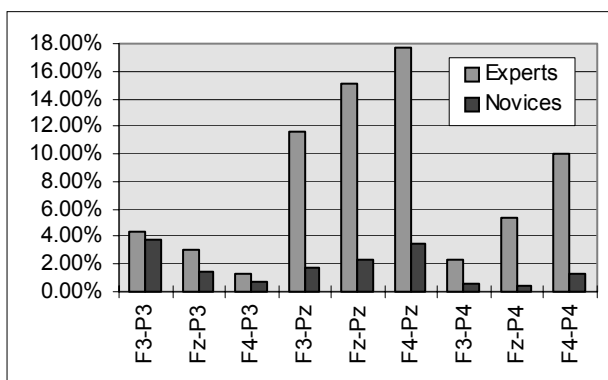


Figure 21: RDHrCs for the Classification and Comparison of TIM-Objects, Experts and Novices

Similar to the situation for the TIM-Design and the TIM-Object identification assignments the RDHrCs between the frontal and parietal regions are longer for the expert than they are for the novice (Figure 21).

The average time needed for the TIM-Object classification and comparison assignments was 1,78 sec for the experts and 2,43 sec for the

novices.

The distribution of the RDHLoCs for these assignments is shown in Figure 22. It can be seen that there is a longer frontal activation for the novices and a longer parietal activation for the experts. Based on the assumptions described in 3.2 this can be interpreted as a sign of the deductive approach used by novices and a more experience based approach used by experts.

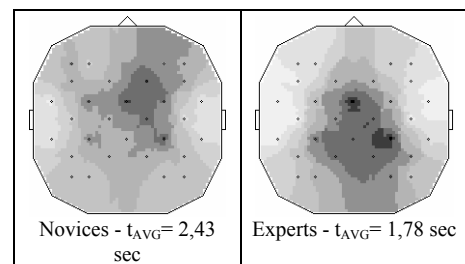


Figure 22: RDHLoC distribution during the TIM-Object classification and comparison assignments, Experts and Novices

3.5.4 Effects of the solving an assignment repetitively

To analyze learning effects, we asked the test persons to solve an assignment several times with other assignments solved in-between each trial.

Figure 23 shows the development of the RDHrCs during the repetitive solution of Assignment 1 by test person Tp4. As Tp4 is an expert, he is familiar with the assignment and knows its solution.

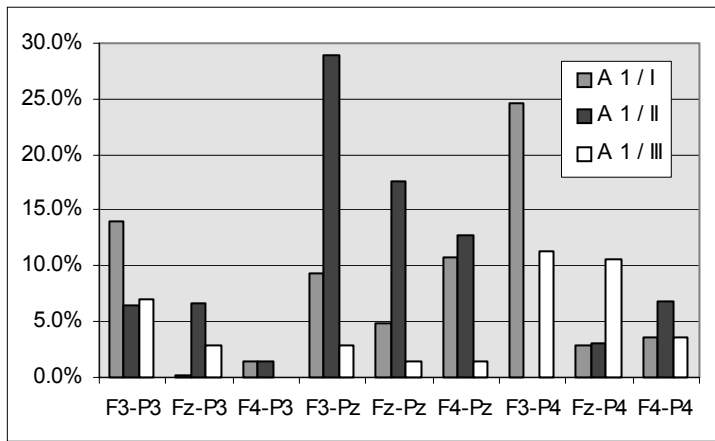


Figure 23: Development of the RDHlrcs during the repetitive solving of Assignment 1, Tp4 - Expert

In the development of the RDHlrcs a longer coupling between F₃-P₃ and F₃-P₄ can be discerned during the first trial of the test person. This can be interpreted as a recognition of the assignment and the retrieval of a solution. During the second trial the coupling between the frontal regions and P_z are very long. This is similar to the effect of experience observed in

Figure 17 and looks as if the solution retrieval time is gaining weight over the time needed to recognize. In the third trial, only the coupling between F₃-P₄ and F_z-P₄ is worth mentioning. Looking at the distribution of the RDHLoCs for this trial, this can be interpreted as a visual recognition of the assignment (Figure 24).

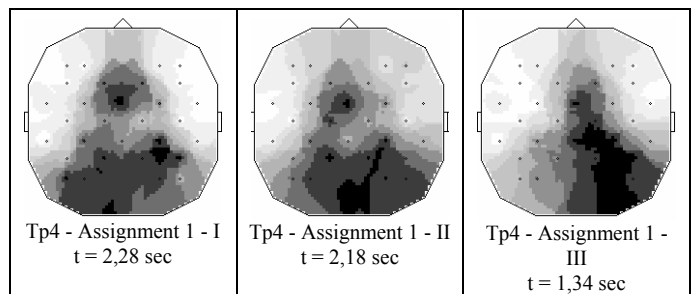


Figure 24: RDHLoC distribution during the repetitive solution of Assignment 4, Tp4 - Expert

The time needed to solve this assignment was

t₁=2,28 sec for the first trial, t₂=2,18 sec for the second, and t₃=1,34 sec for the third trial.

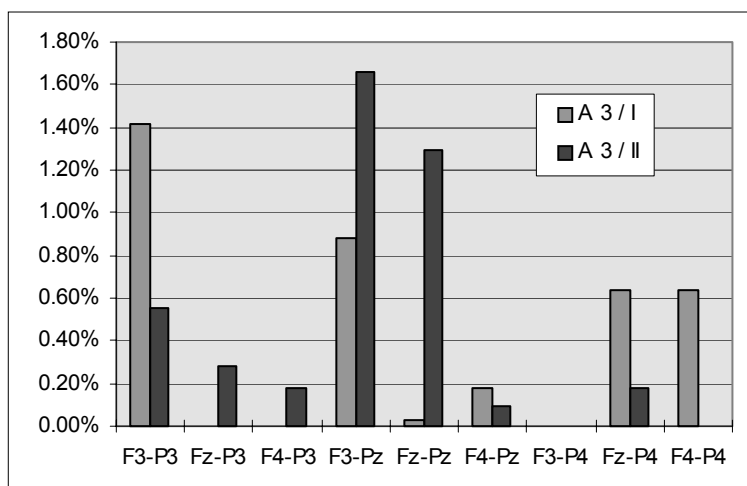


Figure 25: Development of the RDHlrcs of novice Tp9 during the repetitive solution of Assignment 3

The distribution of the RDHLoCs (Figure 24) shows a shift from a longer activity parietal-left and -central (verbal-abstract and visual) towards long activity parietal-right (visual).

The development of the RDHlrcs of the novice Tp9 during the repetitive solving of Assignment 3 is shown in Figure 25. A long RDHlrc can be

observed between F₃-P₃, F_z-P₄ and F₄-P₄ during the first trial. In the second trial these relative durations decrease

and a longer RDHrC between F_3 - P_z and F_z - P_z can be observed. This resembles the difference between experts and novices that could be seen in the TIM-Design assignments. With growing experience the coupling to P_z gets longer. It should be mentioned that assignment 3 was not the first assignment of the test person, so that visual experience could also be processed (activity around P_4).

The total time needed to solve the assignments was 23,05 sec for the first trial and 4,24 sec for the second trial.

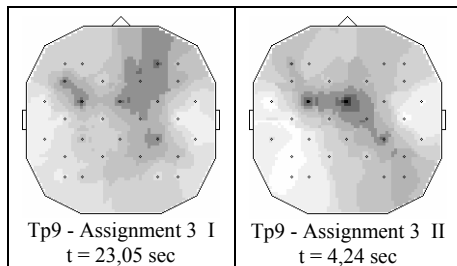


Figure 26: RDHLoC distribution development during the repetitive solution of assignment 3, Tp9 - novice parietal-right (visual) (Figure 26).

Comparing Figure 25 to Figure 23 it can be seen that the RDHrCs for the novice are in general much shorter than the ones of the expert.

The distribution of the RDHLoCs shows a shift of the activity from the frontal regions (reasoning, planning) towards the

parietal-right (visual) (Figure 26).

4 Summary of the Electrophysiological Experiments and Future Work

Due to the limited number of test persons, the described experiments for the electrophysiological measurement of the activity distribution during problem solving can only be regarded as case studies. Nevertheless, the activity distributions seem to mirror the results observed in the behavioral experiments described above and in [1, 2, 3]. The RDHrCs seem to be dependent on the availability of and need for experience (Table 3). Usually the RDHrCs between the frontal and parietal regions are longer for the expert than they are for the novice. This hypothesis also matches the more deductive approach during problem solving observed of novices and the more

<i>Experience</i>	<i>available</i>	<i>not available</i>
<i>not needed</i>	RDHrCs short	RDHrCs short
<i>needed</i>	RDHrCs long	RDHrCs short

Table 3: Hypothesis for the level of RDHrCs with respect to the availability of and need for experience

experience-based approach utilized by experts.

To check if the statistical significance of the results could be verified, we calculated the

significance for some samples. The calculation showed, that the differences in the RDHrCs for novices and experts in the TIM-Object identification and TIM-Object classification and comparison experiments are highly significant for the coupling between the frontal region and P_z (t-test for independent samples [16]). Nevertheless the experiments should be repeated for a larger number of test persons to be able to verify the hypotheses and their significance.

The analysis of the RDHLoC distributions showed a shift from a longer activity in the frontal regions to a longer activity in the parietal regions. As can be seen in Figure 27, with growing experience the activity in the region parietal-right seems to increase. This matches the observation made during the behavioral experiments, that, with growing experience, the usage of visual information replaces abstract functional models.

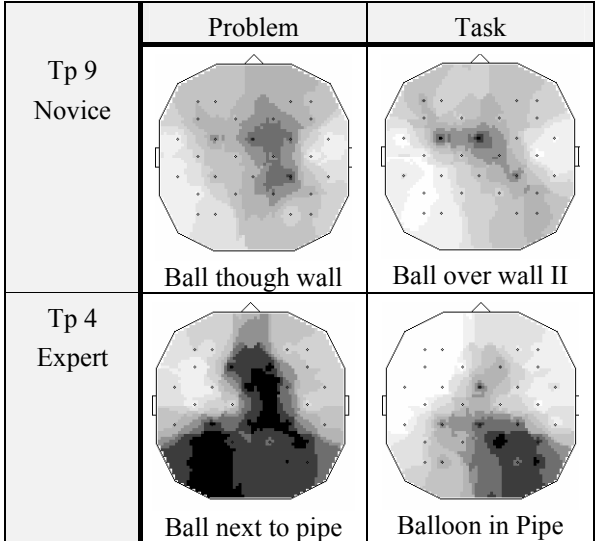


Figure 27: RDHLoC distribution for problems and tasks for experts and novices

Similar results are also reported by Petsche [4]. In comparison of artists with non-artists during the viewing, memorizing and the creation of pictures, a short activity in the frontal and a long activity in the parietal-right region is observed for the artist. The non-artist shows a longer activity in the left hemisphere.

The experiments described here can only be considered a first step in the analysis of the effects of experience on the activity distribution during problem

solving. They enable us to formulate more precise hypotheses regarding this influence and to conduct experiments to verify them with more rigid and fixed boundary conditions and a higher number of test persons. Due to the fact that the relevance of the interregional coherence to the way the human brain functions is not understood entirely, the assumptions regarding the coupling effects have to be verified through elementary analysis. Additionally the interregional coherences for other electrode pairs should be calculated and the statistical significance of the results have to be checked.

5 References

- 1 M. Göker, H. Birkhofer, "Entwicklung, Einsatz und Einfluß von Erfahrung beim Problemlösen und Folgerungen für die rechnerunterstützte Wissensverarbeitung", Tagung für "Wissensverarbeitung in Entwicklung und Konstruktion", VDI-EKV, 20-21 September 1995 Nürnberg, VDI- Bericht 1217, VDI-Verlag, Düsseldorf, 1995
- 2 M. Göker, H. Birkhofer, "Problem Solving with 'The Incredible Machine' - An Experiment in Case-Based Reasoning", in M. Veloso, A. Aamodt (Eds.), "Case-Based Reasoning Research and Development, Proceedings, First International Conference on Case-Based Reasoning ICCBR-95, Sesimbra October 23-26, 1995", pp 441-450, Springer Verlag, Berlin Heidelberg New York, 1995
- 3 M.Göker, "Einbindung von Erfahrung in das konstruktionsmethodische Vorgehen", Ph.D. Thesis, Technische Hochschule Darmstadt, 1996, Fortschrittsberichte VDI, Reihe 1, Nr. 268, VDI-Verlag, Düsseldorf, 1996
- 4 H. Petsche, "Die flirrende Welt der Aufmerksamkeit: Zur Neurophysiologie kognitiver Prozesse", EEG - EMG, Zeitschrift für Elektroenzephalographie Elektromyographie und verwandte Gebiete, Heft 1, 26. Jahrgang, März 1995, pp. 1-18, Georg Thieme Verlag, Stuttgart, 1995
- 5 B. Schack, E. Bareshova, G. Grieszbach, H. Witte, "Methods of dynamic spectral analysis by self-exciting autoregressive moving average models and their application to biosignals", Medical & Biological Engineering & Computing, pp . 492-498, May 1995
- 6 B. Schack, G. Grieszbach, M.Arnold, J.Bolten, "Dynamic cross-spectral analysis of biological signals by means of bivariate ARMA processes with time-dependent coefficients", Medical & Biological Engineering & Computing, S. 605-610, Juli 1995
- 7 P. Rappelsberger, H. Petsche, "Probability Mapping: Power and Coherence Analyses of Cognitive Processes", Brain Topography, Vol. 1, Nr. 1, 1988, pp. 46-54, Human Sciences Press, 1988
- 8 W. Krause, B.Schack, "Fortschritte bei der Messung begrifflicher und bildhaft-anschaulicher Vorstellungen", Werkstattgespräch Bild und Begriff II, Naupoldsmühle 22-24 Oktober 1994, pp. 116-130, TU Ilmenau - Fakultät für Maschinenbau FG Konstruktionstechnik und FSU Jena - Institut für Psychologie, 1994.
- 9 E. Sommerfeld, W. Krause, "Zur Messung des kognitiven Aufwands im Konstruktionsprozeß", Werkstattgespräch Bild und Begriff III, 20.10.1995 - 22.10.1995 in Diesbar-Seußlitz, P.Sachse und W. Hacker ed., 1995
- 10 I. Kupfermann, "Localization of Higher Cognitive and Affective Functions: The Association Cortices", in "Principles of Neural Science", 3. Edition , E.R.Kandel, J.H.Schwartz und T.M. Jessel (eds.), Prentice Hall international Inc., London, 1991
- 11 N. Birbaumer, R.F. Schmidt, "Biologische Psychologie", Springer Verlag, Berlin, Heidelberg, New York, 1989
- 12 A. Friederici, "Neurobiologische Grundlagen kognitiver Funktionen", in "Wissenspsychologie", H.Mandl und H. Spada (Hrsg.), Psychologie Verlags Union, München - Weinheim, 1988
- 13 N. Birbaumer, "Physiologische Psychologie", Springer Verlag, Berlin, Heidelberg, New York, 1975
- 14 M. Raichle, "Visualizing the Mind", Scientific American, pp 36-42, Volume 270, Number 4, New York, April 1994,
- 15 W. Krause, "Werden beim Konstruieren wirklich Begriffe aktiviert?", Werkstattgespräch Bild und Begriff III, 20.10.1995 - 22.10.1995 in Diesbar-Seußlitz, P.Sachse und W. Hacker ed., 1995
- 16 J. Bortz, "Statistik für Sozialwissenschaftler", Vierte Auflage, Springer Verlag Berlin, Heidelberg, New York, 1993