Biological, psychological, and sociological basis
of the daily structure of work and free time

An interdisciplinary study

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Aims and Deliveries

ClockWORK plans to investigate the interaction of biological, psychological, and sociological factors that contribute to the daily structure of work and free time. Its goal is to optimise the individual's structure of work, free time, and sleep. There is a large body of evidence that life in unstable and un-biological temporal structures (e.g., in shift work) increases the risk for accidents, sleep problems, psychiatric and somatic disturbances and other pathologies, and can even shorten life expectancy. Any optimisation of daily structure will, therefore, increase health and quality of life, will reduce risks and costs, and will foster a motivational balance between 'work & play'.

Chronobiology and sleep research have reached a stage were excellent techniques and well founded models are available in conjunction with experience in scientific field studies, so that human temporal issues can now be successfully approached in 'real life' situations. To create the link between biology and real life, new networks have to be created expanding the bio-medical research to other disciplines, such as cognitive psychology, work and organisational psychology, specialists of neuro- and motor programs, or the sociology of motivational drives. This network creates – for the first time – a platform for such an interdisciplinary approach.

The goal of **ClockWORK** is to create an integrated view of the interacting factors through a field study approach. The expected results of this pioneering endeavour are an important basis for further studies and they will help to develop new strategies to make endogenous and external temporal programs more compatible both on the individual and the organisational level. The consequences of such strategies include a reduction of short and long term costs, i.e., a reduction of risks and mistakes, an increase of production efficiency as well as an increase health and quality of life.

Background

Our daily life is organized by three different clocks: a solar clock, providing light and warmer temperatures during the day, a social clock, which we see or hear first thing on a working day, and a biological clock which we sense most vividly when jet-lagged, during shift work, or when adjusting to daylight savings time. When shielded from the other clocks (constant external conditions), the biological clock "runs free" with its own timing. In real life, circadian clocks are usually synchronized (entrained) to the 24 h day. The major entraining signal (zeitgeber) is light which, in mammals including humans, can only act through the eyes.

The circadian clock controls our bodily functions at many levels, from gene expression to complex behaviours, such as sleep and performance. The control of the circadian clock is profound. At specific times of day, many different genes are switched on or off in all organs and tissues. These systematic changes of the cells' biochemistry form the basis for a temporal program that concerns every aspect of life.

This circadian program has a strong genetic basis. As with other genetic traits, individual differences in circadian properties depend on variations of specific genes (so-called "alleles" of "clock genes"). In a given population including human populations, free-running periods are distributed around a species-specific mean. These genetic differences can also be seen when the clock is entrained because the position of the internal clock in relation to the external clock (e.g., sleep in relation to dawn) depends on the individual's free-running period. Thus, human preferences in the timing of sleep and wake (called "chronotypes", such as "larks" and "owls") are, at least partly, based on genetics. The relationship off chronotype and shift-work tolerance and preferences are questions dealt with, in detail, in project 1 but, in general, also in all other projects.

These insights into the bio-medical aspects of daily life have changed the way we look at social temporal structures in modern society. The circadian clock of shift workers, for example, is rarely appropriately adjusted to the enforced social schedules, which has severe consequences on performance, quality of life, sleep quality, and general health. These consequences are central to several chronobiological studies and are the central question of project 1. It is, however, important to link the insights of chronobiology with many different, equally important aspects of daily life. Only if many different aspects of

daily life are investigated in a coordinated and interactive way, it will be possible to devise strategies to optimise the structure of daily work.

We, therefore, propose **ClockWORK**, a network of specialists that combines circadian research with research into cognitive and socio-psychological aspects of work and free time. The first two projects represent the chronobiological bases for daily structure. They specialise in the formal basis of the biological clock, epidemiological and genetic as well as field studies (project 1) and measurements of sleep quality and clinical parameters under controlled conditions (constant routines, project 2). The variables in these projects are individual circadian differences in conjunction with light-exposure, age, temperature, and diet. Projects 1 and 2 will also be responsible for circadian know-how and methodology in all other projects.

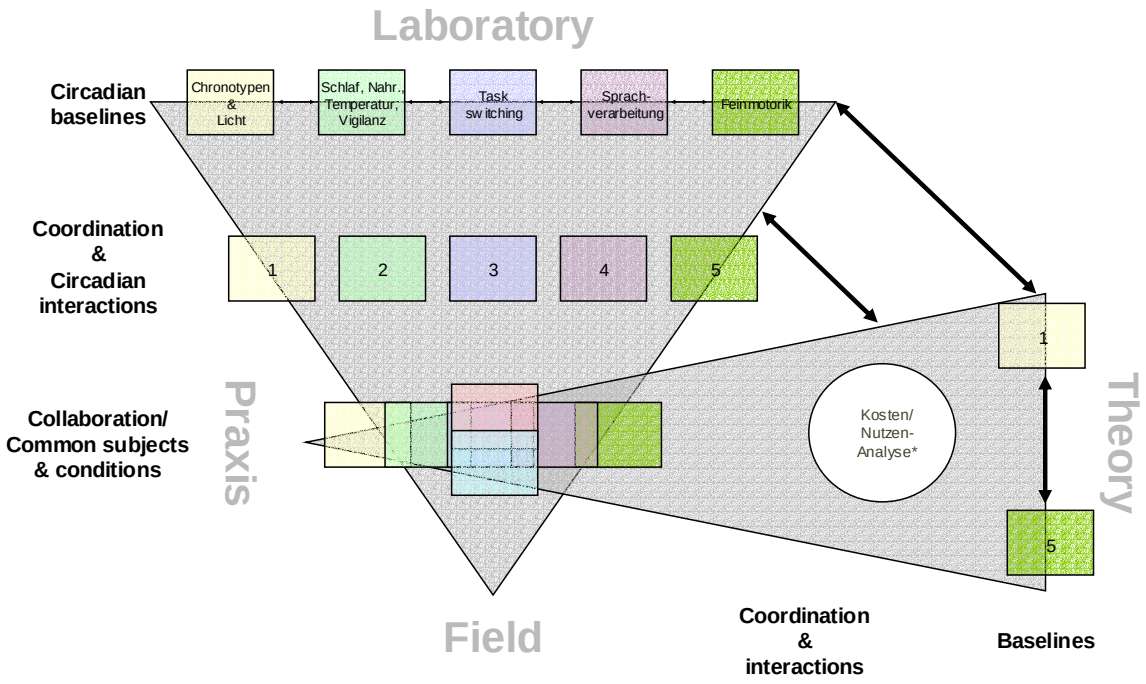
In daily life and work, people have to frequently switch between different tasks. Cognitive and experimental psychologists have investigated the specific mental work load of task switching. In this context, task switching refers to switches on lower levels of tasks (switching between reading and writing, between counting and sorting, between pipetting different volumes, etc) rather than switching between entirely different tasks (e.g., switching between manual work at the bench to writing a protocol or report). This low level task switching is a main source of mistakes and is, therefore, important for costs and quality standards. It has been shown, that task switching demands a reconfiguration of cognitive processes before one can proceed to the new task. This mental reconfiguration is effortful, requires time, and is subject to more errors than continuously and repeatedly performing the same task. Several factors contribute to such switch costs, e.g., memory processes necessary to retrieve the corresponding task set. The efficiency of memory retrieval processes is impaired by many different variables, including time-of-day, sleep dept or fatigue. The circadian and sleep-related variables of task switching costs will be investigated in detail and will be related to individual preferences in structuring the 24-h-day (project 3).

Language is a species-specific faculties of man and is central to any kind of work but especially within a team. Producing a sentence means transforming an idea into structured strings of sound or graphic symbols. Listening means analysing physical inputs (sound, symbol), extracting the content and understanding the message or idea. It allows verbal (oral and/or written) communication and is the most important instrument for information exchange. Language communication is the prototypical activity for coordinating tasks. Speaking, listening, reading and writing either face to face or electronically medi-

ated, man/machine interaction, job training and continuous education form a crucial component of the daily structure of work. The core activity of communication is language processing, a special case of cognitive information processing. Quality and speed of language processing depend largely on a person's capacity to concentrate and focus his attention on the involved mental activities. There are convincing theoretical reasons for the assumption that the communicative performance is affected by vigilance and sleepiness, respectively and that these qualities vary over the course of the day with individual characteristics that are related to chronotype. A detailed investigation of the daily variation in language processing will be instrumental in optimising the daily structure of work and team efforts (project 4).

Practically all aspects of work demand the fast and precise execution of psychomotor processes. Especially skilled and dextrous manual manipulations constitute an inherent feature of every day life (eating, toileting, dressing, handwriting, etc.) and are indispensable in any skilled activity. The neuronal system controlling dexterous hand function in primates, including man, is uniquely characterized by a specific organization, the direct cortico-motoneural connection. A number of outstanding studies have demonstrated the high precision and effectiveness of the system coordinating dexterous hand function by measuring movement parameters such as forces produced by the fingers during manipulation of objects. As any other system, dexterous hand function is vulnerable to specific disturbances. After section of the pyramidal tract (in monkeys), for example, most motor deficits disappear after a while, but independent finger movements remain permanently impaired. Apart from structural lesions in the nervous system, many other factors affect fine motor control. Among these are perturbations of environmental conditions, drug consumption, fatigue, distractors etc. Given this evidence it seems obvious that structural and temporal aspects of work affect fine motor control. A detailed analysis of the variance during daily work and under different shifts of flexible work schedules is, therefore, of high importance (project 5).

Organisational Structure of the Network



* A social-psychological Analysis of the cost/benefit-balance of shift work (planned)

ClockWORK: An interdisciplinary project – Organisational scheme

Individual projects

What follows are short synopses of the five individual projects. Each project is described separately only to illustrate the specific backgrounds, aims and methods as well as to facilitate the respective allocated funds for each group. The major aim of ClockWORK is, however, to create a highly interactive research network as it is a long tradition in circadian research. Most aspects of the research within each project will be shaped and fine-tuned by the interaction of the groups as a team. While the main coordination of the five projects will be achieved at the kick-off meeting in Ladenburg, interactive fine-tuning of experiments, evaluation, and joint presentation will continue throughout the entire research period. It is anticipated that the network will be enlarged during the second or third year by a group that specialises in motivational psychology. The reason for a later expansion lies in the necessity of the initial network to create baselines and standard operating procedures enabling further coherent investigations of motivational parameters.

0. Central Services

The Central Services-unit will assist the chairman, Prof. Till Roenneberg, and vice-chair Prof. Rainer Dietrich in coordinating the individual projects and in the administration of the central budget (see also: Coordination and Time frame). Central Services will be located at the Ludwig-Maximilians-University in Munich.

Central services will, in particular, be responsible for:

- the organization of the project's mailing list,
- the installation of shared software, databases, and other central electronic resources (data and literature),
- the development of a unified design of the project's 'calling card',
- the continuous up-dates of the central records of the project,
- contact with the media,
- ongoing information of the project members,
- preparation of the regular project meetings.

Project 1 – Chronobiological basis I: Shift-work, chronotypes and risks

Responsible Partners

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Specific background and knowledge

The expertise of Munich and Groningen concerns circadian mechanisms at all levels of biology and society. We use the knowledge derived from basic research to understand the relationship between the clock, everyday life, and the consequences of industrialisation. Our methods range from epidemiological and genetic studies to the psychology, physiology and clinical chemistry.

Specific question and aims

Our contribution to the research within the network is four-fold. (i) Support in planning, performing and analysing circadian experiments measuring the daily changes of higher cognitive functions, as they are carried out by the respective other participants. (ii) Fostering an intensive exchange between **ClockWORK** and **EUCLOCK** (iii) Investigating the role of chronotype in shift-work tolerance and adaptation. (iv) A meta-analysis of the literature reporting detrimental effect of shift-work on health and quality of life.

Chronotype and shift-work:

In a large experimental study in collaboration with the VW plant in Wolfsburg, we investigated the effects of chronotype and light on how shift-workers adapt to night shifts. Our results show that both factors influence the adaptation in a very specific way. Chronotype had a large effect both on the adaptation AND on the action of light. In this sub-project, we will to scrutinize our preliminary findings with the aim of using knowledge about chronotype to reduce the adverse effects of shift-work. The influence of how chronotype affects shift-work tolerance and adaptation will be investigated in detail with the help of different shift-work schedules (exploiting our connections to industries (VW, OSRAM, Phillips, etc.).

Meta-study on detrimental effect of shift-work:

A large body of literature exists describing various heath risks due to long-term shift work. Aim of this sub-project is a comprehensive study that collects, catalogues, scrutinises, and summarises the published findings. An additional aim of this sub-project is also to use the solid evidence for health risk to estimate the costs that arise from shift work on the economy at large.

Approach and Methods

Methods for the chronotype study include questionnaires about sleep habits, chronotype, general physiological and psychological well-being, as well as (at a more advanced stage of the study) continuous measurements of activity and light-exposure as well as vigilance. The protocol design will depend on available possibilities and feasibility within a given shift-work environment. The meta-study will use the traditional methods, criteria and tools of literature evaluation. Cost analysis will be based on statistical information by official health care sources (government and insurance companies).

Project 2 – Chronobiological basis II: Sleep, Diet, Temperature, and Vigilance

Responsible Partners

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Specific background and knowledge

The expertise of the Centre for Chronobiology in Basel is in human chronobiology and sleep. We have studied circadian and seasonal rhythms in healthy young and old subjects, major depression, seasonal affective disorder, Alzheimer's disease, schizophrenia. Epidemiologic and questionnaire studies related to sleep-wake behaviour, daytime vigilance and performance, mood and eating behaviour. Analysis and statistics of complex data from long-term online (repeated) physiological measures. Therapeutic modalities from chronobiological concepts: light therapy, melatonin (and its analogues), carbohydrate diet, sleep deprivation.

Specific question and aims

How does the circadian clock and sleep regulation interact to determine vigilance state and mood? How does sleep affect memory consolidation? What is the role of thermoregulation in alertness (e.g. sleep inertia on waking)? What strategies can be applied to maintain performance (e.g. timing and duration of naps; brighter lighting)? How can light therapy be used in the work place and in sleep disorders? What is the mechanism of melatonin's soporific effect? Can diet (e.g. carbohydrate vs protein-rich) affect sleepiness, performance, mood state and sleep itself? Strategies to implement sleep deprivation and adjuvant therapies for depression in everyday clinical practice.

Our project could be dovetailed into ongoing project in young and older men and women (20-35, 55-75) and focus on specific data analysis from this huge data set that addresses quality of sleep, vigilance, performance, cognitive function, decision making etc. and the role of naps and their timing in decreasing sleep pressure. Title: *Two kinds of sleepiness*.

Approach and Methods

The first part of the main project in young and older shift workers (20-35, 50-65) will be performed “in the field” (IST ZUSTAND) using the Eating Style Questionnaire, the Daily Food & Drink Questionnaire, and Sleep and Mood Logs. Depending on possibilities within the work environment, these will be supplemented by measuring performance, neuropsychological status sensitive to sleep debt (executive function, prefrontal cortex, memory) and possibly Wake EEG as objective measure of sleepiness. Some of these measurements will also be performed under controlled conditions in so-called Constant Routines.

To improve vigilance and sleepiness at the appropriate times of day (or night, in the case of shift work, the following interventions will be applied and accompanied by the test battery described above: Adjuvant bright light in the work place or at home, cooling, and controlled diet strategies.

Project 3 – Circadian Factors in Task Switching

Responsible Partner

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Specific background and knowledge

Our expertise in the proposed network lies in the investigation of task-execution and task-switching. The execution of tasks and the switching between different tasks is performed by the cognitive information processing system, which consists of perceptual, memory retrieval, decisional, and motor processes to name a few. Experimental results have shown that task performance depends on the available mental resources and these resources determine the amount of parallel processing. Measuring task-switching costs will shed light on the issue whether time of day influences the degree of parallel processing within the cognitive system.

Specific question and aims

The present project will develop feasible methods for assessing and evaluating task-switching costs in normal work situations. Specifically, these methods will be employed to address two issues. (a) Does time of day modulate the costs of task switching? (b) Does time of day affect the degree of temporal processing overlap of two tasks, that is, do people tend to perform two different tasks successively rather than simultaneously when they are less alert?

Approach and Methods

We will employ standard techniques of experimental psychology to assess task-switching costs. The task-switching paradigm consists of successive trials. In each trial a stimulus is presented which requires a speeded response. The stimulus defines the kind of response. In the standard paradigm, the results of two experimental conditions are contrasted. First, in the switch condition the task changes from trial to trial. Second, in the non-switch condition the same task is required in successive trials. For example, in each trial a different two-digit number between 10 and 99 will be presented. In the switch condition, participants are required to add 3 in one trial and to subtract 3 in the next trial. In the two non-switch conditions, however, participants are required either to add or to subtract 3 in each trial. Reaction times are usually longer in the switch than in the non-switch condition, often 30% or even more. Thus the difference of reaction time between both conditions reflects the amount of switch costs. We will measure such switch costs and demands of attentional reallocation as a function of time of day and sleep loss. In addition, we will employ different tasks, and tasks with different difficulties, to infer the amount of parallel processing. Finally, we will use psychophysical methods to measure how time of day influences the duration of specific processes within the cognitive processing stream. The methods will be tailored to work-place specific tasks.

Project 4 – Circadian Factors in Language Processing

Responsible Partner

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Specific background and knowledge

Language production and comprehension are special cases of complex cognitive information processing. They are performed by the neuro-cognitve system consisting of coupled and task specific programs: production, comprehension and mental dictionary. The performance of these programs depends on various factors such as complexity of input/output structures, task load, time pressure and vigilance, and has a pronounced time-of-day variance. We are specialized in the experimental investigation of complex language production processes, especially conceptualization and syntactic coding under single and multiple task conditions. There is a rich experience in interdisciplinary projects investigating language processing under conditions of workload and at the work place in general. The development of qualitative, chronometrical eye-tracking methods and their implementation in experiments are a long standing routine in our lab.

Specific question and aims

Quality and speed of language production and comprehension determine the success of communication in normal work and in incident management. Two questions are central to the project: (1) How does linguistic performance vary with time-of-day and specifically, (2) How does sleepiness and fatigue affect linguistic performance?

Both, language production and comprehension will be investigated. The investigation focuses on cognitive routines which are central to these procedures. A core activity in listening is sentence comprehension. It comprises word recognition, syntactic analysis (parsing), understanding the sentence content, referencing to reality and, finally, drawing inference to reality. We will investigate the performance (a) at the interface between formal and semantic processing and (b) at the sentence interpretation level.

Typical activities of oral utterance production are phonological encoding and articulation. The systematic variation of the phonological and the articulatory processes under conditions of different day times and different measures of sleepiness will be investigated.

Depending on the results of the first period of the project, efforts will be undertaken to tap on the distinction between the linguistic performance and the underlying system of the language faculty.

Approach and Methods

The precise assessment of performance differences requires methods which are fine grained and, at the same time, simple. There is a battery of standard procedures for measuring the performance of the different linguistic subsystems: Tests for auditory and visual perception, lexical access, syntactic parsing, text comprehension and production. There is, however, almost no reliable knowledge as to which parts of the language faculty are sensitive to circadian oscillation in which way. The first step will, therefore, be a series of experimental explorations the results of which will – hopefully – indicate differences in the mechanisms of circadian oscillation in the language system. Relevant areas/ modules will then be investigated in more detail and – finally – tested under conditions of shift work.

Project 5 – Circadian Factors in Motor Control

Responsible Partner

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Specific background and knowledge

In studies of fine motor control, precise measurement of behaviour has gained outstanding importance. In their epoch-making study on grip function, Johansson and Westling (1984) measured the grip and load forces during the grasping and lifting of objects. They showed a near perfect degree of coordination between the forces and a highly accurate anticipation of environmental demands such as objects weight and surface friction. The paradigm of Johansson and Westling was further developed and used in many different fields of interest such as neuroscience, neurology, rehabilitation, biomechanics or ergonomics. In parallel, other techniques to measure fine motor control were developed and improved which enable the measurement of free hand, arm, and finger movements or the registration of writing movements.

In our studies, we used these methods to define factors which influence normal hand function. For example, we explored the effects of (1) individual control mechanism, (2) changes of environmental conditions, such as mechanical perturbations and changes of gravity, (3) alterations of skin sensibility by anaesthesia and cooling, and (4) dysfunction of the central nervous system. The high precision and reliability of the methods used have been demonstrated repeatedly in these studies.

Quantitative research on circadian rhythms in motor control is scarce and to our knowledge limited on two aspects, namely the production of maximum grip force and fast reciprocal finger movements. The results proved the existence of circadian rhythms for some tasks. However, findings were heterogeneous and sometimes ambiguous. Thus, mechanisms of circadian factors in motor control could not be determined. Therefore we plan to adapt our sensitive methods to analyse circadian rhythms of different aspects of dexterous hand function.

Specific question and aims

The study should determine alterations of fine motor control during the day and with structural and temporal aspects of work, such as shift work, assembly-line work etc. Different aspect of dexterous hand function will be analysed: (1) elementary finger movements and force generation abilities, (2) grip force control during object manipulation, distinguishing highly automated, reactive, and proactive control modes, and (3) hand writing movements. Quantitative measures derived from appropriate methods are then related to circadian rhythms and work characteristics, so that alterations of hand function can be precisely and differentially determined.

Approach and Methods

Dexterous hand functions are evaluated during specific tasks, with an emphasis on realistic natural manual activities. (1) On a more elementary level, the ability to perform fast finger movements and fast grip force changes, to produce high forces, and to coordinate force output with visual target signals (visuo-motor tracking) is tested. (2) Functional grip force control is evaluated during static tasks and during dynamic tasks which include the need to compensate movement-induced inertial loads. In addition, self-

produced and externally-produced perturbations (catching a falling load) are applied to differentiate proactive (anticipatory) and reactive grip force control. Forces and movements are measured by technical sensors incorporated into a test object. (2) Automated hand writing of sentences and of component movements are analysed using a digitizing tablet and performing kinematical analyses. In all task stable performance is reached after short practice and reliable data can be gained with short measurement durations, so that performance can be evaluated several times during one day.

Writing movements are registered with commercially available graphic tablets which enable elaborated kinematic analyses with software developed by our group (CS). To enable analyses of natural-like object manipulation a wire-less, autonomous test object is required. Such an object ("Tunacan") has been developed and successfully used in our studies. However, in its actual configuration the device cannot be applied to the planned measurements, in addition several technical and compatibility problems have occurred with time. Thus, a re-design on the basis of the former prototype is necessary to enable save measurements, particularly under the demands of repetitive measurements during one day. Two parallel devices are required for time-critical group studies (e.g., in a "constant routine").

One part-time researcher (e.g., graduate student of engineering) is primarily requested for the re-design of the test object and for the development of the procedures for data analysis. A second part-time researcher (e.g., graduate student of psychology) primarily develops the procedures for examinations, collects and analyses data, and presents the results.

Structure of and interrelations within ClockWORK

The projects will closely cooperate on all levels, experimental planning and study design, analysis and evaluation, and publication (see also graph below). All results and insights will be discussed by the researchers in bilateral or joint workshops on demand as well as annually within the entire network. Final results and potential recommendations for improving of the daily structure of work will be presented at the occasion the project's final conference. Authors seek publication in highly visible peer reviewed journals and will also publish a synopsis of the networks achievements in the form of an integrated interdisciplinary book at the end of the project.

Coordination and Time frame

The project will be coordinated by Prof. Till Roenneberg, Munich. Prof Roenneberg is the central coordinator and the speaker of the project as a whole. All temporal aspects of **ClockWORK** and its deliveries will be defined at the first meeting of the project in autumn 2005.
The future members of **ClockWORK**, together with external advisers, came together in several meetings over the past 18 months to prepare and streamline the aims and contents of this network. These meetings have proven the integrative spirit of the group and have already lead to the first 'quasi constant routine' experiments, carried out by the group of Prof. Rainer Dietrich in Berlin with the support of all other participants.

ClockWORK will strongly collaborate with the European Network EUCLOCK, which specialises on basic circadian research with emphasis on entrainment of the clock in humans and experimental model systems.

The current external advisory board of ClockWORK consists of:

- Prof. Serge Daan, Groningen (general and ecological aspects of the circadian clock)
- Dr. Martha Merrow, Groningen (circadian genetics; Dr. Merrow is also responsible partner in project number 1)
- Prof. Simon Folkard, Paris (circadian clock and shift-work)
- Prof. Monika Bullinger, Hamburg (motivational psychology)