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Hanse-Wissenschaftskolleg (HWK) –
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Herausgegeben von
Reto Weiler und Heidi Müller-Henicz

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Sascha Bernholt, Jan Lenk (Eds.)

Interdisciplinary Perspectives on Cognition, Education and the Brain

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Table of Content

Preface

The cognitive neurosciences offer a large body of findings which may be highly relevant for learning and instruction. Even though the practical use of data from the neurosciences for education has been proven to be modest at present, brain imaging in particular holds a strong fascination for educators. Unfortunately, this fascination is often nourishing unrealistic expectations with regard to potential improvements of teaching methods. Within the scientific community, the potential usefulness of results from neuroscience for educational research and practice is a matter of ongoing debate but it is commonly agreed that there is still a long way to go to better bridge the gap between neuroscience and education. Indeed, in most cases, results from the neurosciences are rather complementary and confirmatory to what is already known from developmental and educational psychology. In some instances however, the neurosciences provide experimental data that is not available from behavioral studies alone and tools that may be used to further investigate how the brain gets reorganized during learning.

Fruitful connections between the field of neurosciences and educational research are impeded by considerable differences in methods, approaches, levels of analyses, research goals, data and philosophy. We believe that in the long run, further refinements of theories and advancements in neuroscience methods will only be helpful to indicate which teaching strategies and remediation programs are most effective if such developments are accompanied by a close collaboration of neuroscientists with educational scientists. Interdisciplinary educational neuroscience approaches that foster the interaction of researchers from different disciplines are now being pursued in many countries. In Germany, an integrated research approach was triggered by the initiative “Learning and Instruction under a Neuroscientific Perspective” funded by the Federal Ministry of Education and Research (BMBF).

The workshop “Cognitive Neuroscience, Educational Research and Cognitive Modeling” was organized by members of one of the funded projects[1] and the Hanse-Wissenschaftskolleg in Delmenhorst. The aim of this international and interdisciplinary meeting was to further facillitate the exchange and cooperation between neuroscience, education and modeling by providing a platform to present ongoing work with all its promises and challenges, to identify prerequisites of fruitful cooperation, and to identify future areas of interdisciplinary research and approaches. The papers published in the workshop book thus mirror the wide diversity of the field. They cover large scale research projects investigating mathematical abilities or reading and writing which have already started to span the bridge between neuroscience and education as well as work in progress and future research plans and ideas intended as a basis for discussion.

Jale Özyurt and Christiane Thiel

Oldenburg, March 1, 2011

1 Project: “Impact of affective and informative feedback on learning in children before and after a reattribution training. An integrated approach using neuroimaging, educational research and modeling”. Project partners: Prof. Dr. Christiane M. Thiel, Prof. Dr. Barbara Moschner, Prof. Dr. Ilka Parchmann, Prof. Dr. Claus Möbus. Funded by the BMBF, Grant No. 01GJ0805.

– Keynotes –

Science Education and Neuroscience – A Bridge too Far?

C. v. Aufschnaiter
Justus-Liebig University, Giessen, Germany

In his paper entitled „Education and the brain: A bridge too far“, Bruer argued that “[…] we do not know enough about brain development and neural function to link that understanding directly, in any meaningful, defensible way to instruction and educational practice” (Bruer, 1997, p. 4). Is the bridge, almost 15 years later, still “too far”? Can we at least build a bridge connecting research on (science) education with neuroscience research? What is it that might need to be “bridged”? In order to explore how bridges can be built, the talk will discuss the current state of science education research, followed by a presentation of research focusing on the individual student’s learning of physics concepts. Results of this research will be used as a starting point to discuss how the different disciplines might be connected.

Research in Science Education

Research on science education addresses the learning and teaching of subject-matter competences. This includes knowledge of subject-matter concepts, but also a learner’s abilities to solve subject-matter related problems and utilize his/her conceptual knowledge while working on these problems. Science education is a relatively young discipline (roughly 30–40 years old), which explains why we do not yet seem to share a common understanding of main assumptions on teaching and learning. However, at least two clear trends in what science educators do can be identified: A design-oriented trend, focusing on learning material and its effects and a second trend oriented towards modeling and assessing learners’ competences. Both trends will be described and the reasons for why these are not very prominent “candidates” for building bridges will be argued. From a critical reflection of the field, research on individual student’s subject-matter learning processes will be introduced as a “niche area” in science education research. It will be discussed why this kind of research has not (yet) established itself in the discipline and how it can help to connect science education with neuroscience.

Investigating Individual Student's Learning Processes: Methods and Main Results

Based on our own work in physics education, the talk will present how we assess students' development of physics concepts. With the notion of "concept" we focus on those scientific ideas and theories that need extended learning activities before they can not only be repeated by students, but will also be understood in a meaningful way and be able to be applied to (various) situations. Using videos of small groups, we investigate how individual students develop and utilize concepts while working on learning material. Typically, students are videotaped in four to six successive lessons so that we can document learning processes over a longer period. Videos are analyzed with coding procedures that give rough information on the different student activities (e.g. reading, writing, setting up and carrying out experiments, discussing physics), how long these activities take, or how often students skip working on tasks. Those sequences in which students discuss specific phenomena, observations, experiences or concepts in particular are then investigated further. For these sequences, students' verbal and non-verbal activities are transcribed and analyzed sentence by sentence or activity by activity. Such in-depth analyses try to reveal which kind of intermediate steps students take before arriving at a particular conceptual understanding, how they cross-connect similar and different phenomena and ideas, under which conditions they experience the learning situation positively and so on.

The following main results of our research will be illustrated by examples and used for further explorations of building bridges between the disciplines:

1. Time scales seem to play a crucial role: Students take no longer than 30 seconds for a line of thought and do not spent longer than 5 Minutes working on a (sub-)task (e.g. S. von Aufschnaiter, C. von Aufschnaiter, 2003). If within this span of time students are not successful on a task, they are likely to express negative emotions (e.g. C. von Aufschnaiter, S. von Aufschnaiter, 2003).
2. Forming concepts cannot be fostered by just "explaining" the concept to students. Rather, students seem to need personal activities (tackling objects and language) before they behave as if they have already understood the concept. At that stage, students typically cannot explain the

concept. It then seems to take more individual activities before students explicitly express conceptual knowledge. Also, the specific experiences that students have made prior to the lessons have a strong impact on how "hard" it is for them to understand the concept offered (e.g. C. von Aufschnaiter, Rogge, 2010).

3. Even after students have expressed (correct) conceptual knowledge at least once, this understanding does typically not show up immediately while working on similar tasks. Concept formation is obviously not a linear process (Rogge, 2010).
4. Those concepts for which we have a clear indication that students had understood them cannot be "retrieved" a few days after being learnt (e.g. C. von Aufschnaiter, S. von Aufschnaiter, 2003).

Building Bridges

Obviously, the bridge is (still) too far between neuroscience and education. Various attempts to describe how to design "brain-based instruction" either overestimate conclusions that can be seriously drawn from neuroscience in respect to education, or underestimate what education and learning of concepts is about – not just memorizing and retrieving facts. Whereas there might not (yet) be a bridge between neuroscience and education, the "human brain" is the focus of both science educators researching learning and neuroscientists, and is therefore the common ground that offers potential opportunities for building bridges.

The talk will try to explore why and how science education research can be of interest for neuroscience research and vice versa. More specifically, time scales and the importance of specific personal activities and experiences will be used as issues that can connect both disciplines. Furthermore, a strong argument will be made about the need to agree on basic terms and how we understand them. What is meant with the word "information"? Can "information" be transferred from outside into the brain? Can it be stored in and retrieved from memory? What is memory, what is its architecture? Why should we distinguish between activity and learning? These terms and their meaning are the building blocks of our bridges – if we do not agree on them, we are not likely to be successful in connecting the different disciplines.

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Prefrontal Cortex Contributions to Child and Adolescent Development

E. A. Crone
Leiden Institute for Brain and Cognition, Leiden, Netherlands

Cognitive control is important for a range of abilities, including cognitive, emotional and social reasoning. Using functional magnetic resonance imaging (fMRI) we study how changes in brain function are related to changes in cognitive control over the course of child and adolescent development.

We tested these changes using three approaches: (1) the flexibility of the cognitive control system in childhood using training and longitudinal analyses, (2) the balance between limbic and prefrontal cortex contributions in adolescence using affective reasoning tasks, and (3) the contributions of developing brain regions to intention understanding in social reasoning using interaction paradigms.

I will show that brain development should be examined in terms of a window of flexibility with a relative imbalance between brain regions important for control and affect regulation.

Together, these studies provide a multidisciplinary approach towards understanding the complex changes which occur in brain and behavior during childhood and adolescence.

Literature

Crone, E. A. (2009). Executive Functions in Adolescence: Inferences from Brain and Behavior. *Developmental Science*, *12*(6), 825–830.

Grant

NWO-VIDI-European Research Council

Brain Mechanisms of Successful Mathematics Learning

R. H. Grabner
ETH Zurich, Switzerland

The successful acquisition of mathematical competence is one of the key aims of institutional learning and has been at the center of behavioral research for several decades. This research has provided important insights into the cognitive processes that are required in mathematical tasks, how these processes change over development and how mathematics learning can be fostered. Building upon the findings from behavioral studies, educational neuroscience research has recently begun to investigate the brain correlates of these processes. In my talk, I will present current studies from three research lines that illustrate the ways in which the application of neuroimaging and neurophysiological methods (in particular, functional magnetic resonance imaging and electroencephalography) can yield incremental insights into mathematical cognition. First, I will present studies on arithmetic strategies, revealing how retrieval (of arithmetic facts from long-term memory) in contrast to procedural strategies (such as transformation or counting) are characterized in brain activation patterns. These findings can serve as a starting point for the development of neuroscientific indices of problem solving strategies in mental arithmetic. Second, I will focus on the neural mechanisms underlying individual differences in mathematical competence. The reported studies suggest that the left angular gyrus, as part of the left temporo-parietal cortex, is a key region of mathematical competence and may support the semantic processing of mathematical symbols. In the third part of my talk, research on knowledge representation in bilingual mathematics learning is presented, which asks for the source of cognitive switching costs when the language of application differs from the language of instruction. I will show neuroscientific evidence indicating that language switching costs in arithmetic are due to additional calculation processes rather than to mere translation of retrieved knowledge into the language of application. In conclusion, future directions of the presented research lines and potential implications for education are discussed.

Capable Learners

Characteristics and Needs of the Upper 15%

E. Stern
ETH Zurich, Switzerland

It is without question that the distribution of most measures of cognitive capabilities follows the bell curve, which means that 70% are within one standard deviation of the mean, while 15% score higher than one standard deviation above mean. In principle, during childhood and adolescence, this group of people is especially well prepared for taking advantage of learning environments provided by schools. There is also growing evidence that the prosperity of modern information societies considerably depends on the contributions made by the workforce with good cognitive preconditions. Amazingly enough, however, research on human learning has only very rarely focused on the upper 15% as a group of capable learners. Rather, the majority of research on high cognitive capabilities has been on giftedness, which, by definition, only involves 1–2% of the people with top psychometric scores. In the meantime, this line of research has demystified the concepts of giftedness and genius because it has been shown that, although top scores in intelligence tests clearly increase the probability of academic and professional success, there is no evidence for principle qualitative differences in cognitive processing between the top 2% classified as gifted and those scoring somewhat lower. At the same time, however, there is evidence for the existence of qualitative differences in learning and thinking between average scoring learners and capable learners. Scientists focusing on how to exploit high cognitive capabilities through education should therefore broaden the scope of cognitive capabilities in their research. In my talk, I will present findings from behavioral learning research as well as from neuroscience research that indicate characteristics of cognitive processing in the group of capable learners. Educational implications will be discussed.

Threaded Cognition, a Model of Human Multitasking

N. A. Taatgen
University of Groningen, Netherlands

People show a strong inclination for multitasking: they use multiple devices while driving a car, students do homework while sending text-messages and watching television and office workers rapidly switch from one task to another. It is crucial to understand the role of multitasking in modern society, whether in terms of setting legal limits to multitasking in cases where it leads to unacceptable risks, or designing work situations in which productivity is supported or security is maintained.

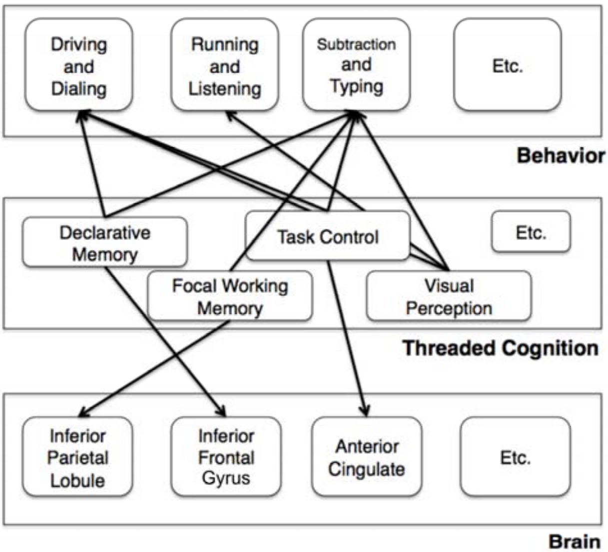

Fig. 1 Threaded Cognition theory predicts both behavior and brain activity

The goal of our project is to understand under what circumstances people profit from multitasking, and under what circumstances their performance suffers, or poses a danger to themselves and their environment. There are no quick and easy answers to these questions, and that is why we employ cognitive models to try to predict the effectiveness of multitasking in particular situations. To this end, we develop threaded cognition (Salvucci, Taatgen, 2008, 2011), a theory about multitasking within the ACT-R cognitive architecture (Anderson, 2007). Threaded cognition follows the assumption that the cognitive system can be subdivided into a number of cognitive resources (Figure 1), like vision, long-term memory, working memory (called "problem state" in our theory), manual control, perception of time, etc. These resources can operate in parallel: long-term memory can be busy retrieving information while visual perception processes a stimulus and the manual system programs a keystroke. However, each resource can only work on one task at a time. A second, and novel, assumption in threaded cognition is that multiple goals can be active *at the same time*, contrary to all earlier models that always assumed explicit goal switches. The third assumption of threaded cognition is that there is no central scheduling process that determines which goal has access to which resource.

Threaded cognition has proved to be a powerful theory that can explain a wide range of multitasking phenomena: multitasking in driving, a classical experiment of reading and taking dictation, the Schumacher et al. (2001) perfect multitasking experiments, but also sequential multitasking in laboratory experiments as well as practical work-place settings.

In my talk, I will explain the central theory on the basis of a number of examples of multitasking. A first group of examples are drawn from the domain of concurrent multitasking, for example Schumacher et al.'s perfect time-sharing experiments, but also from more real-life examples of driver distraction (Salvucci, Taatgen, 2008).

A second group of examples concerns sequential multitasking, where people alternate between tasks or are interrupted during their main task. Here I will discuss an experiment and model by Borst et al. (2010), in which alternation between tasks works well under certain circumstances, but is disrupted in a slightly different condition.

The topic of multitasking also raises the question of how tasks are defined: when is something a *task*? Many tasks can be considered as cases of multitasking themselves. We are currently studying this in the context of the game

Set, which we can understand best by assuming a perceptual and a planning thread (Nyamsuren, Taatgen, submitted). I will finish with an example that shows that multitasking is not always bad or neutral, but that there are even examples in which performance improves with multitasking (Taatgen et al., 2009).

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– Talks –

Impact of Affective and Informative Feedback on Learning in Children before and after a Reattribution Training

An Integrated Approach using Neuroimaging, Educational Research and Modelling

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Theoretical Background

There are many situations where feedback provides essential information needed for performance evaluation and subsequent adaptation. Feedback is thus a major topic in educational, cognitive and neuroscientific research and is of high relevance for every day educational practice. On the one hand, feedback is necessary and can be expected to be particularly supporting in areas were systematic learning is crucial, such as in science education, since it provides the essential information needed for adaptation. On the other hand, it has been shown that feedback can interfere with the learning process and it has been suggested that this is due to the affective component of feedback (Dweck, 1999; Dweck, Legget, 1988). So far, only a few studies have tried to disentangle these two aspects of feedback (Edwards, Pledger, 1990). For example, findings on ways to provide effective feedback are still a matter of controversy. When observing teachers in their everyday classroom practice, several studies showed that the frequency of giving feedback is low, especially when looking at powerful feedback (Bond et al., 2000). There are few studies that have explicitly manipulated the effects of affective feedback. One remediation program which has been successfully employed in schools and aims to change the way one copes with feedback in learning situations, is the reattribution training (Ziegler, Schober 1997, 2001). Ziegler and Schober (2001) showed that this training which aims to change maladaptive attributions improves learning. The overarching aim of the current interdisciplinary approach is to investigate learning strategies and the role of feedback on learning. The project was carried out by four project groups at the University of Oldenburg and the IPN Kiel and covered the areas of cognitive neuroscience, educational research, science education and cognitive modelling (Table 1). The cognitive neuroscience approach provided neural data on feedback processing, which is not accessible by behavioral research alone. The classroom study was carried out with the intention of investigating (a) the role of corrective and affective feedback on learning processes behaviorally; and (b) the students' understanding of rules for basic chemical formulae, the strategies students developed during the learning process, the use of supporting tools and their correlations with personal characteristics, e.g. their beliefs about causalities for success or failure. Finally, cognitive modelling has allowed us to investigate whether a cognitive architecture (Anderson et al., 2004) could be used to model the learners' behaviors in tasks relying on individual strategies.

Tab. 1 Research questions of the four different research areas

Research group	**Research questions**
Research on Learning and Instruction	What kind of effects does an attributional retraining have on the learning process in children under the conditions of corrective and affective components of feedback in learning tasks?
Cognitive Neuroscience	What are the neural correlates of affective components of feedback and are these modulated by a reattribution training?
Cognitive Modelling	How do a non-algebraic task domain, modelling paradigms, and multi-dimensional strategy spaces affect the BOLD prediction capabilities of the ACT-R cognitive architecture? Can affective and informative components of feedback be modeled with an ACT-R model, which also predicts behavioral and neural data?
Chemistry Education	How can the acquisition of the chemical formulae be influenced by supporting tools and the development of strategies?

We chose a science learning situation and designed an experimental task where students had to match a chemical formula or model with a respective designation, or vice versa and received different types of feedback. The exact type of task and the feedback provided varied slightly between project groups (see Fig. 1). Our subjects were young high school students (age 10–13 yrs). They were assigned to two groups, one receiving the reattribution training and one receiving normal teaching. All students were measured once before and additionally 15 weeks after the intervention.

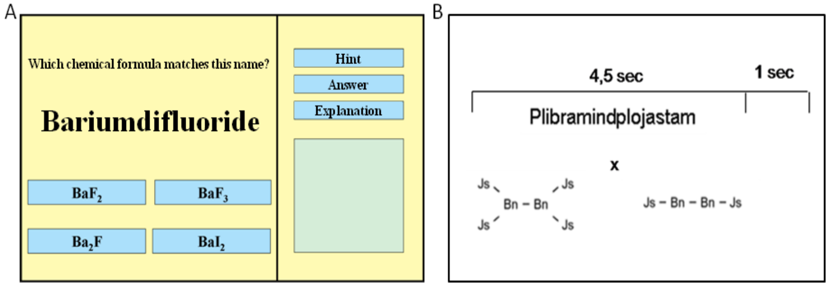

Fig. 1 Illustration of the task of the paradigms
A. Task used by the project groups Learning and Instruction and Chemistry Education. In the chemical formulae paradigm, students got a series of tasks to be solved in a self-paced manner after a short introduction. Within each task a chemical formula and four possible names were presented and the students had to decide which name matches the formula or vice versa. The complexity of the tasks increased gradually, ranging from simple element names (e.g. Lithium – Li) to compounds (e.g. Bariumdichloride – BaCl2). While working on the tasks, the students had the chance to use different supporting tools. Scale and depth of the supporting tools increased, starting with a general hint to focus on a certain aspect or offering an analogy and ending with the proper answer including an explanation. The choice whether and which supporting tools are used was up to the student.
B. Task used by the project groups Cognitive Neurosciences and Cognitive Modelling. The task required rule-based matching of chemical structures (pseudo formulas) with their respective names. Children were acquainted with the rules prior to the first scanning session. They were shown two simultaneously presented chemical pseudo formulae and one name for 4.5 seconds. Within 5.5 seconds, they had to decide via button press which of the formulae matched the presented name. After a variable delay (2–18 sec.), they received the affective feedback (2.5 sec.) shown in Figure 2.

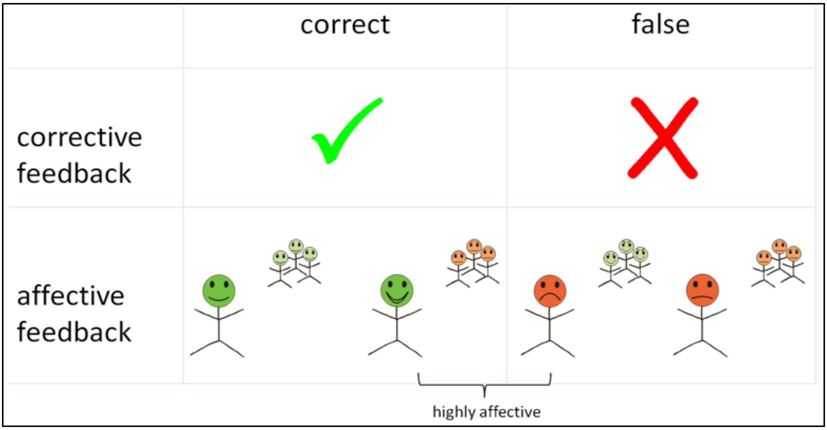

Fig. 2 Illustration of the feedback phase of the paradigms. Following each trial shown in Figure 1A, two different types of feedback could occur. One group received corrective feedback indicating correct or false performance and the other group received corrective feedback that was additionally related to the performance of an alleged peer group. The affective value of this feedback was manipulated within subjects by providing feedback of high affective value (indicating that the performance was better or worse than those of an alleged peer group) or feedback with low affective value (indicating that the performance was similar to that of an alleged peer group). Note that in the Cognitive Neuroscience study only affective feedback was provided after the learning phase shown in Figure 1B.

527 children were tested at three time points with the paradigm depicted in Figure 1A. These children also performed an additional set of psychological tests and questionnaires. Another 30 children were tested with fMRI with the paradigm shown in Figure 1B. This data was also used for the modelling approach aiming at predicting behavioral and neural data on an individual level.

Methods and exemplary results of the four disciplines

Project Group: Research on Learning and Instruction

According to the attribution theory, students are more or less motivated due to their beliefs about causalities of success or failure. With this in mind, the aim of reattribution trainings is to change causal explanations from a lack of ability to a lack of effort and to improve the students' beliefs in the cause of their failures and successes e.g. to promote future motivation. Ziegler and

Schober (1997, 2001) designed attributional retrainings to be applied in everyday classroom situations.

One focus of the current study was to evaluate the effects of such reattribution training in relation to possible reactions to affective and corrective feedback processing. We expected that the reattribution training would lead to more adaptive reactions to feedback (i.e., better subsequent performance and reaction times in our learning task even in conditions with highly affective feedback). In regard to this we aimed to investigate the role of an attributional retraining on different feedback conditions on subsequent learning in children.

In our study, five teachers applied the training for 15 weeks during regular instruction in a classroom setting. Half of the children (n = 260) were assigned to the intervention group and got the reattribution training, and half of them (n = 267) served as control group without training. Children who were not trained continued to receive normal instruction in their classrooms. All children were unaware of the intervention.

Analysis of subsequent learning processes in the learning task suggest that the reattribution training had an effect on the reaction times following different conditions of feedback. Whereas we found no differences in the condition of corrective (correct or false) feedback when comparing the training and control groups, there were significant effects in the highly affective feedback conditions. As expected, children in the training group were significantly faster in the post-test on the following trial when they received the highly affective feedback "you are better than your peers" than before the training ($F(1,177)=4.27$, $p<.05$). In comparison, children in the control group showed no differences in the pre- and in the post-test. The same effect of the training was also evident regarding the reaction times following the highly affective feedback condition "you are worse than your peers" ($F(1, 173)=3.85$, $p\leq.05$). A possible explanation for this effect can be that social comparisons, which are disturbing to the learning process, had lost their importance for the trained children.

Project Group: Cognitive Neuroscience

One of the main goals of the project was to investigate whether the reattribution training, which aims to modulate the way feedback is processed, has an impact on feedback-related brain activity. By modulating the self-relevant affective value of the feedback, we hypothesized that children who had previously participated in the training would show a different recruitment of brain areas known to be involved in affective and self-related processes. As the reattribution training is specifically designed to encourage controllable failure attributions, training effects were mainly expected for the highly affective negative feedback condition.

Fourteen of the 30 participating children received the reattribution training (operated by the project group Research on Learning and Instruction) in between the first and second fMRI session. In the fMRI scanner, all children performed a task requiring rule-based matching of structures with their respective names, receiving high or low affective corrective feedback (see Figure 1B and Figure 2). Data were analysed with a three-way ANOVA model and we mainly focussed on interaction effects.

Group analyses revealed that the reattribution training had a clear effect on behavioural and neural data. Both revealed significant effects for the interaction time (pre-/post-test) x group (trained/not trained) that were confined to the negative feedback condition. Behaviourally, we obtained a significant time x group interaction for accuracy performance: Proportion correct responses in trials after negative feedback in the pre-test did not differ between groups, but were significantly higher in the post-test for the group with training compared to the group without training ($p<.05$). Analyses of the fMRI data, yielded a significant time x group interaction in the right superior temporal cortex, among others, which was due to higher neural activity for the trained group as compared to the group without training in the post-test ($p<.001$, uncorrected; feedback condition "worse than peers").

To our knowledge, this is the first fMRI study demonstrating that emotional-motivational training has a significant influence on negative feedback processing in children. Training effects were obvious in both the behavioural and the neural data. As expected, they were largely confined to the negative feedback condition that we assumed would invoke affective and self-related processes, which then impacted performance in the following trial. In line with this, brain regions shown to distinguish between trained and untrained children in our study have previously been reported to be part of a larger network involved in mentalizing and in processes that bear a relevance to the self (Gallagher, Frith 2003; Schmitz, Johnson 2007). Thus, the results obtained revealed a clear beneficial effect of the reattribution training on performance when children are faced with negative outcome information. We propose that heightened activation of brain areas, known to process self-relevant information, reflect cognitive processes associated with the more controllable failure attributions assumed to underlie this efficient performance.

Project Group: Cognitive Modelling

The Adaptive Control of Thought-Rational (ACT-R) theory (Anderson et al., 2004) is a cognitive architecture, which is used to model simple and complex behavior in various domains. ACT-R can be used to quantify and visualize the relationships among cognitive variables involved in learning and problem solving. In addition, Anderson (2007) postulates a neurophysiological analogy between the cognitive architecture and particular brain regions. These regions are captured within ACT-R by a set of seven modules with specific functions. Assuming the viability of the Anderson's Brain Mapping Hypothesis, the modules predict BOLD signals for the corresponding brain regions, making it possible to compare BOLD signal predictions generated from strategy-specific ACT-R models (Möbus, Lenk, 2009) with BOLD signals obtained from actual fMRI scans.

The ACT-R models had to solve the same problem as the participants in the fMRI experiment (Figure 1B) before the reattribution training. Based on task analysis and interview results (cf. section Chemistry Education), six different major strategies of the participants were modelled using ACT-R. Using Bayesian identification analysis, the problem solving strategies were matched to participants (Möbus et al., 2010). Finally, the strategy-based predictions of BOLD-curves were compared to the obtained fMRI data (cf. section Cognitive Neuroscience). The individual BOLD curves for the trials were aggregated onto a trial template of 10 scans (Carter et al., 2008). Comparing the strategy-dependent module-region correlations between measured and predicted BOLD-curves showed mixed results. For six out of seven modules, correlations between $.73 < r < .95$ were obtained for the best-fitting strategy (Möbus et al., 2011). Negative correlations for the GOAL module possibly point to faulty assumptions with respect to goals and sub-goals in the modelling process. Generally, the modelled strategies differ in their implementation and need further revisions, but the results obtained show that Anderson's Brain Mapping Hypothesis may not be dismissed, but the accuracy of predictions largely depend on modelling paradigms and techniques.

Project Group: Chemistry Education

From the perspective of science education, the project should shed light on the question of how the acquisition of chemical formulae could be optimized. The application and interpretation of chemical formulae is crucial for chemists, but also one of the most difficult and unpopular topics in chemistry education (Schmidt, 1997). The computer-based learning environment aims to trace students' development of strategies over time and how different supporting tools can facilitate the formation or adjustment of strategies.

Although the supporting function was not used frequently (many students stated in interviews that they wanted to solve the problem without extra help), it can be considered very useful to the students, as expected. Average answer probabilities were raised considerably by the use of the different supporting tools. As expected, the increasing amount of information within the supporting tools (from a general hint to an explanation) resulted in increasing answer probabilities.

Within the learning environment, students were asked which strategies (see section Cognitive Modelling) they used to identify the underlying rules of this symbolic language after each of three difficulty levels as well as in additional interviews (N=8). Different strategies were extracted with regard to their responses to the open-ended questions and the interviews. The students expressed 25 indicators to match formulae and names (partially combinations). These were categorized into six levels of strategy quality. Over the course of the learning environment, the strategy quality increased slightly, but significantly (one-way repeated-measures ANOVA, □= .98, F(1.96, 777.9) = 108.54, p < .001, □²= .12). In addition, the quality of the applied strategy correlated with the amount of correct answers (r_s= .22, p < .001). With regard to the supporting tools, the students' learning gains (standardized residuals from pre- to post-test) were not directly predicted by the general use of supporting tools but by the quality of their strategies ($F(5,412)=1.64$, $p < .05$, $R^2 = .06$). The results stress the usefulness of supporting tools but raise questions concerning their target course (supply of content information vs. strategy building) and implementation into classroom practice.

Conclusions

Our interdisciplinary research project provides insights into the brain processes involved in processing the affective content of feedback, its impact on the way that individual students deal with feedback, the strategies students apply to solve highly systematic tasks, such as interpreting chemical formulae and their effect on learning outcomes. The behavioral results provide evidence that only highly affective feedback impacts performance in the following trials. We show compelling evidence that a reattribution training improves performance in highly affective conditions and that these improvements were associated with signal changes in brain areas involved in the processing of affective and self-relevant information, respectively. An interesting approach for cognitive modelling would be the integration of affective information into the ACT-R model. The experimental results obtained in the Chemistry Education Group together with the interviews underline the role of development of elaborated strategies to solve highly systematic tasks, such as interpreting chemical formulae. The experimental feedback provided here was shown to be less important for chemistry learning. Accordingly, the different feedback conditions (see Fig. 2) did not result in different scores.

Further research is needed to bridge the gap between the different disciplines and to develop descriptive and prescriptive models of student learning (Mason, 2009). Nevertheless, the current project illustrates how the complementary use of different approaches (e.g. educational research, neuroimaging and cognitive modelling) seems especially fruitful with regard to the evaluation of interventional studies. While in most cases the differences between disciplinary methods, with each focusing on different levels of analysis, is regarded as problematic, the alignment of these methods here provides a multilayered picture of feedback and its impact on learning processes.

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Locating the Neural Correlates of a Multitasking Bottleneck

Analyzing fMRI Data on the Basis of a Computational Cognitive Model

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Theoretical Background

If one wants to find the neural correlates of a theorized cognitive process using the classical fMRI analysis method of *cognitive subtraction*, the first step is to translate the theory into suitable experimental conditions. Then, an experimental condition placing demands on the process of interest is compared to a control condition. The control condition is the same as the experimental condition except for the absence of the process under investigation. Brain areas that are more active in the experimental condition than in the control condition are assumed to be involved in the cognitive process of interest. However, especially for more complex tasks, the translation of theory into experimental conditions is non-trivial. In complex tasks, central cognitive processes are often used in all experimental conditions, which makes it difficult to find a good control condition that does not include the process of interest. One way to address this problem is to use model-based fMRI analysis (e.g. Gläscher, O'Doherty, 2010). In model-based fMRI analysis, information coming from a computational model that simulates the process of interest is correlated against fMRI data, showing which brain areas are consistent with the process of interest in the model.

Here, we will use the model-based fMRI method to analyze data of a relatively complex experimental paradigm, which was developed to investigate the neural correlates of the 'problem state resource' (Borst et al., 2010a). The problem state resource is defined as the part of working memory that is available at no time cost (Anderson, 2007), as opposed to other elements in working memory that take time to retrieve and use. It is normally used to represent intermediate information in a task, and can at most contain one chunk of information (Borst et al., 2010b). Thus, the concept of a problem state resource is comparable to the focus of attention in working memory theories that pose an extremely limited focus of attention (e.g. Garavan, 1998; McElree, 2001).

Recently, we have shown that the problem state resource is a source of interference when required by multiple tasks at the same time (Borst et al., 2010b). A computational cognitive model was developed to account for the observed multitasking interference. The model was developed in the ACT-R architecture (Anderson, 2007), and uses Threaded Cognition theory to account for multitasking aspects (Salvucci, Taatgen, 2008; 2010). The basic assumption of the model is that when multiple tasks require a problem state, the contents of the problem state resource have to be replaced on each switch between tasks. That is, on every alternation the problem state of the previous task is stored in declarative memory, while the problem state of the current task is recalled from declarative memory and restored to the problem state resource. The model incorporating these time-consuming and error-prone problem state replacements provided a good match with the interference effects in the data. The current experiment was performed to locate the cognitive resources of this problem state resource.

Methods

To find the neural correlates of the problem state resource, we used an experimental design in which participants alternated between solving 10-column subtraction problems and entering text. Both the subtraction task and the text-entry task had two versions: an easy version that did not require maintenance of a problem state and a hard version that did. For the subtraction task this meant that in the easy version the upper term was always larger or equal to the lower term (i.e., no carrying was required), while in the hard version participants had to carry in 6 out of the 10 columns. In the easy version of the text entry task a letter was shown, which the participants then had to enter, followed by a new letter, etc. In the hard version, a complete 10-letter word was shown once at the start of a trial, but as soon as the participant entered the first letter, the word disappeared and had to be entered without feedback. Because participants had to alternate between the tasks after every number and letter, they had to keep track of whether a carry was in progress and what word they were entering (and the position within the word) while giving a response on the other task in the hard versions of the tasks. As confirmed by previous experiments (e.g. Borst et al., 2010b), we assumed that participants used their problem state resource to keep track of the carries and words. A detailed description of the methods can be found in Borst et al. (2010a).

Results

To perform the model-based fMRI analysis we first fitted the cognitive model described above to the data. To approximate the cognitive processes at trial level (necessary for regressing the model activity directly against the fMRI data), we ran the model for each participant on the same stimuli as the participant received, in the same order, including all non-experimental components, such as fixation and feedback screens. To further improve the timing of the model, we lined up the model's responses with the participant's responses.

As the next step, we convolved the model's problem state activity with a hemodynamic response function. Figure 1 shows the results for four trials in the experiment: The blue spikes show the activity of the problem state resource, the red line shows the results of the convolution with the HRF. The convolved activity was then regressed against the fMRI data, to identify regions that correspond to the problem state activity of the model. Figure 2 shows the results: we found a region in the inferior parietal lobule that significantly corresponded to the model's problem state activity (a threshold of $p < .01$, FWE-corrected, and 100 contiguous voxels was applied to the results, crosshairs are located at the most significant voxel). The best fit within this region was located around the intraparietal sulcus.

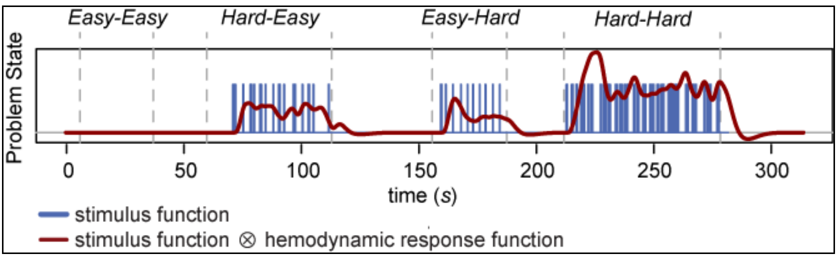

Fig. 1 Example of problem state activity (blue spikes), and its convolution with a hemodynamic response function (red line) for four trials in the experiment. *Easy-Easy* etc. mean *Easy Subtraction – Easy Text Entry*.

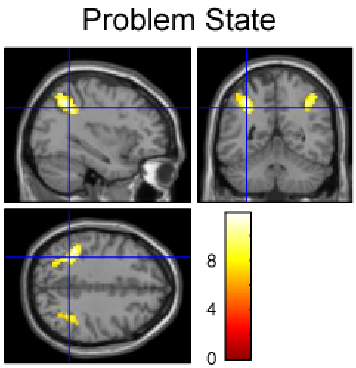

Fig. 2 Results for the problem state resource

Conclusions

The model-based method identified the neural correlates corresponding to the problem state resource. Instead of focusing on one process, as is common practice in the neurosciences, using a high-level model integrated in a cognitive architecture allows for analyzing all cognitive processes that are involved in the task, and thus localizing multiple resources in one experiment. For example, while we have shown the results of the problem state resource, the same methodology can be used for the visual resource, yielding an area in the occipital cortex. The model-based fMRI analysis is not only suitable for use with models developed in the ACT-R architecture, but can also be applied to every data set when there is a model available that is more detailed than the global trial structure of the experiment. Finally, because this analysis is inherently based on a cognitive model, the fMRI results are grounded in the theoretical framework the model was built on, directly providing a functional explanation of the results.

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The Behavioral and Neuro-Physiological Data Associated with the Fruition of Multimedia Products

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Theoretical Background

Multimedia learning materials can provide individuals with rich cognitive environments where concepts can be understood, elaborated, and learned in multiple formats: written texts, oral narratives, static pictures, animated videos, audio elements, etc. Paivio's (1986) dual-coding theory has provided a rich foundation for research on multimedia learning. Dual-coding theory contends that verbal and non-verbal information are processed parallel to one another and therefore normally do not compete for resources. Verbal representations are composed of words for objects, events and ideas while non-verbal representations are embedded in non-verbal representations with some resemblance to the perceptions that give rise to them.

Mayer's (2001; 2005) Cognitive Theory of Multimedia Learning is an applied model that has tested Paivio's dual-coding theory with multimedia learning materials. Mayer's theory is an empirically supported model inspired by a learner-centered approach. According to the theory, people learn better if information is learned via both systems, that is, when learning occurs with verbal and non-verbal information, than with verbal information alone (Mayer, Moreno, Boire, Vagge, 1999; Mayer, Dow, Mayer, 2003; Mayer, Moreno, 2003).

The efficacy of the principles drawn from Cognitive Theory of Multimedia Learning varies depending on individual differences. Antonietti (2003) argues that cognitive styles (e.g. visualizers, verbalizers, etc.), which can be defined as the way an individual perceives, remembers and re-elaborates information, modulates their way of dealing with information, effectiveness of cognitive processing and learning in general.

Another point of interest concerning the processing of multimedia stimuli is the cognitive load theory, as proposed by Sweller and colleagues (e.g. Sweller, 1988; Sweller, van Merriënboer, Paas, 1998; Chandler, Sweller, 1991). It refers to the load on working memory during cognitive elaboration: Since working memory is limited, if the complexity of materials is not properly managed, this will result in a cognitive overload which can impair schema acquisition, later resulting in a lower performance.

Another main theoretical concept is narrative thinking (Bruner, 1986), defined as the set of mental processes that allow one to create and negotiate meanings. Through narrative thinking, the individual gives meaning to experiences, by the way of sorting and representing it according to his or her socio-cultural framework.

Are these assumptions valid when materials present high level of emotional content and cognitve elements necessitating elaboration during a multimedia presentation?

Research has shown that emotional information is able to capture attention and to enhance memory in cognitive tasks (Cahill, McGaugh, 1995; Hamann et al., 1999), since the attentional system ensures that the brain prioritizes the processing of highly salient and unexpected stimuli at the expense of other ongoing neural activity and behavior (Corbetta, Shulman, 2002). Both neuropsychological and behavioral studies suggest that emotional stimuli are highly salient, are recognized rapidly, and consequently are especially likely to capture attention (for reviews, see Compton, 2003; Vuilleumier, 2005). Moreover, Nummenmaa et al. (2009) showed how early saccade target selection and execution processes are automatically influenced by emotional picture content: This reveals processing of meaningful scene content prior to overt attention to the stimulus.

Methods

The present study was aimed at exploring the link among those aspects, by the way of exploring the cognitive elaboration of emotional multimedia stimuli (audio+video) using eye-tracking technology and biofeedback data. More specifically, we were interested in exploring the effect of expertise, cognitive style, different format of multimedia emotional presentation (coherent vs. incoherent) on cognitive elaboration and emotional responses.

Eye tracking was selected to explore participants' cognitive behavior, starting from the assumption that eye movements are directed and reflect neuro-activities (see the *Mind-eye-hypothesis*; Just, Carpenter, 1980).

Biofeedback was used on the base of literature reporting strong links between emotional responses and psychophysiological data. Examining self-rate responses and psychophysiological correlates to emotional pictures, researchers highlighted higher skin conductance levels as a response to more emotive stimuli (Bradley, Codispoti, Cuthbert, Lang, 2001). Additionaly, pulse volume amplitude and pulse frequency appear to be linked to negative stimuli (Bradley, Codispoti, Cuthbert, Lang, 2001).

To better highlight the role of individual differences, we took the right/left thinking style (Torrance et al., 1978) as a reference point, which was inspired by the theory of brain hemispheric dominance in order to distinguish between the tendency to prefer a verbal-abstract code, together with analytic and sequential procedures and the tendency to use a visual-motor code, and linked to innovative procedure and intuitive behavior (intuitive-holistic vs. systematic-analytical thinking style).

Materials

A multimedia presentation was built using 20 portrait photos, paired with different musical comments. Images belonged to two different categories: Emotional and non emotional stimuli. The first category consists of 10 pictures, chosen from the works *Testigos* and *Under My Skin* from Spanish artist Pierre Gonnord, whose work explores the concept of community and its members, encouraging everyone to demonstrate their uniqueness and sense of belonging.

Non-emotional images consist of 10 photographs created by researchers who tried to obtain images similar to those of Gonnord in framing, the use of colors, etc., but without the same dramatic connotation and with an expressionless face.

A randomized sequence of photos was created and they were pretested to assess the actual difference in emotional content, as perceived by a sample ($n=27$) similar to the experimental one.

We have obtained significant results on IAPS rating scales (sadness ($t = 9.94$; $p<.001$), anger ($t = 3.08$; $p<.01$), fear ($t = 5.84$; $p<.001$), compassion ($t = 6.73$; $p<.01$), interest ($t = 4.31$; $p<.001$), guilt ($t = 3.51$; $p<.01$), anxiety ($t = 5.14$;

p<.01), tenderness (t = 3.48; p<.01), hopelessness (t = 5.069; p<.001)) and on the two SAM's scales (pleasantness (t = 5.70; p<.001), involvement (t = 6.46; p<.001)).

Music to accompany the photos was selected by an expert (Gian Luca Lastraioli, Ph.D., professor at "A. Scontrino" Conservatory – Trapani, Italy):

Anxious music: First movement from Quartet op. 132 , A minor, by L. W. Beethoven

Sad music: Variation on "*Amate mie stelle*" by C. Milanuzzi (Italian composer; b Sanatoglia; d c 1647).

Neutral music: "*Voiles*" (Book 1, L 117, Preludes) by C. Debussy.

Behavioral data derived from ET were: fixation and observation length, fixation and observation count and time to first fixation, concerning 5 main Areas of Interest (forehead, eye, nose, mouth, body).

The biofeedback equipment was set in order to measure: skin conductance level, skin temperature, blood volume pulse, pulse volume amplitude and pulse frequency.

After the multimedia fruition, participants were asked to answer a questionnaire about their cognitive style (*SOLAT* – Torrance, 1988), the emotions they felt (using a rating scale from the *International Affective Picture System –IAPS-*; Lang, Bradley, Cuthbert, 2005 and the *Self Assessment Manikin*; Lang, 1985) and a few questions related to cognitive elaboration of the multimedia stimuli (*narrative questionnaire*): participants were asked to name their favorite photo, to assign a title and narrate a plausible history of the represented person).

Sample

The sample consists of thirty-nine participants (age between 18 and 40), balanced by gender. According to their level of expertise concerning artistic language, they were split into two subsamples: 19 participants had certified experience in managing artistic language and constituted the "experts" group, while the other 20 individuals (who had no experience in our target field) formed the other subsample.

Results

Analyses are still ongoing – the main findings are summarized below. Altogether, as occurred during the pretest, the photos that moved participants were those of the photographer (emotional images).

General gender differences

Considering the data derived from a self-report emotive questionnaire, female scored higher than male, especially considering emotive images.

Influence of music

Non-emotional images led to greater differences in emotive activation depending on the type of music while, on the contrary, neutral music has enhanced the emotive communication of emotional images.

Influence of cognitive styles

Left thinkers appeared to be more involved and activated than right and balanced thinkers, by both emotional and non emotional images. Yet, recoding the variable on two levels (instead of three) – we were able to highlight specific images that were able to activate right thinkers more than left thinkers.

Influence of music and images on psychophysiological activation

Running a Repeated Measure analysis, aimed to compare differences among different images through the three music conditions, we found a main effect of Image ($F=454.61$, $p<.001$) on skin conductance level. Differences were concentrated mainly around one of the emotional images, which had higher scores in all music conditions. Participants were apparently unaware of this higher activation, since this specific image did not score higher in the self-report questionnaires.

We found an effect of Image and musical condition on pulse volume values ($F=21.62$, $p<.001$) – where anxious music promoted higher values in almost all images. We were also able to highlight individual images that promoted different trends with neutral or sad music.

Pulse frequency was afflicted by different images and different musical backgrounds ($F=2.96$, $p<.01$). Anxious music affected responses to specific images – while sad music appeared to cause values to rise for almost all of the images.

Influence of expertise on psychophysiological activation

Skin conductance level was affected both by images ($F=3.52$, $p<.001$) and by the joint effect of images and expertise ($F=2.52$, $p<.001$): experts tend to have more diversified levels of activation for different images (their scores are either higher (non-emotive images) – or lower (emotive images) – with respect to non-experts).

Considering pulse frequency, experts scored higher for most images ($F=1374.49$, $p<.001$). On the contrary, non-experts had higher values for pulse volume ($F=109.77$, $p<.001$) while examining most images. Skin temperature levels highlighted differences between the two subsamples ($F=4743.03$, $p<.001$) concerning the response to specific images (two non-emotional and one emotional).

Behavioral data

Non-emotional images appear to have promoted a more activated and diversified exploration of the stimuli. On the whole, the mouth was the most fixated area, and sad music promoted fewer and shorter fixations. Experts had a more active behavior, especially while exploring emotional stimuli. Non-emotional stimuli appeared to require higher elaboration – possibly because artistic stimuli presented a more explicit interpretation schemata and were easier to understand in their meaning.

Narrative data

Applying cross tabulations between groups and the variable "communication of the photographer" [χ^2 (39,4) = 1.o2], it was possible to highlight how "experts" tend to identify themselves more with the author of the photographs.

Analyzing participants' narrations, the Pearson correlation was significant between content and motivation ($r =. 31$, $p <.05$), and feeling and communication ($r =. 47$, $p <.05$). These tests have shown that people's choices are influenced by their first impression, which was mostly negative in our specific setting. Descriptive data allow us to argue that experts are more capable of identifying with the character portrayed by the photographer, creating a long, detailed narration.

Conclusions

Interesting data emerged from the first data analyses. Different kinds of multimedia presentation appeared to promote different levels of activation and different exploration behaviors. Individual differences seem to play an important role, as does level of expertise. This last variable appears to be more linked to response to different types of cognitive load.

Quite surprisingly, coherence between audio and video emotional content didn't seem to promote more adequate activation (audio showed to be more important than images in influencing participants responses) while the opposite was true with neutral music background.

Finally, the results derived from narrations denote an interesting difference between the two experimental groups, which, once again, can be explained by referring to the concept of "expertise". Experts appear to be able to better understand the message of the author of the portraits and are better able to empathize with the character. Therefore, they write more complex and profound narrations. Participants' choices are deeply influenced by their first impression, especially if they are linked to strong negative emotions. Non-experts, on the other hand, tend to draw a more naïve analysis, focusing on external details of the protagonist, like a scar, writing a simple and ordinary narration.

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ERP Evidence for the Role of Cognitive Control in the Acquisition and Retrieval of Episodic Information in Children and Young Adults

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Theoretical Background

Children acquire vast amounts of new information every day, although many cortical areas recruited during memory formation and retrieval in young adults have not reached functional maturity in children (Sowell et al, 2004). Despite huge potential implications for formal education and for clinical populations, little is known about the cognitive processes supporting memory encoding in developmental populations. Based solely on behavioral outcome during memory retrieval (for instance types of memory errors), it is difficult to dissociate memory development per se from generalized cognitive control abilities contributing to reliable memory judgments (Czernochowski, Mecklinger, Johansson, Brinkmann, 2005). Moreover, surprisingly few studies to date have examined both mnemonic and cognitive control abilities in the same participants.

Methods/Project Plan

Event-related potentials (ERPs) allow real-time tracking of cognitive processes during both memory encoding and retrieval on a trial-to-trial basis and are well-suited for developmental populations. In a combined cross-sectional and longitudinal design, four groups of children and adolescents between 5 and 13 years of age will be compared to young adults as well as at two distinct points of their development.

Expected Results

The first goal of the proposed project is to characterize the developmental trajectory of cognitive control, memory encoding and memory retrieval in more detail. Cognitive control comprises at least two subcomponents, response conflict detection and control functions necessary to counteract response conflict. With the aid of ERPs, it will be examined whether both types of control functions mature at different rates (Bunge, Wright, 2007). Even young children are expected to detect response conflict. However, the ability to recruit cognitive control for avoiding high-conflict errors, for instance at the expense of slowed RTs, is expected to depend on functionally mature PFC structures. (Manzi, Nessler, Czernochowski, Friedman, 2011) Hence the ability to effectively counteract response conflict should be observed in older, but not young children.

Memory encoding processes in childhood so far are poorly understood (Menon, Boyett-Anderson, Reiss, 2005). Taking advantage of ERPs, potential qualitative differences in encoding operations between children and young adults will be investigated. Specifically, it will be examined whether electrophysiological subsequent memory effects in children depend on the type of cognitive processes carried out during memory encoding (for young adults, see e.g. Otten, 2007), and by what age children start to consider semantic information along with perceptual item features during memory formation. Memory retrieval processes can be subdivided into memory for content and context (Czernochowski, Mecklinger, Johansson, 2009). Both will be assessed for various types of material (pictures, locations, verbally presented concepts), and across testing formats (cued recall, recognition). Specifically, the role of identical perceptual repetition for the development of a-contextual familiarity as compared to recollection of contextual features will be examined (Czernochowski, Becker, Mecklinger, 2009).

The second main goal is to integrate the above findings from all three cognitive functions to examine the respective role of cognitive control and memory development within the same individuals. Structural equation modeling will contribute to a more integrated in-depth account of cognitive development during middle childhood and early adolescence. Specifically, it will be examined to what extent children's performance difficulties during complex memory tasks reflect failure to monitor response conflict rather than memory development per se.

Conclusions including Potential Links and Cooperation

Practical implications of this approach include the evaluation of educational programs, for instance whether or not cognitive control training will influence performance on memory tasks. Understanding the biological processes underlying improved performance with increasing age could be useful to shed light on the precise mechanisms responsible for developmental progression. Finally, more detailed knowledge about the typical developmental trajectory of memory and cognitive control functions will eventually allow earlier and more reliable diagnoses of atypical developmental patterns, which in turn would potentially allow for more effective interventions (Crone, 2009).

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ERP evidence for the role of cognitive control for the acquisition and retrieval of episodic information in children and young adults (DFG)

Mathematical Cognition: Psychophysiological Correlates, Domain Impacts and Sources of Individual Differences

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Theoretical Background

Mathematical cognition is one of the most important tasks a child must master. However, the scientific investigation of mathematical object representation (e.g. numbers, calculi) and calculation is a relatively recent enterprise. Mathematical cognition depends on retrieval of learned facts and rules, as well as on general cognitive abilities like fluid reasoning. Individuals with high general cognitive abilities therefore have a double advantage when solving mathematical problems: first, they are up to deal more rapidly and accurately with the task and second, caused by the first advantage, can draw on more practiced routines (Blair, 2006). Aim of this study was to compare the processing of arithmetic and algebraic tasks with graded levels of difficulty in individuals with average and superior general cognitive abilities. Furthermore, we examined to which extent the pupil dilation as an aggregate measure of neural activation (Just et al., 2003) can help to identify cognitive resource allocation underlying mathematical cognition (Landgraf et al., 2010; van der Meer et al., 2010). There are three contrasting predictions about the effects of general cognitive abilities and task difficulty on performance and pupil dilation (cf., Ahern, Beatty, 1979; van der Meer et al., 2010):

First, individuals with superior general cognitive abilities commonly allocate more resources independent of task difficulty (*effort hypothesis*). Thus one expects shorter or the same response times, lower or the same error rates and *greater* task-evoked pupil dilations *across all types of tasks* compared to individuals with average general cognitive abilities. Second, individuals with superior general cognitive abilities have more cognitive resources available and thereby can solve *more demanding tasks* (*resource hypothesis*). Thus one expects shorter or the same response times, lower or the same error rates, and *greater* task-evoked pupil dilations only in the most difficult tasks compared to individuals with average general cognitive abilities. Third, individuals with superior general cognitive abilities use cognitive resources more efficiently compared to individuals with average general cognitive abilities (*efficiency hypothesis*). Thus one expects shorter or the same response times, lower or the same error rates, and *smaller* task-evoked pupil dilations *across all types of tasks.*

Methods

Ninety-one 11th grade students (24 female, mean age 17.5 years, SD = 0.5) from three Berlin schools specializing in mathematics and natural sciences participated. Fifteen months prior to the experiment all participants were screened for their fluid intelligence through administration of the Raven Advanced Progressive Matrices test (RAPM, Heller, Kratzmeier, Lengfelder, 1998) and for their numerical, verbal, and geometric figural intelligence through the administration of the short version of the Berlin Intelligence Structure-Test (BIS, Jäger et al., 1997).

First, participants were divided into two groups based on their RAPM scores (whole sample: M = 115.9, SD = 15.4): 47 participants were assigned to the average fluid intelligence group (M = 102.7, SD = 7.5), whereas 40 participants were assigned to the superior fluid intelligence group (M = 131.4, SD = 8.9). The two groups differed significantly in their IQ-scores ($p \leq 0.001$).

Second, participants were divided into another two groups based on their numerical BIS scores (whole sample: M = 100.6, SD = 6.2): 42 participants were assigned to the numerical intelligence group below the mean of the sample (M = 95.3, SD = 3.5), whereas 48 participants were assigned to the numerical intelligence group above the mean of the sample (M = 105.3, SD = 4.0). The two groups differed significantly in their numerical BIS scores ($p \leq 0.001$).

The experiment consisted of a control condition and an experimental condition. In the control condition, which served to control for visual and motor activity, two one- or two-digit numbers or two algebraic terms with one variable had to be evaluated in terms of their identity (e.g. 17 = 17). In the experimental condition, a prime composed of one of the following problems was presented: a) multiplication of two one-digit numbers (e.g. 6 x 8), b) cancel down of two one- or two-digit numbers, c) operations with fractions (a and b combined), d) simplifying basic algebraic expressions, e) simplifying advanced algebraic expressions, f) simplifying complex algebraic expressions (c and e combined). Participants were instructed to solve the problem as quickly and accurately as possible. The prime was displayed until a candidate answer (the target stimulus, e.g. 48) was requested by button press. Participants then had to decide whether the given answer was correct. Half of the trials served as distractors, that is, incorrect answers that had to be rejected. The experimental condition consisted of 168 items, equally distributed among the six problem types and randomly presented.

Participants were seated in front of a computer screen at a distance of approximately 100 cm. Response times for prime and target, accuracy, and pupil dilation were registered (240 Hz iViewX Hi-Speed system; SensoMotoric Instruments GmbH, Teltow, Germany). Before starting pupillary data analysis, trials with excessive blinking were discarded and small blinks were replaced by cubical interpolation. The pupillary responses were baseline corrected for each trial by subtracting the average pupil diameter of a 200 ms period before stimulus onset. We conducted a repeated measure analysis to determine the influence of task-difficulty and IQ on reaction times and peak pupil-dilation. Additionally we intend to characterize the time course of the pupil dilation and to determine when it differs between individuals with superior fluid intelligence and individuals with average fluid intelligence by multiple t-tests (Siegle et al., 2003; Guthrie, Buchwald, 1991). To analyze task demands and specific impact of composition in more detail we computed a linear regression analysis on response times. In addition, the pupil dilation data were subjected to a Principal Component Analysis (PCA). PCA can serve as method to structure the pupillary data according to main factors. A preliminary repeated measure analysis was conducted on the factor scores with IQ-group as between-subject factor in order to identify differences dependent on fluid intelligence in the cognitive processes underlying mathematical cognition (experimental conditions a-f). For all these preliminary analyses, a rejection criterion of $p < 0.05$ was chosen.

Preliminary Results

Preliminary behavioral and pupillary results – ANOVA

With increasing task difficulty response times, error rates and peak pupil-dilation increased. Except the easy multiplication condition (a), individuals with superior fluid intelligence solved the tasks faster, more accurate, and with higher peak dilation than individuals with average fluid intelligence.

Similarly, individuals with superior numerical intelligence solved the tasks faster and more accurate. The preliminary ANOVA revealed no significant effect of numerical intelligence on the peak dilation.

Preliminary behavioral results – Regression analysis

As expected the preliminary analysis proved the reaction times for the difficult conditions (c and f) to be predictable by the reaction times in the single conditions from which they are composed (b, resp. c and e). However the identified predictors were not sufficient to explain the total variance. Fluid intelligence was detected to have an additional distinct stake in the prediction of the performance in the difficult conditions.

Unlike fluid intelligence numerical intelligence had no additional predictive value to the reaction times.

Preliminary pupillary results – PCA

For each experimental condition we extracted two principal components. In the difficult conditions c and e ANOVA discovered higher factor scores (individual manifestation of these factors) for individuals with superior fluid intelligence compared to individuals with average fluid intelligence in the late component. For interpretation on the time-scale, the latency of the pupillary response (characterized by a lag of 300–500 ms following the stimulus, cf. Loewenfeld, 1993) has to be taken into consideration. Thus this component is associated with the period before and after the (latency-corrected) behavioral response. This suggests that the component mainly reflects the completion of the computing processes. Pearson's product-moment correlation between fluid intelligence and factor scores confirmed this relationship and moreover revealed the same for the third difficult condition (f). No other correlations were significant.

Preliminary Conclusions including Potential Links and Cooperation

In summary individuals with superior general cognitive abilities (fluid and numerical intelligence) perform better in arithmetic and algebraic tasks. Evidently task performance is associated with numerical intelligence. However, our study makes the crucial point that fluid intelligence assists the explanation of performance differences based on allocation of cognitive resources. In accord with the effort hypothesis (cf., Ahem, Beatty, 1979) our results suggest that individuals with superior fluid intelligence generally allocate more resources independent of task difficulty. In addition, the PCA analysis of pupillary responses revealed processing differences between individuals with superior vs. average fluid intelligence particularly in difficult tasks. The final computing and monitoring processes which take place before and around the decision are more pronounced in individuals with superior fluid intelligence. In line with our findings regarding task composition fluid intelligence seems to provide additional resources that are only necessary for solving difficult tasks thus favouring the *resource hypothesis.* Previous findings (cf., van der Meer et al., 2010; Bornemann et al., 2010) supported the resource hypothesis by providing evidence that individuals with superior general cognitive abilities allocate more resources only in demanding tasks. Neubauer and Fink (2009) considered knowledge and automatization of cognitive functions to be crucial for the relationship of task performance and resource allocation. These deliberations will be discussed.

Future research should cover individual processing strategies as potential cornerstone of higher-order mathematical cognition to a greater extent. Pupillometry could thereby constitute an appropriate tool to use neuroscientific methods and take their advantage also within the real scope of mathematics, for example in the school environment. Findings might support the improvement of intervention programs in students' mathematical education.

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The Cognitive Architecture Based on Biologically Inspired Memory

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The past thirty years are characterized by evident progress in the field of autonomous robotics concerning the integration of new mechanical robot components, comprehensive sensors, and sophisticated algorithms of artificial intelligence. The unsolved problem in this domain is still the adaptability of agents in unpredicted situations resulting from permanent autonomous learning.

Such biological systems as mammals show admirable adaptation abilities in their behavior and could serve as a potential source of inspiration for the development of adaptive learning technical architectures. The remarkable fact thereby is the similarity in the functionality of the main brain circuits and the principles of information processing in the brains of this species. The new profound neuroscience findings about the organization of the brain confirm the remarkable role of memory structures in its functionality. These structures build the base for information processing and are the precondition for all kinds of cognitive processes. Our contribution describes the first steps in the development of the cognitive architecture that is predominantly substantiated by data processing principles of biologically inspired multiple memory systems. Several projects have already dealt with modeling of single aspects of biological memory structures. Our project aims at the high-level modeling of the whole interrelated configuration of multiple kinds of memory structures including the inherent methods which are conducive to generation of memory content, generalization of data, and its mutual use for learning and adaptation. The current memory configuration involves the incipiently simplified realizations of long term and working memory units.

The long-term memory embodies a sophisticated architecture and consists of explicit and implicit components. The explicit (episodic and semantic) memory is realized as the relational database. This type of memory could be recollected to the working memory as a fact, event or behavior model.

The *episodic memory* consists of time ordered sequences of single events. Up to now, two types of episodic events could be supported through our system:

The state-oriented events represent the sequences of robotic states, including environmental states. These events are stored in the EM during exploration.

The scene-oriented events depict the time sorted representations of the perceived scene, the action of the robot and the outcome of the action referring to the determined goal. This information arises through execution of specified tasks.

The content of *semantic memory* is the detailed information about each already seen object, generalized or cached-value knowledge about the solved tasks and the abstract symbolical internal models of explored environments.

The very generally composed request subsystem of the explicit long-term memory enables flexible inquiries and simultaneous activation of the multiple associations connected with the requested cues.

The *procedural memory* emerges through implicit learning and comprises motion skills which could be used automatically in distinct, often iterating situations. The existential motion skill of our autonomous agent is moving in the desired direction or to the specified position while avoiding the obstacles. Rotation and this motion operation are currently the only skills in the procedural memory of our robot and allow its reactive flexible navigation in highly cluttered environments. The implemented algorithm is based on the reactive collision avoidance approach (Muiahad et al., 2009) adjusting the motion rules of Smooth Nearness-Diagram Navigation (SND) method (Durhan, Bullo, 2008) to plan the reliable routes for the robot in complicated scenes. The algorithm includes three phases: it first detects all appropriate gaps within the robot's field of view. Second, it selects the gap with the best correlation to the preferred direction. Third, the motion direction will be optimized depending on the obstacles in the vicinity of the robot.

Our model of working memory correlates with the psychological model of Baddeley (2007) and is composed of four main components:

Short-term memory (STM) buffer is a time-limited buffer with the last moment information about the perceived surroundings. The duration of storage in STM-buffer could be varied by the user. The input to this buffer could be controlled by a bottom-up attention module;

Visuo-spatial pad is a kind of visualized map with a spatial configuration of the objects in the current scene and can be manipulated or matched with the help of image processing methods (for example elastic matching). It will be built on the base of laser range data;

Volume-limited *manipulation (episodic) buffer* is dedicated for the representation of the most salient linked information across all working memory domains and forms an integrated view of the current situation. The volume of this buffer can be varied by the user. The semantic content of the data retrieved from WM buffers and long term memory strongly depends on the current task of the robot unit. So references the manipulation buffer in case of object novelty detection in the explored area to most newly first time seen objects.

The *processing unit* can be seen as the central executive of the system with the following future tasks:

- Calculation of situation specific information
- Binding of information from all kinds of working memory buffers and LTM to the common situation description
- Realization of knowledge-based attention control
- Conducting different kinds of learning
- Action selection based on the robot`s goal and representation of current situation in the manipulation buffer
- Shifting between the tasks and strategies, for example, in the case of complex hierarchical problems

Development and test of the memory structures were accomplished with the help of physically based 3D simulation frame SIMORE, which has been developed in the GET Lab (Kutter et al., 2008). Its tools enable the realization of the robotic environment with different kinds of objects and surrounding structures. Additional software units realize the tasks of the higher visual cortex areas V4/IT, performing analysis of sensory information and recognition of free spaces, gaps and objects. Image processing and recognition issues are outside of the scope of this paper and have been elaborated in frame of other projects of our team. The Robot Operation System (ROS) (ROS, 2010) was used as a base for the implementation of memory units and their communication. The ROS offers a framework for robot software development and allows, if necessary, the distribution of software units on a heterogeneous computer cluster. The realized system could be envisioned as the graph with independent processing nodes (memory or service units), which can concurrently send and receive messages using the operating system-like functionality of the ROS.

The first tests of our system take place in the rescue robot domain. The robot operates thereby in a simplified world containing two kinds of important semantic elements: the objects (temporarily only different colored balls and boxes) and gaps (openings in the walls and between the obstacles). The locomotion of the robot through the area is accompanied by its sensing of information about the objects and gaps that could be seen from varying positions. This data is selectively stored in different special memory structures, supplying the foundation for generalization of the saved knowledge and learning processes. Perception of the surrounding world in our autonomous agent is derived from those of the complex biological systems. The representation of space by humans or primates is often assumed to be a kind of a cognitive map. The primary base of this map is the data which was saved in hippocampus (episodic memory) during the exploration of the relevant area. This data emerges partly from the retinal information, which is processed in two different pathways. The object describing data enters the hippocampus through the perirhirnal cortex. The space data comes from the parahippocampal cortex. Subsequently, these two information streams converge on specialized neural formation and build due to comprehensive synchronization of the network of object-place associations (Sato, Yamaguchi, 2010). This hierarchical asymmetric structure enables simultaneous activation of the multiple associations connected with the requested cues. We utilize these kind of multiple spatial relations for abstraction and formation of an internal spatial model.

Our reinforcement learning approach used to search for specified object in a maze uses high-level symbolic description of the task space, which is strongly associated with the landmark-oriented situation representation in working memory. Our results show significant acceleration of learning in comparison to the conventional method. The event data sequences that were gathered in episodic memory during the object search are used for generalization of the knowledge about the explored area. The learned dynamic Bayesian Network summarizes the spatial relations with possible motor actions and could be used for calculation of robot paths if the new start and goal locations are given and implied in the model.

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Fit for School: Effects of an Evening 4-Week Parental Intervention Program on School Performance in Relation to Sleep in School Children

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Theoretical Background

Sleep Disorders in children are presently not uncommon. With a high prevalence of 20%, they are widespread and carry a high burden (Fricke- Oerkermann et al. 2007). An essential condition of the individual learning efficiency or the lastingness of learned material is an individual's daytime well-being, which closely correlates with restorative sleep. In addition, 36% of 15-year-olds in Germany report being tired in at least four school mornings / weeks. Own studies suggest that the amount of the prevalence of sleep disorders occurring several times a week in children and adolescents is about 15–20 % (Fricke et al. 2006; Kinkelbur 2004).

Disturbed sleep impairs complex cognitive functions and skills as well as performance, attention and emotional competence (Plihal, Born 1997).

A main prerequisite of efficient learning is daytime well-being, which is closely related to the rejuvenation of sleep. Many studies have clearly demonstrated that sleep deprivation and sleep disorders are prevalent in school children and that sleep loss results in decreased learning and memory functions in young adults. However, sleep restriction is ethically disputable for studying the impact of sleep on learning function in children. Furthermore, no studies on the effect of positive interventions exist (Millman et al. 2005; Sadeh et al. 2003; Schabus et al, 2005).

We therefore investigated whether learning content and stress-coping would be enhanced by improving sleep behaviour of children by means of a parental education program and whether potential changes would also be reflected in neuroendocrinological parameters.

The aim of the project “Fit for School” was to examine in a pilot study with 30 children in 2 groups, whether:

- a learning competence improvement can be achieved by a positive intervention and
- changes will also be reflected in neuroendocrinological parameters.

The results of this interdisciplinary explorative pilot study should give a very wide overview of neuro-scientific parameters that may reflect an improved learning efficiency and learning competence and offer a base for later field studies.

Methods

Twentyone out of 30 4th grade children (9–11 years) were randomly placed into either an intervention or a control group (15 per group). Children with sleep disorders or extremely high or low levels of academic success were excluded. Within the intervention group, the children should get 15 minutes of parental interaction each evening for four weeks, including reading out loud and conversation about the previous school day and positive daytime events. The parents were trained weekly. No evening interaction and parental education was done in the control group.

Before and after the four weeks urinary cortisol was sampled over at least three consecutive nights, and sleeping times and daytime activity were measured by actigraphy in all participants. Furthermore, mathematics, text comprehension, and stress coping were investigated by standardised tests (DEMAT, ELFE, SVF-KJ).

Results

Although validated for age and sex, pre-tests indicated that sleep parameters correlated to DEMAT in boys, but to negative stress coping in girls. Text comprehension was increased in both groups, while mathematics insignificantly decreased in the intervention group, possible due to excellent values in the pre-tests. Stress coping and overall cortisol excretion did not change in either group. Since post-tests started one week before the summer holiday, sleep initiation was delayed in both groups, and sleep efficiency and duration decreased.

Within the intervention group, the increase of text comprehension depended on the frequency of evening parent-child interaction and a smaller increase of cortisol excretion. Furthermore, the higher the frequency of parent-child interaction was, the lower the decrease in math scores was. The frequency of reading out loud correlated positively to a later morning rising time and a greater increase in positive stress-coping due to parental education. The recall of school lessons and talking about positive daytime events prevents the delay in sleep latency. The statistical analysis was arranged with Excel® and SPSS®.

Conclusions including Potential Links and Cooperation

Our results are too inconsistent to draw reliable conclusions. However, they demonstrated that school performance and stress coping could potentially be altered by parental sleep education and regular evening interactions. In future research, the schedule of the ongoing school year and sex differences concerning the impact of sleep on test performance, stress coping, and cortisol excretion must be taken into consideration.

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Using a Cognitive Architecture to Specify and Test Process Models of Decision Making

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Theoretical Background

Imagine you are asked which city is larger, York or Stockport. About York you recently read an article in the newspaper. You remember that it had some mentionable industry, but no international airport and also no premier league soccer team. Of the city of Stockport you have never heard before. Which city will you answer to be the larger one? According to the recognition heuristic (Goldstein, Gigerenzer, 2002), if you recognize one of the alternatives, but not the other, you should infer that the recognized one to is larger. Your answer would be York. As an alternative to the recognition heuristic, you may rely on a strategy that uses your knowledge about the city's attributes as cues. Following corresponding compensatory models of decision-making, (e.g. unit-weight linear strategy), you might conclude that the absence of an airport and a premier league soccer team speak against York being a large city. Consequently, you might infer Stockport to be larger.

The example illustrates a debate that has received much attention in the decision-making literature. Are decisions better described by non-compensatory simple heuristics, or by complex compensatory decision strategies? A large amount of evidence has been gathered in support of as well as against both positions – for support of the recognition heuristic (e.g. Gigerenzer et al., 2008; Pachur, 2010; Volz et al., 2006), and for challenges of the heuristic: (e.g. Beaman et al., 2010; Dougherty et al., 2008; Oppenheimer, 2003). However, non-compensatory and compensatory processes are broad categories that subsume a number of different strategies. For instance, compensatory strategies propose that knowledge about the alternatives is used in some way; however, they do not agree on how this is done. Constraint satisfaction models, for example, assume that all available information is integrated at once, in a parallel, automatic fashion (Glöckner, Betsch, 2008). Evidence accumulation models, on the other hand, assume that evidence for the alternatives is accumulated sequentially until a decision boundary is reached (e.g. Lee, Cummins, 2004).

In assessing different proposed strategies against each other, research has encountered various problems. First, theories are often specified at varying levels of detail, making it difficult to directly compare them. Second, they are often formulated at a verbally qualitative level and are therefore underspecified relative to the empirical data against which they are tested. Consider the city size example again. Based on the different theories, one might generate predictions about decision times, i.e., the time participants need to decide which of the two cities is larger. However, participants' decision times will not only depend on the decision strategy itself, but also on other factors, like the time it takes to read the names of the cities, to retrieve information from memory, and to enter a response. Consequently, the contribution of the decision strategies themselves might be drowned out by these additional factors.

In the project we report here, we try to tackle both of these issues. First, we implement different strategies that have been proposed for decisions from memory into one cognitive modeling framework. This results in directly comparable quantitative predictions of the strategies. Second, by using a cognitive architecture for this implementation, we take into account the contribution of and interaction with additional components of cognition, like reading, memory retrieval and giving a motor response. This allows us to assess the contribution of different decision strategies in a more detailed way and to directly compare them against empirical data.

Methods: Empirical Data

To test different decision strategies against each other, we reanalyzed data from Pachur et al. (2008), which has been argued to provide evidence for both the recognition heuristic and compensatory strategies (Gigerenzer et al., 2010). Pachur et al. presented their participants with choices between cities, as in the introductory example: a recognized city with three associated cues and an unrecognized city about which nothing was known. The cues were industry, airport and soccer and they could be either positive (speaking for a city being large) or negative (speaking against a city being large). The cities varied in the pattern of associated cues, with three, two, or one of the cues being negative as shown in Table 1. The participants' task was to decide which of the two cities was larger. Decisions and decision times were assessed.

Tab.1 Cues Patterns associated to the recognized cities in Pachur et al. (2008) (+ = positive cue value; - = negative cue value).

	City					
Cue	Aberdeen	Bristol	Nottingham	Sheffield	Brighton	York
Industry	+	+	+	+	+	+
Airport	+	+	–	–	–	–
Soccer	+	+	+	+	–	–

Cognitive Model

The models were implemented in the cognitive architecture ACT-R (Anderson et al., 2004), which takes into account both sub-symbolic and symbolic components of cognition as well as perceptional and motor processes.

Assessing Recognition

There is evidence that, when asked to make a decision between alternatives, people will first assess the recognition of the alternatives (Pachur, Hertwig, 2006). In modeling recognition, we follow Anderson et al. (1998) and Schooler et al. (2005) in assuming that an alternative is recognized if it can be retrieved from memory. The probability and the time required for the retrieval depends on the frequency of encounters with the alternative in the past and its usefulness in the current context. The more often it was encountered and the more useful it is in the current context, the higher the chance that it will be retrieved and the faster the retrieval (see Anderson et al., 2004 for the computational details).

Assessing Cue Knowledge

We assume that the same kind of retrieval processes that enable reasoners to retrieve the alternatives themselves from memory will be used to retrieve knowledge associated to these alternatives. To reflect the fact that positive cue knowledge about alternatives seemed to be remembered more easily by the participants than negative cue knowledge, we assume that positive cues are retrieved faster than negative ones.

Decision Strategies

All models share the assumption that, when presented with alternatives on the screen, these alternatives will be read and their recognition will be assessed. The models differ in the steps that followed this initial assessment of recognition.

1. Non-Compensatory Strategies

The first group of models implements different versions of the non-compensatory recognition heuristic. They *always* decide for the recognized city. However, they differ in the amount of knowledge they retrieve from memory before this decision is made, and therefore, produce different decision time predictions.

Model 1. Implementing the simplest version of the recognition heuristic, Model-1 directly uses the outcome of the recognition assessment and responds with the recognized city.

Model 2. Implementing a more complex version of the recognition heuristic, Model-2 retrieves knowledge about the three cues of the recognized city from memory. After all cues are retrieved, the model responds with the recognized city, without using the retrieved cue knowledge.

Model-1&2. This model presents a combination of Model-1 and Model-2, in assuming a race between their strategies. After recognition is assessed, the strategies to directly decide that the recognized city is larger and to retrieve a cue race against each other. This race is repeated until the decision is made.

Model-1&2-F. This model is identical to Model-1&2, but it additionally assumes that retrieved cues will at times be forgotten. Forgetting is implemented by an additional race between retrieve-a-cue, respond-with-recognized and forgetting that starts as soon as at least two cues have been retrieved from memory.

2. Compensatory strategies

The second group of models implements versions of compensatory strategies. Depending on the cue knowledge associated to a city, they can decide for and against the recognized city. They differ in how the cue knowledge is used in this decision and they produce different decision time predictions.

Model-3. This model implements a strategy that assumes that cue knowledge is used implicitly by memory activation processes. It retrieves knowledge about the three cues of the recognized city from memory. After all cues are retrieved, the model tries to form an impression about the recognized city's size. It does this by attempting to retrieve information that indicates whether the city is large. The probability that this information can be retrieved depends on memory activation spreading from positive cues. The more positive cues a city has, the more activation is spread and the higher the chance that the city is assessed as large. If the model cannot assess the city as large, it will enter the unrecognized city.

Model-1&3. In assuming a race between the strategies of Model-1 and 3, this model implements a combination of the non-compensatory recognition heuristic and a compensatory decision strategy. After recognition is assessed, the strategies to directly decide that the recognized city is larger and to retrieve a cue race against each other. This race is repeated until the decision is made or all cues are retrieved. If all cues are retrieved and no decision has been made yet, the model can additionally try to form an impression about whether the city is large by using memory activation as implemented in Model-3.

Model-1&3-F. This model is identical to Model-1&3, but it additionally assumes that retrieved cues will at times be forgotten as in Model-1&2-F.

Model-4. This model uses cue knowledge explicitly by testing cues against a decision criterion. It retrieves knowledge about the cues for the recognized city after assessing recognition. If enough positive or negative cues are retrieved to meet its decision criterion, it responds with the recognized city (in case of positive cues) or the unrecognized city (in case of negative cues). To reflect different possible decision criteria, the model is implemented in different versions. Model-4.1, responds as soon as one positive or negative cue is retrieved. Model-4.2, needs two positive or negative cues for a decision, and Model-4.3 needs all 3 cues to be positive or negative to reach its criterion. If the model cannot retrieve enough cues to reach its criterion, it uses recognition as its best guess.

Results

Pachur et al. (2008) found that part of their participants always answered in accordance with the recognition heuristic, whereas other participants seemed to sometimes use their cue knowledge to decide against the recognized city.

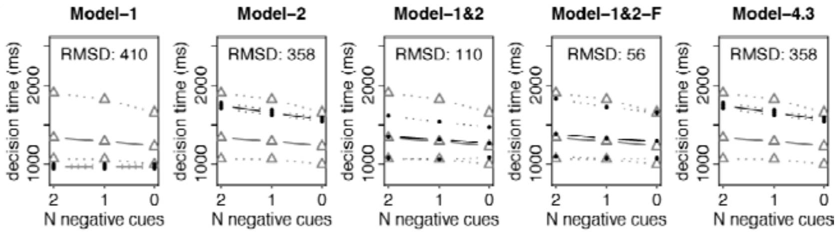

Fig. 1 Decision times (median and quartiles) for participants (grey) and models (black) that always chose the recognized city. RMSDs were calculated separately for the median and the quartiles and then averaged

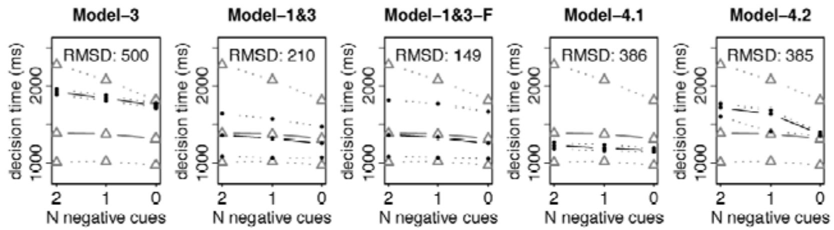

Fig. 2 Decision times (median and quartiles) for participants (grey) and models (black) that chose the unrecognized city in part of the trials. RSMDs were calculated separately for the median and the quartiles and then averaged

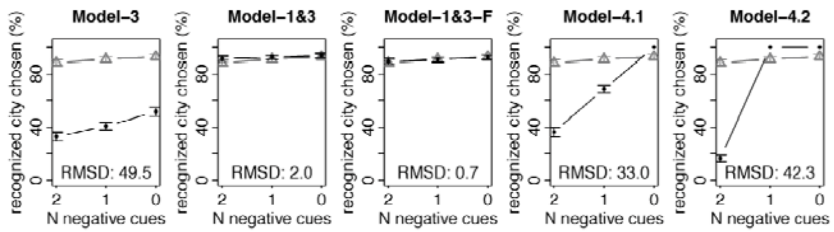

Fig. 3 Proportion of choices for the recognized city for participants (grey) and models (black) that chose the unrecognized city in part of the trials

To investigate the effect of cue knowledge, we analyzed decisions (% of choices for recognized city) and decision time distributions (medians and quartiles) separately for the different amounts of positive and negative cue-knowledge.

Recognition Group

As one would expect, the three non-compensatory models always decided for the recognized city, modeling the decisions of the recognition group. Also Model-4.3 showed this decision behavior, because it could never reach its decision criterion of three negative cues that would have been necessary to decide against the recognized city. The models largely varied in their decision time patterns (Figure 1). The empirical decision time patterns of the recognition group were best fit by Model-1&2-F, where decision times had a large spread and increased in a linear fashion with the amount of negative cues associated to a city.

Cue Group

The compensatory models (except for Model-4.3) decide for the recognized city in part of the cases, with the exact proportion depending on the amount of positive and negative cues and differing between the models (Figure 2). The decisions of the cue-group are fit best by Model-1&3-F, where the proportion of choices for the recognized city is overall high, but decreases in a linear fashion with the number of negative cues. This model also fits the decision time pattern of the cue group best (Figure 3).

Conclusions

A number of strategies have been proposed for how people make memory-based decisions between alternatives. In the current project, we explore how such strategies can be evaluated against each other by using the precision of a cognitive architecture. By implementing a number of decision models that have originally been defined at different levels of description into one architectural modeling framework, we make these models directly comparable to each other. By modeling not only the decision processes, but also the interplay of these processes with perceptual, memory, intentional, and motor processes, we produce quantitative predictions that can be directly compared to the empirical data. Our results suggest that models, which implement a race between competing decision strategies, best predict people's decisions and decision time distributions. This demonstrates how simplifying dichotomies that are so often used in psychological research can dissolve when using quantitative models that specify the interplay of underlying cognitive processes.

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Second-Order Theory of Mind in Strategic Games

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Theoretical Background

Whenever the outcomes of our actions depend on the decision of others, and vice versa, we need to reason about one another. For example, if a researcher wants her paper to be accepted, she not only needs to have interesting empirical results, she also needs to get her story across. She needs to reason about what an intended reader knows beforehand and about what he will infer from reading her story. She may even wonder whether a particular reviewer knows that she knows that he was the one who wrote that glowing review. The ability to reason about the knowledge, beliefs, desires and intentions of others, in this case the reader, is often referred to as Theory of Mind (Onishi, Baillargeon, 2005; Wimmer, Perner, 1983; Premack, Woodruff, 1978).

So far, empirical findings have shown theory of mind to be far from optimal, especially in more complex social interactions (Flobbe, Verbrugge, Hendriks, Krämer, 2008; Keysar, Lin, Barr, 2003; Hedden, Zhang, 2002; McKelvey, Palfrey, 1992; but see Goodie, Doshi, Young, 2010). The conclusion often drawn from these findings is that theory of mind is difficult and cognitively demanding (e.g. Verbrugge, Mol, 2008). In contrast, we claim that performance depends on the task. For example, participants seemed to have little difficulties applying theory of mind in false-belief story tasks (Flobbe, et al., 2008).

Hedden and Zhang (2002) presented participants with matrix games to investigate higher-order theory of mind such as „I think that you think that I think...“. Matrix games require theory of mind because the outcomes of one player depend on the decisions of the other. Hedden and Zhang found that participants correctly used higher-order theory of mind in approximately 65% of the trials.

Figure 6depicts five example matrix games. Each cell of a matrix game contains a pair of rewards, so-called payoffs, that both range from 1 to 4. The first payoff in a cell is Player I’s, the second Player II’s. For both players, the goal is that the game stops in a cell that contains the player’s highest possible payoff. This is common knowledge between both players. Participants were assigned to the role of Player I, the computer played the role of Player II.

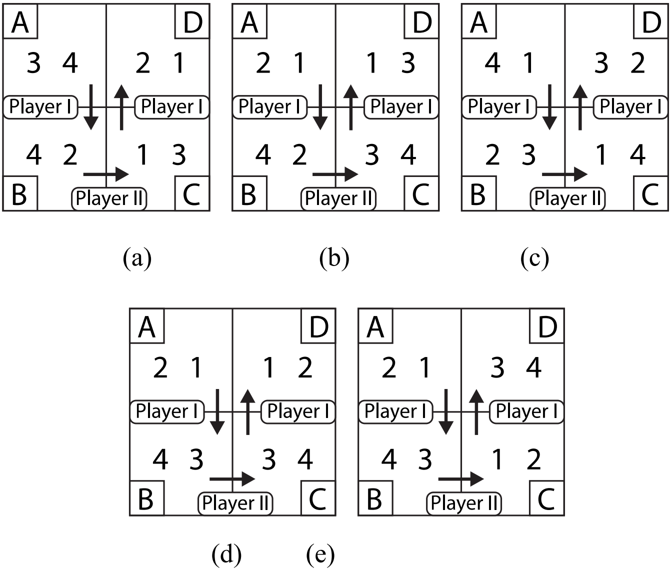


Fig. 1 Five example matrix games. Each cell in a game contains two payoffs. The first payoff is Player I’s, the second Player II’s. Each game starts in cell A. For both players, the goal is that the game ends in a cell that contains their highest possible payoff. In example game *a*, a rational Player I should decide to continue the game to cell B, as a rational player II should decide to stop in cell B, because Player I should decide to continue from cell C to cell D. Example games *b* to *e* were excluded because they did not require second-order reasoning, or a correct second-order prediction or decision was equal to a first-order prediction or decision.

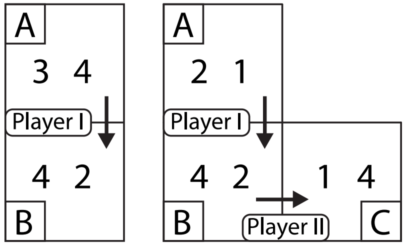
Each game started in cell A. Participants (Player I) were asked to decide whether to stop the game in that cell or to continue it to cell B. If a participant decided to continue the game, the computer (Player II) decided whether to stop the game in cell B or to continue to cell C. If the computer decided to continue, the participant was asked to decide whether to stop the game in cell C or in cell D. When a game was stopped in a particular cell, both players received their payoffs in that cell. The game required higher-order reasoning because participants had to reason about the computer's decision in cell B, and thus reason about what the computer thinks that a participant's decision should be in cell C.

In Hedden and Zhang's study, participants had difficulties playing matrix games, which was reflected in suboptimal performance. A possible explanation for suboptimal performance is task difficulty, which can be overcome by providing participants more/better support. Applying higher-order theory of mind involves interplay between multiple serial and concurrent cognitive processes, and task properties such as instruction, training, procedure of asking for social reasoning, and game representation (i.e., game interface) can each contribute to structuring this interplay.We examined the effect of supporting structure in these task properties, and hypothesized that by closely mapping supporting structure with the reasoning steps required by matrix games, social reasoning would improve.

Method

Hedden and Zhang did explain the rules of the matrix games and provided training, however we think that their training could be improved by explaining step-by-step how social reasoning comes into play. We incrementally explained the depths, or orders, of social reasoning in matrix games. Figure 7 depicts example games in which the order of reasoning increases with each additional decision. Zeroth-order or non-social reasoning suffices for the game in Figure 7a, because Player I does not need to reason about Player II. The game in Figure 7brequires first-order reasoning as Player I has to reason about Player II's decision. Stepwise instruction and training not only explains how social reasoning comes into play in matrix games, it also explains the rules of matrix games. We assigned half of the participants to training with supporting structure (i.e., stepwise instruction and training), the other half to training that did not provide supporting structure.

Whereas Hedden and Zhang (2002) did not provide supporting structure in their training, they did provide it in their procedure of asking for social reasoning. They asked participants for two responses: (1) predict the opponent's move in cell B, and (2) decide what to do in cell A. We explicitly tested whether this procedure had a positive effect on social reasoning. We asked half of the participants to predict the opponent's move before making a decision, whereas we did not explicitly ask the other half to make predictions.



(a) (b)

Fig. 2 A zeroth-order (a) and first-order (b) matrix game. These example games unambiguously require zeroth- and first-order reasoning

Besides supporting structure in instruction, training, and procedure of asking for social reasoning, we examined the effect of supporting structure in game representation. Besides matrix games, we presented so-called Marble Drop games that provided supporting structure (Figure 8). In Marble Drop games, a white marble is about to drop, and its path can be manipulated by removing trapdoors. Experience with world-physics helps players to see how their decisions affect the course of the game. Moreover, the interface of the game is very insightful because the trapdoors (i.e., the decision points) are color-coded for whoever controls them.

It is important to note that Marble Drop games are game-theoretically equivalent to matrix games: both have the same extensive form (Osborne, Rubinstein, 1994). The sets of trapdoors in Marble Drop games correspond with the transitions, from one cell to another, in matrix games. The payoffs in Marble Drop games are color-graded marbles that can be ranked according to grade (1–4), equivalently to the ranking of numeric payoffs in matrix games.

Figure 8 depicts an example of a second-order Marble Drop game. The goal is to let the white marble end up in the bin with the darkest color-graded marble of the player's assigned color. Note that for illustrative purposes the color-graded marbles are replaced with labels: a1–a4 represent the participants' color-graded marbles and b1–b4 represent the computer's color-graded marbles (of another color); 1–4 being light to dark grades. The diagonal lines represent the trapdoors. In the example game in Figure 8, a participant (Player I) should decide to remove the right trapdoor (dashed black line), because the computer (Player II) will decide to remove the left trapdoor (dashed grey line) as the participant should remove the left trapdoor of the last set of trapdoors.

Half of the participants were presented with matrix games, the other half with Marble Drop games.

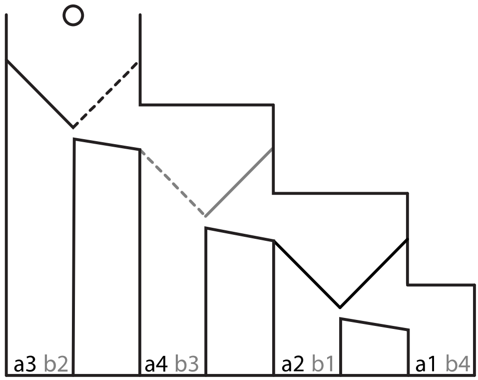


Fig. 3 Illustration of a second-order Marble Drop game. Marble Drop games are game-theoretically equivalent to matrix games. Each bin contains a pair of payoffs. Player I's payoffs start with *a*, Player II's start with *b*. The game has three decision points, which are trapdoors. The first set of trapdoors is controlled by Player I, the second set of trapdoors is controlled by Player II, and the third by Player I. The dashed lines represent the trapdoors that a rational Player I and Player II should remove. In actual Marble Drop games, the payoffs are color-shaded marbles, with preference ordered from light to dark shades.

Results

Ninety-five first-year Psychology students participated in exchange for course credit. Each participant gave informed consent prior to admission into the study.

The data were analyzed with linear mixed-effects models (LMEs) to account for random effects of participants and payoff combinations (Baayen, Davidson, Bates, 2008). We fit logistic LMEs on the individual decisions.

We found that supporting structure had a positive effect on social reasoning in each of the task properties. Participants that were assigned to training without supporting structure did not perform as well as participants assigned to stepwise training (i.e., with supporting structure): $\beta = -1.23$, $z = -3.34$, $p < .001$. Furthermore, participants that were asked to predict the opponent's move were better at making a decision than participants that were not explicitly asked to make predictions: $\beta = 1.28$, $z = 3.32$, $p < .001$. There was also a positive effect of supporting structure in game representation, but this effect was less profound as the other effects: $\beta = -.66$, $z = -2.25$, $p < .05$.

In sum, supporting structure in instruction, training, procedure of asking for social reasoning, and game representation significantly improved social reasoning.

Conclusions

Previous studies argued that applying higher-order theory of mind is difficult and cognitively demanding. In contrast, we claimed and demonstrated that social reasoning in strategic games is not that difficult as long as supporting structure is provided in instruction, training, procedure of asking for social reasoning, and game representation. Participants learned to play matrix and Marble Drop games, and played them proficiently.

In follow-up studies we are investigating what cognitive mechanisms are involved in social reasoning. We are constructing cognitive models to describe, explain, and predict behavior in complex social interactions (Van Maanen, Verbrugge, 2010). For those models, it is very important to know what strategies participants used, as these determine for a large part what cognitive mechanisms are employed and to what extent (Gosh, Meijering., Verbrugge, 2010). A strategy could, for example, heavily rely on working memory or be more algorithmic and depend on processing speed. These cognitive models might prove very useful to acquire a more detailed understanding of the brain regions involved in social reasoning (Borst, Taatgen, Stocco, Van Rijn, 2010).

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Neural Correlates of Fraction Processing in Secondary School Students – A Project Plan

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Introduction

Recent discussions on the promises and potential pitfalls of applying brain imaging in the context of mathematics education have pointed out that generating research questions from mathematics education can help to increase the ecological validity of imaging studies. The present study therefore addresses an open question of mathematics education where brain imaging might add to behavioral findings. Based on the experience of our previous research on natural number processing in primary and secondary school students (Dresler et al., 2009; Obersteiner et al., 2010), we present the framework of a study on the neural correlates of fraction processing in secondary school students[1]. To better explain why this issue can make important contributions to research in both the educational and the neuroscientific field, three aspects will be addressed in the following section: First, secondary school students' performance on fraction processing; second, their neural correlates in fraction processing; and third, effects of specific training on behavior and brain activation patterns.

Theoretical Background

The meaningful and flexible use of numbers is an essential component of mathematical competence (NCTM, 2000). This does not only refer to natural

1 Note that according to German curricula fractions are not taught systematically before the secondary school level (age 10).

numbers, but also to other types of numbers such as fractions. In mathematics education, there has been intense research on behavioral aspects of fraction processing, showing that it is often difficult for students to understand the magnitude of the symbolic representation of fractions. Even if students may be able to perform calculations on the symbolic level, this does not mean that they have understood the meaning of their calculation. As described in the triple-code-model by Dehaene (1992), symbolic number representations need to be linked to an internal magnitude representation in order for their meaning to be understood. Accordingly, the development of students' magnitude representation of fractions is an important aim of mathematics classroom instruction. There is, however, a lack of empirical studies on the effects of classroom instruction on students' mental representations of fractions.

Behavioral studies with adult participants have addressed the question whether they process fractions as a whole or componentially, i.e., processing numerator and denominator separately (e.g. Bonato et al., 2007; Meert et al., 2009; Gabriel et al., 2010; Schneider, Siegler, 2010). The results are divergent, suggesting that fractions can be processed in both ways, depending on the specific numerical values and tasks. As behavioral research can only assess students' performance, it is not possible to decide whether the understanding of fraction magnitudes is related to a different way of mental processing, which in turn should be related to differences on the neural level.

A large number of brain imaging studies have revealed the neural correlates of natural number processing, with the intra-parietal sulcus (IPS) as the key region for representing number magnitudes. In accordance with the triple-code-model, these brain regions can be differentiated from those activated in symbolic (occipito-temporal visual cortex) and verbal (left-hemispheric language areas) representations of number. Only few brain imaging studies have addressed the mental representation of fractions (Schmithorst, Brown, 2004; Jacob, Nieder, 2009; Ischebeck et al., 2009). Using functional magnetic resonance imaging, Schmithorst and Brown (2004) showed that fraction processing in adult participants activates the same brain areas that have been identified as the neural correlates of the triple-code-model for natural number processing. In particular, the IPS appears to be involved in the processing of fraction magnitudes. In addition, Jacob and Nieder (2009) found that the activation is independent of the presentation format, such as number symbols (e.g. 1/6) or number words (e.g. one-sixth). The finding that fraction magnitude is represented within the parietal brain is supported by the study of Ischebeck et al. (2009). Using fraction comparison tasks, they found a distance effect with respect to the activation of parietal brain areas. Interestingly, this effect was only found for the numerical distance between the to-be-compared fractions but not for the partial distances between the numerators or the denominators, indicating a holistic representation of fraction magnitudes rather than a separate representation of numerator and denominator within the parietal brain.

Taken together, these studies support the idea that parietal brain areas play the key role in the mental representation of fraction magnitudes in adults. To date, there are no studies on the mental representation of fractions in children and adolescents or on the effects of specific training. However, studies on natural number processing in children hint to a shift from frontal to parietal brain activation during development as well as after training (see Zamarian et al., 2009, for a review). Therefore we can hypothesize that specific training on representing fraction magnitudes also leads to an increase in parietal brain activation.

Aims and Methods

It is the aim of our present study to explore a) secondary school students' strategies (holistic vs. componential) in fraction processing, b) the neural correlates of fraction processing and c) training effects on brain activation. As outlined above, we hypothesize that after training, students will process fractions holistically to a larger extent and that this is accompanied by an increase in parietal brain activation.

A sample of 40 sixth-grade (secondary school) students will be tested twice on tasks involving magnitude representations of fractions, such as fraction comparison, approximate calculation, or number line tasks (see below). In between, half of the students will take part in an intervention program aiming at the development of magnitude representations of fractions. During the intervention, external representations such as a number line are used to train students' ability to represent the numerical value of a given fraction. The contents for the intervention program can be drawn from studies that suggest positive effects on students' understanding of fractions, using rectangular representations and number lines (e.g. Schwank, 2009).

With regard to brain imaging methods, we aim to maintain a balance between neuroscientific and educational needs. As discussed by Obersteiner et al. (2010), it is important that the brain imaging technique is not too restrictive for the students in order to measure number processing in an ecologically valid way. On the other hand, most brain imaging methods require a highly artificial environment and are highly sensitive to head motions. Near-infrared spectroscopy is easily applicable and has proven to detect parietal brain activation for natural number processing (Dresler et al., 2009). However, electroencephalography has an even better temporal resolution and may provide more reliable results. Functional magnetic resonance imaging has the advantage of measuring the whole brain and subcortical structures. Considering these aspects, the methodological question is a matter of discussion.

Preliminary Work

In a behavioral pilot study, 54 students of grade 6were administered a speed test (paper-pencil) on fraction processing involving a number line task and an approximate calculation task. Both tasks can be considered to rely on magnitude representations. In the number line task, students had to indicate the position of a given fraction on an empty number line, with '0' at one end and '1' at the other end (cf. Siegler, Opfer, 2003). In the approximate calculation task an addition or subtraction involving two fractions was given, and students had to choose between four alternative results. While all of these results were incorrect, one was very close to the correct result. The other results were chosen according to well-known misconceptions in fraction computation.

Results show that students performed well on the number line task (average score: 92%), indicating that virtually all students can give an adequate representation of fraction magnitudes at least for simple fractions. However, in the approximate calculation task the average score was only 59%, indicating that students have more difficulties in using appropriate representations in tasks where they are not explicitly forced to use magnitude representations. Moreover, in the approximate calculation task, 63% of the students used the inappropriate strategy of componential addition or subtraction (adding or subtracting the numerators and denominators separately) at least once. Even if these tasks tap students' use of representations on the behavioral level, they cannot directly reveal the underlying cognitive processes.

Conclusions

Our findings show that students can use magnitude representations of fractions under some conditions (number line task). Difficulties occur in tasks where no specific cues are given (approximate calculation task). Specific training could help students to activate magnitude representations more flexibly. Such behavioral changes should be accompanied by changes on the neural level.

This study is relevant to mathematics education, as it contributes to the question whether instruction can lead to qualitative changes of mental processing. It is also relevant to neuroscience, as it can extend our knowledge about the learning brain in the context of mathematics, going somewhat beyond basic numerical processing to the more complex domain of fraction processing.

At the workshop, we will discuss the theoretical framework of the present study. In particular, we will discuss methodological considerations against the background of our previous research on natural number processing.

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The Role of Immediate Informative and Non-Informative Feedback on Overall Performance and Subsequent Learning

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Theoretical Background

The current talk focuses on selected results of the first funding phase of a larger interdisciplinary project that aimed to achieve a particular close cooperation between the Cognitive Neurosciences and the Educational Sciences. Both fields of research focused on a conjoint topic which was to elucidate the role of immediate informative and non-informative feedback on performance in the following trial (i.e. subsequent learning) and overall performance. At the same time, each of the participating disciplines had an agenda that enabled to pursue their own research goals by investigating different aspects of the main research question, amongst others, while informing each other whenever possible.

In educational research on effective learning, an important debate is related to the question of whether errors should be corrected immediately or not. Although it is quite plausible that we need feedback about our mistakes in the learning process, it is also conceivable that emotional consequences of feedback might interfere with future learning. People may feel bad, frustrated or emotionally disturbed when confronted with their own mistakes. They may wish to hide them since they attribute their mistakes to a lack of ability (e.g. Dweck, 1999; Dweck and Legget, 1988) and are afraid to be classified as stupid or not intelligent. For such people, mistakes are indicators of stable personal traits and they are afraid that there might be no way to improve their results in certain tasks because of their low ability. Hence, in these cases error feedback might not be helpful for the process of learning, since those people are emotionally disturbed to such an extent after feedback that subsequent learning is negatively affected. In light of those findings, it is obvious that more knowledge on how individual differences e.g. in different personality traits, modulate feedback effects would be advantageous to step forward to a more personalized teaching and learning. Accordingly, the two groups from the Educational Sciences participating in our project (Research on Learning on Instruction & Chemistry Education) were particularly interested in investigating how individual differences (like memory capacity, attention, frustration tolerance, self concept) modulate the effects of feedback, using experimental tasks related to two different subject areas: languages and sciences (chemistry). An additional goal was to explore alternative ways to elementary instruction in chemistry by investigating feedback-based learning of chemical formulas in 5^{th} and 6^{th} grade children, who had not experienced instruction to the language of chemical formulae before (Table 1).

As feedback is a key variable for cognitive control and learning, it is also a topic of particular interest to the cognitive neurosciences. There is now much research showing a set of brain areas, especially in the lateral and medial prefrontal cortices, the striatum and posterior parietal cortex to be involved in negative and positive feedback processing. Although studies with children are still rare, some recent investigations revealed that the ability to flexibly adjust performance based on feedback signals is premature in children and undergoes a long developmental trajectory until young adulthood (Bunge, Crone, 2009, van den Bos et al., 2009). Children receiving performance related negative feedback recruited brain areas known to be essential for performance adjustments differently compared to young adults, suggesting that they were less able to utilize negative feedback signals for performance in subsequent trials. In these studies, participants were required to infer sorting rules based on positive and negative feedback (van Duijvenvoorde et al., 2008) or to switch between multiple rules (Crone, van der Molen, 2004). Thus feedback information bore essential information with respect to performance in the following trials. To investigate whether changes in task relevant brain areas also rely on maturational changes when feedback information is much less relevant for performance in the following trials, we used a task where negative or positive feedback merely provided outcome information that could be used to evaluate performance and/or possibly focus more closely on task demands. Accordingly, in contrast to the approach of the Educational Sciences Group, this experiment was also conducted with an adult group. Based on results of a larger sample of subjects obtained in the behavioral study of the Educational Sciences Group, we further aimed to investigate the impact of selected individual differences on the neural correlates of feedback processing (Table 1).

Tab.1 Research goals of the groups participating in the interdisciplinary project

Research group	**Main research goals**
Educational Sciences Groups: Research on Learning and Instruction & Chemistry Education	Investigating how individual factors modulate performance when informative and uninformative feedback is given Investigating alternative ways of teaching the language of chemical formulae in the context of elementary instruction in chemistry
Cognitive Neurosciences	Neural correlates of cognitive processes involved in feedback processing in children and young adults. Role of individual differences on neural correlates of feedback processing.

Methods

The paradigms used were associative learning paradigms. In the educational study, two tasks were used: one that resembled vocabulary learning and one that required chemical formulae learning (Figure 1). In the imaging study only the former task was used.

For the Educational Sciences study, a large sample of 250 children (10–13 yrs.) was tested in a classroom setting at school. They were randomly assigned to one of the two experimental tasks as depicted in Figure 1 and, for each task, to one of two feedback groups (either receiving corrective feedback after retrieval or receiving no feedback but a neutral stimulus). In the vocabulary learning task, each object-name association was only shown once, whereas in the chemistry learning task some of the formulae were repeated during the experiment, such that a basic conceptual understanding and transfer of knowledge should have occurred during learning. During the task, reaction times and % correct responses were taken as measures for short term retention of the material. Long term retention was tested in a final recall test administered after the end of the respective task. To investigate the role of immediate feedback in relation to individual differences a number of standardized psychological tests were administered to collect data related to imaging (fMRI, 1.5-T Siemens Sonata), children (N=34, 10–13 yrs) and

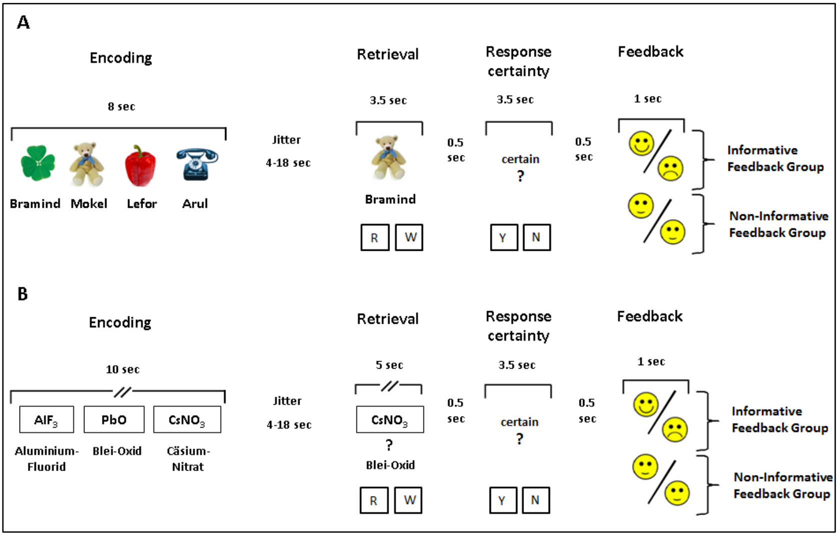

Fig. 1 Time course of stimulus presentation in a single trial of the associative learning tasks as used in the Educational Sciences Group. A. In the vocabulary learning task, each trial involved an initial encoding phase lasting for eight seconds and consisting of four successively presented object-name pairs. During the presentation of each object, a pseudoword was presented auditorily as the corresponding object name. Participants were instructed to memorize the objects and their appropriate names. Delayed recognition was tested in a retrieval phase that involved the presentation of one of the objects with one of the pseudowords. Participants had to indicate whether the pseudoword matched the object presented and responded on one of two buttons of a response pad. Afterwards they had to indicate by the use of same buttons if they were sure or unsure regarding their response. Feedback was provided immediately. In the informative feedback group, feedback indicated success or failure, depending on performance (indicated by a positive or negative smiley). In the non-informative feedback group a neutral smiley appeared after each trial giving no indication about success or failure. The next trial followed with another jitter of 4–18 seconds. The task consisted of 40 trials. B. In the chemical formulae learning task, chemical formulae and their names were used instead of objects and their names and only three instead of four associations were shown in the encoding phase. This task consisted of 30 trials. In all other respects the two tasks did not differ.

adults (N=34, 18–30 yrs) were scanned in the associative learning paradigm requiring object-name associations (Figure 1 A). Unlike the task used in the Educational Sciences Group, they were not required to indicate response certainty. To ensure a comparable difficulty level, the task for adult participants contained five instead of four object-name associations in the encoding phase. Participants in each age group were randomly assigned either to the informative or the non-informative feedback group. Reaction times and errors were recorded during task performance in the MRI scanner. To investigate the role of immediate feedback in relation to individual differences in children, we used the same psychometric tests as in the study of the Educational Sciences Group. For adults, we collected data related to sensitivity to punishment and non-reward (BIS/BAS; Carver, White, 1994) and additionally on attitudes to errors and on respective coping styles (EOQ; Rybowiak, 1999). For group analyses, we performed regions of interest (ROI) analyses with five ROIs obtained from the factorial design. In the medial frontal cortex, the ROIs were located in the pre-supplementary motor area (pre-SMA), the anterior cingulate cortex (ACC), and the medial orbitofrontal cortex (medOFC). In the lateral prefrontal cortex, ROIs were located bilateral in the inferior frontal cortex (IFC). We focused on positive interaction effects (age by feedback group and age by performance [correct/incorrect]), including the results of the non-informative feedback group. In other words, we performed a ROI-based search for brain areas that show maturational changes by statistically testing signal differences between correct vs. incorrect trials and informative vs. non-informative feedback for differences between age groups. In order to perform more informed and constraint regression analyses when testing for individual differences, we only used results of those personality tests that proved to show a significant impact on performance in the educational study.

Results

In the large study of the Educational Sciences Group, no significant differences were obtained when comparing the two feedback groups (informative/ non-informative feedback), indicating that neither short nor long term measures of retention were affected by feedback. Thus the immediate feedback used in the present study did not substantially improve task performance, but it also did not interfere with long term retention (Moschner et al., 1998). Noteworthy, a tendency for an improved long-term retention was observed for the chemical formulae in the informative, compared to the non-informative feedback group ($p < .10$). While investigating the way in which individual differences modulate the effects of feedback, we found that age, intelligence, goal orientation, attention and memory capacity were significant predictors of test performance, but we observed different relations depending on paradigm and feedback group. For the task requiring learning of chemical formulae, no significant correlation was obtained between age and performance, suggesting that chemistry may be introduced in even earlier years at school. Further, ego-orientation (Goal Orientation Questionnaire [Köller, Baumert, 1998]), the strong tendency to define success in relation to the performance of others, was a negative predictor for test performance in the informative feedback condition of this task ($p < .01$). In other words, those students with higher scores on ego-orientation performed worse when working on the experimental task.

Comparing informative and non-informative feedback groups in the fMRI study, we obtained the expected activation clusters in medial and lateral prefrontal areas, known to be associated with negative and positive informative feedback, respectively. Interestingly, activation evoked by informative and non-informative feedback proved to be similar for children and adults. In contrast, developmental changes in feedback-related areas were obvious for activation differences between correct and incorrect responses. We found a positive interaction effect for age by performance in two clusters, located in the pre-SMA and the medOFC. In the pre-SMA, activation increases obtained for positive and negative feedback were similar in children but differed in adults, the latter showing a significantly higher BOLD response to negative compared to positive feedback. The pre-SMA is known to play an essential role in conflict detection and cognitive control. The results obtained suggest that efficient performance in adults compared to children is based on a stronger recruitment of neural sources devoted to performance monitoring and possibly signalizing needs for performance adjustments. The interaction effect (age by performance) observed for the medOFC was mainly due to the finding that error trials evoked a pronounced deactivation (indicating aversive processing) in adults but not in children for both the informative and the non-informative feedback condition. We therefore assume that error awareness without external feedback or at least a presentiment of possibly having failed was largely confined to the adult group.

Investigating the impact of individual differences on neural correlates of feedback processing in children, we found that higher ego orientation, was correlated with lower activation of the ROI in the pre-SMA (Beta= -.52, p=.035) when faced with negative feedback. Additionally, results of a non-standardized questionnaire that served to assess participants' perception of positive and negative feedback events (administered after task performance in the MRI), revealed that stronger annoyance of children when faced with error feedback, was associated with slower mean reaction times on error compared to successful trials (Beta=.-59, p=.012). For the negative feedback condition, higher annoyance with errors was also correlated with higher activation of the right IFC (Beta=.57, p=.016). For children who were more annoyed in view of failures we also observed a tendency to be more task oriented (Beta=.41, $p<.1$). This may suggest that those children who were more ambitious responded more cautiously with response uncertainty and showed a higher recruitment of a brain area known to be involved in error processing after having failed. Individual differences related to brain activation were also observed in the adult group. Here, the higher the sensitivity to punishment (BIS scale) and the higher the scores obtained on error strain (EOQ), the lower the activation in the ROI of the left inferior frontal cortex when negative feedback was received (Beta=.-59, p=.012 and Beta=.-55, p=.022). Thus both in children and adults, individual differences in error coping were shown to have an impact on a brain area associated with error processing after unfavorable outcomes.

Conclusion

The results of both the large behavioural study and the fMRI study revealed significant influences of individual differences in children on behaviour and brain activation in learning tasks. Findings of both project groups underscore the important role of ego-orientation in relation to error feedback. In children participating in the Educational Study, ego-orientation was the best predictor of efficient performance in the informative feedback group when the learning material is structured and meaningful, with high scores related to low test performance. In the fMRI-study, we found that such individual differences may have a clear impact on brain activation when faced with unfavourable performance outcomes. Analysing individual differences in the adult group that participated in the fMRI study, we found that participants, stating that they were more strained by errors, less activated a brain region associated with error processing after failures. Our results indicate that this trait, which implies high emotional reaction to failures and fear of error occurrence, interferes with learning. It is well known that certain personality traits and attribution styles are disadvantageous with respect to error coping and negative feedback processing. More knowledge on individual differences would enable a more informed adoption of remediation programs, e.g. by using feedback to alter coping styles that interfere with efficient learning.

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Literacy Breaks the Symmetry of Alphabetic Visual Object

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All primates, including humans, recognise images in a left-right invariant-way. This mirror-invariance is useful to recognise objects both from left or right perspectives, but this very competency has to be 'unlearned' for reading acquisition in order to correctly identify letters (e.g. to distinguish a 'b' from a 'd').

In a first study, we presented pairs of visual stimuli (faces, houses, tools, strings and falsefonts), whose left-right orientation was manipulated, to adult literates and illiterates. The task was to judge if the pairs were 'same' or 'different', regardless of orientation (identity task). The subjects were explicitly instructed to assign 'same' for mirror-inverted pairs. The results showed an important behavioural cost to respond 'same' in mirror-trials, proportional to the literacy level, but only for strings and falsefonts. A strong bias to respond 'different' in mirrored-strings was also observed in good readers but not in illiterates.

In a second study (Neuroimage, in press), we used an fMRI priming paradigm to probe the neural discrimination of mirror-inverted pairs of stimuli in skilled readers. We demonstrate that the left occipito-temporal cortex, namely the Visual Word Form Area (VWFA) distinguishes the left-right orientation of single letters, and yet exhibits mirror invariance for simple matched pictures.

These results clarify how letter shapes, after reading acquisition, escape the process of mirror invariance which is a basic property of the ventral visual shape recognition pathway.

Deductive Spatial Reasoning: Connecting Neural Findings and Cognitive Modeling

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Theoretical Background

Recent findings indicate that inferences about spatial arrangements are drawn by the construction and manipulation of mental models (Knauff et al., 1995; 1998; Fangmeier et al., 2006). One central assumption of the mental model theory (Johnson-Laird, Byrne, 1991) is that the human reasoning process can be divided into three phases: (1) Model construction, where a first integrated representation of the given verbal or visual information is developed, (2) model inspection, where the previously developed model is inspected to derive a putative conclusion, and (3) model validation, where a counter-example (a model contradicting the putative conclusion) is searched.

If several mental models are consistent with one spatial description – a so-called multiple model case – the reasoner is supposed to initially construct a preferred mental model (PMM) only. Compared to all other possible models, the PMM is easier to construct and easier to maintain in working memory (Knauff et al., 1995). The principle of economicity is the determining factor in explaining human preferences (Manktelow, 1999). This principle also explains that a model is constructed incrementally from its premises. Such a model construction process saves working memory capacities because each bit of information is immediately processed and integrated into the model (Johnson-Laird, Byrne, 1991). In the model variation phase, the PMM is varied to find alternative interpretations of the premises (Johnson-Laird, 2001).

Empirical and formal investigations have lead to the development of a computational and cognitive model – the so-called SRM-Model (Spatial Reasoning by Models) – that explains various results reported in the literature on spatial relational reasoning by the number of operations (Ragni et al., 2005; Ragni, Knauff, 2008; Ragni, 2008). This model provides a cognitive complexity measure accounting for the processing phases and demands involved in spatial relational reasoning.

Empirical behavioral findings substantially support the PMM theory and inspired a recent fMRI study (Fangmeier et al., 2006; 2009). The corresponding fMRI data, however, must be interpreted and related to conventional behavioral data such as error rates and response times-data that is not necessarily available at the desired level of detail due to the demands the fMRI method imposes on the data acquisition process. Here, cognitive models recently offer a bridging function by replicating existing behavioral and neural findings from different sources. That way a cognitive model implementing a processing theory can be used as a verification tool as it independently makes extensive testable predictions even for brain activations. In that context, the cognitive architecture ACT-R (Anderson, Lebiere, 1998; Anderson et al., 2005) provides an environment that maps its modularly organized components to certain brain regions.

Each ACT-R module has its own scope of processing responsibility and associated interface, called buffer, with which it can communicate with other modules. At any one time a buffer can keep exactly one information unit – a so-called chunk. Hence, processing chunks in a buffer is a strictly serial process, whereas modules can be active in parallel and that way multiple chunks may be processed at the same time as long as each chunk resides in a different buffer.

While chunks represent elements of declarative knowledge, procedural knowledge is represented by an underlying production system that controls module activity. Any time a production involves a certain module, an additional prediction of localized brain activity is made. For instance, the visual module processes visual information from the external world and is associated to activities in the *fusiform gyrus*. The goal module controls the current stage in the problem solving process and is related to activities in the *anterior cingulate cortex* (ACC). The *lateral inferior prefrontal cortex* (LIPFC) is associated with the declarative module that processes information retrieved from declarative memory and finally, the *posterior parietal cortex* (PPC) is associated with the imaginal module that maintains and updates the current problem representation.

There is not, however, a one-to-one identification between the ACT-R modules and the Brodman Areas (BA) in the human brain. Only about ten areas have been associated with modules. This identification of brain regions was originally derived from participants trained on a specific strategy in the context of Algebra tasks and Tower of Hanoi problems (Anderson, 2007) and is called the *ACT-R-to-brain* mapping hypothesis (Möbus et al., 2010). The partial mapping between modules and brain regions are mostly identified with regions playing an important role for functions involved in higher cognition. But, whether or not the current identification of modules for and the application to deductive spatial reasoning holds as well has not yet been investigated.

Methods/Project Plan

The behavioral and functional MRT studies have already been conducted. An additional effort was necessary to re-analyze the brain scans by an analysis of the raw timecourse data of related scans for the ACT-R specific regions (cp. Anderson, 2007).

To compare the predictions of the previously developed SRM-model with the empirical findings – the SRM-model has been carefully implemented in the cognitive architecture ACT-R. The activation of the peak voxel in the specific region as well as the complete cluster has been correlated with the predictions of the SRM-model.

Future methods will cover a computational re-analysis for identifying those regions to which extending the ACT-R-to-brain mapping would be desirable. New model predictions are tested in on-going and future fMRI experiments.

Results

In general, we can support the *ACT-R-to-brain* mapping hypothesis to some extent. The implemented SRM model using the (restricted) Bold-function in ACT-R 6.0 can partially predict and explains behavioral findings and brain activations. An in-depth analysis shows that there are differences, depending on the time resolution and the buffers of the ACT-R to brain mapping. The declarative module predictions related to activations in the LIPFC and the imaginal module predictions related to activations in the PPC are significant ($r=.51$ and $r= .61$, resp.), in contrast to the visual module ($r=.12$, n.s.). These comparisons shows the potential of ACT-R regarding task analysis and cognitive effort and the limits regarding perception.

Conclusions including Potential Links and Cooperation

Cognitive Modeling provides a substantial contribution to the structure of the field and to identify task specific of problems. Still, the ACT-R-to-brain mapping is preliminary. The starting points are promising as with respect to specific modules good predictions are possible, even though participants were not trained on a certain strategy. We are interested in extending the behavioral and fMRI predictions to other fields of higher cognition; currently, we are implementing ACT-R models for Tower of London and mental arithmetics. We are interested in additional behavioral and fMRI data sets for the domain of reasoning and problem solving to compare those with the predictions of the respective models and to work out responsible aspects for a unified theory of cognition.

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Connecting Neuroscience and Experientialism to Analyse Students' Understanding of Complex (Biological) Phenomena

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Theoretical Background

Growth through cell division, the inheritance of genes, or the global carbon cycle – our research showed that students' conceptions of these topics differ from the scientific explanations (e.g. Riemeier, Gropengiesser 2008). But why do students understand complex phenomena in the way they do and how can such concepts be taught successfully? These two questions could be answered by analyzing students' conceptions based on the framework of experientialism (e.g. Lakoff, Johnson, 1999, Gropengiesser 2003). Following this framework we hold to be true that thought is embodied, that is, our basic conceptions grow from our bodily experience. Our basic categories and concepts arise out of perception, body movement, and experience with our physical and social environment. Thought is imaginative as well. For concepts that cannot be directly experienced, we need to think in an imaginative way to explain them. We employ, for instance, metaphors and analogies. Thus, the framework used distinguishes between embodied conceptions and imaginative conceptions. The latter are not directly grounded in experience, but they draw on the structure of our experience. We employ conceptions from a source domain and map it onto an abstract target domain to understand abstract phenomena. Thus the use of metaphors and analogies can be seen as a source-target mapping. The structure of a source domain is projected onto the target domain. For example, the average person generally does not have any direct medical understanding of viruses. So when explaining influenza, people often use the concept of a fight to describe the relationship between a virus and the human body. If the body "wins" and the virus "loses", you become well. Therefore, the concept of a fight serves as a source domain that is well understood. This concept structures our common understanding of how a cold virus acts in the body.

The talk will offer insights into experientialism and will address the question of whether or not neuroscience can help achieve a better understanding of how students comprehend complex phenomena. Lakoff and Johnson (1999) claim that experientialism is to some extent neurally motivated. They argue that semantics uses perceptual processing, particularly topographic perceptual maps, to build meaning. By connecting experientialism and neuroscience we hope to find support for our findings that thinking of an imaginative conception is located in the same cortical areas like thinking of the source domain.

Methods/Project Plan

By utilizing experientialism, we are able to identify the source domains of students' understanding and to develop activities that foster students' learning of scientific concepts (e.g. Riemeier, Gropengiesser, 2008). We use teaching experiments to study students' conceptual development with these learning activities. This empirical method offers a good chance of combining teaching situations (interventional aspect) with interview situations (investigational aspect). Therefore the analysis of our teaching experiments offers information about students' pre-instructional conceptions and their development during the teaching process. The role of the researcher is, to be an interviewer and to identify students' concept formation on the one hand, and to be a teacher and to organise learning activities according to students' progress on the other hand. All data are video-recorded and investigated by qualitative analysis (e.g. Mayring, 2003). By means of this method, the video material is condensed, interpreted and analyzed in a systemic way through five steps: (a) Word by word transcription, (b) Editing (this means to transform students' utterances into grammatically correct statements), (c) Condensation (this means to combine almost identical statements), (d) Explication (this means to interpret students' statements, to explain underlying conceptions and to find experiences on which these conceptions are based) and e) Structuring (this means to formulate students' concepts). All transcripts were analyzed independently by at least two researchers to ensure reliability and validity. Based on this method, learners' "pathways of thinking" were inferred and linked to the learning activities. By these means, students' conceptions before, during, and after working with a learning activity were combined for each group, allowing us to study the effect of the learning environment on students' conceptions.

In order to connect neuroscience and experientialism, it is likely necessary to combine this approach with neuroscientific methods that are able to measure neural activity in the brain or spinal cord of humans (i.e. fMRI).

Expected Results

To shed more light on our research, results of our teaching experiments to investigate students' conceptions of cell division are documented. In these teaching experiments, which lasted about 75–90 minutes, we examined teaching and learning processes in five small groups, each consisting of three students (aged 15 years). At the beginning, students were asked to describe how onion roots extending into a water-filled jar were grown. After discussing the conditions of growth (like the need for water) for some time, the students explained the growth of onions roots through multiplication of cells. Shortly thereafter, the process of multiplying cells was named cell division, where the students imagined the cell would divide into two halves. In contrast, the scientific view of cell division combines the concepts of growth and dividing in a special way: After division the two small cells have to grow before a new division starts. Students' conceptions indicated no idea of cells growing in connection with division – they only think about the multiplication of cells through division. Viewed from experiential realism, it makes sense for the students to think of growth through division. Based on our everyday experiences, we conceptualize different meanings of division according to the various outcomes of the process of splitting. Thus, a conceptual scheme of "Division" would be: (a) there can be *more* individual pieces, (b) pieces can be *smaller* than the whole object, (c) a collection of pieces can be shared among people. In each case, the individual pieces amount to *less* than the collection as a whole. In the teaching experiment the students only think about the meaning of becoming more without recognizing the meaning of becoming smaller. They were not aware of the decrease in size of individual cells through division. Our data show how these conceptions hinder and foster understanding of cell division in the sense of scientific cell theory. In order to understand cell division, students have to reflect upon the different meanings of »division« so that they can focus on division and growth in combination. To demonstrate this, we used chocolate to enable students to experience different aspects of division. In subsequent teaching sessions, we asked students to compare their findings with scientific concepts of cell division. This practical experiment helped students to develop appropriate concepts of cell division.

Our data demonstrated that students' understanding of growth through cell division is based on a basic schema of division. This schema is grounded in everyday experience and is thereby embodied. In an attempt to understand cell division (i.e., a field of little or no previous experience), imagination comes into play. The structure of the division schema that serves as a source domain is projected onto cell division that serves as a target domain. The vague occurrence of cell division in the microcosm is understood in terms of an embodied division schema developed from everyday experience. By re-experiencing and reflecting on the conceptual schema of division, students are able to develop conceptions that are more scientifically accurate.

Connecting neuroscientific methods with experientialism could bring deeper insights relating to the questions why students understand phenomena the way they do. Rohrer compared fMRI results "from a hand stroking/grasping task to those from a semantic comprehension task involving literal and metaphoric hand sentences, as well as to a set of non-hand control sentences" (Rohrer 2005, 19). He showed that our semantic understanding via literal metaphors is located in the same cortical areas that are known to map the corresponding physical activity. But what does this result mean for students' understanding of science? For instance, there is the question of whether students' fMRI results show that thinking of an imaginative concept is located in the same cortical areas as thinking of the source domain. Results to this and other questions could generate further hypotheses about students' understanding of complex phenomena.

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Working Memory Training

Transfer Effects on Executive Control Processes

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Theoretical Background

Working memory (WM) is a cognitive process which enables us to store and manipulate information for short periods of time (Baddeley, Hitch, 1974). Extending the capacities of WM by practice has been the interest of research for decades, but many of these attempts were restricted in the way that they improved the participants' performance only in the task at hand and with particular stimuli (Butterfield, 1973; Ericsson et al., 1980). As there was no transfer observed to other tasks with new stimuli, these experiments did not succeed in improving WM processes as such. However, modern training paradigms that include extensive, adaptive WM training have not only managed to show training effects which generalize to new tasks with new stimuli (Klingberg et al., 2005), but a recent study has also shown that performance in measures of fluid intelligence can be improved by such WM training (Jaeggi et al., 2008).

As exciting as these results are, it is still unclear as to which alternative cognitive functions WM training effects transfer. Potentially, these effects may transfer to executive control processes that are recruited in complex task situations. Such a transfer is plausible because converging evidence from different research areas suggests that executive control and WM processes rely on related mechanisms. For example, Braver et al. (1997) assume that task representations are maintained in WM during ongoing interference task processing; as executive control is usually operating on these task representations (e.g. Dreisbach, Haider, 2009), the availability of a sufficient amount of WM resources must be considered as an important precondition for an efficient operation of executive control. The present study aimed to investigate the relation between executive control processes and WM functions, and set out to investigate the transfer effects from adaptive WM training to executive control processes in another WM task as well as in task-switching and dual-task situations.

Methods

Altogether, 33 participants took part in the experiment for monetary compensation. They were divided into two groups: a training group (15 participants: four male, mean age 24 years) and a control group (18 participants: four male, mean age 24 years). Both groups attended pre- and post-testing on the three transfer tasks as well as on the training task. Between pre- and post-tests was a 14-session period (approximately three weeks), during which the training group trained on the training task whereas the control group underwent no training.

The training task was a dual *n*-back task described by Jaeggi and colleagues (Buschkuehl et al., 2007; Jaeggi et al., 2008). This task consisted of simultaneously presented sequences of visuospatial and auditory stimuli (Figure 1). The task was to attend to both sequences and to decide for both individually, whether the current stimulus matched an item that was presented *n* steps back. Participants received feedback during the training sessions and the level of difficulty (i.e. the level of *n*) was adjusted in every trial for each participant according to their individual performance. The dependent variable (DV) was the mean level of *n*-back achieved by the participants.

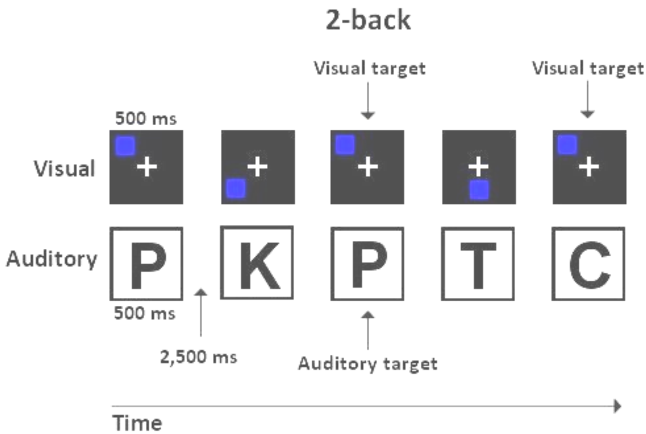

Fig. 1 Example of a 2-back run in the dual *n*-back task that was used as the training task. The visual and auditory stimuli are presented simultaneously at identical rates

The WM transfer task required constant updating of WM contents and it comprised three different types of blocks. All blocks involved lists of different lengths consisting of sequentially presented stimuli. The first block contained an auditory task, in which participants were presented with spoken digits through headphones and they were asked after each list to report the four last digits of that list in the correct order. In the second block, the participants completed a visuospatial task, in which the four last locations of a black bar presented on a computer screen were to be reproduced in the correct order after each list. In the last block, the auditory and visuospatial material was presented simultaneously and participants were randomly required to report either the last four digits or the last four bar positions in the correct order after each list. The DVs were the amount of correctly reported 4-stimulus sequences in each block.

The second transfer test was task switching. In this test, stimulus pairs consisting of a letter and a digit were presented and participants classified the presented letter as a consonant or a vowel or classified the digit as odd or even (Rogers, Monsell, 1995). The stimulus pairs were presented in single-task blocks, in which participants exclusively classified letters or digits. In mixed blocks, participants were instructed to switch between the two tasks after every second trial. Thus, these blocks included trials with task switches and trials with task repeats in subsequent trials. The DVs in the task switching experiment were the RTs in each trial type.

In the third transfer task, the dual task, we administered an auditory-manual task (Task 1) and a visual-manual task (Task 2). In Task 1, we presented low, middle, or high pitched sine-wave tones and participants responded according to the pitches of the auditory stimuli. In Task 2, a small, middle, or large triangle was presented and participants responded according to the size of the visual stimuli. Task 1 and Task 2 were presented in single-task blocks and in dual-task blocks of the Psychological Refractory Period (PRP) type (Pashler, 1994). In single-task blocks, only one task was presented, while in dual-task blocks, both tasks were presented within one trial and the interval between the onset of the auditory stimuli in Task 1 and the visual stimuli in Task 2 varied (stimulus onset asynchrony, SOA, of 50, 100, and 400 ms). In dual-task blocks, participants were asked to put priority on Task 1. In this task, the DVs were the reaction times (RTs) for the first stimulus [reaction 1 (R1)] and for the second stimulus [reaction 2 (R2)], for each SOA separately.

Results

Due to technical problems, the pre-test data of two participants in the control group was lost in the *n*-back task and therefore the analyses for this task included only 16 control participants. A session (pre-test vs. post-test) × group (training vs. control) mixed-measures analysis of variance (ANOVA) on the achieved mean *n*-back level revealed significant main effects of session [$F(1, 29)=69.08$, $p<.001$] and group [$F(1, 29)=33.97$, $p<.001$] and also a significant session × group interaction [$F(1, 29)=63.14$, $p<.001$], indicating that training affected the performance differently compared to no training (Figure 2). Separate analyses for the training and control groups demonstrated a significant difference between pre- and post-test *n*-back levels for the training group but not for the control group ($p<.001$ and $p=.46$, respectively).

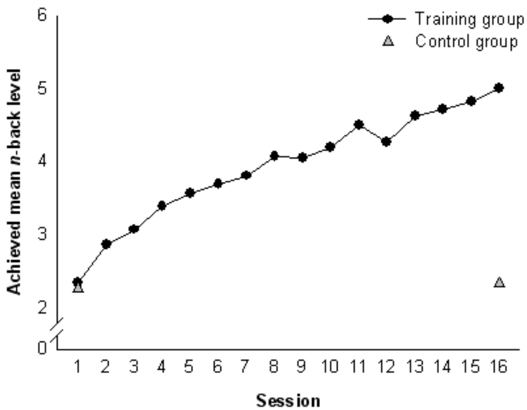

Fig. 2 Improvement in the performance of the training group (session 1 – 16) and the performance of the control group in the pre- and post-tests (sessions 1 and 16, respectively) in the dual n-back task. For each session the achieved mean *n*-back level is presented

In the transfer WM updating task, a session × modality (auditory vs. visual vs. dual modality) × group ANOVA on the amount of correctly reported stimulus sequences revealed main effects of session [$F(1, 31)=13.18$, $p<.01$] and modality [$F(2, 62)=52.45$, $p<.001$]. Additionally, the session × modality × group interaction was significant [$F(2, 62)=3.55$, $p<.05$]. Further analyses revealed a significant difference between the post-test performance of the training group and the control group in the visual updating task ($p<.05$) as well as a trend towards differences between groups in the post-test of the auditory updating task (p=.065). The pre-test performances between the two groups did not differ in either of the tasks (both p´s >.2), therefore indicating a significant improvement of the training group in the visual task and a tendency towards improvement in the auditory task, whereas the improvement from pre- to post-test in the dual modality task was equal for both groups (Figure 3).

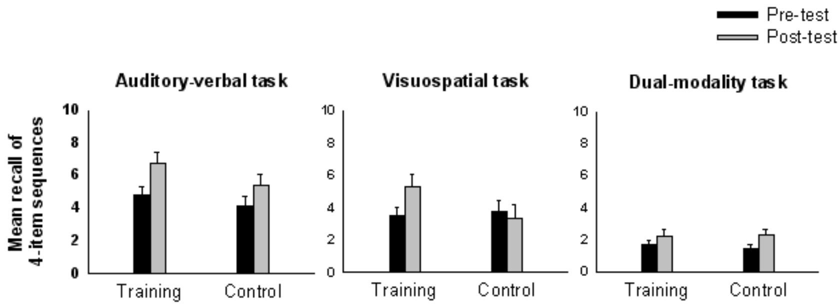

Fig. 3 The number of correctly reported four-item sequences in each task: auditory, visual, and dual-modality. Performance for both groups is illustrated separately for pre- and post-tests. Error bars indicate standard errors of the mean

Before the analysis of the task-switching data, for every subject the mean correct RTs for each condition (switch trials, repeat trials, and single-task trials) were calculated and every RT that was more than two standard deviations from the mean of the trial in question was considered as an outlier and excluded from the analysis. A session × condition × group ANOVA revealed significant main effects of session and condition [$F(1, 31)=35.82$, $p<.001$ and $F(2, 62)=225.92$, $p<.001$, respectively] and also a session × condition interaction [$F(2, 62)=10.75$, $p<.001$] wich indicated that the gain in the RTs from pre-test to post-test was largest for switch trials. The main effect of group was not significant (p=0.30) and neither were the other interactions (all p's >.07). However, a condition × group ANOVA for the post-test RTs revealed not only a main effect of condition [$F(2, 62)=184.85$, $p<.001$] but also a significant condition × group interaction [$F(2, 62)=3.59$, $p<.05$]. Further comparisons revealed a tendency towards differences between the two groups in the post-test RTs in switch trials (p=.06) while differences between the post-test RTs in repeat and single-task trials as well as differences between pre-test RTs in all trials types were not significant (all p's >.2). This indicates a tendency towards improvement of the control group in the switch trials whereas in the repeat and single-task trials there were no differences between the groups (Figure 4).

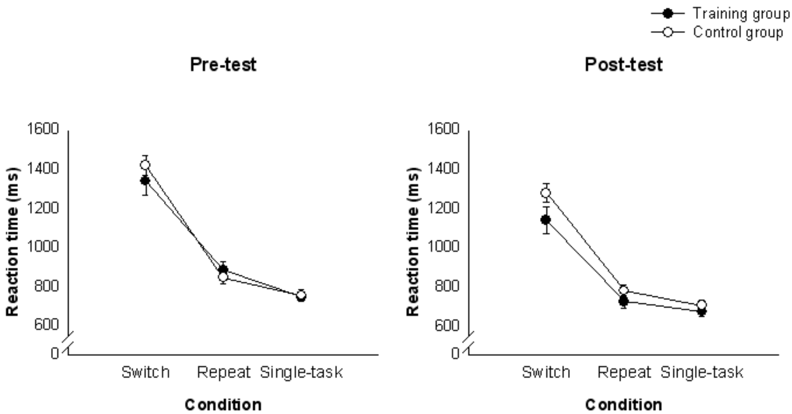

Fig. 4 Reaction times in task switching experiment for training group (black dots) and control group (white dots), in pre-test (left) and post-test (right), depicted separately for switch, repeat, and single-task trials. Error bars indicate standard errors of the mean

For the dual task, a session × SOA (50 ms vs. 100 ms vs. 400 ms) × group ANOVA revealed significant main effects of session for both R1 and R2 [$F(1, 31)=10.13$, $p<.01$, and $F(1, 31)=30.50$, $p<.001$, respectively], confirming a general improvement of both groups from pre-test to post-test (R1: pre-test M=955 ms, post-test M=893 ms; R2: pre-test M=1115 ms, post-test M=1009 ms). For R2 there was also a main effect of SOA revealed, $F(2, 62)=538.47$, $p<.001$, which shows that the RTs became shorter as the SOA increased (1196 ms, 1137 ms, and 852 ms for SOAs of 50 ms, 100 ms, and 400 ms, respectively). This manifested the typical PRP effect as longer R2 for shorter SOAs. There were no significant interactions found (all p's >.4).

Conclusions including Potential Links and Cooperation

This study set out to investigate the effects of extensive WM training to executive control processes. We focused on transfer effects from training on a dual *n*-back task, which requires simultaneous performance of an auditory and a visuospatial WM task, to a WM updating task as well as to task switching and dual-task situations. Compared to a non-trained control group it was shown that training on the dual *n*-back task led to improvements in the trained task as well as in the visuospatial part of the transfer WM updating task. Moreover, a tendency towards improvement was found in the auditory part of the WM updating task. The finding that WM training led to an improved WM performance in the training task support the results of previous studies showing the effects of extensive WM training on WM capacity (e.g. Dahlin, Nyberg, Bäckman, Stigsdotter Neely, 2008; Klingberg, et al., 2005). As this effect was transferred to another WM task that was not trained, the training effect was not purely stimulus- or task-specific. The tendency towards an improvement after training in task switching implies transfer of improvement in switching between two task streams, which is an integral component of the training task. For the dual-task, there was no transfer from WM training. Both the WM updating task as well as task-switching require constant updating of WM components: for WM updating task it concerns the updating of stimulus representations, while in task-switching it concerns the updating of task-set representations. Therefore, the results of the present study show that WM can be trained and that training can transfer to tasks that are not part of the training.

Due to the potential transfer effects of the dual *n*-back training on functions of fluid intelligence (Jaeggi et al., 2008) and executive control processes as shown in the present study, this training regime may be of great interest for a wide community; in particular, because the related functions are responsible for many changes in cognitive aging or for disease-related changes. WM training may therefore prove to provide a marked optimization of intelligence and executive control functions to individuals with a decline in them. This potential practical application of WM training offers links to other areas of research and cooperation with researchers in these areas.

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Learning to Read Shapes Neuronal Lexical Representations

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Theoretical Background

Written language processing and spoken language processing appear to be tightly linked (for an overview see Frost, Ziegler, 2007). There is not only evidence that phonological knowledge influences the acquisition of reading and writing, but also that acquired knowledge about spelling rules influences speech comprehension. For example, adults were quicker to decide whether two words rhymed when words were orthographically similar (e.g. rye-tie) compared to orthographically dissimilar words (e.g. pie-tie; Seidenberg, Tannenhaus, 1979). Using different tasks, facilitation has been observed for words with consistent spelling (one possible spelling, e.g. -ust in must and just) compared to words with inconsistent spellings (multiple spellings, e.g. -ough in through and tough; Ziegler et al., 2004; Ziegler, Ferrand, 1998). These findings in adult listeners imply that learning about orthography alters the way of processing spoken language.

It is an ongoing debate whether orthographic representations are co-activated with phonological input that in turn leads to the activation of lexical representations (Grainger, Ferrand, 1996) or whether separate phonological representations are restructured in the course of learning an alphabetic writing system (Castro-Caldas et al., 1998; Reis, Castro-Caldas, 1997). The former account assumes that influences of orthography on phonology (and vice versa) take place on-line on sub-lexical and/or lexical levels; whereas the latter account assumes that not the direct lexical route, but a separate phonological route undergoes changes due to learning reading and writing. Using Event-Related Potentials (ERPs), we tested whether lexical, phonological or both processes in neural spoken language comprehension differ in reading children compared to pre-reading children.

Methods/Project Plan

We compared behavioral and neurophysiological data in reading pupils (8 years) and pre-reading preschoolers (6 years) using an auditory word onset priming paradigm. To exclude an age-confound, we also included reading preschoolers (6 years). Children heard spoken primes and targets and were instructed to respond to targets (word and pseudowords) whenever they hear a real word. Targets matched the preceding prime (e.g. mon-monster; Identical condition), varied in the first speech sound (e.g. non-monster, Variation condition) or were unrelated to the prime (e.g. trep-monster, Control condition). We were mainly interested in the modulation of the P350 and the central negativity. The P350 is an event-related potential deflection that is discussed to reflect lexical access in word onset priming (Friedrich, 2005; Friedrich et al., 2004a,b, 2008, 2009; Schild et al., 2010); whereas the central negativity is assumed to reflect phonological processing in this task (see Friedrich et al, 2009).

Results

All children responded faster in the Identity condition than in the Control condition. However, in both groups of reading children, priming was less effective for prime-target word pairs that varied in the first speech sound; whereas for pre-reading preschoolers priming in the Variation condition was as effective as priming in the Identical condition (Figure 1). This was also mirrored in the P350 in the ERPs (Figure 2). P350 amplitudes differed between the Identical and Variation condition in both groups of reading children, but not in the pre-reading children.

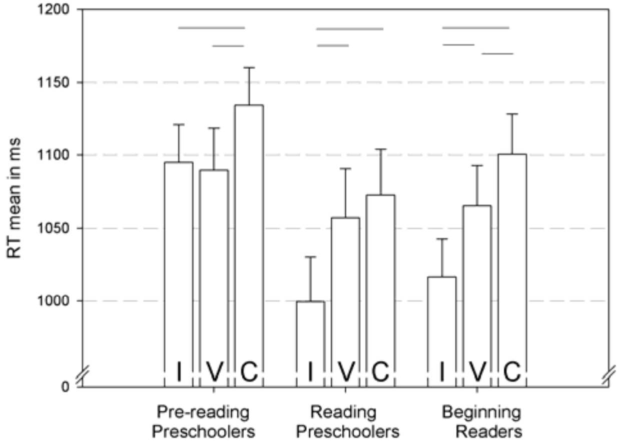

Fig. 1 Reaction times (bars indicate standard errors)

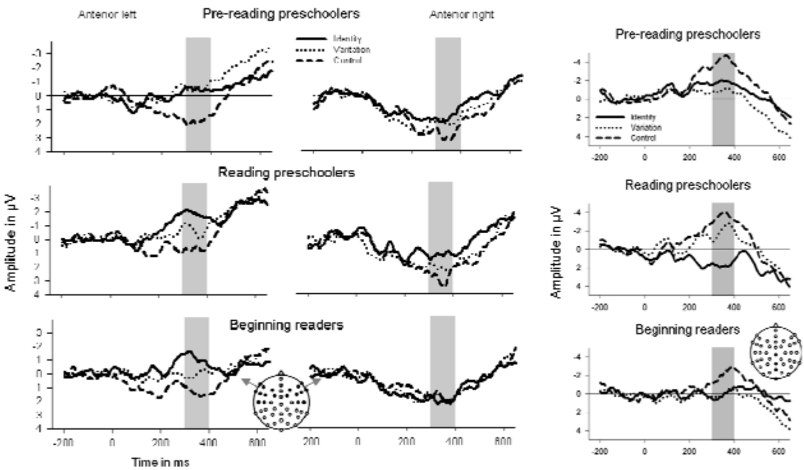

Fig. 2 Mean ERPs for all groups. Right panel: P350 effect over left and right anterior ROIs (means of plotted ERPs were calculated across electrodes that are indicated by black circles). Left panel: Central negativity effects of posterior central ROIs. Grey bars indicate the time window of the analysis of the P350 and central negativity

Together, these results reveal that reading children take more acoustic detail into account than pre-reading children do. This effect seems to take place at the level of lexical access.

Conclusions including Potential Links and Cooperation

Our findings might inform diagnosis of and intervention strategies in children with reading and writing difficulties. Most of the research on developmental dyslexia focuses on deficits in phonological processing (e.g. Goswami, 2002). The finding that a lexical word form level is substantially restructured by learning to read and write, raises the question whether this processing level is also crucially involved in successful reading acquisition.

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Physical-Exercise-Intermezzi for Improved Learning at School

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Theoretical Background

Associative learning underlies episodic and semantic learning and thus is relevant for diverse educational settings. Executive functions, e.g. shifting between multiple tasks, operations, or mental sets, are also linked to academic achievement (St Clair-Thompson, Gathercole, 2006). Given the relevance of associative learning and executive functioning for education, optimizing such processes may provide a means to meet present and future demands in the educational system. A growing body of research in sports- and neurosciences suggests that physical exercise can improve cognitive functioning in general, and executive functions (Colcombe, Kramer, 2003) and associative learning in particular (Winter et al., 2007). A neurobiological mediation is proposed with physical exercise inducing changes in cerebral blood flow, neurotransmitter concentrations, and neurotrophic factors, which in turn foster cognitive processes. In healthy adults, Winter et al. (2007) found faster learning and increased BDNF and catecholamine levels after short, intense physical exercise compared to moderate exercise and a period of rest.

Methods/Project Plan

Our interdisciplinary research group, which consists of neurologists, sports physicians, and psychologists, is investigating the effects of a short high-impact physical exercise intermezzo on associative learning and set-shifting in eighth- and ninth-grade students. In this project we investigate whether the findings of Winter et al. (2007) can be replicated under field conditions with an unselected sample of 300 male and female high school students (aged from 14 to 16 years) in different school forms. Up to now, our sample includes 99 participants (55 male, 54 female, mean age 15.72 ± 0.69 years).

The current investigation is organized as a field study, using a cross-over design measuring performance in: a) an implicit associative learning paradigm (Wernicko), a modified method from Breitenstein, Knecht (2002), and b) a set-shifting task after a short, intense physical exercise intervention on a bicycle ergometer versus a period of rest. The order of exercise and rest is counterbalanced across participants.

a) Wernicko is a word-learning task in which participants decide whether or not pairs of daily objects and artificial words presented on a computer screen are correct. Learning the correct pairs is based on different frequencies of occurrence of correct and incorrect pairs.

b) The set-shifting task involves two simple cognitive tasks. Half of the trials require increased executive control in shifting from one task to another (shift-trials), which typically increases reaction times. The difference between reaction times in shift trials and no-shift trials (shifting costs) reflects executive performance.

In contrast to previous studies, the present sample consists of healthy high-school students, and the complete experimental procedure is run in schools. To standardize the conditions across schools, a mobile laboratory in a motor-coach was used to visit the attending schools.

Preliminary Results

Intermediate analysis of 99 subjects was conducted using repeated measures analysis of variance. With respect to a) the associative learning performance, two groups of participants were examined: students who did not show any learning progress and those who showed a solid increase in learning performance. Learning or not learning may have been related to parameters like learning style, impulsivity, or intelligence; this will be further tested.

Regarding the group with learning progress ($n=32$) the data analysis revealed an interaction between intervention condition (exercise vs. rest) and order of intervention ($F\,[1,30] = 7{,}623$, $p = .010$): even though the participants practiced all tasks previously, their performance increased from the first to the second intervention. However, performance increased more after the exercise intervention than after rest. Gender, BMI and physical activity as potential covariates were not related to the results.

Performance in b) the switching paradigm consistently benefited from the exercise intervention. Physical exercise significantly reduced reaction times (RT) in shift trials (F [1,91] = 4,061, p = .047), while RT to no-shift trials (F [1,91] = 2,043, p = .156) and shifting costs (= shift RT – no shift RT, F [1,91] = 1,419, p = .237) did not differ between conditions. After correcting for outliers, the pattern of differences between conditions was corroborated: physical exercise significantly reduced RT in shift trials (F [1,74] = 5,784, p = .019) and shifting costs (F [1,74] = 6,981, p = .010) while exercise had no effects on RT in the no-shift trials (F [1,74] = 1,029, p = .314). No effects of covariates such as gender, BMI or physical activity were found.

Conclusions

Preliminary results showed that it is possible to replicate the laboratory-based results of Winter et al. (2007) in a field setting. There are preliminary indications that short high-impact physical exercise interventions are beneficial for learning and attention in 14–16 year-old high-school students, independent of gender, BMI, or weekly physical activity. However, the exercise effect vanished when the learning task was too difficult. The further analysis of blood parameters is targeted to reveal whether basic neurobiological mechanisms such as changes in BDNF-levels are mediators of these findings. Our research group aims to discuss and examine the results and its implications to the school context from an educational perspective.

Future interdisciplinary research in the field of cognitive neuroscience and education may help to design physical exercise interventions that are best suited for the implementation in the daily school program.

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Trial-by-Trial Adaptation of Decision Making Performance – A Model-Based EEG Analysis

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Theoretical Background

Whenever we engage in a task, it is crucial we monitor our performance to make sure that it does not decline. When it does decline, the performance monitoring system takes action to remedy that, e.g. by slowing down responding (Laming, 1979; Rabbitt, 1966). Botvinick, Braver, Barch, Carter, and Cohen (2001) proposed that this slowing of response times (RTs) reflected conflict that stirred a performance monitoring system to action. There exist various decision systems that adapt performance (Daw, Niv, Dayan, 2005), each of which have been associated with specific neural correlates. Some of the behavioral adjustment is thought to be implemented by the medial frontal cortex (MFC), thought to implement reinforcement learning mechanisms for behavioral adjustment (Cohen, Ranganath, 2007). This is contrasted to the striatum that is thought to implement rule-based behavioral adjustments.

Activity of the MFC in EEG (electroencephalography) is typically associated with two components: the error-related negativity (ERN) in the first 100 ms after a response, and the feedback-related negativity (FRN) about 200–400 ms post-response. Both components are more negative after errors when compared to correct trials, and opinions differ about what cognitive processes they reflect. The ERN covaries with individual differences in personality traits, e.g. with a participants' tendency to learn more from negative than from positive feedback (Frank, D'Lauro, Curran, 2007). The FRN covaries with valence of the feedback but not so much with its magnitude (Hajcak, Moser, Holroyd, Simons, 2006), although this has been disputed (Bellebaum, Daum, 2008). The ERN and FRN have both been related to reinforcement learning (RL) models of learning in decision making, and are thought to reflect prediction errors. Although good at describing across-trial dynamics, these RL models do not describe within-trial dynamics.

While Drift Diffusion Models (DDMs; Ratcliff, 1978) of decision making do not describe learning from successive decisions, they do describe within-trial dynamics. We have begun to relate electrophysiological data to DDMs (van Vugt et al, in preparation), and we wondered whether the ERN and/or FRN could have a role in setting the speed-accuracy trade-off (SAT) in a perceptual decision making task. Answering this question could elucidate how the ERN and FRN, which are fairly similar potentials, differ (e.g. Heldmann, Rüsseler, Münte, 2008), and how these across-trial dynamics relate to the within-trial dynamics described by the DDM.

Drift diffusion models describe decision processes as random walks toward thresholds corresponding to the response alternatives, e.g. “left” and “right”. As soon as a threshold is crossed, the participant emits the corresponding response. The drift rate of the random walk reflects the quality of the data on which the decision is based, whereas the decision threshold is under the participant’s control and reflects SATs. When a participant increases her decision threshold, she will accumulate more evidence before responding, i.e., act more conservatively. Her RT consists of the time it takes to reach the decision threshold, together with a non-decision time, reflecting fixed perceptual and motor delays.

We predict that behavioral adjustments after errors are reflected in an increased decision threshold. Furthermore, if the ERN/FRN not only reflects error awareness but also commitment to behavioral adjustment, then we predict that the magnitude of this component predicts the magnitude of the threshold adjustment. Finally, the magnitude of the ERN within a subject should predict RTs on the next trial.

Methods

Task: Participants performed a perceptual decision making task in which they judged the direction of motion of a display of randomly moving dots, a subset of which moved coherently to the left or the right. These random dot kinematograms were similar to those used in a series of psychophysical and decision making experiments involving monkeys (e.g. Britten, Shadlen, Newsome, Movshon, 1992; Gold, Shadlen, 2001; Shadlen, Newsome, 2001). Stimuli consisted of an aperture of approximately 7.6 cm diameter viewed from approximately 100 cm (approximately 4 degrees visual angle) in which white dots (2 x 2 pixels) moved on a black background. A subset of dots moved coherently either to the left or to the right on each trial, whereas the remainder of dots were distractors that jumped randomly from frame to frame. Motion coherence was defined as the percentage of coherently moving dots. Dot density was 17 dots/square degrees, selected so that individual dots could not easily be tracked. Following the procedure used in Simen, Contreras, Hu, Holmes and Cohen (2009), stimuli remained visible until participants made a response, at which point the stimulus disappeared and a variable response-to-stimulus interval ensued. Correct responses were rewarded with $0.01, errors were unrewarded. Reward feedback was displayed visually and signaled with a tone after each trial.

We manipulated response bias and response-to-stimulus interval (RSI; see Simen et al. (2009) for a review of the effects of these variables on behavioral performance in two-alternative forced-choice tasks with response-terminated stimuli, and a comparison to the predictions of Bogacz, Brown, Moehlis, Holmes and Cohen (2006)). Response bias was manipulated by changing the probability that the dots would move in one of the two directions from 0.5 (no bias) to 0.6, 0.75 and 0.9. For the purposes of this analysis, we collapsed across the two RSI levels. The experiment presentation code was written in PsychToolbox (Brainard, 1997). Dot stimuli were presented with PsychToolbox extensions written by J. I. Gold (http://code.google.com/p/dotsx/).

Participants: Twenty-one members of the Princeton Community (15 female, mean age 20.1) participated in our experiment in exchange for payment. The experiment was approved by the Institutional Review Board of Princeton University. Subjects participated in four separate hour-long training sessions in which they became familiar with the task. At the end of these training sessions, we used performance on a psychometric block to determine the coherence at which they performed at approximately 80% correct. This coherence level was used for the two hour-long EEG sessions.

Recording Methods: We recorded EEG data from 128 channels using Neuroscan EEG caps with a Sensorium EPA-6 amplifier. All data were referenced to the average of the mastoids and off-line rereferenced to an average reference after automatic bad-channel removal (Friederici, Wang, Herrmann, Maess, Oertel, 2000; Hestvik, Maxfield, Schwartz, Shafer, 2007).

Data Analysis: We fitted the behavioral data to the Drift Diffusion Model using the DMA toolbox (VandeKerckhove, Tuerlinckx, 2007). We computed the error- and feedback-related negativity in electrode Fz, where it is known to be maximal, on 12-Hz low-pass filtered data (Holroyd, Nieuwenhuis, Yeung, Cohen, 2003). We baseline-corrected each trial to the 100 ms prior to the response. The ERN was taken to be the average of the signal between 0–100 ms post-response. The FRN was taken to be the difference between the positive peak in the window 120–200 ms post-response and the first negative peak thereafter, but before 325 ms (Holroyd et al., 2003). This peak window was determined from visual inspection of the ERN waveforms.

Results

We first asked whether participants adapted their decision threshold height after an error on the previous trial. Figure 1 shows that as predicted, participants adapt their decision thresholds after they commit an error, especially for trials in the highly biased conditions. Post-correct and post-error thresholds differ from each other for the 0.75 and 0.9 bias conditions [$t(20) = 2.41$, $p = 0.026$ and $t(20) = 5.86$, $p < 0.001$, respectively], marginally for the 0.6 bias [$t(20) = 1.77$, $p = 0.092$] but not in the no-bias condition [$t(20) = 1.039$, *n.s.*]).

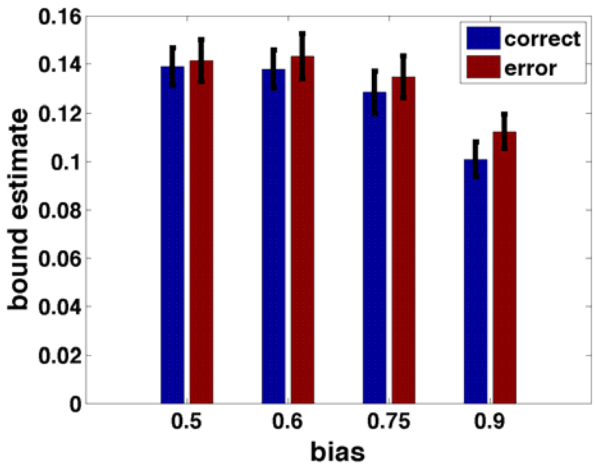

Fig. 1 Fitted DDM decision thresholds in the trials after a correct (blue) and incorrect (red) response. The thresholds are shown separately for the different response bias levels. Error bars reflect standard error of the mean

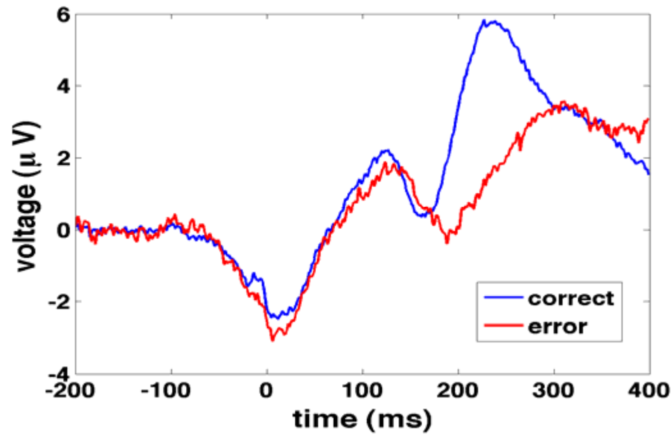

Fig. 2 Error-related negativity for the 0.75 bias condition (the condition that shows a modulation of the decision threshold)

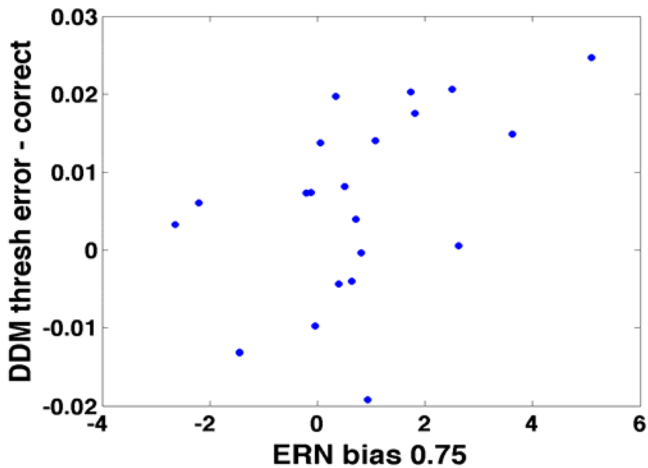

Fig. 3 Individual differences in threshold adaptation correlate with the magnitude of the ERN in the 0.75 bias condition [$r(19) = 0.47$, $p = 0.032$]

We then examined the ERN magnitude to replicate the basic ERN finding: a more negative EEG amplitude after error compared to correct trials. Figure 2 shows that there is both a difference between correct and error trials across all conditions in the ERN window [0–100 ms post-response; $t(83) = 2.13$, $p = 0.036$] and in the FRN window [approximately 200–400 ms post-response; $t(83) = 3.91$, $p < 0.001$].

Next, we asked whether the magnitude of the ERN correlates with individual differences in adaptation of the decision threshold. Figure 3 shows that for the 0.75 bias condition (which showed a significant difference in decision threshold between post-correct and post-error trials), there is indeed such a relation. For the other bias levels, this relation is suggestive, though not significant. In contrast to the ERN, there was no relation between the later FRN (appearing around 200–400 ms) and decision threshold adaptation [all correlations $p > 0.17$], except for a negative correlation between change in bias level and FRN magnitude at 0.9 [$r(20) = -0.56$, $p = 0.0081$], which we think may be spurious because this correlation is negative, rather than positive, as we would expect. Moreover, in the 0.9 bias condition participants typically resort to non-integrative responding (Simen et al., 2009).

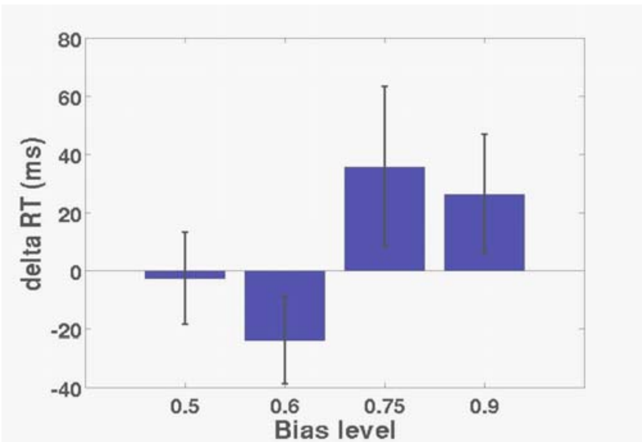

Fig. 4 Increases in the ERN are associated with a longer RT for the next trial in the 0.75 bias condition ($p = 0.0291$; sign-rank test). Error bars reflect standard error of the mean

If the ERN is related to decision threshold adjustments, then that should have consequences for behavior. We therefore asked whether the magnitude of the ERN in the 0.75 bias condition could predict RT on the next trial. In other words: an increase in the decision threshold should result in a longer RT. To assess this, we split each participant's data in two halves based on ERN magnitude. We then computed the average RT in the small ERN and large ERN trials for every participant. Figure 4 shows that as the ERN increases, the average RT will tend to increase for the 0.75 bias level [$p=0.0291$, signrank test]. Although this is different from predicting RT on a single trial, it is, given the noisy nature of EEG, nevertheless a step in the right direction.

Conclusions and Future Directions

We have shown that after an error, the decision threshold increases. At the intermediate bias level of 0.75 for which the thresholds differed significantly between post-correct and post-error trials, this increase in decision threshold was associated with individual differences in the magnitude of the ERN (but not the later FRN). The ERN may therefore reflect consequences for performance in the next trial through an adjustment of the decision threshold, and this process of performance adjustment occurs very early on after error detection. This further supports findings by Bellebaum, Kobza, Thiele, and Daum (2010) that the ERN is modulated by the extent to which people learn from task performance. It also agrees with Gentsch, Ullsperger and Ullsperger (2009), who found that the ERN was associated with an adjustment of performance, whereas the FRN was not. Post-error behavioral adjustment effects have previously been described in the N2 component in a flanker task (Forster, Carter, Cohen, Cho, 2010). It remains to be determined whether N2 modulations also occur in our perceptual decision task, and if so, whether they too relate to decision threshold adaptations.

One may wonder why we only observe decision threshold adjustments and ERN effects at the intermediate bias level (0.75), where more than half of the trials the stimuli move in a biased direction. It may be the case that participants are more focused on learning in these trials, because they are trying to figure out whether there is a bias, and how they should adapt to that. When there is no bias, participants simply focus on the stimuli; when there is a large bias participants resort to pre-emptive responding and do not pay too much attention to the stimulus (Simen et al., 2009).

Our results have potentially important applications in the field of education research. The demonstrated relation between the ERN, one of the most robust electrophysiological indices, and adjustments in cognitive control, could be used to assess the effectiveness of educational interventions. Many of these interventions involve monitoring current behavior and adjusting it as necessary (i.e., executive function), making the ERN a viable target for assessing its effects on the human brain.

Additionally, our work forms a bridge between cognitive modeling and cognitive neuroscience, by giving a formal description of the ERN in terms of model components. This link between the DDM and the ERN could be used to make strong predictions about the effect of behavioral manipulations on the ERN. Finally, this work suggests that it may be useful to extend the DDM to account for sequential effects, such that it can explain the post-error threshold adjustment that we observed.

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– Poster –

Emotions and Cognitive Processing in Musical Communication – An Experiment on the Role of the Gaze

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Theoretical Background

Several studies have been conducted on the role of body movements and their influence on perception and evaluation of musical performances.

The important role that movements and facial expressions play in the perception of the performance has been studied by Davidson and Malloch (2009) in the case of Amy Wu. Amy is probably the most famous Cantonese singer of both classical opera and pop music. This is very unusual because there is a dramatic gap between the two genres' behavior, etiquette, and audience. So Amy developed two different ways of singing and acting on stage, which was the key of her success. As Davidson and Correia (2002) affirm, music is a multi-componential experience. Indeed, the way musicians act on the stage considerably influences the audience's evaluation of the performance.

Afterward, Kurosawa and Davidson (2005) took into consideration some kind of movements musicians made while they were playing: these behaviors were categorized into 5 groups; 3 of which are very important for the present study: illustrators movements, used to simulate some content or to highlight a rhythm or intensity of execution; affect displays, movements that express some emotional states; and adaptors, interpersonal behaviors which are used to display and maintain the bond between the musicians.

In an educational prospective, Sloboda (1985) suggests that musicians spend much time and energy improving their technical abilities in order to become as "virtuoso" as possible. On the other hand, musicians don't care about the "communicative part" of musical experience (what to do on the stage; how to relate with the audience; how to make connections with other members of the band).

Yet, it is well known that gazes have an extremely important social role: they are relational devices and they carry emotional meanings between people. Only few works, however, have focused on the role of musicians' gaze.

Antonietti, Cocomazzi and Iannello (2009) studied the influence of a pianist/ singer's gazes on the audiences' evaluation of some songs. The results reveal a positive correlation between the evaluation of musician's expressiveness and the increase of the number of gazes. In addition, the emotional response and the aesthetic evaluation also positively correlate with the number of gazes performed by the musician.

Methods

The present study was designed as an experiment where participants observed three movies in which a musician performed a song. The movies were characterized by a different number of gazes of the musician towards the listener (no gaze, three gazes and six gazes). The other variables were emotional connotation and musical structure: the first song was emotionally negative and had a complex structure; the second song was emotionally positive and had a simple musical structure; the third song was emotionally negative and had an average complex structure.

Our experimental sample was composed of 49 people, 14 (28.6%) were male and 35 (71.4%) were female, aged between 21 and 56 years ($M = 28.29$, $SD = 9.16$).

Psychophysiological data (skin conductance, blood flow, temperature) were recorded using Schuhfried Biofeedback 2000 and eye movements were recorded using Tobii X120 Eyetracker. Participants' evaluation of emotional values of songs and performances were evaluated using self-report questionnaires composed of three parts: a self-evaluation section about participant's musical skills; a musician's expressiveness evaluation section (7 point Likert scale); and a memory task section.

Our main aim was to examine how the number of gazes of the performer influences the way the audience observes, processes, and recognizes songs and their related emotional value. Furthermore, we explored how the complexity of a piece of music (in terms of form and structure) affects the role of the gaze.

Results

Analyzing the heat maps derived from eyetracker data, we found that, regardless of the type of songs and the number of gazes, the most looked at areas were those in which movements were concentrated (hands and face). This result confirms the hypothesis proposed by Davidson (2001) and demonstrates the importance of a performer's movement in the transmission of musical meaning.

However, Davidson noticed that the way people watch videos was related to the number of the performer's gazes.

Considering the cluster maps derived from ET data, we noticed that the face and hands are observed by 100% of subjects; areas outside the body of the musician (the neck of the instrument and the environment) are observed more frequently as the number of performer's looks decreases.

This result emphasizes again the importance of a musician's movements and also confirms gaze's function in building and maintaining attention on a specific task.

By analyzing the outcomes of self-report questionnaires, it was possible to see how gazes affect both the perception of positive hedonic value of a musical stimulus, and the perceived expressiveness of the musician.

Although it had not revealed any clear statistical significance, it was possible to observe a tendency (MANOVA was performed) to consider the executions of tracks (especially song 2) in versions with 3 or 6 gazes as more expressive. This trend is especially noticeable in the group of people with no musical experience ($F=6.43$, $p=06$). It is likely that people with musical experience (assessed by self report questionnaire) tend to focus more on technique and are less influenced by the behavior of the musician.

More noteworthy data emerged from the analysis of questionnaires in relation to Song 2 with no gazes. The feeling associated with that song was anger (and the association was statistically significant). It is interesting to highlight that the song itself does not express anger – rather, it seems to express positive emotions such as joy (emotion that is more easily associated with the tracks with three and six gazes). The fact that many people have experienced a negative feeling in this passage, however, could be due to an inconsistency between what they saw and what they heard. Listening to a musician playing a happy tune lead them to expect that his conduct would be in accord with the music. In our case, the fact that the performer never looked at the listener might have caused a cognitive frustration that led the subjects to attribute a negative hedonic value to the song.

Considering the results of the self-report questionnaires in relation to activation categories derived from skin conductance data (low, medium and high activation), we found that higher levels of activation are linked to a tendency ($F=5.29$, $p<.05$) to judge a song that already expresses itself a positive value (Track 2 with 6 gazes) as more joyful. Moreover, the evaluation of expressiveness is influenced by the level of activation: the second track was rated as more expressive in the condition with 6 gazes, by participants with high level of physiological activation ($F=5.79$, $p<.05$). The assessment of sadness of track 3 with 0 gazes, was also higher for this category ($F=4.60$, $p<.05$). When the positive hedonic value of the song is consistently supported by the musician's gazes, a higher number of looks causes an increase of pleasure and positive assessment of the performance. A similar trend, but in the opposite direction, was noticed in the data derived from song 3: in this case, the sadness expressed in the song was supported by the absence of gazes.

The analysis of eye movements revealed that with an increase in the number of gazes by the musician, the listener's attention moves increasingly toward the face. This happened in song 1: in the 0 gazes condition, both the length and the number of fixations were higher in the neck area; in the condition with 3 gazes there was a shift of attention to the right hand. The significant indices were: length and number of fixations ($F=13.53$, $p<.05$), length ($F=4.78$, $p<.05$) and number of observations ($F=9.03$, $p<.05$); in the condition with 6 looks there was a significant shift in focus to the face, as highlighted by the number of the observations ($F=10.98$, $p<.05$), which were significantly higher. The same trend was found for song 2: the condition with 0 gazes shows an increase in the number of observations in the area of the neck ($F=3.76$, $p<.05$); while with 6 gazes there was a shift of attention to the face, as evidenced by the significance of the variables "length of observations" ($F=7.42$, $p<.05$), and "number of observations" ($F=3.82$, $p<.05$).

We also explored the influence of the complexity of a musical piece on the role of the gaze. From the analysis of variables representing the time between the beginning of the song and the moment of the first fixation, it was found that: in a complex song (track 1) with 6 looks, people address the gazes first on the face of the musician, then on the neck, and finally on the left hand. In the same track with 0 gazes, the focus falls immediately on the right hand. These results show that if performance is supported by appropriate behavior of the musician, lead subjects an emotional processing, and to focus their attention on the vertical axis of face – right hand. When the musician does not give any clues using non-verbal behavior (in our case, the 0 gazes condition), the attention of the audience shifts on a cognitive, technical and formal level. In this case, subjects focus their attention on the axis left hand – instrument handle, looking for technical information useful for understanding.

A similar trend was also found for song 2 (easier piece) but with some differences. During the 6 gazes condition, the duration of fixations and the duration of observations declined from the face and becomes higher on the hands, while in the 3 gazes condition, participants' visual behavior (in terms of number and duration of fixations and duration of observations) remained focused on the face.

A possible explanation to this difference may lie in the characteristics of videos and experimental conditions. The second track has proven to be both more activating and more understandable (on an emotional level) than the other two. The fact that the musician is forced to run six gazes, given the fact that the song lasts just less than 2 minutes, created a very unnatural and artificial situation. It is likely that the participants, bothered by the fact of being subjected to such frequent eye contact in such a short time, tended to feel uncomfortable and looked away from the face to focus on other areas. The second track, actually, was not hard to understand and the emotional value was clearer than in the other two, so the information given by the musician by his gazes was superfluous.

Conclusions

The results reveal the positive influence of eye contact on songs and performance evaluation, and stress how the complexity of music influences the exploratory behavior used by participants in order to process each song cognitively and emotionally.

These results could be used in an educational prospective of musical behavior. As Sloboda (1985) said, many musicians do not care about the communicative side of music experience, so they do not pay attention to their behaviors during the performance. The findings of this experiment show how these features are very important in order to get attention and a good evaluation from the audience.

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The Challenge to Judge Individual Learning Prerequisites in Classroom Scenarios

What Kind of Information and Knowledge Do Pre-Service Teachers Use to Make a Diagnosis?

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Theoretical Background

One of the responsibilities of teachers and instructors is the continuous diagnosis of an extremely wide variety of learning prerequisites and opportunities for their students. Focusing on the learning goal, teachers have to align their actions accordingly (Bischoff, Brühwiler, Baer, 2005). Making a competent diagnosis in teaching situations means that a teacher, while instructing the class, has to recognize indications given by the students that express their learning requirements within the scope of social interaction. Additionally, the teacher has to gather further specific information relevant to this diagnosis or to recall this information to be able to utilize it (Barth, 2010).

A review of the pertinent literature showed that until now, neither the process nor the content of such a diagnosis is fully describable (Barth, 2010). The DIAL pilot study (Empirical clarification of the basis for the diagnosis of situative learning requirements of students during classroom sessions), conducted at the University of Education Weingarten, examines what information and knowledge pre-service teachers use to make a diagnosis concerning comprehension as a situative learning requirement. The student's comprehension is certainly one of the most important learning prerequisites in learning situations. The definition of comprehension used in DIAL refers to approaches by Albert, Pawlik, Stapf and Stroebe (1984) and Dörner (2005). These definitions describe comprehension not only as a result of learning processes, but as a continuous learning process and a prerequisite of further learning. In scientific publications, a wide variety of definitions are used to explain comprehension. One aspect of comprehension described frequently is to ‘make sense’. Dörner (2005) explained comprehension in the following way: we comprehend something if we are able to relate it flexibly to other memory contents. That means comprehension is a result of connecting new information to previous knowledge. Understanding leads to further previous knowledge, which is, according to Süß (1996) or Renkl and Stern (1994), one of the most important prerequisites for learning success. Comprehension can not be directly observed. Thus, it is difficult for a teacher or a pre-service teacher to diagnose comprehension adequately. Instead of a direct observation, the teacher has to draw conclusions from, for example, the student’s oral statements, work results (e.g. right or wrong solutions, typical mistakes), or his or her way of working (e.g. Laucken, 1984; Weigert, Weigert, 1993).

According to these aspects in the DIAL-project, three different information and knowledge sources are assumed to be useful for teachers to make a proper diagnosis of the student’s comprehension.

Situation-dependent information: this information results from observable aspects of the teaching situation, for example obtained from the social interaction in the classroom or from the individual interaction with the content.

Person or class-specific information: this is information about individual students which is available to the teacher, such as school grades or the student’s gender (e.g. combined with the stereotype ‘girls have difficulties with natural sciences’).

Professional and experiential knowledge: Both knowledge types are operant at the same time, because it is supposed that both are integrated in the individual knowledge structures of the teacher. These individual knowledge structures can be described as subjective theories (Wahl, 1992; Steinke, 1998; Groeben et al., 1988).

Therefore, the main research questions of the DIAL-project are: What kind of class-specific information (information that is independent of the specific situation) do teachers use to make a diagnosis (e.g. basic information about the class)? What kind of situation-dependent information (verbal, nonverbal and paraverbal signs of the students) do teachers use to make a diagnosis? What kind of professional knowledge and experiential knowledge do teachers use to make a diagnosis? How important is each category type of information and knowledge for the diagnosis?

Methods / Project Plan

To answer these research questions, this study used a quasi-experimental design. 36 pre-service teachers (29 female, 7 male) were asked to watch videotaped classroom sessions. All participants were students of the University of Education Weingarten and had already absolved at least one practical training in a school, which means they already had some teaching experience.

Each participant was confronted with a school lesson in both a school subject that was part of his or her course of studies and with an unfamiliar school subject. Altogether, three school subjects were available: German, chemistry and geography. Furthermore, information about the school class (information vs. no information) and modes of classroom interaction (individual work/ work in pairs vs. interaction of the teacher with whole class) were varied.

For data collection, an online questionnaire was used. After the participants had watched the videotaped classroom session, they were asked to make a diagnosis of the comprehension of different students and to explain what information or what knowledge led to this diagnosis. The participants made this diagnosis by answering a closed question 'What do you think about this student?' The answer categories were: He or she comprehends / does not comprehend. The next open-ended question concerned the information and knowledge sources which were used to make this diagnosis: 'From what do you deduce that?' The written responses concerning this question were the textual basis of a qualitative content analysis. The aim of this qualitative analysis was to find out categories of different information and knowledge sources which were relevant to the diagnoses of the teachers. Further quantitative methods (quantitative content analysis, chi-square tests) will be used to find out how often specific categories are used under the different experimental conditions.

First Results

As a first result, the identified categories of different information and knowledge sources the participants used to make a diagnosis will be presented (Table 1). To develop a set of categories, a qualitative content analysis (Mayring, 2003) was used. The following categories were found and matched to the aforementioned information and knowledge sources.

As a remarkable result, it becomes apparent that the participants didn't explicitly refer to the provided class-specific information. Further analyses will show whether the class-specific information, which was given to some participants, really has no influence on the diagnosis and the information used to make the diagnosis. Further detailed qualitative and quantitative analyses are in progress.

Tab.1 Categories of information and knowledge sources

Situation-dependent information (perceptions)	Body language (e.g. the student's viewing direction, facial expression, posture/ gesture).
	Interaction between the people (e.g. existing or missing interaction between different students, interaction between students and teacher).
	Actions of the people (e.g. verbal expressions of the students, reactions to external stimuli, behaviour of their classmates).
	Participation in class
	Observed way of working (e.g. positive or negative assessed way of working, writing behaviour)
Situation-depended information (interpretation)	Interpreted student's appearance (e.g. positive appearance, negative appearance)
	Interpreted way of working (e.g. effective way of working, ineffective way of working)
	Stereotypes of students activated by watching the videotape (e.g. stereotypes about personality traits, student's skills)
Person or class-specific information	This category has not been found in the empirical data, yet.
Professional and experiential knowledge	Knowledge concerning teaching, methods and contents of instruction
	Knowledge concerning student's behaviour in general
	Knowledge concerning adequate or inadequate answers of the students

Conclusions including Potential Links and Cooperation

Currently, little is known about how teachers make diagnoses of students' comprehension in teaching situations. The DIAL-project is only a small step toward finding out what information and knowledge sources teachers use to make a diagnosis of the student's comprehension. One problem in particular remains unsolved: Are teachers actually able to provide information about what information and knowledge sources they use? If not, new methodological ways have to be developed in order to identify the information on which the teacher's diagnosis is based. Beyond that, it could be fruitful to imply approaches of cognitive modelling and maybe also a neuroscientific perspective to find out more about how the teacher's diagnosis is made. Perhaps these approaches and their methods can help to answer the question of what kind of information processing takes place while a teacher is making a diagnosis concerning the student's comprehension. Particularly, the following questions cannot be answered by classical methods of educational research: How is it possible for teachers in a classroom session to pay attention to a wide variety of information to make a diagnosis? Which memory processes take place during this diagnosis? In this sense, a connection between neuroscience, cognitive modelling and educational research would not only enhance the understanding of how students learn (e.g. O'Boyle, Gill, 1998), but also of how teachers process information in classroom sessions.

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Evading a Multitasking Bottleneck

Presenting Intermediate Representations in the Environment

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Theoretical Background

While multitasking can be performed effortlessly in certain situations, like walking and talking, other examples suggest it is nearly impossible to execute two tasks at once (like reading a paper and talking to a colleague). There are several theories that discuss multitasking interference (e.g. Pashler, 1984; Meyer, Kieras, 1997; Salvucci, Taatgen, 2008). These theories differ in their explanation of what causes interference during multitasking. One of these theories, the theory of threaded cognition (Salvucci, Taatgen, 2008), assumes that there are multiple processing bottlenecks in multitasking. One of the resources that can act as a multitasking bottleneck, called the problem state resource, was identified by Borst, Taatgen and Van Rijn (2010). The problem state is the cognitive resource that holds intermediate results of processing. For example, while solving an equation like $6x - 4 = 26$, a likely intermediate representation that is stored in the problem state is $6x = 30$. The idea of a problem state is similar to the focus of attention in memory in the sense that it has a size of only one element and it can be accessed without time costs. It does take a small amount of time (around 200 ms) to change from one problem state to another (Anderson, 2007).

Borst et al. (2010) showed that the problem state acts as a cognitive bottleneck in multitasking using a dual task experiment in which both tasks varied in whether they needed a problem state or not. They found an over-additive interaction effect on reaction times and accuracy when both tasks needed a problem state. Consistent with the minimal control principle, which proposes that internal top-down control should be minimized to obtain the best performance with the least cognitive processing (Taatgen, 2007), people will try to find ways to avoid the interference that arises when two tasks need to maintain a problem state. Instead people will offload (a part of) their problem state to the environment.

Methods/Project Plan

We hypothesize that people use their environment to relieve their problem state, if possible. To test this claim we used a modified version of the dual task experiment from Borst et al. (2010). In that experiment, participants had to perform two tasks concurrently: a subtraction task and a text entry task. Both tasks had two versions: an easy version, in which no intermediate results had to be stored, and a hard version in which participants had to maintain an intermediate result from one response to the next. We extended this setup with a version of the task in which the problem state for the subtraction task is displayed on the screen. Because the intermediate outcome was presented on the screen, it was not necessary to maintain a problem state in the hard version of the subtraction task. This version of the task will be referred to as the 'support condition', while the original version will be referred to as the 'no-support condition'.

In the no-support condition, we expected to find an interaction between task difficulty, in both response times and accuracy, similar to the interaction found in the original study. In the support condition, it is not necessary to maintain two problem states concurrently; therefore we expected to find that participants respond faster and more accurate when both tasks are hard. Thus, we expected the interaction effect to decrease or disappear.

Results: All *F*- and *p*-values are obtained from repeated measure ANOVAs; all error bars depict standard errors. Accuracy data was transformed using an arcsine transformation before being submitted to the ANOVA.

Response Times

Response times on the text entry task are defined as the time between entering the previous number and the current letter. First responses of each trial were removed. The results for the text entry task are shown in the upper panels of Figure 1. In summary: we found an interaction effect between Subtraction Difficulty and Text Entry Difficulty in both the no-support and the support condition, but in the support condition this interaction is much smaller. In the text entry task we found a three-way interaction between Subtraction Difficulty, Text Entry Difficulty and Support ($F(1,23) = 9.29$, $p = 0.01$, $\eta_p^2 = 0.29$). This indicates that the interaction between Subtraction Difficulty and Text Entry Difficulty differed based on whether support was displayed on the screen.

Response times on the subtraction task are defined as the time between clicking on a letter in the text entry task and clicking on a number in the subtraction task. First responses of each trial were removed. The results for the subtraction task are shown in the lower panels of Figure 1. In both conditions there is an interaction, but in the support condition this interaction is smaller: We found a three-way interaction between Subtraction Difficulty, Text Entry Difficlty, and Support ($F(1,23) = 5.05$, $p = 0.03$, $\eta_p^2 = 0.18$).

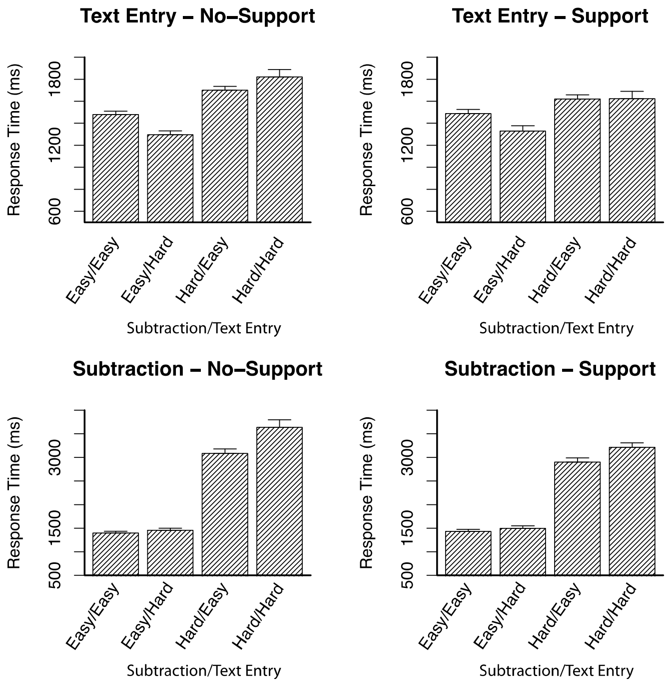

Fig. 1 Connecting chemical equations to model representations adopted (from Nurrenbern, Pickering, 1987)

Both tasks show a decreased interaction in the support condition, which indicates that displaying an intermediate representation externally reduces interference in the problem state resource.

Accuracy

Accuracy is defined as the percentage of correctly entered responses. First responses of each trial were removed. The upper panels of Figure 2 show the results for the text entry task. For the text entry task no three-way interaction was found ($F(1,23) = 1.07$, $p > 0.1$, $\eta_p^2 = 0.04$). This means that adding external support did not influence the interaction effect in accuracy on the text entry task.

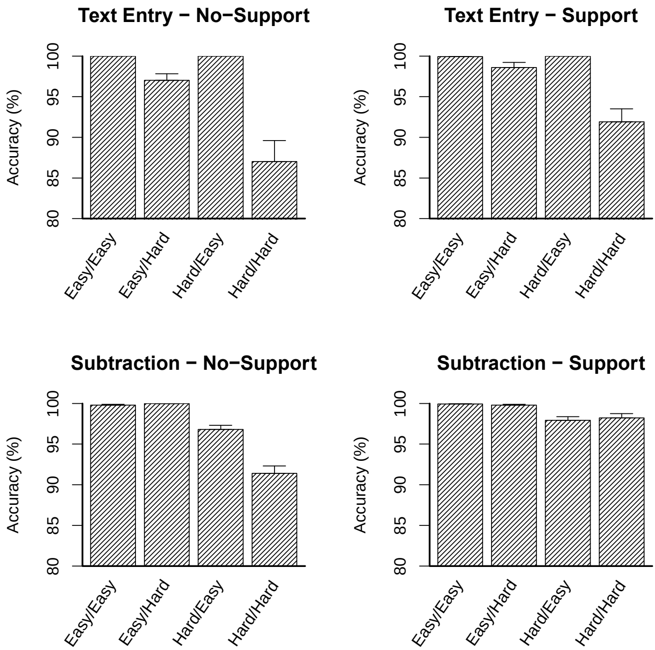

Fig. 2 Accuracy in percentage correct answers on both tasks

The results of the subtraction task are shown in the lower panels of Figure 2. The interaction effect that is present in the normal condition has disappeared in the support condition. On the subtraction task we found a significant three-way interaction between Subtraction Difficulty, Text Entry Difficulty and Support ($F(1,23) = 21.41$, $p < 0.01$, $\eta_p^2 = 0.48$), which shows that there is a difference between the interaction of Subtraction Difficulty and Text Entry Difficulty with respect to support. This indicates that while adding external support for the problem state did not influence the accuracy on the text entry task, the interference that was present in the subtraction task without support disappeared when the support was displayed.

Conclusions including Potential Links and Cooperation

The findings presented here show interactions between Subtraction Difficulty and Text Entry Difficulty in the no-support condition in both response times and accuracy. This effect was predicted because a bottleneck occurs when two tasks concurrently need to maintain a problem state (Borst et al., 2010). In addition, the support condition demonstrates that displaying an external representation of the problem state improves performance on the tasks, not only in the subtraction task (where the support was implemented) but also in the text entry task. These results are similar to the ideas of the minimal control principle (Taatgen, 2007), which showed that cognitive control is shared between perceptual input and internal cognition.

Although these results indicate that the external representation does indeed take over part of the role of the problem state resource and thereby reduces interference, we expected to find a larger decrease of the interaction effect in both response times and accuracy of the subtraction task. However, while the interaction effect in the accuracy data indeed disappeared, the interaction in the response decreased, but is still present. For the subtraction task this can be explained by the time it takes to look at the supporting symbol on the screen: the time it previously took to recall the problem state from memory is now used to look at the supporting symbol. However, this does not take into account that there is still an interaction effect in the text entry data.

A more plausible explanation is that at least some participants still store a representation of the subtraction task in their problem state. During the text entry task, this representation is replaced by the representation of the text entry task. When returning to the subtraction task, the problem state does not have to be recalled from declarative memory and because the support on the screen is always correct it is more accurate. This explanation can also account for the interaction in the response times for the text entry data. Because there is still a problem state for the subtraction task, this problem state has to be exchanged for the problem state of the text entry task. Thus, while participants did not need a problem state to perform the task, they still seem to create one. Although it seems clear that participants use their environment to relieve the interference in the problem state, it seems like they still initially create a problem state for the subtraction task. The current experiment does not provide a sufficient explanation for exactly what happens in the problem state. Constructing a cognitive model of the task could give more insight into what exactly occurs.

Nevertheless, externally representing intermediate results of a task can prevent interference in the problem state resource. Hereby, one of the bottlenecks that keep us from efficient multitasking can be circumvented.

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Sleep Disturbance in Adolescents

Protective Resources – Results of a Representative Study

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Theoretical Background

Sleep disturbances, such as trouble falling asleep, waking at night and having difficulty falling back asleep (i.e. trouble maintaining sleep) or daytime sleepiness, are known to be common in adolescents, with prevalence rates ranging from 4 to 40% (Vignau et al., 1997; Ohayon et al., 2000). Adolescence is associated with a natural delay in circadian rhythm (Carskadon et al., 1993), so sleep disturbances are not surprising and often considered to be temporary and without any long-term sequelae. However, sleep disturbances have been shown to be correlated with deficits in mental and somatic well-being. For example, disturbed sleep in adolescents is closely related to depressed mood, anxiety, low self esteem, inattention and poor concentration, as well as an increase in headaches, stomachaches and backaches (Price et al., 1978; Mahon, 1994, 1995; Vignau et al., 1997; Tynjälä et al., 1999; Fredriksen et al., 2004). Moreover, sleep disturbances have been reported to be associated with poor academic performance, such as lower grades or increased class failure rates (Blum et al., 1990; Hoffamn, Steenhof, 1997; Wolfson, Carskadon, 2003; Shin et al., 2003; Millman, 2005; Salcedo et al. 2005), which is in line with findings connecting sleep functions with memory consolidation and learning (for review see Diekelmann, Born, 2010). Thus, the need for information on how to prevent sleep disturbances is substantiated. A worthwhile strategy might entail the identification of both risk factors for the occurrence of sleep disturbances and resources that can modify the effects of existing risks. As shown by developmental studies, resources pertaining to mental health include: personal resources (factors specific to the adolescent's personality, such as self-efficacy, optimism, or sense of coherence), familial resources (factors specific to the family of the adolescent, i.e. family coherence), or social resources (factors specific to the social environment of the adolescent, such as social support outside the family). Furthermore, physical activity was considered to be positively related to adolescents' sleep (Price et al., 1978; Shapiro et al., 1984; Brand et al., 2010). The objective of the present study was to identify a possible association between resources in a sample of adolescents and the prevalence of sleep disturbances.

Methods

The study is part of a representative survey about the health of adolescents in the city of Stuttgart, Germany, undertaken in 2005. All eighth and ninth grade school students were evaluated by standard questionnaires (such as the Social Status Questionnaire, Strengths and Difficulties Questionnaire, Self-Efficacy Scale, Familial Climate Scale, and the Social Support Scale), specific questions, and a physical exam. For 546 students (aged 13 through 18 years, mean age 14.7 years), there was a complete data set (response rate 64%).

Sleep disturbances were registered among a wide range of relevant health and sociodemographic aspects: Students were asked 1) if they suffer from trouble falling asleep or trouble maintaining sleep and 2) how often they felt tired or exhausted during the daytime in the previous week. In this study, insomnia was defined as suffering from sleep disturbance with either trouble initiating or maintaining sleep in addition to reporting having frequently or always felt tired or exhausted during the daytime in the previous week. Personal resources, familial resources and social support were classified as "inconspicuous", "below average" or "obvious deficits", physical activity as "three times a week or more", "once or twice a week" or "less than once a week". Statistical analysis was done using the Mantel-Haenszel-Chi-Square-Test.

Results

Trouble falling asleep was reported by 23.3% of the total sample, while 11.2% of the students complained of trouble maintaining sleep and 10.4% were suffering from insomnia. The presence of personal resources was related to a significantly reduced risk for insomnia ($p = 0.016$), trouble initiating sleep ($p < 0.001$), and trouble maintaining sleep ($p = 0.001$). Additionally, unaltered family coherence was strongly associated with reduced occurrence of insomnia, trouble falling asleep and trouble maintaining sleep ($p < 0.001$;

p = 0.007; p < 0.001, respectively). However, no such association between sleep disturbances and social support was observed (all p > 0.3). Significantly less frequent insomnia was observed in those students reporting physical activity three times a week or more in comparison to less frequent activity (p < 0.001).

Conclusions

The data suggest that sleep disturbances are quite common in German adolescents. Nearly one quarter of the sample reported trouble initiating sleep, and every tenth subject was suffering from the basic symptoms of insomnia. Given that changes in circadian rhythm – a tendency to fall asleep later and greater difficulty waking up earlier – has been shown to be associated with pubertal development (Hagenauer et al., 2009), this may, at least in part, represent a delayed sleep period in relation to required sleep-wake times and following sleep deprivation. Because sleep deprivation and daytime tiredness can preclude full participation in school lessons, and sleep disturbances have been shown to be related to poor academic performance (Pagel, Kwiatkowsky, 2010), a chronobiologic perspective should be taken into consideration when discussing school start times. Furthermore, in line with the finding that physical activity is beneficial to sleep (Price et al., 1978; Shapiro et al., 1984; Brand et al., 2010), our data suggest physical activity three times a week or more might be of protective value regarding insomnia. In addition, the presence of personal and familial resources, such as self-efficacy, optimism, or unaltered family coherence, seems to be positively related to adolescents' sleep. These results correspond well with data indicating that subjective sleep quality is associated with self-esteem, self-perception and home atmosphere (Price et al., 1978; Tynjälä et al., 1999; Fredriksen et al., 2004). Surprisingly, no correlation between social support and sleep disturbances was found, although we cannot exclude that – as suggested by Vilhjalmsson (1994) – social support in general has a salutary effect on adolescents' well-being and therefore possibly an indirect influence on sleep. However, because of the cross-sectional design of our study, causal inferences cannot be drawn. Moreover, the associations need to be explored with further multivariate analysis. So far, this study highlights the need for increased awareness of sleep disturbances and suggests that there may be possibilities to reduce sleep disturbance by educating adolescents, parents and teachers on possible protective factors. Sleep functions and its disturbances should be appropriately taken into consideration in future educational research.

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Cross-Curricular Problem Solving

An Empirical Study of Demands on Teaching and Learning in Higher Education

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The concept of cross-curricular competencies is regarded as one of the most important topics in current educational and political debate (Rychen, Salganik, 2001; Baumert et al., n.d.). In addition to discipline-specific skill development, the debate on university reform sees the development of 'generic', 'key' or 'core' skills as a principal objective in any academic program (e.g. Clanchy, Ballard, 1995). Though the importance of key competencies in higher education is not new to the educational dialog (e.g. Mertens, 1974), it was not until the Bologna-process began that the discussion of 'generic' or 'key skills' and the question of their implementation regained momentum (e.g. De la Harpe et al., 2000). This is due to the fact that key skills now focus on the student's development towards *employability*, one of the central concepts of the European higher education reform (Bologna-process).

The focus on generic skills therefore complements the disciplinary expertise. Accordingly, graduates expect and are expected not only to have a specific discipline-based knowledge but also to be able to apply this knowledge to efficiently solve problems in their future professional life (e.g. Bennett et al., 2000; De la Harpe et al., 2000; Barnett, 1994). However, solving domain-specific problems is not the only challenge students will face in their later professional life: they also need the competencies to deal with new and unknown situations in their work life, and being able to adapt to these situations is essential. Therefore, promoting the transfer and development of cross-curricular problem-solving (*CCPS*) competencies is a fundamental goal of teaching (Butterfield, Nelson, n.d.).

Despite being recognised as important, the concept of cross-curricular competencies has remained somewhat vague in both theoretical and empirical respect (Baumert et al., n.d.; De la Harpe et al., 2000; Clanchy, Ballard, 1995). The empirical study presented here will address these shortcomings.

First of all, the project will focus on diagnostics of *CCPS*: after developing cross-curricular problem-solving tasks, the study intends to empirically verify these theoretical aspects and to address the question how developed cross-curricular problem-solving competencies of university students can be described. The findings will contribute to the discussion on modelling and shaping *CCPS* competencies in higher education. Moreover, the study will highlight the issue of domain-specificity of *CCPS*. In addition, the project will indicate the importance of teaching generic skills and offer suggestions of how to best address the requirements necessary to their development and implication.

Theoretical Background and State of Research

In situations where routines are not established, problem-solving in the form of goal-oriented thinking and acting (Funke, 2003) is regarded as the most important cognitive activity in everyday and professional contexts (Jonassen, 2000; Jonassen, 1997; Didi et al., 1993). Therefore problem solving is a central research topic (e.g. Funke, 2003) and cognitive problem-solving skills are a well known scientific research area as well as an important educational aim (e.g. Dochy et al., 2003; Margetson, 1994; Picus, 1983). In addition, the subject of cross-curricular skills has been discussed for many years (e.g. Billing, 2007; Bridges, 1993; Perkins, Salomon, 1989; Rychen, Salganik, 2001; Mertens, 1974).

However, despite the relevance of *CCPS* in higher education, there are several desiderata:

Beginning with formal methodological aspects, problem-solving research mostly took place in experimental settings. The intent of most of these studies in cognitive psychology was to derive general principles of problem solving. However, the PISA-2003 project abandoned the experimental approach and aimed for a high ecological validity (Klieme et al., 2005).

Moreover, PISA studied cognitive processes in *CCPS* for the first time.

While PISA examined school children, some other studies have concentrated on university students and their general problem-solving competencies (e.g.

MacPherson, 2002; De Lisi, Staudt, 1980; Tomlinson-Keasey, 1972; McKinnon, Renner, 1971). These studies found differences in problem-solving skills and indications that these differences could be attributed to age, study experience, or field of study, among others (De Lisi, Staudt, 1980). However, these studies can be criticized for their low ecological validity and the fact that important cognitive processes relevant to (cross-curricular) problem solving were disregarded.

Finally, instructional design research – aside from problem based learning – has devoted too little attention to the study of problem solving (Jonassen, 2000). In general, the focus on cross-curricular problem solving has been marginal until now.

The study presented here aims to address these four shortcomings. First and foremost, it is imperative to define the central aspects that constitute the underlying concept of *CCPS*.

What are Cross-Curricular Competencies?

There are different theoretical and normative ideas that can be summarized as follows (Baumert et al., n.d.):

1. Cross-curricular competencies are independent from situations and contexts.
2. Correspondingly, cross-curricular competencies are relevant in different disciplines and can be distinguished from domain-specific knowledge and competencies.
3. The main characteristic of cross-curricular competencies is that they can be transferred to new situations.
4. As a result, cross-curricular competencies help to deal with complex requirements.

With regard to these criteria, studying *CCPS* would mean assessing problem-solving competencies that are independent of situations and contexts; or, in other words, knowledge-lean problems. In addition, the goal must be to assess those problem-solving competencies that are important in *different* situations; which implies those problem-solving competencies that can be transferred to a variety of situations.

How Should "Problems" and the Process of Solving Problems Be Defined?

As Funke (2003) described in regards to the common definitions of problem solving, a problem exists if there is an incongruity between starting point, aim and, in particular, available instruments.

Apart from this most fundamental definition, there are other aspects that specify problems: Considering the problem-solving process, commonly used descriptions characterize it as a process that encompasses subprocesses ranging from the *understanding of the problem situation* to the step-by-step *modification of problem constituting variables* (Mayer, 1992). In this regard, problem solving always means that there are different stages that have to be passed through (Pólya, 1945). According to Pólya's phase model, these stages are: understanding the problem, devising a plan, carrying out the plan, and reflection (in terms of evaluating one's goals).

Regardless of how well-known and important this model is, it is still primarily descriptive and has only heuristic value (Baumert et al., n.d.). Although the study presented here uses Pólya's phase model as a guideline, the following cognitive aspects and processes relevant in problem solving were the crucial points of reference:

To assess cross-curricular problem solving, the study focused on the following problem-solving stages: (1.) analyzing situations, (2.) recognizing constraints in evaluating aims and (3.) sequencing sub-steps as a part of action planning. In this context, the following cognitive competencies had to be addressed: (1.) recognizing relevant variables, (2.) discriminating variables, (3.) comparing, (4.) linking, (5.) interpreting and (6.) sequencing variables, (7.) recognizing constraints and missing variables as well as (8.) making decisions.

As Fleischer et al. (2010) point out, until now there has been a lack of a theoretical and empirically grounded taxonomy in cognitive processes relevant in solving problems. However, they found that domain-specific and cross-curricular problems differ in some aspects. Therefore, the level of performance, dependent on the problem variations (structuredness, complexity, and situatedness), was defined based on the following assumptions:

Cross-curricular problems in this study are designed as knowledge-lean, with a low level of formalization (without technical terminologies). The problems were designed in the form of demands (in contrast to questions) in a stimulative and realistic way. Moreover, only closed, analytical problems have been designed.

The level of complexity has been produced through the following aspects: the kind of cognitive operation (e.g. deductive thinking, inductive thinking, linking variables, recognizing constraints etc.), the number of cognitive operations (e.g. linking variables and interpreting variables, etc.), the kind of variables that have to be manipulated (e.g. numeric, figurative) and the number of variables that have to be manipulated.

Finally, the requirements in cross-curricular problem solving consist of a high level of performance of the cognitive operators, the recognition of (constraining) conditions relevant for the solving of the problem and goal-oriented acting (Fleischer et al., 2010).

Co-Variables of Cross-Curricular Problem Solving

In addition to these requirements on designing cross-curricular problems, the study intends to clarify some important co-variables of efficient cross-curricular problem solving.

Previous knowledge (operationalized as study experience) and intelligence (APM, Raven; dt. Bulheller, Häcker, 1998) will be controlled: Previous research showed that the degree of previous knowledge[1] interferes with problem solving ("Elshout-Raaheim-hypothesis", Leutner, 2002). Furthermore, the degree of previous knowledge could explain the correlation between intelligence and complex problem solving (Leutner, 2002); someone who does not have any previous knowledge is depending on a trial-and-error behavior. Someone with a large amount of previous knowledge operates more systematically and with much more routine. In case of an average familiarity with a complex system, strategies in deductive reasoning can be applied in an effective way. In this case, clear correlations between intelligence and problem solving have been proven.

In addition, other psychological conditions have to be both respected and analyzed with regard to efficiently solving cross-curricular problems. As different scholars have pointed out, the combination of cognitive, motivational and volitional constructs in modeling study success is important (Schiefele, Schaffner, 2006; Schiefele, Urhahne, 2000; Helmke, Weinert, 1997). Within

1 Since this study focuses on knowledge-lean problems, procedural rather than declarative knowledge is relevant.

the context of this study, it was not possible to consider the whole spectrum of relevant factors for study success. However, the most important aspects could be addressed: self-efficacy, study interest, and student beliefs have been evaluated as meaningful aspects affecting study success.

Self-efficacy: Cognition of one's own competence affect behavior. According to this, students' confidence in effectively accomplishing difficult challenges has an impact on their selection of tasks (level of difficulty), the effort put into achieving their objectives, and their persistence in overcoming difficulties and barriers (Schwarzer, Jerusalem, 2001).

Students' beliefs: Beliefs – that is, perceptions and ideas about the structure of knowledge and knowledge acquisition – affect learning. However, they also are associated with motivation and self-concept (Urhahne, Hopf, 2004).

Study interest: Not only cognitive valuations but also emotional aspects affect learning behavior and study achievement (Schiefele, Urhahne, 2000). The individual interest of students has an especially significant affect on learning success and study behavior (Schiefele et.al. 1993).

Methodological Aspects and Study Design

The study follows three steps and focuses on two fields of interest: First, the designed instrument will be tested concerning its fit to explore students' cross-curricular problem-solving competencies. The underlying construct of cross-curricular problem solving will be analysed according to its components (analyse situations; evaluating proposals for solutions; action planning). Second, different co-variables will be analysed regarding their correlation with cross-curricular problem solving. Third, the influence of different study domains will be explored.

The study pursues two functional interests: First, the assessment allows one to identify how developed cross-curricular problem-solving competencies really are. Second, it will be possible to develop strategies for improved teaching of cross-curricular problem solving (teaching for transfer).

Thereby, the study follows a multifactor cross-sectional design. A case study according to current theories of problem solving and cognitive competencies in thinking processes was designed. Within a between-subjects design, students in their first, third and sixth semester from different fields of study (humanities: european studies and english studies / social sciences: journalism studies and school-psychology) will be compared. Self-efficacy (Schwarzer, Jerusalem, 2001), study interest (Krapp et al., 1993), students and teachers beliefs of relevance of cross-curricular problem solving (own design, Urhahne, Hopf, 2004), study experience, age, vocational experience and lecturer's teaching expertise will be correlated. Intelligence (APM, Raven, Set I, dt. Häcker, Bulheller, 1998) will be controlled.

Expected Results

Based on the results of previous studies there are some basic hypotheses for this research project:

1. There are differences expected with regard to study experience (semester), age, and vocational experience. That is, older and more experienced students are expected to have a higher level of cross-curricular problem-solving competencies.
2. Aspects such as self-efficacy, study interest, and beliefs have an effect with regards to solving cross-curricular problems. That means more interested and confident students are expected to produce better results.
3. The field of study is expected to have an influence on student's ability to efficiently solve cross-curricular problems. In particular, it is assumed that students in social sciences are more skilled in for example avoiding irregular syllogisms.
4. It is assumed that previous results in the correlation of intelligence and problem solving can be reproduced regarding cross-curricular problem solving.

Conclusions

Recent research in education aims to individualize teaching and learning processes and tends to analyze the complexity of teaching. In this regard, the presented study focuses on the question of the development and dependency of students' cross-curricular problem-solving competencies and aims to clarify possibilities to support students' development of cross-curricular competencies.

Thereby, the study seeks to provide results and conclusions that matter beyond psychology and beyond a theoretical and empirical perspective. Three possible directions – educational and didactical implications depending on the discipline, implications for new forms of teaching, and implications for new and profound exchange between theory and job market – should be mentioned here:

Due to the focus on "employability" in higher education development, the study aims to question how students' cross-curricular problem-solving competencies can be improved. In this regard, the study addresses the question of whether there are differences depending on the study field as well. Consequently, the results should allow the discussion of how teaching must be conceptualized to develop students' competencies depending on the discipline (e.g. journalism studies or psychology versus European studies or English studies).

Relating to higher education teaching, the results allow to consider new forms of teaching or forms of interdisciplinary or team teaching to support transfer and practical application of competencies. In this regard, it would be important to reflect and involve existing (national and international) approaches in problem based learning and teaching (e.g. medicine).

In a more general perspective and with regard to a broader connection of theory and practice, the results could form the basis for a profound exchange between higher education and the job market: Due to the importance of cross-curricular problem solving in future jobs it could be interesting to discuss possibilities to connect higher education teaching and practical job situations. The possibility to perform in practical job situations should support the perspective of transfer.

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Grant

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The Impact of Socio-Emotional Factors on Learning Processes Considering Neurobiological Processes

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Theoretical Background

"Most of us have assumed that the kind of academic learning that goes on in school has little or nothing to do with one's emotions or social environment. Now neuroscience is telling us exactly the opposite. The emotional centers of the brain are intricately interwoven with the neocortical areas involved in cognitive learning. When a child trying to learn is caught up in a distressing emotion, the centers for learning are temporarily hampered. The child's attention becomes preoccupied with whatever may be the source of the trouble. (…) In short, there is a direct link between emotions and learning (Goleman, 2004; p. 7f)."

Decades before neuroscientific research discovered the field of learning, this link between emotions and learning was considered in studies that investigated the teacher-student relationship (Nohl 1933, 1957; Lewin, Lippit, White 1939; Brophy, Good 1976; Rosenthal, Jacobsen, 1968; Tausch, Tausch 1991; Nickel, 1981). Recent studies have demonstrated that the interactions between teachers and their students follow specific cognitive and emotional schemata, which are determined by social-cultural factors (Klem, Connell, 2004; Lee, Smith, 1999; Wild, Hofer, Pekrun, 2006). Furthermore, functioning relationships with teachers and peers are relevant for the development of students' identity and self-perception (e.g. Horstkemper, 2000; Wentzel, 1998). Based on Nickel's transactional model of the teacher-student-interaction, current social relationships and experiences might have an influence on the learning processes and outcomes of students, which should not be underestimated (Nickel, 1981). Both educational-psychological (e.g. Haselbeck, 2007) and cultural-anthropological (e.g. Raufelder, 2007) findings indicate that social relationships and the emotions one experiences within social relationships are important predictors of academic achievement. In contrast, findings from motivation research reveal the “phenomenon” that some students’ school achievement is constant (good or bad) and not dependent on teachers or classmates (Deci, Ryan, 2000). The distinction between intrinsic and extrinsic motivation could be a possible starting point to explain this “phenomenon“. A highly intrinsically motivated student might work hard at school because he or she enjoys learning, whereas an extrinsically motivated student might learn at school because he or she wants to be liked by their classmates or teachers. Thus, students’ extrinsic motivation might be determined by their socio-emotional relationships within the school environment.

Based on the extant research, this study is built upon two main research questions: (1) How are socio-emotional factors related to academic learning processes? (2) Why are these factors only relevant for some students and not for others and what role does the type of motivation play?

Methods/Project Plan

A central issue of the current project “Socio-Emotional Learning Factors” (SELF) is to investigate the meaning of socio-emotional factors in students’ school context. Due to the complexity of the relationship between socio-emotional factors and learning processes in school contexts a (1) quantitative data acquisition using questionnaires, (2) a neurobiological experimental design and (3) qualitative interviews will be combined. Therefore, in a *first step* we designed a questionnaire that attempts to take the impact of social, emotional and motivational aspects of learning into account in order to investigate the interplay between cognitive and emotional learning processes. Random samples of 7th grade students (N=900) from two different school types (Gymnasium[1], Gemeinschaftsschule[2]) in Berlin and Brandenburg will be analyzed.

We predict four types of learners: *Type I* is a peer-dependent learner, which means that students’ school performance (whether high or low) depends on the quality of the relationship with their schoolmates or peers; *Type II* is a teacher-dependent learner, meaning that students’ school performance depends on the quality of the relationship with their teachers; *Type III* is a peer- and teacher-dependent learner, meaning that both the quality of the relation-

1 high-track school
2 low-track school

ship with schoolmates or peers and to teachers influences the learning of the students; finally, *Type IV* is a peer and teacher-independent learner, meaning a highly intrinsically motivated student whose learning outcome is not influenced by their relationship with peers or teachers. To test the stability of or changes in the influence of socio-emotional factors on students' learning outcome over time, a second measurement point will be conducted two years later (i.e. 9th grade).

In a *second step*, functional magnetic resonance imaging (fMRI) will be used to analyze neurobiological factors that affect emotional learning processes in students. The orbitofrontal cortex is known to be important for motivational behavior (e.g. Rolls, 2000). Neuroimaging studies have shown the involvement of the orbitofrontal cortex in the processing of punishment and reward stimuli (O'Doherty, Kringelbach, Rolls, Hornak, Andrews, 2001; Elliott, Newman, Longe, Deakin, 2003). Such studies have also demonstrated the ventral striatum to be engaged in reward processing (e.g. Delgado, Nystrom, Fissell, Noll, Fiez, 2000). Thus, the ventral part of the striatum and the orbitofrontal cortex are presumed to be crucial in processing of punishment and reward. Therefore, we wish to test for the differences in striatal activation between the diverse learning types using a probabilistic learning task in an event-related fMRI study (Remijnse, Nielen, Uylings, Veltman, 2005). With an experimental design, a representative sample out of the 900 students (N=48) with 12 individuals from each learning type will be tested twice following both questioning periods. This study will be designed and conducted in cooperation with the Charité Berlin (University Medical Center Berlin).

In a *third step,* the 48 students from the fMRI study will be interviewed to gain a more detailed description of the four different learning types and the empirical reality of the teacher-student relationship, student-student relationship and the daily learning processes in school from a cultural-anthropological point of view.

Expected Results

The main goal of this study is to identify and establish a typology of learners concerning socio-emotional factors and motivation (intrinsic and extrinsic) in the school context. We expect to discover a minimum four different types of learners: (1) peer-dependant learner, (2) teacher-dependant learner, (3) peer- and teacher-dependant learner, (4) independent learner (see figure 1). Possible differences in neurological processes between the different types should be investigated using fMRI. The expected results will help to understand basic principles of reward learning processes of adolescents. Due to the longitudinal design of the study, changes concerning the typology and the neurological processes can be investigated. In regard to that predictions if the classification of the types is either flexible or solid can be devised. The interdisciplinary approach contributes to the enhancement of empirically founded educational research. The integration of anthropological and neuroscientific research methodology is particularly crucial for understanding the complexity of learning processes comprehensively.

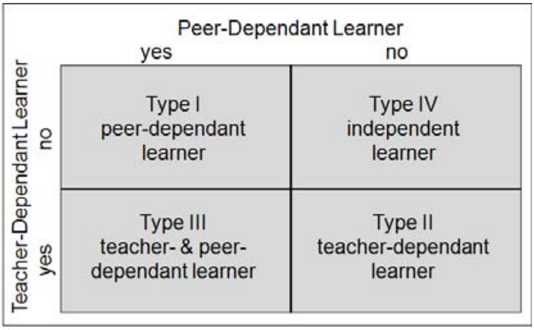

Fig. 1 Four different types of learners

Conclusions including Potential Links and Cooperation

The interdisciplinary contribution of the three different empirical methods allows for the enhancement of founded educational, psychological, cultural-anthropological and neuroscientific research. In cooperation with the neuroscientific research group from the Charité, headed by Prof. Dr. Andreas Heinz (Director and Chair), basic principles of reward learning processes of adolescent students should be determined. Results from the study can help to foster and support each student individually within the school setting. Findings may also be helpful for improvements of teacher education and training. The knowledge of specific socio-emotional factors relevant to learning processes could help to improve both the school and classroom climate.

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Teacher Rated Attention Problems Predict Academic Achievement in Very Preterm and Fullterm Adolescents

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Theoretical Background

Attention is an important prerequisite for learning, both in the classroom and at home. In the general population, middle childhood attention problems predict later academic performance (Duncan et al., 2007). However, the specific pathways from attention problems to academic achievement remain poorly understood, as they have primarily been studied cross-sectionally, with longitudinal studies being the exception.

Children born very preterm (VP; < 32 weeks of gestation) and/or with very low birth weight (VLBW; < 1500 g birth weight; referred to as VLBW/VP subsequently) are at increased risk of poor academic achievement (Aarnoudse-Moens, Weisglas-Kuperus, van Goudoever, Oosterlaan, 2009), which may be due to global cognitive impairments of VLBW/VP children (Johnson et al., 2009; Schneider, Wolke, Schlagmüller, Meyer, 2004). In addition, neonatal (Johnson, Wolke, Hennessy, Marlow, 2011) and family social factors (Taylor, Burant, Holding, Klein, Hack, 2002), parenting (Jäkel, Wolke, 2011, under review), as well as attention deficits (Jäkel, Bartmann, Wolke, 2011, under review) may contribute to the suboptimal developmental trajectories of achievement in VLBW/VP children.

Very premature children are consistently diagnosed with attention problems (Hack et al., 2009; Johnson et al., 2010), which are not explained by IQ deficits (Anderson, Doyle, Victorian Infant Collaborative, 2003; Samara, Marlow, Wolke, 2008). It has been suggested that this increased risk for attention problems may result from global changes in brain anatomy, connectivity, or functional architecture of very preterm children's development (Johnson, et al., 2010; Kapellou et al., 2006). For example, intrauterine growth restriction (IUGR, resulting in being small for gestational age, SGA) can lead to reduced brain volume (Toft et al., 1995), whereas a premature birth involves different mechanisms acting on the brain including alterations in white matter microstructure (Dudink, Kerr, Paterson, Counsell, 2008) and cortical folding (Kapellou, et al., 2006). Results of one of our own studies suggest that SGA is more likely to reduce brain volume, while prematurity appears to alter brain function (Hall, Jäkel, Wolke, 2011, under review). Whereas both of these adverse outcomes predict later attention problems, longitudinal associations are additionally moderated by child gender (Hall, et al., 2011, under review). To our knowledge, there is only one longitudinal study on LBW and fullterm children that investigated the association of attention problems at school entry with adolescents' academic achievement after accounting for IQ and family social factors (J. Breslau et al., 2009; N. Breslau et al., 2010). To elucidate the pathways from early brain development and dysfunction to academic underachievement of VLBW/VP children, we need more information about the long-term contributions of attention to academic achievement. This study investigated teacher-rated attention problems at 6 years of age and assessed academic outcome at 13 years of age in VLBW/VP and fullterm children.

Methods

Data were collected as part of the prospective Bavarian Longitudinal Study (BLS) (Riegel, Ohrt, Wolke, Österlund, 1995; Wolke, Meyer, 1999), a geographically defined whole-population sample of very premature children and fullterm controls in southern Germany.

Very Low Birth Weight (VLBW) and/or Very Preterm (VP) Children. Of 70,600 children born in South Bavaria during a 15-month period in 1985/86, 682 were VLBW (birth weight < 1500 g) or VP infants (< 32 weeks gestation), or both. Of these VLBW/VP children, 172 died during the initial hospitalization and seven died during the first six years of life. Seven parents did not give written consent to participate and 48 parents and their children were non-German speakers (i.e. the parents did not speak German and the children scored < - 2 SD on German language tests at 4 years of age). These mother-child dyads were excluded from the study as their verbal behavior could not be coded and the cognitive assessments not administered. Of the 448 VLBW/ VP survivors eligible for inclusion, 174 children had complete data across all three measurement points, i.e. neonatal, 6; 3 and 13 years of age.

Fullterm control group. Of 936 controls (>36 weeks gestation; normal postnatal care) identified at birth from the same hospitals in Bavaria, 350 survivors (5 died) were selected to match the overall distribution of child gender, family socioeconomic status (SES), and maternal age of the VLBW/VP group. 220 fullterm control children had complete datasets across the three time points.

Procedure

Details of pre-, peri-, and neonatal data have been described elsewhere (Gutbrod, Wolke, Söhne, Ohrt, Riegel, 2000; Wolke, Meyer, 1999). Participating parents were approached within 48 hours of the infant's hospital admission and were included in the study once they had given written consent for their child to participate. Ethical approval was obtained from the University of Munich Children's Hospital. At 6;3 years, participating children and their mothers were assessed by the interdisciplinary study team for one whole day including neurological assessments (done by pediatricians), parent interviews (done by psychologists), cognitive assessments and behavior ratings (done by psychological assistants and the whole team). All assessors and raters were blind to group membership (VLBW/VP vs. fullterm children).

Measures

Biological and medical variables. Gestational age was determined from maternal reports of the last menstrual period and serial ultrasounds during pregnancy. When the estimates of these two differed by more than two weeks, postnatal Dubowitz scores were used (Dubowitz, Dubowitz, Goldberg, 1970). Birth weight was documented in the birth records. Infant risk was assessed with the Intensity of Neonatal Treatment Index (INTI) (Gutbrod, et al., 2000).

Social variables. Information was obtained by standardized interviews within the first 10 days of life. Maternal education was entered into 11 categories. Family adversity after birth was determined by eight psychosocial variables as a composite index score (FAI) (Rutter, Quinton, 1977; Wolke, Schmid, Schreier, Meyer, 2009).

Parenting. At 6;3 years, maternal sensitivity and verbal control behavior was recorded during a dyadic play situation using an Etch-a-Sketch. Maternal behavior was analyzed with a standardized coding system, the “Assessment of Mother-Child-Interaction with the Etch-a-Sketch” (AMCIES) (Jäkel, Wolke, 2011 (under review); Wolke, Rios, Unzer, 1995).

Cognitive Assessments. At 6;3 years of corrected age, children’s intelligence was assessed with the German version of the Kaufman Assessment Battery for Children, K-ABC (Kaufman, Kaufman, 1983; Melchers, Preuss, 1991).

Attention. Teacher ratings of child attention in the 1st grade were obtained from end of year primary school reports.

Academic Achievement. Child academic achievement at 13 years (secondary school) was based on level of educational track in the German secondary school system according to the following criteria: 1. school type (special school, secondary school low stream (Hauptschule), mid-stream (Realschule) or high stream (Gymnasium), 2. whether the child had ever repeated a class (i.e. is in age appropriate class or not), and 3. performance within each track in the core subjects Mathematics and German (average or above versus below average) (Schneider, et al., 2004).

Results

Compared to fullterm controls, VLBW/VP children were at higher risk for attention problems in first grade of primary school ($T(392) = 6.13$, $p < .001$). Teacher ratings of attention in first grade predicted academic achievement in both very preterm and fullterm adolescents after controlling for biological and social variables, parenting, and child IQ. Prediction models were similar for preterm adolescents and controls.

Conclusions

This study investigated whether teacher rated attention in first grade is predictive of adolescents’ academic achievement. We found that VLBW/VP children were at higher risk for attention problems compared to fullterm controls. This pattern did not change when raw scores were adjusted for social factors and child IQ. Child attention consistently predicted academic achievement seven years later, even after controlling for biological and social variables, parenting, and child IQ in both VLBW/VP and fullterm children. If the mechanisms underlying academic achievement are similar in VLBW/VP and the general population of children, the study of preterm children may help to understand the global pathways from early brain development and dysfunction to attention problems and academic underachievement.

We found support that attention represents an independent predictor of subsequent academic achievement in both VLBW/VP and fullterm adolescents. Early identification of specific attention problems, especially in at-risk groups, is essential for effective prevention strategies. ADHD inattentive subtype may be accurately characterized as a dimension rather than a categorical diagnosis (Krueger, Markon, 2011; Sonuga-Barke, Halperin, 2010), thus observational measures of attention have the added advantage of detecting subclinical levels in children that are nevertheless relevant for learning and essential to reliably predict academic achievement.

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Sequential vs. Simultaneous Visual-Spatial Processing and Mathematical Skills in VLBW/VP vs. Fullterm Children

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Theoretical Background

A recent paper on mathematics deficiencies in VLBW/VP children indicated that, although these are more frequent in preterm populations, little is known about the nature of mathematics deficiencies in very premature children (Taylor, Espy, Anderson, 2009). In addition, research has shown that with increasing cognitive workload (for example when simultaneous visual-spatial processing is required) preterm children fall behind in test scores, as neurological impairments may cause severe resource constraints. The aim of this study is twofold: (1) to apply the 4CAPS cognitive neuroarchitecture model (Just, Varma, 2007) to explain differences in sequential compared to simultaneous visual-spatial processing abilities in a prospective epidemiological sample of children with gradual degrees of prematurity (N = 1431). In the model, it is proposed that four differently specialized centers dynamically cooperate in spatial problem solving, whereas overall resource constraints shape cognition. In preterm individuals, neurological impairments may cause early spillover to less specialized centers (Nosarti, Murray, Hack, 2010). In addition, overall resources may be more limited in preterms, thus explaining incremental performance deficits with increasing cognitive workload. The 4CAPS model may hereby help to illustrate the interface between behavioral and neurological findings in preterm populations (Just, Varma, 2007). (2) Our second aim is to investigate associations between neurological predictors, sequential vs. simultaneous visual-spatial processing, and children's math abilities (test scores and school marks) while controlling for social factors, parenting, and child IQ. The findings will yield information about the origins and neuropsychological correlates of poor math achievement both in preterms and more generally.

Project Plan

Data were collected as part of the prospective Bavarian Longitudinal Study (BLS) (Riegel, Ohrt, Wolke, Österlund, 1995; Wolke, Meyer, 1999), a geographically defined whole-population sample of all children born between January 1985 and March 1986 in southern Germany who required admission to a children's hospital within the first 10 days of life (n=7505; 10.6% of all live births). In addition to this at-risk sample, the BLS selected a further 916 healthy control infants (>36 weeks gestation; normal postnatal care) identified at birth from the same hospitals in Bavaria to match the overall distribution of child gender, family socioeconomic status (SES), and maternal age. Due to changes in the design of the study when children were 6;3 years old, the final sample for this study will consist of N = 1431 of the original pool of children who participated in all six assessment points from birth to 8;5 years of age.

Participating parents were approached within 48 hours of the infant's hospital admission and were included in the study once they had given written consent for their child to participate. Ethical approval was obtained from the University of Munich Children's Hospital. At each of the subsequent assessment points (5, 20, and 56 months, 6;3 and 8;5 years), participating children and their mothers were assessed by an interdisciplinary study team including neurological assessments (done by pediatricians), parent interviews (done by psychologists), cognitive assessments and behavior ratings (done by psychological assistants and the whole team).

Measures

Longitudinal assessments of biological, social, and parenting variables were carried out over the course of the whole study (for example, infant risk was assessed with the Intensity of Neonatal Treatment Index (INTI) (Gutbrod, Wolke, Söhne, Ohrt, Riegel, 2000); family adversity after birth was determined by eight psychosocial variables as a composite index score (FAI) (Rutter, Quinton, 1977; Wolke, Schmid, Schreier, Meyer, 2009); maternal sensitivity and verbal control behavior was analyzed with a standardized coding system, the "Assessment of Mother-Child-Interaction with the Etch-a-

Sketch" (AMCIES) (Jäkel, Wolke, 2011 (under review); Wolke, Rios, Unzer, 1995).

56 months of age: Developmental Test of Visual-Motor Integration (Beery, 1982), Child Behavior Indices (attention span, inhibition, self-regulation) (Riegel, et al., 1995).

6;3 years of age: Children's intelligence was assessed with the German version of the Kaufman Assessment Battery for Children, K-ABC (Kaufman, Kaufman, 1983; Melchers, Preuss, 1991), clinical DSM-IV diagnoses of child behavior problems were obtained with the structured Mannheimer Parent Interview (for example Attention Deficit Hyperactivity/Impulsivity Disorder) (Esser, Blanz, Geisel, Laucht, 1989; Jäkel, Bartmann, Wolke, 2010, under review).

8;5 years of age: Mathematic Test, School reports (Mathematic achievement in 1st grade will be obtained from end of year primary school reports and ranked according to the following criteria: 1. school type (special school or primary school), 2. whether the child is in age appropriate class or not, and 3. Mathematics performance (above average, average, or below average).

Expected Results

The vast longitudinal data of our study will allow for investigation of the processes underlying individual differences in visual-spatial processing and math abilities. Which neurological variables are early precursors of visual-spatial processing and math abilities? Will application of the 4CAPS cognitive neuroarchitecture model (Just, Varma, 2007) help to explain differences in sequential compared to simultaneous visual-spatial processing abilities in children with gradual degrees of prematurity? Finally, after controlling for social factors, parenting, and child IQ, what are the pathways from early brain development and dysfunction to children's visual-spatial processing and math abilities across the whole strata of gestational age?

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Therapy Software for Enhancing Numerical Cognition

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Abstract

We present a novel software for the acquisition of central components of number processing and representation as well as mathematical understanding. The software is based on current neurocognitive concepts and insights. The learning process is supported through multimodal cues encoding different properties of numbers. The learning environment features 3D graphics and interaction components and thus allows immersion in a playful 3D world. To offer optimal learning conditions, a Bayes net user model completes the software and allows adaptation to a specific user. A first version of the software will be tested with normally achieving and dyscalculic children within a multi-center study in Zurich, Berlin, and Potsdam starting in 2011.

Introduction

Developmental dyscalculia is a specific learning disability affecting the acquisition of arithmetic skills. Genetic, neurobiological, and epidemiological evidence indicates that developmental dyscalculia, like other specific learning disabilities, is a brain-based disorder, although poor teaching and environmental deprivation have also been implicated in its aetiology (Shalev, von Aster, 2008). The prevalence of developmental dyscalculia in German-speaking countries is about 6% (von Aster et al., 2005).

Previous Work

In a previous study, we developed and evaluated a computer-based training program for children with developmental dyscalculia (DD)(Kucian et al.). In general, children with and without DD could benefit from the training. This was indicated by: (i) improved spatial representation of numbers and (ii) the number of correctly solved arithmetical problems. During the training, the control children showed the typical fronto-parietal network brain activations associated with number processing. In contrast, dyscalculic children showed main activation in medial frontal areas. Statistical group comparison corroborated that children with DD showed less activation in bilateral parietal regions. After training, less brain activation was evident in mainly the frontal lobes in both groups. Taken together, the training improves the spatial representation of numbers and arithmetical performance. Reduced brain activation in children with DD may reflect neurophysiological deficits in core regions for number processing. After the training, children rely less on frontal areas associated with reduced working memory and attentional needs. Our study shows that the training leads to an improved spatial representation of the mental number line, which facilitates processing of numerical tasks, and hence requires less neuronal capacity.

Concept

Design

The presented software is based on two important models of dyscalculia and the development of mathematical understanding.

The triple-code model (Figure 1) postulates three modules for number processing, each of them using a different representation of number (Dehaene, 1992). In the verbal module (auditory verbal word frame), numbers are represented as number words. In the Arabic module (visual Arabic number form), the Arabic notation is used for the representation of numbers. And in the analogue module (analogue magnitude representation), numbers are depicted as an analogue locus on an internal number line. There are different abilities attributed to each module. Counting, exact mental calculation, and arithmetical fact retrieval are mainly executed in the auditory verbal word frame. The visual Arabic number form is responsible for parity judgments and multi-digit operations. Approximation tasks as well as number comparisons are attributed to the analogue magnitude representation.

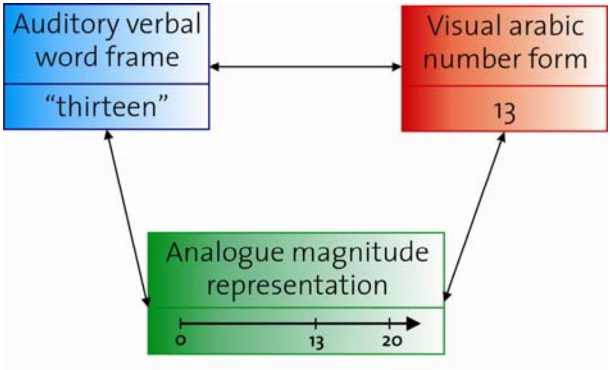

Fig. 1 Triple-code model according to Dehaene (1992)

According to the 4-step developmental model (Figure 2), this modular system develops hierarchically over time depending on the capacity and availability of functions of general intelligence (attention, working memory, processing speed) and on experiences (von Aster, Shalev, 2007). Babies can already capture and differentiate sets according to their cardinality. This core-system representation of cardinal magnitude and its functions provide the basic meaning of number (Step 1). This is a necessary precondition for children to associate a perceived number of objects with spoken or written symbols. The linguistic symbolization (Step 2) as well as abilities such as the principles of counting, increase/decrease schemes and simple arithmetic operations performed by counting, develop in pre-school age without systematical teaching. The Arabic symbolization (Step 3) of numbers is then learnt in school. It is a precondition for the development of the analogue magnitude representation.

The three different number representations and the translation between them form the basis of number processing. Therefore, we developed a special number design to enhance these representations and at the same time facilitate numerical understanding. We encode the properties of numbers with auditory and visual cues such as color, form and topology. The different positions (one, ten, hundred) of the place-value system are represented with different colors. This aspect is enhanced by showing a graph where each digit of a number is attached to a different branch (Figure 3). This representation facilitates the development of the Arabic symbolization as well as the translation between the auditory verbal word frame and the visual Arabic number form.

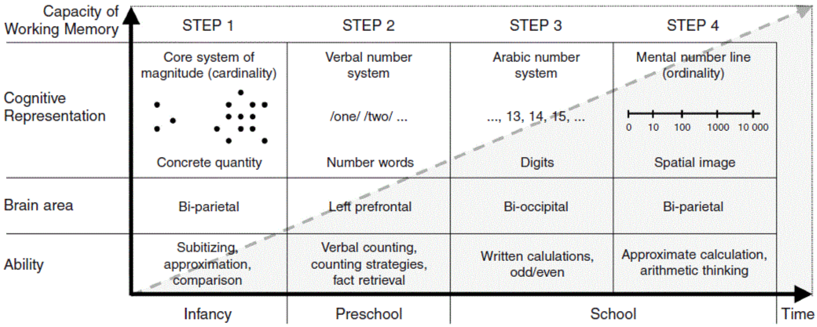

Fig. 2 4-step development model. The shaded area below the dashed line denotes the increasing capacity of the working memory

Furthermore, the cardinal magnitude of a number is emphasized by illustrating the number as a composition of blocks with different colors, i.e., as an assembly of one, ten and hundred blocks (Figure 4, top). In this way, we highlight the fact that numbers are composed of other numbers and again refer to the Arabic symbolization. These different blocks are arranged on a line from left to right to make a connection to the analogue magnitude representation. To stress this representation even more, we also show a diverse perspective of the blocks, where they are directly integrated in the number ray (Figure 4, bottom).

Fig. 3 Visualization of number with color and topology

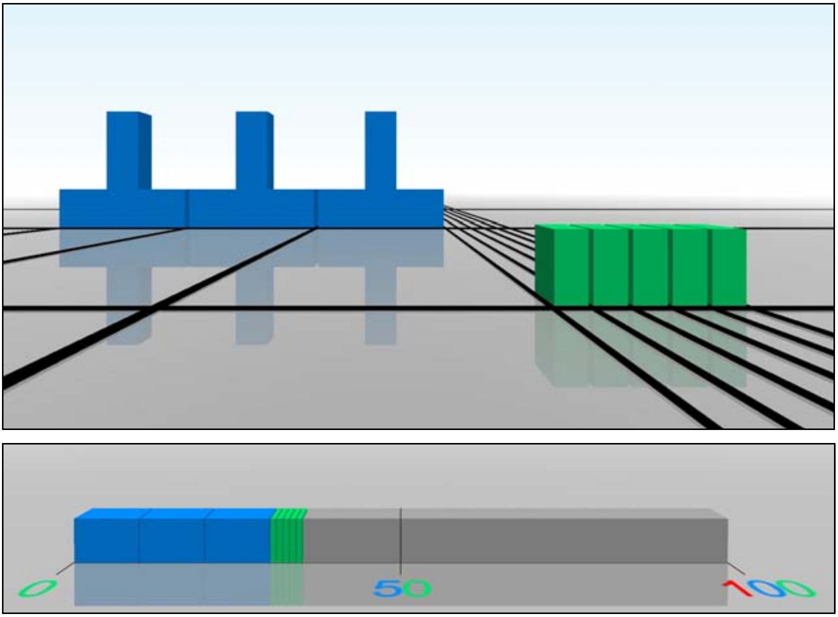

Fig. 4 Visualization of number using colored blocks (top) and colored blocks integrated into the number ray (bottom)

All of these special number designs are shown simultaneously in each sub-game of the software.

As a complete mathematical understanding requires the presence of all three number representations and the translation between them as well as the ability to master operations and procedures with numbers, the software is structured into two areas. Each area consists of individual therapy games constructed in a way to use the special number design:

(i) Cognitive number representation and numerical understanding

The first area focuses on cognitive number representation and numerical understanding as well as transcoding between different numerical representations. Furthermore the games concentrate on different aspects of numerical understanding that support the development of cardinal and ordinal principles of numerosity (Stern, 2005). Basic games feature either a specific translation between two different number representations or highlight an aspect of numerosity. The more difficult games require a combination of translations and knowledge about principles of numerosity. One important game in this area is for example the landing game (Figure 5). In this game, the child needs to find the analogue position of an Arabic digit on a number ray.

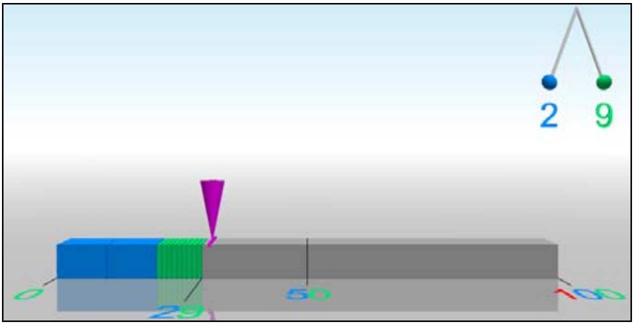

Fig. 5 Illustration of landing game in the number range from 0-100

(ii) Cognitive operations and procedures

The second area focuses on cognitive operations and procedures. Each of the games in this area trains a mathematical operation at a specific difficulty level. To consolidate the skills acquired in the first area, the representation of the task and its solution makes use of different number representations. The games in this area are hierarchically ordered according to their difficulty. We differentiate between two types of difficulty. The so-called vertical difficulty denotes the inherent difficulty of the task, e.g. an addition in the number range from 0–10 is easier than an addition in the range from 0–100. The horizontal difficulty depends on the presentation of the task and on the allowed means to solve the task, e.g. solving an addition with material is easier than doing a mental calculation.

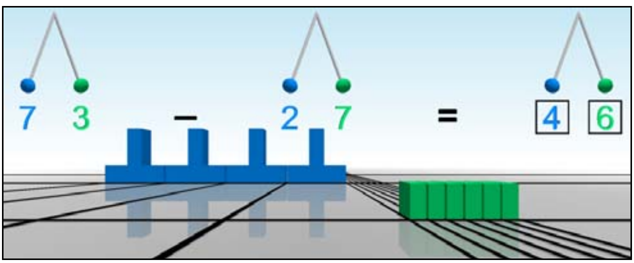

Fig. 6 Illustration of addition game in the number range from 0-100

Game Control

In order to offer optimal learning conditions, the software adapts to the needs of a specific user. At the beginning of the training, all users start with the same game. After each input, the software estimates the actual knowledge state of the user and displays a new task adjusted to this state. In this way, the velocity of advancement can be adapted to each user and specific problems of a user can be recognized and addressed.

In order to do so, the software holds an internal representation of the user's knowledge. In our case, the knowledge is modeled using a dynamic Bayes net. This net consists of a directed acyclic graph representing different mathematical skills and the dependencies between them. These skills can again be associated with the two areas of the software:

(i) Cognitive number representation and numerical understanding

The first area contains skills regarding number representations and general number understanding. The skills are ordered hierarchically according to two criteria. The coarse criterion is the separation between the different number ranges. Within each number range, the hierarchical ordering is based on the 4-step development model.

(ii) Cognitive operations and procedures

Skills regarding procedures and operations with numbers are attributed to the second area. Again, a hierarchical ordering of the skills is performed. Here, the first criterion is the split into the different operations, i.e., addition and subtraction. Within a specific operation, we order the skills according to their vertical and horizontal difficulty described above.

As we cannot observe the skills of the user directly, the software has to infer them by posing specific tasks and evaluating the user actions. Such observations indicate the presence or absence of a particular skill with some probability. Therefore, we assign all types of tasks and their outcome to the different skills (Figure 7).

Each input of the child is now evaluated and fed into the Bayes net accordingly. In this way, the net can be updated with each input of the student and compute an estimate of the student's actual knowledge state. Based on this estimate, the next game to play is then selected and adapted to the specific student.

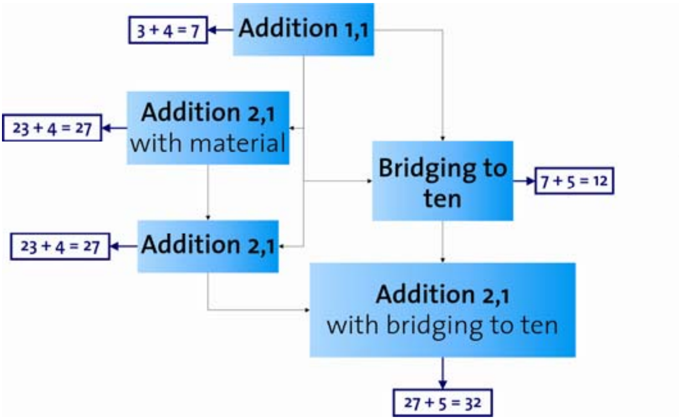

Fig. 7 Extract of skills, dependencies among them, and associated tasks in second area

Study

A first version of the software will be tested with normally achieving and dyscalculic children within a multi-center study in Zurich, Berlin, and Potsdam starting in 2011. The study will be conducted using a cross-over design, both groups of children will be divided into a training group, a control training group and a waiting group. They will play with the software for 20 minutes per day on five days per week during six weeks. As a control training, the computer-based dyslexia therapy software Dybuster will be used (Kast et al., 2007). To prove the effect of the training and its temporal stability, psychometric data will be collected at four specific points in time. Tests include measurements regarding intelligence, attention and working memory, as well as different methods to measure number processing and calculation, math anxiety and the so called "spontaneous focusing on numerosity" (SFON) (Hannula et al., 2010). We expect that the training with our software will have positive effects on the development of mathematical understanding, which will be reflected in the different measurements on number processing and calculation as well as in the SFON test.

Conclusion

We presented a new software for the acquisition of central components of number processing and mathematical understanding. The structure of our software is based on neurocognitive models. The number design developed for the software enhances important aspects of number understanding and facilitates learning of important concepts of number. The adaptivity of the software allows to adjust learning speed and to focus on the specific problems of each particular user. Pilot tests with a first prototype have shown that the playful environment and the interaction components increase motivation of children positively, one of the most important qualities of a successful training. In the multi-center study starting in 2011, we will be able to assess our software in terms of progress in mathematical understanding as well as other effects such as increased motivation. With the data gathered during the study, we will also analyze and in a next step further improve the control mechanism of the software in order to make the software even more adaptive to the user.

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How to Assess ACT-R Models Predicting BOLD Curves for a Complex Problem

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Introduction

Cognitive architectures provide a modeling framework with constraints preventing modelers from creating unrealistic models of human cognitive processes (Gray, 2007; Gluck, Pew, 2005). One of the most prominent architectures is the ACT-R-architecture (Anderson, 2007). It has a long tradition, dating back at least to 1983 (Anderson, 1983).

The ACT-R (Atomic Components of Thought-Rational) cognitive architecture (Anderson, 2004; 2007) consists of eight modules: The Visual, Aural, Manual, Vocal, Declarative, Imaginal, Goal, and Production modules. Obviously, they perform specific functions: The Visual and Aural modules control the perceptual input of an ACT-R model, while the Manual and Vocal modules constitute its action apparatus. The Goal module stores the current goal, while the Imaginal module represents working memory. The Declarative module's purpose is to retrieve facts from long-term memory. All of these modules interface to the Production module via buffers. A buffer may hold a single chunk (i.e. fact) at a time. The Production module represents the procedural memory and matches, selects, and executes production rules, which compare and manipulate the buffers' contents. Each action triggered by a production in a specific module consumes a certain amount of time. A model based on this architecture is an executable program in the form of production rules which may be used to determine predict a participant's performance in various tasks on trials of various domains, such as algebraic problem solving.

Anderson's Brain Mapping Hypothesis (Anderson, 2007) maps the activity of the ACT-R modules onto specific brain regions. Thus, ACT-R implements a tooling that enables Blood-Oxygen Level-Dependent (BOLD) signal predication for these brain regions. However, these regions only cover a very small volume of the brain, and most studies were conducted using simple tasks with a limited strategy space.

Research Question

The first research question of our sub-project was to study the robustness of the Brain Mapping Hypothesis towards a non-algebraic task, a multidimensional strategy space, and programming or modeling errors.

Methods

A trial problem consists of the visual and auditory presentation of a name for a chemical compound and two structural formulae which were presented to the left and the right on the screen. The participant has to decide which one of these matches the compound name (for task details see Anschütz et al. this volume). The following constraints are known to the participant (Möbus, Lenk et al., 2011).

1. The abbreviation for an element is defined by two letters
2. The first letter of the abbreviation is the same as the first letter in the name of the element.
3. Both letters appear in the element’s name.
4. An element may have a multiplicity from 1 to 4 in the compound. Distinct three letter words served as numerals to denote the multiplicity:
    a. 1 /–
    b. 2 /pli
    c. 3 /pla
    d. 4 /plo
5. The position of a numeral is always in front of the owning element in the compound name.
6. The central element of the structural formula is always the first in the compound name.

We used data from 62 children, ages 10 to 13, who took part in the fMRI experiment (see Özyurt and Thiel, this volume for details on the fMRI experiment). Each participant underwent a total of 80 trials during two sessions.

The chemical formula language is usually not known to children of that age group. Nevertheless, fictitious chemical elements and their abbreviations as well as numerals were used to prevent carry-over effects. The children were familiarized with the above constraints by undergoing an extensive instruction and training phase.

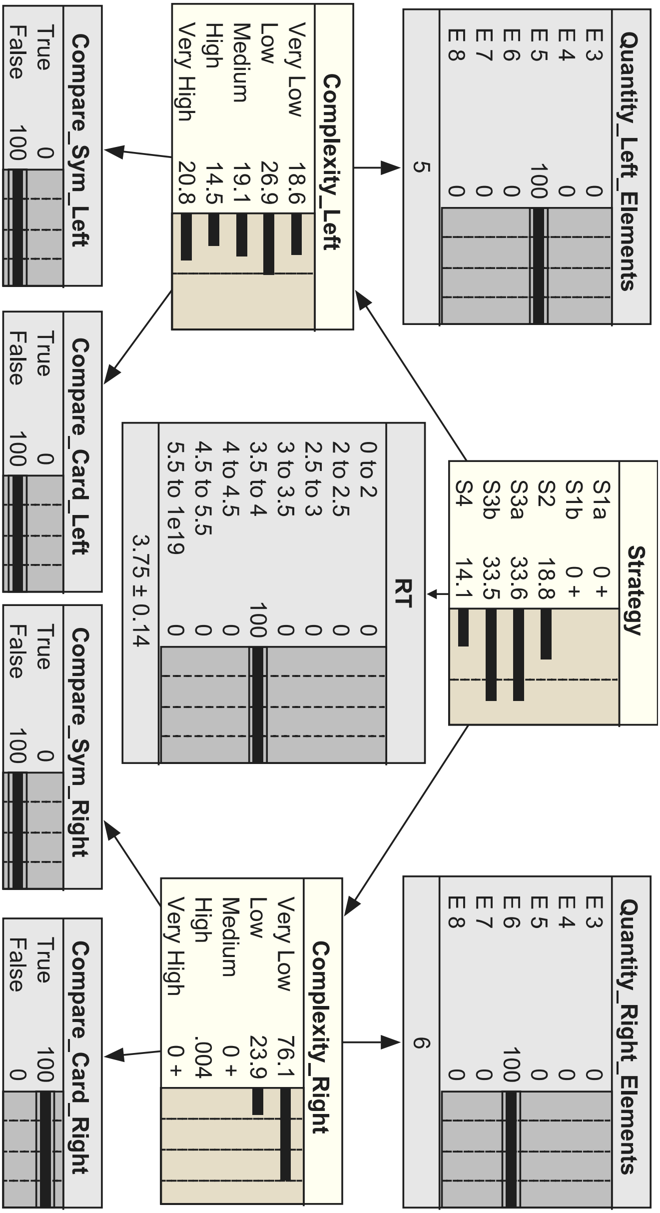
Models

During the task analysis, it became clear that this seemingly simple problem may be solved by applying a multitude of strategies. For instance, the participant may constrain him- or herself to study either only the left or the right structural formula exclusively and subsequently decide whether it matches or not. Alternatively, the participant could check characteristics on both formulae until a violation of the above constraints is detected for one formula. Also, some aspects of the trial may be processed multi-threaded as opposed to single-threaded processing. Still, there is a great degree of freedom for the ACT-R modeler to implement these strategies. A participant may change the strategy across trials, or in the worst case, during a single trial.

Out of these considerations, six ACT-R models were implemented. Model S1a and S1b were multi-threaded and evaluated only one structural formula, either the left or the right. Model S2 is also multi-threaded, but checks certain characteristics on both formulae for violations. Along these lines, S3a and S3b were single-threaded counterparts of S1a and S1b evaluating only one formula. S4 is single-threaded and again checks both formulae.

Data Aggregation

Individual BOLD curves were extracted for each participant from the regions defined by Anderson. Each module was mapped onto two regions for each brain hemisphere. Then, the individual BOLD curves were aggregated. For this purpose, we constructed a Bayesian Belief Network (BBN), which allowed us to infer the probability that a specific strategy had been used by a participant based on the participant’s response time (RT) and characteristics of the trial (Figure 1). The BBN had been trained prior with ACT-R model data. These probabilities were used as weights for the aggregation of the individual BOLD curves, which resulted in a strategy-specific BOLD curve that was then compared with the BOLD prediction of the corresponding model.


Quantity_Left_Elements
E 3 0
E 4 0
E 5 100
E 6 0
E 7 0
E 8 0
5
Complexity_Left
Very Low 18.6
Low 26.9
Medium 19.1
High 14.5
Very High 20.8
Compare_Sym_Left
True 0
False 100
Compare_Card_Left
True 0
False 100
Strategy
S1a 0 +
S1b 0 +
S2 18.8
S3a 33.6
S3b 33.5
S4 14.1
RT
0 to 2 0
2 to 2.5 0
2.5 to 3 0
3 to 3.5 0
3.5 to 4 100
4 to 4.5 0
4.5 to 5.5 0
5.5 to 1e19 0
3.75 ± 0.14
Compare_Sym_Right
True 0
False 100
Quantity_Right_Elements
E 3 0
E 4 0
E 5 0
E 6 100
E 7 0
E 8 0
6
Complexity_Right
Very Low 76.1
Low 23.9
Medium 0 +
High .004
Very High 0 +
Compare_Card_Right
True 100
False 0

We first compared the complete time series of the time series with about 400 data points which showed generally low correlations (Möbus, Lenk et al., 2010). We then applied the aggregation method from Carter, Anderson et al. (2008), which allowed us to align the scans from different trials and individuals onto a template and subsequently aggregate the data. However, we modified the method by using the probabilities from the BBN as weights in the aggregation again. Model predictions were likewise aggregated and Pearson's correlation coefficients have been computed for strategy model predictions and strategy-specific BOLD curve aggregations.

Results

These coefficients (Table 1) are high for all modules but the Goal module. This indicates a faulty assumption in the modeling process. Indeed, all strategies place a single chunk in the Goal buffer at the start of each trial and thus produce little activity in this module. Generally, most correlation coefficients were heightened by the weighting process. This is especially the case for the Manual module, which may be easily explained as the RT (triggered by manual action) is the prime indicator for a strategy in the BBN.

Tab.1 Correlation coefficients between models' BOLD predictions and brain regions in the left hemisphere for weighted (w.) and unweighted (Uw.) aggregation (Möbus, Lenk et al., 2011)

	Production		Imaginal		Goal		Declarative		Visual		Aural		Manual	
	Uw.	w.	Uw.	w.	Uw.	w.	Uw.	w.	Uw.	w.	Uw.	w.	Uw.	w.
S1a	0.985	0.992	0.858	0.892	-.917	-.930	0.938	0.966	0.888	0.827	0.917	0.916	0.733	0.840
S1b	0.983	0.990	0.858	0.890	-.917	-.931	0.934	0.966	0.888	0.824	0.917	0.919	0.740	0.856
S2	0.977	0.974	0.858	0.861	-.917	-.930	0.934	0.941	0.981	0.982	0.917	0.930	0.600	0.665
S3a	0.894	0.888	0.870	0.876	-.917	-.914	0.875	0.858	0.862	0.854	0.918	0.924	0.302	0.351
S3b	0.891	0.886	0.870	0.875	-.917	-.912	0.871	0.853	0.863	0.856	0.918	0.923	0.295	0.345
S4	0.829	0.851	0.870	0.822	-.917	-.837	0.825	0.778	0.500	0.480	0.918	0.896	0.074	0.320

Also, asymmetries can be found in the data. Most module and region pairs correlate higher with the left hemisphere (Figure 2), with the notable exception of the Imaginal module, which correlates slightly higher with the right. The Manual module correlates negatively with the right hemisphere. This is in accordance with the literature (Mattay et al., 1998), as the participants responded with their right hand. No model performs best for all module/region pairs, but generally the multi-threaded model S1a, S1b, and S2 show the most accurate BOLD predictions.

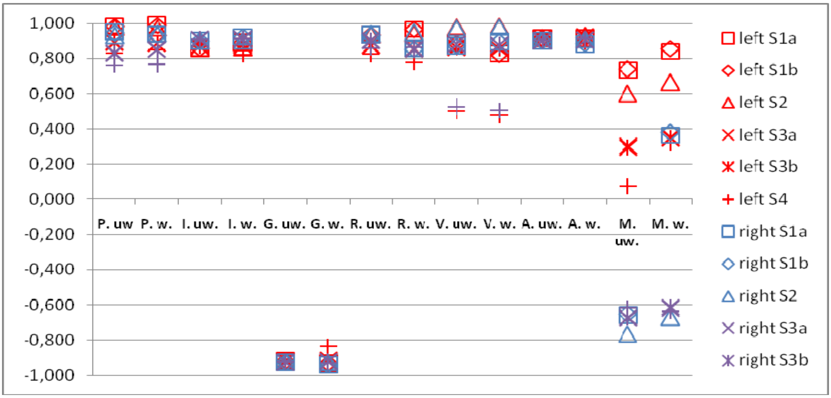


Fig. 2 Correlation coefficients for both hemispheres. On the horizontal axis are the module/region pairs and weighted (w.) vs. unweighted (uw.) aggregation. The vertical axis shows the correlation coefficient ranging from -1 to 1

Conclusion

We were able to show that the ACT-R Brain Mapping Hypothesis also holds in large parts for tasks with multi-dimensional strategy spaces. However, it has been shown that an ACT-R model which explains behavior does not necessarily predict fitting BOLD curves, and thus, due to ACT-R being underconstrained, the modeler cannot hope to conceive a valid model, even if based on fit to behavioral data, for BOLD prediction in the first run. Thus, we suggest four options for our further research: First, one could try to simplify the problem, in order to separate the cognitive functions (such as transformation, perception, and goal setting) in time. But this would also mean missing out on the opportunity to study the Brain Mapping Hypothesis in relation to complex problems, and this is also already a prominent approach in prior research by Anderson and others.

Second, one could try to tune the parameters of ACT-R's BOLD prediction tooling (Anderson et al., 2008). This is an interesting approach as these seem to affect shape and magnitude of the predicted BOLD curves greatly.

The third approach is to find alternative Regions-of-Interest (ROIs) in an independent data set since the current ACT-R Brain Mapping Hypothesis covers only a small fraction of the brain. This could be done for example by Independent Component Analysis (ICA) (McKeown et al., 1998; Friston, Büchel, 2007). Such approach would enable to identify feedback-related brain regions and to incorporate these in to the model. Finally, the modeling itself may be questioned. We implemented only six ACT-R models, but many more are conceivable. Indeed, the goal setting strategy has to be refined, which is clearly shown by our results.

The models we presented here may be called first-pass models (Carter et al, 2008). Our second-pass models will incorporate the findings from the fMRI analysis, and should, along with Bayesian strategy classification, provide better insight on how to handle ACT-R's BOLD prediction capabilities within multidimensional strategy spaces.

Furthermore, we had to realize that at the present moment it is not within the state of the modeling art to generate an ACT-R model of a human student with motivational states as curiosity, happiness, or frustration. This is due to the fact that the granularity of process descriptions that ACT-R requires and that educational psychologists are willing to provide differs widely.

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Brain Development from an Attachment Point of View

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“Serious mental illnesses do not emerge de novo when individuals reach adulthood, but rather reflect early developmental processes.”
(Ellen Leibenluft, NIMH)

Cognitive (perceptual, memory, and attention) as well as emotional brain systems are relatively plastic and responsive to environmental input early in development, i.e. they are adaptive to the child’s immediate developmental context – the parent-child relationship. Thus, aversive attachment experiences may render the child’s brain prone to subsequent maladjustment at later developmental stages (Pollak, 2005), conferring a vulnerability to certain kinds of psychopathology.

Attachment-related vulnerability has been found to become especially salient, and eventually manifest, in dysfunctional (e.g. externalizing) behaviour as the child enters new life contexts and forms new relationships in late childhood and adolescence. As the complexity of the adolescent’s social interrelatedness grows in the course of autonomy development, so does the risk for maladjustment and psychopathology (Allen, Moore, Kuperminc, Bell, 1998; Allen, Marsh, McFarland, McElhaney, Land, et al., 2002).

Adolescence from a Clinical Perspective

Adolescence is a time of increasing incidence of several classes of psychiatric illnesses, including anxiety and mood disorders (Kessler, Chiu, Demler, Walters, 2005). As indicated by the National Survey Comorbidity Survey Replication (NSC-R), the peak age of onset for any mental disorder is 14 years. Adolescent onset is associated with more-severe and more-disabling forms of affective and anxiety disorders (Andersen, Teicher, 2008; Birmaher, Axelson, 2006; Beesdo, Bittner, Pine, et al., 2007). The psychophysiology of these disorders is increasingly understood in terms of normal developmental changes gone awry within the adolescent brain. While it is undisputed that anomalies of brain maturation act in concert with psychosocial factors (e.g. school transmissions or divorce of parents) and/or biological-environmental factors (e.g. pubertal hormonal changes), the interplay of these processes is poorly understood (Paus, Kashavan, Giedd, 2008).

Adolescence from the Perspective of Developmental Psychology

Adolescence has, since Aristotle, been described as a period of "storm and stress", characterized by raging hormones, intense emotions, risky behaviours, experimental drug use, and autonomy struggles with parents. Empirical findings, however, lead to a modified version of the "storm and stress" view of adolescence – the "storm and calm" thesis – which assumes that problems such as mood disruptions or antisocial behaviours are not inherent characteristics of adolescence but during this period are more likely to arise than at other ages (Arnett, 1999). Attachment-related differences in the ability to regulate strong emotions (especially within the context of autonomy development) have been found to mediate this developmental risk (e.g. Zimmermann, Mohr, Spangler, 2009); an insecure attachment organization might thus be seen as a risk factor for developing affective or behavioural disorders during adolescence. In community samples, adolescent insecure-ambivalent attachment has been linked to internalizing symptoms (depression, anxiety, and social withdrawal), while insecure-avoidant attachment has been found to be more strongly associated with externalizing symptoms (Allen, Moore, Kuperminc, Bell, 1998; Kobak, Cole, 1994). Studies with clinical populations have consistently reported an overrepresentation of insecure and disorganized attachment representations among adolescents diagnosed with affective, behavioral, or personality disorders (Adam, Sheldon-Keller, West, 1996; Rosenstein, Horowitz, 1996; Wallis, Steele, 2001).

Adolescence from a Neurodevelopmental Perspective

However, adolescence might as well be seen as bearing new chances: As neuroimaging data of the developing adolescent brain show, a second phase of axon growth spurt and subsequent pruning takes place right at the intercept between late childhood and early adolescence (Thompson, Giedd, Woods et al., 2000; for a critical review see Paus, Keshavan, Giedd, 2008). This finding has been interpreted by the authoring NIMH research group as a kind of 'second chance' for those who have not been dealt life's most fortunate cards so far (in terms of impoverished or dangerous neighbourhoods, harsh and hostile parenting styles, or even abuse and maltreatment). This phase of heightened brain plasticity further coincides with the development of formal-operational thinking (Piaget, 1972). From an attachment approach towards these results, entering formal-operational modes of thinking at a time of heightened brain plasticity might indeed be interpreted as a chance to re-approach one's own (negative) attachment experiences and to re-appraise them. In other words: to actively remodel one's own brain.

Indications of remodelling processes are evident but hardly acknowledged in attachment research. Recently, though, Roisman and colleagues (2002) complemented attachment classifications (Main, Goldwyn, 1998) with a category that they dubbed "earned secure" (as opposed to "continuous secure") to emphasize that such individuals actually gained their attachment security despite aggravating circumstances. Not surprisingly, at least not from a neuro-developmental approach to attachment, the earned secure category cannot be found before adolescence.

Adolescence from a Multidisciplinary Perspective

However, attachment research and clinical research within the framework of attachment theory only begin to link with neurosciences (e.g. Buchheim, Erk, George, 2006; Lemche, Gieampietro, Surguladze, 2006) and to acknowledge the necessity of a multidisciplinary approach towards the neural underpinnings of attachment, (mal-)adjustment, and psychopathology in adolescence (Goldsmith, Pollak, Davidson, 2008).

It is only within a multidisciplinary framework, however, that we might actually begin to explore and grasp the far-reaching implications of NIMH's findings. Firstly, these data – if thoroughly understood – could have fundamental practical implications for psychological interventions (Pollak, 2005). We can now examine how psychological treatments can induce neural changes at critical developmental turning points and thus foster recovery or prevent mental illnesses in the first place (Paus, Keshavan, Giedd, 2008, p. 955). Secondly, as it diffuses into common knowledge, the finding of brain (re)modelling processes during adolescence might also have economic consequences, well comparable to the discovery of prenatal learning processes that lead to a whole new industry of 'train your baby's brain' commercial products like "Beethoven for Babies: Brain Training for Little Ones" or the "Baby Einstein" product line by Disney. Moreover, as it tackles the philosophical question of agency and taps into the relation not so much of mind and body but, more specifically, of mind and brain, NIMH's findings might also have a substantial impact on our image of humanity itself – and thus need to be handled with great care with regard to neuroethics. An example of such a careful handling would be the annual "Brain Awareness Week" (BAW), an interdisciplinary science and health education fair with the purpose of teaching children and adolescents how their brains work.

With neuroimaging techniques, we now have a means to directly, but non-invasively, explore the neural mechanisms that may moderate the above-mentioned relationship between attachment-related vulnerabilities, formal-operational thinking, and brain (re-)modelling processes. Teaming up with clinical psychologists, developmental psychologists, and educational scientists, neuroscientists could begin to explore the intricate interplay between the developing adolescent brain and the adolescent's potential to actually make use of his/her brain's potential for self-improvement. With my application I wish to take a first step towards establishing such a multidisciplinary collaboration on brain development and brain awareness with the purpose of originating a developmentally sensitive health education program, such as the BAW, for children and adolescents.

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Modeling Bottom-up Visual Influence in Decision-Making

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Background

How do people make decisions? It is an obvious fact that decision-making is a product of bottom-up and top-down processes. However, the exact nature of interaction between two types of processes is still an open question. Let’s consider two situations in relatively similar environments, but with different goals. In the first situation, the person is in a parking lot and looking for his or her car. In this case, the top-down processes completely control the direction of attention. The person has an internal conceptual knowledge about the location of the parked car and its visual properties. This knowledge is used to explicitly decide the parts of the visual scene that should be processed. However, let‘s consider a different situation where a person is in an auto salon with a goal of buying a new car. Assuming that the person does not have previous knowledge about the visual world (in this case the auto salon) the explicit top-down control cannot be applied. Instead, he or she has to do an explorative scanning by eye movements, which is the quick direction of the attention from one part of the visual scene to another. Here, an interesting question arises: which car in the salon will grab the attention first? Otherwise, is explorative scanning a random process or a guided process? If it is the second case, then is it guided by internal assumptions about the world or by the perceptual properties of the visual scene itself, or maybe both? Finding the answers to these questions is the aim of the current study. It is our hypothesis that explorative scanning is not a random process. Instead, the pattern of eye movements, otherwise known as scanpath, is defined by the salient elements of the visual scene. We further assume that the saliency of the visual object is dependent on bottom-up and top-down elements of the visuo-spatial cognition. The bottom-up features include the perceptual properties of the objects such as color, shape or size. The top-down features include internal conceptual knowledge and assumptions about the object, previous experience with it and importance to the current goal. Following the previous example with the car salon, the person might choose to look at the closest cars or the cars with shiny colors. Here, the scanpath is defined by bottom-up features, such as color or the perceptual depth. On the other hand, the person might be interested in a small car. This implicit top-down bias may influence the salience and limit the visual scan to small cars. Furthermore, the interaction between top-down and bottom-up features can narrow down the visual areas of interests to small cars with shiny colors.

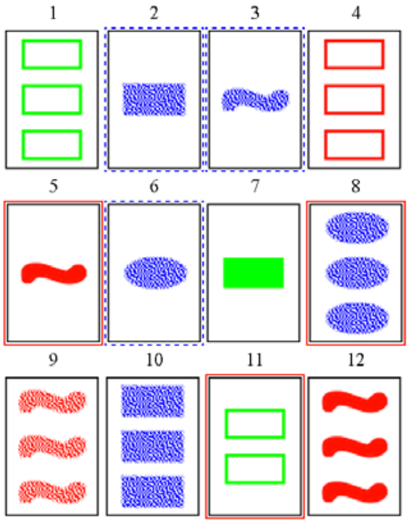

Fig. 1 An example array of 12 cards. The cards with the solid highlight form level 4 set (all attributes are different), and cards with dashed highlight form level 1 set (Shape is different)

Methods

In this study, we are interested in revealing the effects of bottom-up elements on saliency of the visual objects during the visuo-spatial cognitive task such as explorative scanning. For this purpose we have chosen the card game SET. The SET card deck consists of 81 cards. Each card differs from other cards by a unique combination of four attributes: color, number, shape and shading. Each attribute can have one of three distinct values: red, green and blue for the color attribute; open, solid and textured for the shading attribute; one, two and three for the number attribute; and oval, rectangle and wiggle for the shape attribute. The gameplay for SET is relatively simple. At any moment in the game, 12 cards are dealt open, as it is shown in Figure 1. From those 12 cards, the players should find any combination of three cards, further referred to as a set, satisfying the main rule. This rule states that in the three cards, the values for a particular attribute should be all the same or all different. The number of different attributes in set cards can range from one to four. Figure 1 shows examples of level 1 (different shape) and level 4 sets (all four attributes are different).

In earlier studies of SET (Jacob, Hochstein, 2008; Taatgen et al., 2003), it was suggested that the bottom-up features, such as perceptual similarity of the cards, play a dominant role in choosing the path for the explorative scanning. The players prefer to search for a set among a group of cards that have one or more attribute values in common. Furthermore, it was proposed that the choice of the group of cards depends on the group‘s size. For example, if there are six red cards and four green cards, then the player will prefer to look at the group of red cards. If those assumptions hold, then SET is an excellent example of the task where decision-making is heavily influenced by the visual world. We investigate whether the above assumptions hold in our experiment with SET.

As opposed to previous studies, we use eye-tracking equipment to obtain direct evidence about the subject's behavioral data. In total, 14 subjects participated in the experiment. The age of the subjects ranged from 20 to 30 years. All subjects were either students or staff members of the University of Groningen. Every subject was asked to do 60 trials. An EyeLink 1000 eye tracker was used for recording subjects' eye movements during the experiments. The group of 60 trials was the same for all subjects. Each trial consisted of 12 cards shown on a computer screen and arranged in an array similar to the one show in Figure 1. Each trial had exactly one combination of three cards that formed the set. All 60 trials were randomly generated with the constraint that all four levels of difficulty were equally represented in the experiment. In 30 trials, one of the set cards was highlighted with the red border. The highlighted card belonged to the set and served as a clue for the subject to find the other two cards. This abstract discusses the results from the analysis of the trials with highlighted cards only. Finally, it is an interesting research question whether an ACT-R (Anderson, 2007) model can manifest the same pattern of eye movements as the human players.

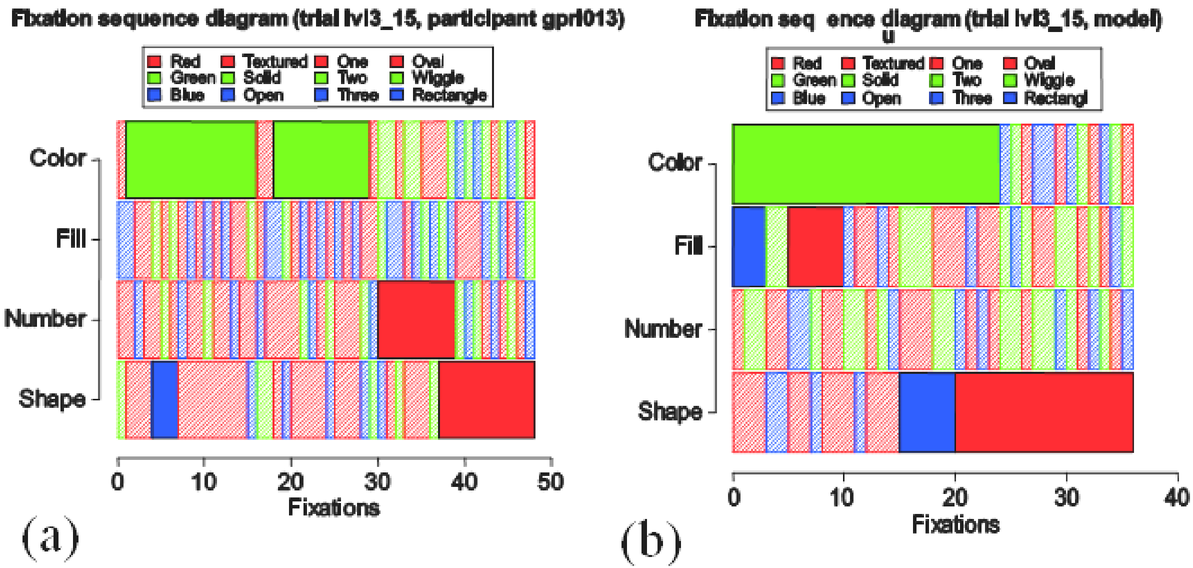

Fig. 2 The fixation sequence diagrams for trial lvl3_15; (a) subject gprl007 and (b) model

Results

Previous sections discuss how the strategy of playing SET is very much dependent on the bottom-up visual properties of the game. Among others, the perceptual similarity of the visual objects plays an important role. To demonstrate how subjects use the perceptual similarity to scan the cards, we first look at a particular example. Figure 2a shows subject's fixation sequence diagram for the trial "lvl3_15". Within the diagram, the subject's fixation sequence is represented four times (four separate lanes), each time from the perspective of one of four attribute types. One unit on the x-axis represents fixation on one particular card, while the corresponding bars on four lanes represent the attribute values of that card. The consecutive fixations on the cards with the same attribute value are shaded with solid color if the probability of such fixation subsequence occurring by chance is equal to or below 0.01. The figure shows that the subject looked at first at cards with green color, then at cards with one shape in it and finally at cards with oval shape. This fixation pattern is not a result of random chance. Figures 3.a and 3.b show the expected proportions of fixations (assuming that the fixations happen at random) on green cards and cards with oval shape. Expected proportions are contrasted to subjects' actual observed proportions. As demonstrated, the observed proportions are significantly higher than the expected proportions, indicating that there is a preference for green and oval. Furthermore, such similarity-based visual scanning is not an effect isolated to one trial only. Our analysis indicates that blocks of fixations with the same attribute value (similar to ones shown in Figure 2.a) occupy on average 80% of a fixation sequence. This result indicates that subjects use perceptual similarity-based scanning on average 80% of the time in each trial. Figure 4 shows how these 80% distribute over the four attribute types. The figure shows interesting effects on subjects' discrimination of attribute types. The subjects are twice as likely to look at the group of cards with the same color than any other attribute type. Overall, the results suggest that the four attribute types have different saliency properties with color being most salient and shape and shading being the least salient. Finally, the saliency of the particular attribute value depends on group size as well as the attribute type. This effect can be observed in Figures 3.a and 3.b describing trial lvl3_15. In this particular trial, the group of green cards is bigger in size than the groups of blue or red cards. As a result the subjects paid more attention to groups of green cards than to groups of blue or red cards (the latter two groups received even less attention than they were supposed to based on random chance). The similar effect of size with the shape attribute can be seen in Figure 3.b. Finally, it is interesting that (Figure 2.a) the subject immediately knew where the green cards were on the screen without paying explicit attention to them. This suggests that the decision about the fixation points, or scanpath, is made implicitly on the bottom-up level without explicit top-down control.

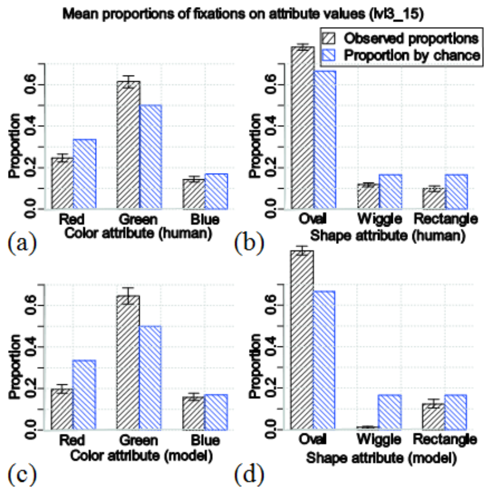

Fig. 3 The figure shows the expected and the observed distributions of fixations' proportions on cards with particular attribute values. The proportions are calculated with respect to color and shape attributes. The calculation was done with the assumption that the choice of the next card to be fixated is random

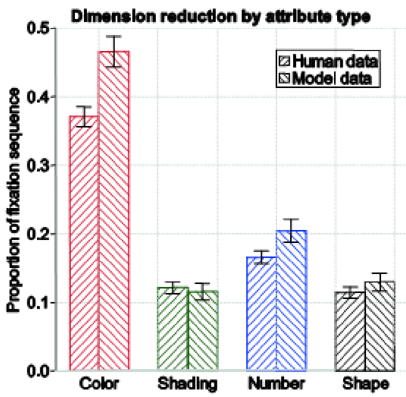

Fig. 4 Mean proportions of attribute types used in similarity-based scanning (overall for all subjects and trials with the highlighted card)

The players generally follow a top-down strategy of choosing a group of cards and looking for a set among those cards. However, as evidence suggests, the choice of the group and resulting scanpath are very much dependent on bottom-up visual features of the cards. The players prefer to look at the groups of perceptually similar cards: sharing one or more attribute values. The choice of the group depends on saliency, which itself depends on group size and attribute type. The bigger the group, the more salient it will be. Among four attribute types, the color is most salient followed by the number, while the shape and shading are the least salient.

Based on the findings of this experiment, the ACT-R model of a SET player was created to test whether it will elicit the same behavior as the human players. The model was required to play the same set of trials as the human subjects. In each trial, 12 cards were presented to the model. In the trial, one card was always highlighted indicating that it belongs to a set. The model had to find the other two cards completing the set.

Similar to the human players, the model searches for a set within group of cards that share some attribute value. If the model fails to find a set in the current group, then it selects another attribute value and corresponding group of cards to search. The cycle repeats until a set is found or the time limit is reached. This strategy works surprisingly well and even produces pattern of eye movements similar to those observed in human players (Figure 2.b). The choice of the attribute value depends on its saliency. Saliency is not a constant feature and is calculated each time a new attribute value is chosen. Saliency depends on several parameters such as number of times the attribute value was used previously, the last time it was used, etc. However two main parameters defining the saliency are attribute type and size of the group. The color is generally the most salient attribute type, followed by number, while the shape and shading are the least salient types. Defining separate saliency values for attribute types works quite well for modeling the players' bias to attribute types (Figure 4). The increasing logarithmic function was used to model the effect of group size on saliency. As is shown in Figures 3.c and 3.d, the resulting effect of the group size is very similar to the one observed in the subjects' trial. Overall, the model is very good at replicating the players' behavior in the game of SET. It has a very nice overall fit to human reaction times as is shown in Figure 5. The model, indeed, supports our assumptions that the bottom-up visual elements play an important and even decisive role in SET.

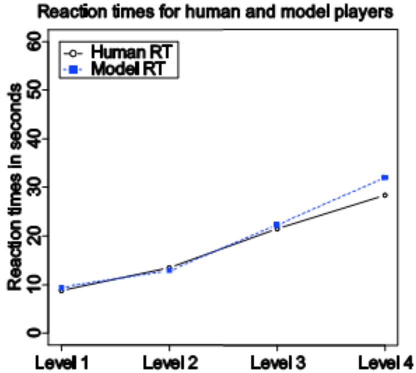

Fig. 5 The mean reaction times of the model comparing to the mean reaction times of the human players

Conclusion

In this study, we have investigated the importance of bottom-up visual elements in the game of SET. It is very likely that the results from this study can be generalized to real-world complex tasks which require complex top-down planning that is also heavily influenced by the visual world. We hope to contribute to the understanding of visuo-spatial cognition where both internal conceptual knowledge and external perceptual stimuli converge in a goal-driven task. In future work, we are interested in a more detailed study of implicit top-down influence on the perception of the visual world. Do conceptual knowledge and the current goal influence the saliency of objects in a visual scene? If such an influence is present, then we are interested in studying its mechanisms and ways to model it within a cognitive architecture.

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Neural Correlates of Affective Feedback Processing in Children

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Introduction

Neural correlates of feedback processing have been investigated in many studies by means of event-related potentials (ERPs) and functional magnetic resonance imaging (fMRI), but studies on children are still rare. The present fMRI study aims to investigate the impact of affective information on feedback processing, which is a key variable of interest in cognitive control. It is part of a larger study that aims to investigate the effects of a reattribution training on behavioural performance and on neural correlates of affective feedback processing (cf. Anschütz et al., this volume). Here we report results obtained on children, before the remediation program was conducted at their schools.

Methods

Forty-eight healthy children (10–13 years) performed a task requiring rule-based matching of chemical structures (pseudo formulas) with their respective names. In a learning phase outside the scanner children performed paper and pencil tasks to learn rules of the pseudo formulas and afterwards attended a short computerized training of the experimental task in a mock scanner. During scanning (Siemens Magnetom, 1.5T) children were shown two simultaneously presented chemical pseudo formulas and one name for 4.5 sec. They had to decide via button press which of the formulas matched the presented name. After a variable delay (2–18 sec.), they received positive or negative visual feedback (2.5 sec) depending on performance. The affective value of feedback was manipulated within subject by providing feedback of high affective value (indicating that the performance was better or worse than those of an alleged peer group) or feedback with low affective value (indicating that the performance was similar to that of an alleged peer group). Overall, 80 chemical formulas were presented in two runs. Data were analysed with a random effects model comparing neural activity to i) positive feedback with high affective value vs. positive feedback with low affective value and ii) negative feedback with high affective value vs. negative feedback with low affective value. Activations are reported at a voxel-level significance threshold of $p<.001$, uncorrected, with an extend threshold of 20 voxel.

Results

Our results revealed that manipulation of the affective value of positive and negative feedback yielded a strong effect in several brain regions. Positive feedback with high affective value (performance better than alleged peers) compared to positive feedback with low affective value resulted in significantly more activation in the perigenual anterior cingulate cortex, the left inferior frontal cortex and the left posterior superior temporal cortex. For the affectively more demanding negative feedback condition (performance worse than those of alleged peers) we obtained signal increases in both posterior temporal cortices. Interestingly, more activation in bilateral orbitofrontal cortex and bilateral striatum was found for the negative feedback condition with low affective value (performance similar to that of peers) compared to the condition with high affective value.

Conclusions

We modulated the affective value of corrective feedback by additionally providing children with information about their performance relative to an alleged peer group. With highly affective feedback we obtained increased neural activity both in reward-related brain areas and areas known to be involved in the processing of self-relevant information. Interestingly, negative feedback with low compared to high affective value was associated with increased activation of reward related areas in the orbitofrontal cortex and the striatum, which may be due to relief when faced with a “better than expected”-outcome.

Acknowledgements

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“A Sound Brain in a Sound Body”

Current Status and Future Prospects on Addiction, Stressful Lifestyles, and Education from a Neuroimaging Point of View

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According to the Latin poet Juvenal, the first thing that people should desire in life is a “*mens sana in corpore sano*”, which can be translated into “*a sound mind in a sound body*”. Even if cognitive neuroscientists are far from an ultimate answer to the relationship between brain and mind, which is one of the greatest issues for neuroscientists, philosophers, and educators, in recent years, the development of neuroimaging techniques such as the Diffusion Tensor Imaging (DTI), the Positron Emission Tomography (PET) and the functional Magnetic Resonance Imaging (fMRI), enable the scientific community to see the brain *in vivo,* and thus what happens to neural structures under certain experimental conditions, which provides fundamental information on structural and functional organization of the brain. However, these promising techniques suffer from spatial and temporal constraints (Logothetis, 2008), and future brain research will aim to achieve better image resolution, improving both the physical principle underpinning the neuroimaging device and the designs of the experimental paradigm. Adopting the neuroimaging perspective, here we focus on three emerging issues that are typical of 21st century society and that can derive benefits from interdisciplinary exchanges between neuroscientists and educators:

- the neurobiological basis of addictive behaviors;
- the relationship between stress and the brain;
- the role of education in delaying the onset of degenerative disease.

By the term addiction, we refer to a physical and psychological dependence on certain substances like tobacco, alcohol, or drugs. Apart from the diagnostic criteria used to label patients suffering from a specific addiction, it is important to note that neuroimaging acted as a propellant to the investigation of neural networks, making brain science an even more rapidly-growing field of research: neuroimaging permits the development of an inter-disciplinary field, hosting cultural crosstalk between psychiatrist, neurologists, neuroscientist, psychologist and educators on certain topics, such as the neural basis of addiction. Thanks to this interdisciplinary field, other sources of addiction have recently been identified. The internet, for example, is a powerful tool we use everyday to work and to keep in touch with friends across the world, but at the same time, it can pose a great risk, particularly for people more susceptible to addiction. In fact, since not all children are equally susceptible to the so called "internet addiction" (Guan and Subrahmanyam, 2009), it is necessary to identify those most at risk and to develop effective interventions as well. This paper mainly focuses on the neurobiology of addiction and on the main aspects that future investigations need to analyze, primarily from the neuroimaging point of view and subsequently through a multimodal approach – namely a combination of genetic, behavioral, psychometric and neuroimaging markers – to prevent the onset of the symptoms of addiction. But before (and also after) this kind of screening approach will be available, the role of the educators is crucial in making young people aware of the potential risks and health dangers they face when they abuse the web services.

Moreover, neuroimaging techniques allow researchers to see the effect of stressful lifestyles on the brain: the impact of a stressful life on the cerebral structures have been extensively investigated since the seminal works by Seyle (1955) and we currently know what the stress cerebral modifications from both a murine (Kolber, 2008) and human perspective (Dedovic et al., 2009) are. Here, we review previous studies that shed light on these modifications and postulate some coping styles derived from clinical psychologist that can be useful in coping with stressful situations.

Our brain is not a static organ, but a rather plastic structure: we have approximately 10^{11} neurons and we have more synapses in the brain than there are stars in the sky (approximately 10^{14}). These neurons have a limited life, since there is a continuous cellular turnover sustained by a certain type of cells (the so-called neural stem cells) that are able to generate new neurons, substituting old cells with new ones at different rates and to different extents according to our life stage. Unfortunately, in neurological disorders – such as Alzheimer's disease, Parkinson's disease, and multiple sclerosis – this mechanism seems to be impaired, thus leading to massive neuronal degeneration that causes cognitive and/or sensory-motor impairments. At the moment, we don't have an ultimate treatment for all of these degenerative diseases, but some educational factors can play a key role in designing successful preventive strategies. Recent neuroimaging studies, in fact, suggest that there are some educational factors that can be encompassed under the umbrella term of "cognitive reserve" (sometimes also called "cognitive buffer"), which acts as a protective factor in neurodegenerative diseases. For example, the variability of clinical manifestation of dementia may be explained, at least in part, by individual differences in environmental and social factors not only in adult or late life but also in childhood and youth (Scarmeas and Stern, 2003); moreover, the "cognitive reserve" can reduce the severity and delay the onset of Alzheimer's disease. But what are the activities encompassed by the word "cognitive reserve"? Evidence-based works indicate that highly educated subjects (as well as subjects with high values of occupational level throughout life) can cope better than less educated subjects with the same level of Alzheimer's disease changes in the brain: since the brain is plastic, it's highly probable that they recruited alternative neural circuits to support cognitive function (Garibotto et al., 2008). In a recent work by Craik and colleagues (2010), the authors discovered that lifelong bilingualism is also an important "cognitive reserve" variable since it confers protection against the onset of Alzheimer's. Other research underlines the importance of the contribution of premorbid leisure activity (such as reading and other hobbies) to "cognitive reserve" in Multiple Sclerosis patients (Sumowski et al., 2010). In the light of this evidence, what can be done by neuroscientists and educators to prevent neurodegenerative disorders through education? This evidence-based scenario provides interesting possibilities for both neuroscientists and educators. On the one side, basic brain research should go on investigating the mechanisms underpinning neurodegenerative disease, but at the same time, neuroscientists should be in close dialog with the education world – perhaps through the creation of a high quality neuroscientific committee – to communicate the result of their discoveries. On the other side, the educators should act as intermediaries between the neuroscientists and the target population, with the aim of promoting behavior capable of increasing the amplitude of the "cognitive reserve". This goal can be achieved, for example, through: 1) the organization of events in primary and high schools, in which early childhood second language education, reading books, and other hobbies are promoted; and 2) the creation of a free, high quality e-learning platform for those who are in the potential pre-morbid age, with different target populations according to the statistical onset of the degenerative disease.

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Application of a New Computational Theory of Mental Imagery to Neuroscientific Results

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Theoretical Background

Fields of research such as brain-imaging methods and eye tracking yield new empirical constraints for theories of mental imagery. Unfortunately, all relevant contemporary theories are described on an often abstract level and partially lack formalization of their assumed structures and processes, so that it becomes hard to judge how well they actually consistently explain all the results from different fields.

We present a new theory of mental imagery, termed attention-based quantification theory, which is also implemented as a computational cognitive model. The model is part of the cognitive architecture Casimir, which emphasizes analogical representation structures in processing of spatial knowledge (Schultheis, Barkowsky 2011). Our model offers a consistent explanation for a range of phenomena not covered by other contemporary theories on their own. Additionally, the model makes predictions about which imagery tasks and inspection processes lead to simultaneous eye movements. The implemented structures and processes suggest new ways of how many imagery phenomena, e.g. cognitive penetration and mental reinterpretation, might come about.

We briefly review selected results of neuroscientific studies, in particular results drawn from studies with brain-damaged patients. We give an outlook on how the theory can be related to these results and how the model can potentially replicate empirical data of, for example, imaginal neglect. We hint at how the application of a cognitive computational model to neuroscientific findings can facilitate further empirical investigations.

Methods/Project Plan

Attention-Based Quantification Theory

Our theory explains mental imagery as the attention-based quantification of information. We assume two distinct structures: the Qualitative Spatial Representation (QSR), which represents concepts, parts, and their spatial relations on a qualitative level, and the Visuo-Spatial Attention Window (VSAW), which corresponds to an internal attention focus that makes spatial relations and shape information conscious by attention shifts. There is no "percept" or quasi-picture of the mental image. Shapes are "imagined", i.e., their properties (e.g. height and width) are made conscious, by executing corresponding attention shifts that define the shape. Accordingly, shape information is stored and retrieved as a set of vectors of relative length connecting and defining visual features, e.g. a right angle.

In the following description of the model, we refer to a long-term memory structure, which is, however, not part of this cognitive model, but of the architecture Casimir (Schultheis et al 2006).

Qualitative Spatial Representation (QSR)

The QSR holds active content retrieved from long-term memory and is implemented as a hierarchical tree structure. It contains the minimal necessary information that is used to generate a mental image. This information includes a qualitative configuration of the imagined scene or complex object, e.g. spatial relations, part-of relations, and relative sizes.

The QSR is extended on demand with new parts and concepts from long-term memory when more details are required. The QSR is used to guide the Visuo-Spatial Attention Window (VSAW) during processing of mental images. Furthermore, it temporarily stores information provided by the VSAW such as concrete coordinates and distances or new spatial relations between imagined entities. This information can be used either for solving a task, feeding it back to the VSAW later, or storing it into long-term memory.

Visuo-Spatial Attention Window (VSAW)

The VSAW operates as an internal focus of attention. It is defined by its coordinates and its resolution. It can be best understood as a circular fraction of an imagined visual field; the radius of this circle is determined by the VSAW's current resolution. We distinguish two possible resolution modes:

high, which results in a smaller radius and low with a larger radius. High resolution is required to process shape information that spans over a smaller extent. These two modes of resolutions can be compared to central and peripheral vision during perception.

The VSAW changes its coordinates successively as if it was moving within a visual field. It is moved only if the to-be-reached coordinates are outside the area currently covered by its circular extent. If this is not the case, a covert attention shift is executed without changing the VSAW's coordinates. Attention shifts that cause the VSAW to move are overt attention shifts, which we predict to correspond to eye movements. We argue that the attention shifts of the VSAW at least partly use processes and structures also used in visual perception. In particular, we assume a connection between the VSAW and motor areas responsible for saccades. This also follows from our assumption that shape information is represented as a set of low-level features and inspection vectors between them, i.e., a shape is represented by how we look at it (cf. O'Regan, Noe 2001).

The VSAW serves two main functions during imagery: 1) determining the location, i.e., coordinates, of entities by making qualitative spatial relations concrete, 2) inferring spatial relations. We further distinguish the application of these functions on what we term "scene level" and "shape level".

First, we will look at the "scene level", i.e., the imagination of a scene or complex object: the qualitative relations of, for example, a scene depicting a tree next to a house are made concrete by linking the concepts and their parts to coordinates by changing the VSAW's coordinates to the respective locations. The concrete coordinates of the center of the tree relative to those of the house are calculated by taking into account the qualitative spatial relation between those entities. For example, the spatial relation includes the qualitative distance "close" and the direction "left of". Based on the extent of the shape of the house and a default quantitative translation of "close" the new coordinates are calculated. The inference of spatial relations can be described as an inversion of the above process. Given the previously calculated coordinates of two entities, the shift of the VSAW makes the corresponding spatial relation between them conscious. On the "shape level" the same functions are executed based on shape information in contrast to the qualitative configuration given by the QSR. Shapes are represented by a set of inspection vectors that indicate the relative position between features. Concrete distances, such as the height of a building compared to a tree, are made conscious by the shifts of the VSAW along the given vectors. Information such as height of a shape and the location of a feature of a shape are temporarily stored in the QSR after they were made conscious.

Neuroscientific Insights into Mental Imagery

Neuroscientific insights pose new arguments and constraints regarding the imagery debate. We will briefly discuss two main topics in this area: 1) imaginal neglect, and 2) the distinction between spatial and object imagery.

Imaginal neglect is a phenomenon documented in some patients that suffer from left unilateral neglect due to damage to their right parietal cortex. Left unilateral neglect is the failure to pay attention to the left side of ones visual field as well as to the left side of objects. It has been shown that some left unilateral neglect patients also show left imaginal neglect, which is the failure to attend to the left side of ones mental images (Bisiach, Luzzatti 1978). Descriptive theorist Pylysyhn (2002) admitted that these results can hardly be explained with propositional representations. Also the visual buffer of quasi-pictorial theory, which is hypothesized to hold mental images as well as percepts from visual perception, cannot directly account for these results as unilateral neglect and imaginal neglect can be dissociated (Bartolomeo 2002).

The existence of two functionally and anatomically distinct processing streams in vision as well as in imagery is a generally accepted neuroscientific finding (Ungerleider and Mishkin 1982, Levine et al. 1985). The dorsal stream, or “where” pathway, is associated with the representation of spatial information, e.g. spatial maps, spatial relations. The ventral stream, or “what” pathway, is associated with the representation of visual information, e.g. color and shape. Furthermore, two types of mental imagery have been distinguished according to these two pathways. They are often referred to as spatial and visual imagery. Results from brain damaged patients have shown that many imagery tasks fall into one of two categories and thus rely on different neural substrates (e.g. Farah, Hammond 1988).

Expected Results

Application of the Model to Imagery Phenomena

The presented theory can in some aspects be understood as a hybrid of descriptive theory (Pylyshyn 2002) and quasi-pictorial theory (Kosslyn 1994). Propositional theory claims that imagery is not based on spatio-analogical representations and that a propositional representation is sufficient to explain the empirical data, whereas quasi-pictorial theory believes mental images to be picture-like “percepts” which are processed. For both theories there are empirical results which support one theory and pose problems to the other, e.g. mental scanning supporting quasi-pictures and hardness of reinterpretation supporting descriptive theory. The two-components structure and the different levels of processing of our model allow it to simultaneously explain both types of empirical data within one consistent explanatory framework. In the scope of this paper, we cannot go into detail and instead refer to Sima (2011) for a detailed evaluation of the model.

Application of the Model to Neuroscientific Results

Imaginal neglect, i.e., the inability to attend and inspect the left side of ones mental images, could be reproduced by modifying the model’s VSAW. The VSAW’s range of coordinates could simply be restricted to one side so that attention shifts into and inside one half are inhibited. The necessary information to generate a complete image would still be represented in the QSR, but it cannot be made conscious without the respective attention shifts that are needed to place, for example, parts on the left side of an object. When changing the imaginal point of view (e.g. looking at the object from behind), patients are – and the model would also be – able to then imagine previously neglected parts of the image (Bisiach, Luzzatti 1978), as they would then be linked to the coordinates on the other side, which are still accessible.

Farah and Hammond (1988) report a brain-damaged patient whose visual imagery ability is impaired while his spatial imagery ability is normal compared to a group of healthy adults. They have employed a set of different imagery tasks both for spatial and visual imagery. We will look at one selected task from each category and try to identify the aspects of our model, which could be responsible for the patients altered ability. A typically visual imagery task employed required a size comparison between objects of similar size, e.g. a pack of cigarettes and a popsicle. It is assumed that this task requires the retrieval of shape information in order to make a successful comparison. The patient performed clearly under par in this task. One of the spatial imagery tasks was the matrix memory task which consists of recalling a previously presented sequence of how the numbers 1 to 8 are placed inside an imaginary 4x4 matrix. The verbal instructions were as follows “Put 1 in the starting square, put 2 in the square to the right, place 3 in the square below, …”. The patient was able to recall the resulting path as accurately as the control group.

Farah and Hammond (1988) conclude that the patient's visual memory recall is impaired while his general ability to generate mental images is conserved.

Our model can easily be adapted to simulate this lack of visual memory recall, as this type of memory is distinguished in the model in that is it retrieved by the VSAW in contrast to other memories that are accessed by the QSR. Furthermore, disabling the visual memory retrieval would lead the model to behave similarly to the mentioned patient: the size comparison tasks could not be fulfilled anymore as the VSAW makes shapes and especially width and height of a given shape conscious based on the retrieved information from visual memory (i.e., inspection vectors defining the shape and its features). The matrix memory task would be unaffected by this impairment as the path connecting the numbers stored in the QSR could still be quantified, i.e., made conscious, by attention shifts of the VSAW without the need for any shape information. Note that this impairment essentially forces the model to only operate on the above mentioned "scene level" and effectively disables the "shape level". This means that the already incorporated processing levels of the model pose a possible explanation of the relationship between visual and spatial imagery.

Conclusions including Potential Links and Cooperation:

We have presented the attention-based quantification theory of mental imagery and its implemented computational model. We showed how the model could be applied to simulate neuroscientific, in particular neuropsychological, imagery phenomena. We believe that the application of a computational model in this area not only has the potential to provide new insights about the relationship between neural substrates and mental representations, but that it may also further facilitate new theoretical and empirical investigations in both neuroscientific research and cognitive modeling of mental imagery. A computational model has the advantage that it can offer precise predictions and pinpoint open theoretical issues. The distinction between the shape and scene level processing, which derives from the implementation, and its possible equivalence to spatial and visual imagery, could, for example, be concretely tested utilizing brain-imaging methods.

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Risk Factors for Sleep Disturbances in Adolescents

Results of a Representative Study

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Theoretical Background

Puberty is a time of transition between child- and adulthood that is paralleled by changes in sleep- and wake behavior in adolescents. While 9–10 year old children usually sleep 10 hours on average on school nights, the number of hours asleep decreases with puberty (Carskadon et al., 1981). This was hypothesized to be caused in part by a biological preference of adolescents for a later circadian phase, meaning that adolescents have the need to go to bed later and get up later in the morning (Carskadon et al., 1993). Delayed circadian preference is thought to be biologically driven and can be influenced by light, especially blue-wavelength light (Carskadon et al., 2004; Millman, 2005). In adolescence school hours often clash with preferred bedtimes resulting in shortened sleep and daytime sleepiness.

Unrestorative sleep and daytime sleepiness in adolescents has been shown to have a large impact on cognitive tasks such as motor performance, reaction times and working memory (Millman, 2005) and might thus lead to decreased school performance. Previous studies have shown an association between media use (Li et al., 2007), including TV exposure and sleep disturbances in 5–9 year old children (Paavonen et al., 2006). Additionally, a study of US-adolescents (age 12–17) has linked alcohol, cigarettes and drug use to sleep problems (Johnson, Breslau, 2001). In a representative study from Finland, adolescents were asked about their sleep quality. This investigation revealed that 10% were satisfied with their sleep quality, 30% of the adolescents had experienced problems falling asleep, while 20% of the students reported having sleep problems at least once a week (Tynjälä et al., 1999).

However, since there are limited representative studies on sleep in German adolescents, the aim of the current study was to identify the role of possible risk factors for sleep disturbances such as socioeconomic status, specific behavior and further socio-demographic variables.

Methods

In 2005, public health services in the city of Stuttgart, Germany, conducted a study “Jugendgesundheitsstudie” (JUGS) to evaluate health status among adolescents. Questionnaires were distributed to students and parents in a representative sample (n = 546, average age = 14.7 years) of eighth and ninth graders and physical exams were carried out.

To identify possible risk factors for sleep disturbances in adolescence, questions concerning sleeping behavior among adolescents were evaluated as well as questionnaires regarding socio-demographic characteristics and habitual behaviors, such as the Strength and Difficulties Questionnaire and the Social Class Index by Winkler. All questionnaires were in German language. The following three questions could be used as a measure for insomnia:

Question 25:	In the last week how often have you felt tired and exhausted?
Possible Answers:	never / rarely / sometimes / frequently /always
Question 40:	How many hours did you sleep last night?
Question 41:	Do you have difficulties sleeping?
Possible Answers:	yes, I have problems falling asleep / yes, I have problems staying asleep / no

Feeling tired and exhausted during the day in addition to difficulties initiating sleep or difficulties maintaining sleep are the important aspects of the criteria for primary insomnia according to the International Classification for Disorders (ICD 10). Therefore, for further analysis of the data, insomnia in this sample was defined as suffering from sleep-disturbance with either difficulties initiating or maintaining sleep in addition to reporting having felt tired and exhausted frequently or always in the previous week.

Data was statistically analyzed by Chi-Square Test and Mantel-Haenzel-Chi-Square Test for ordinal variables.

Results

The total response rate was 64%. For 546 students there was a complete data set. On average adolescents slept 8.04 ± 1.66 h. Difficulties initiating sleep were reported by 23.3%, while 11.2% complained of difficulties maintaining sleep. Insomnia was reported by 10.4%. Those suffering from signs of insomnia slept significantly less than those without signs of insomnia (7.15 ± 1.51 h versus 8.26 ± 2.0 h; Chi-Square Test: $p < 0.001$).

14.8% of the girls reported insomnia, whereas the boys' prevalence was only 4.5%. This sex difference was significant (chi-square test; $p < 0.001$). Similarly, girls reported to have significantly (Mantel-Haenzel-Chi-Square test; $p < 0.02$) more difficulties initiating sleep (27.8%) than boys (19.2%).

Lower social status was significantly associated with a higher frequency of difficulties maintaining sleep (Mantel-Haenzel-Chi-Square Test: $p < 0.02$) but not with difficulties initiating sleep and signs of insomnia.

Drug use could also be linked to sleep disturbances. Smoking was associated with elevated frequencies of signs of insomnia, initiating and maintaining sleep (Mantel-Haenzel-Chi-square test; all $p < 0.001$). Out of students who drink alcohol at least once per week, 16.9% were experiencing signs of insomnia, which was significantly (Mantel-Haenzel-Chi-Square test; $p < 0.05$) more often than in students who drank alcohol less frequently (9.2%).

Daily time spent watching television influenced frequency of signs of insomnia (Mantel-Haenzel-Chi-Square Test: $p < 0.02$) with a prevalence of 6% among the individuals spending less than one hour daily, 9.6% in those watching TV 1–2 h, and 15.2% in those watching TV more than 2 h. Additionally, frequency of insomnia differed in those using no cellular phone and those using one for more than one hour a day (5.5% versus 13%; Mantel-Haenzel-Chi-Square Test: $p < 0.05$). For time spent playing computer games no such associations were found.

A significant increase in frequency of sleep disturbance was also observed for experience of violence (Chi-Square Test: $p < 0.05$), experiencing pain in the last three months (Chi-Square Test: $p < 0.02$), and those exhibiting higher levels of hyperactivity (Chi-Square Test: $p < 0.03$). A strong effect was observed for emotional problems. Those reporting elevated emotional problems demonstrated two to three times more often disturbed sleep (Chi-Square Test: $p < 0.001$).

Conclusions including Potential Links and Cooperation

Every tenth adolescent in this population is suffering from the most important aspects of insomnia. In females insomnia is more common than in males, which is well known from adult populations. Interestingly, social status is associated with sleep disturbance. This might at least in part be due to decreased daily structure in families with lower social status in addition to possibly increased emotional problems. The finding that emotional problems are associated with insomnia is in line with sleep disturbance being a symptom and possibly a cause of depression. In turn, the emotional problems may be related to feelings of material and social insecurity which might be more common in adolescents from families with low social status. However, this needs to be explored in further multivariate analysis.

Insomnia was more common in adolescents who frequently drank alcohol, smoked cigarettes and used drugs. This is in accordance with results from Scandinavian and US studies and may be due to direct drug effects on sleep quality or be related to other factors such as more emotional problems in the adolescents who consume said substances.

Watching television more than 2 hours a day is a risk factor for insomnia. This can possibly be explained by over-stimulating effects of entertainment programs on TV. Unfortunately, the questionnaire did not ask about a TV in the bedroom. It can be hypothesized that adolescents having a TV easily available are more prone to watch TV, also during bedtimes. Consequently, eliminating the TV from the bedroom would have sleep improving effects. Similar aspects may be relevant for the use of cellular phones and the association with insomnia.

The discussed associations do not imply a direct causal relationship. However, in the cases of hyperactivity and being in pain, it is very likely that the link to insomnia is indeed causal. If these physical indispositions were treated, sleep would probably improve.

One further cause of the high percentage of adolescents reporting difficulties initiating sleep and daytime sleepiness may be the misalignment between school hours and preferred bedtimes. Although not specifically explored in this study, it might cause shorter sleep periods and thus lead to unrestorative sleep and daytime sleepiness. The most important factor in synchronizing biological rhythms is bright light. Optimized light in classrooms can do more than just influence circadian rhythm – as measured in an fMRI study (Vandewalle et al., 2007), blue wavelength light induces an instant increase in cortical activation during task performance compared to green wavelength light.

Therefore, it can be hypothesized that optimal bright lighting conditions in class rooms might first synchronize adolescents' sleep-wake behavior to school hours and secondly, enhance cortical activation. Furthermore, bright light is an effective therapy for psychiatric disorders such as depression (Terman, Terman, 2005) and has been suggested to be effective in the treament of alcohol dependence (Schmitz et al., 1997; Landolt, Gillin, 2001). In the classroom, it might not only enhance circadian alignment but also lower rates of drug and alcohol consumption in adolescents. Altogether, this might not only improve sleep quality, reduce daytime sleepiness, and enhance cortical activation, but it might also lead to lower problematic drug consumption in adolescents. Hypothetically, these factors lead to increased school performance.

Further studies are needed to investigate this hypothesis about the interrelatedness of the discussed factors on sleep quality and school performance. Experimental studies should examine the effect of bright light on cognitive task performance and sleep in adolescents, including EEG and fMRI analyses. Regarding lighting conditions and media use, intervention studies optimizing environmental factors at home and in the classroom might also shed light onto these interrelationships.

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Understanding Chemical Formulae – How to Develop Successful Strategies and Supporting Tools

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Introduction

The project „Feedback to Learn“ (cf. Oezyurt et al., this volume) investigated students' strategies on interpreting simple chemical formulae and the impact of feedback and supporting tools on the development of students' understanding. Chemical formulae were chosen as content for this interdisciplinary approach because on the one hand, they represent a highly systematic structure, which is indispensable for chemical education at school and later on. On the other hand, dealing with chemical formulae is very unpleasant and difficult for many students (cf. Schmidt, 1997) and a topic with negative associations in the memory of many adults. This sub-project therefore aims at investigating and developing successful supporting tools and strategies for the teaching and learning of chemical formulae at school. As a first step, the literature will be systematically analysed and enlarged by our own studies to define categories of learning difficulties. Based on these results, several ideas will be developed: a model of representation levels in chemistry, tasks for training teachers as well as an intervention study in schools.

Empirical background

Numerous national and international studies revealed remarkable student difficulties and even freshman students may find it difficult to interpret and apply chemical formulae and chemical equations; some results will be presented in the following paragraphs.[1]

1 A review-article is in progress in which all relevant studies to students' difficulties with chemical formulae and reactions are collected.

Understanding of symbols, factors and indices

In matters of chemical formulae, it is apparent that some students do not understand the meaning of stoichiometric factors, indices and charge numbers or confuse them (cf. Schmidt, 1990; Keig, Rubba, 1993). Moreover, not all students succeed in assigning these figures to the element symbols they belong to (cf. Keig, Rubba, 1993; Fischer, 2008).

Interpretation of meanings of chemical formulae

Simple chemical formulae only offer information about the atoms and their numbers combined in a chemical compound. Still, it could be observed that some students over-interpret chemical formulae. Some students think, for example, that the order of element symbols in a formula gives a hint for the bond sequence within the substances, so that CH_2O is said to represent a carbon attached to water. In addition, some students deduce a structural formula like H – N – O – O – O from a molecular formula such as HNO_3 (cf. Keig, Rubba, 1993).

Relating chemical formulae to particle models

Harsch et al. (2002) reported in their study that some students confuse stoichiometric factors with indices so that they do not connect submicroscopic drawings to chemical formulae in a correct way:

$\boxed{2\,N \rightarrow ●●}$ $\boxed{O_2 \rightarrow ○\ ○}$

It is also said that some students have an additive rather than an integrative view of a compound. This understanding makes them do attributions like:

$\boxed{N_2O_2 \rightarrow ●●\quad ○○}$

In addition, the authors noticed that some students chose integrative formulae for isolated diagrammed particles:

$\boxed{●●\quad ●●\quad ○ \rightarrow 2\,N_2O}$

Formulae in chemical equations

As documented in the literature, there are also several difficulties that students have with chemical equations. Not all students succeed in balancing a chemical equation (Musli, 2008) or in making correct connections between given chemical equations and drawings on the submicroscopic-level (cf. Nurrenbern, Pickering, 1987). For some students it is also difficult to draw adequate diagrams to given chemical equations (cf. Yarroch, 1985; Ben-Zvi et al., 1987; Harsch et al., 2002). Some students think that the chemical reaction symbol has the same connotation as a mathematical equal sign, so that they attribute a static meaning to chemical equations rather than a dynamic one (cf. Yarroch, 1985). Moreover, some students think that chemical formulae in equations represent only one single unit. This perception leads students to make declarations such as "*N_2O_5 cannot be formed – we had N_2 and O_2. Where from did we get three additional oxygen?*" (Ben-Zvi et al., 1987, p. 117).

Taking this literature research about students' difficulties as a starting point, an additional cross-sectional study (age 15 to 18 and student teachers) aimed to trace the development of students' understanding of the chemical formulae language. The questionnaire asked for knowledge about general information of formulae and equations, about levels of meaning of different representations and the overcoming of typical problems and alternative conceptions. The results showed the expected progress over time of schooling, but also underlined that students' difficulties with chemical formulae and equations, which have been found in studies before, are still present (cf. Heuer, 2009).

The literature research mentioned above revealed that in nearly all studies only the students' perspective was researched. The perception and appreciation of chemistry teachers, who may also be responsible for students' difficulties to some degree, were not considered. Hence, an additional interview study was carried out with eight chemistry teachers and seven students in their final semester of a Master of Education program in chemistry. In this study, it was shown that all teachers and student teachers attribute great importance to chemical formulae and reactions in teaching chemistry. It could be noticed that they named some of the students' difficulties mentioned in the literature and were able to determine possible reasons for them. Finally, the teachers and student teachers mentioned different activities to remove or even prevent the causes of the difficulties.[2] (Determining the effectiveness of these activities was not part of the study.) However, the strategies and approaches mentioned were not consistent and based rather on exemplary experiences than on empirical knowledge and systematic models (cf. Taskin, 2010). We took this finding as well as the results of the students´ strategies

2 Further results of this study are available in German from Vahide Taskin, IPN Kiel.

analysed in the “Feedback to learn” – project as a starting point for further developmental research studies, which will be described in the following paragraphs.

Approaches for teacher education

To help students overcome their difficulties with chemical formulae and equations, a number of reflective tasks have been developed. These tasks differ from traditional tasks in a reflective component, which prompts students to think about the demands of a task as well as possible strategies to solve it. In relating chemistry to chemistry education, the so-called *chemical triangle* (see below) is also highlighted.

Theoretical background

The basis for the development of reflective tasks was (1) the so-called *chemical triangle* by Johnstone (2000) and (2) the theory of *metacognition*.

1. The *chemical triangle* by Johnstone highlights three representational levels that are used and combined in chemistry: the macroscopic-level of matter, the submicroscopic-level of particle models and the symbolic level, which includes formulae and equations (cf. Barke, 2006). For the representational level, there are several rules students have to learn, analogous to foreign languages. To develop an understanding for those rules in combination with the meaning of formulae, the level of representation needs to be compared to and combined with the other two levels continuously.
2. The term *metacognition* was coined in the seventies by John Flavell (1984). According to his assumption, metacognition consists of two components: *metacognitive knowledge* and *metacognitive experiences or regulations*. Metacognitive knowledge refers to acquired knowledge about cognitive processes. Flavell further divides metacognitive knowledge into three categories:
    a. The knowledge of *person variables* includes knowledge and beliefs about one’s own learning processes, as well as knowledge about learning and cognitive process information in general. These factors may facilitate or impede the outcome of learning processes.

b. The knowledge of *task variables* involves not only the knowledge about the nature of tasks but also the type of cognitive processing demands the task will place upon the individual. For examples, the requirements for comprehending a science text differ from those needed to understand a novel. This kind of knowledge is supposed to guide the individual in the management of a task.

c. The knowledge of *strategy variables* encompasses the knowledge about cognitive strategies and also about appropriate conditions in which these strategies could be used.

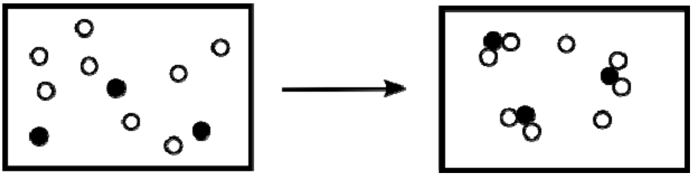
The metacognitive regulation refers to the use of so-called *metacognitive strategies* to oversee and regulate one's own cognitive activities and to ensure that a cognitive goal (e.g. solving a math problem) has been reached (cf. Livingston, 1997).

Design of reflective tasks

According to the theory of metacognition, a learner should be aware of his own strengths and weaknesses (person variables) and also of all cognitive processing demands the occurring task places upon him (task variables). Thus, he may choose that particular cognitive strategy (strategy variables) which best matches his abilities and the demands of the task. That is why a high value was set on developing tasks that included a reflective component, which makes students think about task and strategy variables in particular. Beside the reflective component, the tasks differ from traditional ones in that they include students' misconceptions and inconsistencies of the chemical symbolism. Concerning the selected misconceptions, the students have to explain why the conception is not adequate, and also have to correct it. With other tasks, students should become aware of the inconsistencies of chemical formulae language and find symbolic representations that are less misleading. According to the chemical triangle by Johnstone (2000), great importance was attached to constructing tasks in which students are asked to connect chemical formulae with their representation on the submicroscopic-level.

Examples are shown in the following pictures.

In the following model you can see the reaction between the elements X (●) and Y (○):



To describe this reaction some students had set up the following equations:

a. $3\ X + 8\ Y \rightarrow 3\ XY_2 + 2Y$

b. $3\ X + 6\ Y \rightarrow 3\ XY_2$

Can you explain, why these equations indeed describe the reaction, but are not usual for chemists?

Fig. 1 Task 1: Connecting chemical equations to model representations (adopted from Nurrenbern, Pickering, 1987).

You certainly know that hydroxide ions have the formula OH^-. However, the position of the charge number is misleading.

a. Note the Lewis structure for the hydroxide ion and mark the charge number there.

b. Which alternative formula (instead of OH^-) would you suggest, so it is less misleading for novices?

c. Which alternative formula would you suggest for the ammonium cation (NH_4^+)? Comment.

Fig. 2 Task 2: Inconsistencies in the chemical symbolism (adopted from Parchmann, Venke, 2008).

Conclusions and outlook

This sub-project was started as a result of the literature review on learning difficulties related to chemical symbolism and the results of the project "Feedback to learn" (cf. Oezyurt et al., this volume), which revealed that students are able to understand basic rules of the chemical formulae language and to develop adequate strategies even before their chemistry education at school has begun. Furthermore, students enjoyed this insight into the world of chemical formulae and showed no negative associations.

As a first step, learning difficulties had been categorized and connected to findings about strategies of students and teachers. In the second step, those results were used for a more systematic development of reflective tasks which now have to be tested and analysed in a third step. From this basis, the repertoire of chemical representations will be expanded to more complex structures (e.g. crystal lattice). Using eye-tracking methods, these structures will be used to contrast the approaches of experts and novices. The analysis of this study intends to derive information about different strategies that experts and novices use to interpret chemical display formats. These strategies could then stimulate future interdisciplinary research approaches, including neuroimaging and cognitive modelling (cf. Oezyurt et al, this volume).

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