Neuroscientist Riitta Hari, a pioneer in neuromagnetic brain research (Hari and Lounasmaa, 1989), said in her inauguration lecture as the new Academician of Science of Finland that, at birth, we are all children of the world. The environment in which we live shapes our brain, how we speak, think, interact, behave. Life is all about learning. Even without always being consciously aware of it, we acquire habits, both good and bad, master new skills, gain theoretical and practical knowledge, adapt and adjust. Our brain is pre-wired for lifelong learning. Information processing of the brain underlies thinking, learning, planning, making everyday decisions. Behaviour is the outcome of our cognitive and mental processes. Through thinking we give meaning to what we have seen, heard and felt.

Neural structures of our long-term memory are constantly being upgraded. Due to our unique palettes of intelligence, talents, temperaments, handling of emotions, education, learning through work and hobbies, goals in life, health issues and our life history, each of us has a unique collection of knowledge — theoretical and practical — stored within our brain. In order to be able to use this, our most valuable asset, to the full, our brain should be fit. Promoting brain well-being should be of the highest priority for each of us and its relevance should also be acknowledged in society. The fatigued, overloaded, sleep-deprived brain of a stressed individual does not care, forgets and stops learning.

The internet, World Wide Web, cloud computing, represent various applications of information handling made possible with the emergence of high-capacity information networks and data mining. In ten years a tight and complex network of information highways has been woven around the globe. News, facts, fiction, rumours, opinions, debates, you name it, taking place around the world are forwarded in real time, simultaneously, to people with different societal, cultural and religious backgrounds, educational levels and cognitive aptitudes.

Both everyday living and work life are often perceived as complex and cognitively, mentally and physiologically demanding. In a recent EU survey corporate leaders and human resources directors have expressed their concern on overall brain well-being of the working force (Müller, 2011). In the Work and Health Survey 2009 of the Finnish workforce (Kauppinen et al., 2010), 48% of workers in all sectors reported that their job content and/or job description had totally changed within the last three years. Thus, the ability to constantly learn at work can be seen as an essential work skill. We also need to take a good look at work processes and environments: do they promote learning?

In this chapter we will focus on the advances in research within neuroergonomics, a research field that studies the working brain by linking neurocognitive, behavioural and human factors research together.
Cognitive neurophysiology provides a holistic approach for linking together cognitive and mental performance with the state of the cardiovascular system and brain neurophysiology of an individual carrying out a certain task. This enables us to study the effects of a changing external mental workload on human neurophysiology and cognitive performance. Also, the effects of individual factors on cognition, such as overall vigilance, alertness, fatigue, sleep pressure and hyperactivity due to stress can be evaluated. Age is also an important factor, but this paper will not specifically address this aspect.

A book printed on paper is still considered by many as one of the best user interfaces for information. Most of us feel comfortable with learning based on social interaction: communication and dialogue face-to-face, watching and mentoring.

The constant emergence of new information technologies making e-learning, virtual classes and other social media applications available also within learning challenge the human mind both intellectually and mentally. In these chains of information human and artificial intelligence meet at (information technology application) interfaces. The thought processes of the human brain play the key role in the process where data (know nothing) is first converted to information (know something), then to knowledge (evaluate and understand the meaning of information) and, ultimately, hopefully, also to wisdom (how to best use knowledge). High-power computers can crunch large chunks of data into elementary information, but human brain power is needed to further cultivate it.

Research in cognitive neurophysiology aids in the optimization of our living (everyday learning) environments in such a way that the mental challenges presented to the brain and mind do not exceed their capacity and available resources. In order to achieve this, we also need to understand human-related factors affecting the performance of the human brain.

**Living in a 24/7/365 information-intensive society**

Constant exposure to high amounts of information and sensory stimuli, as well as lack of sleep and insufficient rest and recovery have adverse effects on brain physiology, cognition and mental well-being. The first symptoms of brain overload are often seen in frontal lobe functions. They include deterioration in executive functions, mental flexibility, problem solving and social skills (Tekin and Cummings, 2002). Working memory function and learning decline. Subjective symptoms include overall fatigue, memory lapses, anxiety and depressive mood.

Work-related factors that can cause harmful overloading of the brain are irregular and overlong working hours, intense work pace without adequate rest pauses, information overload and the constant need to carry out cognitively highly demanding work tasks. Work that requires multitasking and fast switching from one task to another can also cause brain fatigue (Szalma et al., 2004). Working in a noisy environment or in one with distractive lights or colours can also cause strain.

In modern work life, information handling is a crucial part of task performance in many professions. Work demands change constantly, and lifelong learning, updating of skills and mastering of new ones is required.

In many task-performance situations the components of overall increasing mental load are due to both increased external task demands and decreased internal physiological resources. This can result in a decrease in performance. As humans are able to maintain acceptable performance levels to a certain point even with increased task demands or under, for example, growing sleep pressure, relying on only performance data may not help in predicting later occurring drops in performance levels (Eggemeier and Wilson, 1991). Humans’ ability to self-monitor and objectively evaluate one’s own performance varies and is often inadequate (Sallinen et al., 2004, 2008; Haavisto et al., 2010). Objective methods for identifying cognitive...
overload and mental fatigue are needed. The optimum would be a method that makes it possible to monitor the overall functional state of the brain during learning and the performing of tasks with different and changing cognitive demands.

**Finding the balance of doing and idling**

Plasticity, the ability to adapt to the challenges that we encounter in our daily life, is an important feature of our brain. New information is constantly being stored in our memory and skills are learned. Activation of neural networks occurs through doing. Different networks are activated by seeing, hearing, speaking, writing, logic-analytical thinking and craftsmanship. What we do shapes our brain.

The information-handling capacity of our working memory is limited. In order to prevent its overloading, we have to make choices on what information is relevant for us. We do this by utilizing the databank of our long-term memory in which life experiences (I remember that) as well as theoretical knowledge (I know that) have been stored. With the aid of our long-term memory we direct, switch and focus our attention on information present that we consider relevant to us at a given time. As individuals we have different talents, education, working experience and life histories. So we ‘see’ and ‘hear’ different things and we give meaning to what has been perceived that is influenced by our brain’s unique data banks. What is new to one, is self-evident to another and not interesting to a third person.

To ensure good performance in both learning and when carrying out everyday tasks and decisions, a seamless collaboration between working and long-term memory networks and the allocation of resources of attention is essential. The frontal lobes of our brain play a key role in orchestrating the dynamics of these cognitive processes and in the monitoring of our behaviour and adjusting it in relation to the demands of tasks at hand and social situations in which we are performing.

The human brain is a complex network of intertwining neural cells and blood vessels. Its functional state is affected by our body’s overall physiological state, which is regulated by energy and glucose metabolism, hormones and chemical reactions, as well as the autonomic nervous system that regulates, for example, our heart rate and blood pressure. Brain physiology, cognition and mental health are tightly linked.

Mental workload has been defined as the amount of an individual’s cognitive processing capacity that is required by a given task in order to perform the task adequately (Wickens, 2008). There is a limit to every individual’s ability to activate more cognitive and physiologic resources in order to maintain good performance while mental workload steadily increases. When the reserve resources have been exhausted, the performance level on tasks drops.

There are, however, individual differences in the ability to adjust to increasing performance demands. In some subjects, cognitive performance is maintained at the expense of physiology. A recent study by van Leeuwen et al. (2010) showed that, while some sleep-deprived subjects still managed to perform cognitively, cumulative sleep debt of one work week had adverse effects on their glucose and insulin metabolism and immune systems. Thus, a salutogenic view on optimal performance is essential to ensure both human health and learning.

Questionnaires addressing subjective experiences of workload or one’s own evaluation of task performance have proven unreliable. Individuals’ ability to monitor their own performance, detect errors, estimate vigilance and alertness varies between subjects (Eggemeier and Wilson, 1991). Also, other factors, such as truthfulness and malingering, trust and distrust, one’s need to protect privacy and anonymity, can affect answering behaviour in many ways and it is difficult to estimate these effects. In a workplace where some workers are facing the risk of unemployment or layoff while others feel secure of their job, subjective questionnaires on well-being at work and how knowledge management, competence and learning issues are being addressed can be biased. Thus, objective physiologic methods linked with different types of cognitive tasks are needed in order to promote good neuroergonomics of learning.
Linking cognition and neurophysiology

In everyday life we seldom have the opportunity to fully concentrate on a tightly restricted (mono) task. Even clearly defined mental tasks usually contain subtasks. In addition, their content can change with time, making it necessary to alter our strategy of doing things. In order to gain knowledge on factors affecting mental performance that can also be used for practical purposes, designing ‘brain friendly’ environments for different human activities, cognitive neurophysiologic research in dual- and multitask settings is needed.

Cognitively multitasking requires co-ordination of attention switching between various subtasks and making decisions on task priorities (see e.g. Just et al., 2008). The ability to divide attention between one or more simultaneously occurring tasks differs between individuals. Studies have shown that the effects of elevation in task demands can often first be detected in neurophysiologic outcome measures while good cognitive performance level is still maintained (Eggemeier and Wilson, 1991; Holm et al., 2009; Kujala and Näätänen, 2010).

Upholding acceptable performance under increasing sleepiness or rising cognitive demands requires the mobilization of further brain resources, which is revealed as increased activation of physiologic systems. This can be detected by observing brain oscillations. They are the biophysical result of complex interactions of neuronal networks, taking place both in the idling and performing brain (Buzsaki and Draguhn, 2004).

The changes in electromagnetic fields generated by small intracellular electrical currents in neurons of the brain can be measured with electroencephalography (EEG) as well as magnetoencephalography (MEG). Brain imaging that is based on detecting changes in magnetic fields of neural networks requires the use of technology and laboratory facilities with magnetic shielding to prevent the interference of magnetic fields present in our environment. Thus, we will focus on those neurophysiologic methods, such as EEG, the recordings of which do not necessarily need high-tech laboratories and can also be carried out in field studies with ambulatory devices.

The era of EEG began with a scientific paper published in the British Medical Journal in 1887 by an English physician, Richard Caton (Spillane, 1974). It described the electrical activity of rabbit and monkey brains. Studies on human EEG were pioneered by the German physiologist and psychiatrist Hans Berger in the 1920s (Millet, 2002). Starting from the 1950s, EEG had developed into one of the main clinical diagnostic tools of neuroscience. Later the development of new brain-imaging techniques such as functional Magnetic Resonance Imaging (fMRI) reduced its use in clinical settings. Today, with the emergence of data mining, applied mathematics, bioinformatics and the development of medical technology and the manufacturing of small mobile measuring devices, new applications for EEG have emerged.

The scalp-recorded EEG represents the synchronous activity of large neuronal populations of the brain. For analysis, EEG spectrum is traditionally classified into four frequency bands: delta (1–4 Hz), theta (4–8 Hz), alpha (8–12 Hz) and beta (12–30 Hz). EEG activity changes due to vigilance, sleepiness, alertness and mental workload of the brain. Age also affects the power of delta, alpha and theta frequencies (Smulders et al., 1997).

The ability to perform concurrently several tasks or fluently to switch from one task to another places demands on cognitive executive functions, attention and working memory resources. The key role of brain prefrontal functions during multitasking is supported by several EEG studies. Increasing task difficulty results in an increase in frontal theta activity and a decrease in parietal alpha activity (Fairclough et al., 2005) and has been suggested to denote increasing memory load (Gevins et al., 1998). Changes in alpha and theta activity have also been linked to short- and long-term memory interaction during information processing. Additionally, frontoparietal EEG coherence in the alpha and theta bands is affected by tasks that require executive functions (Sauseng et al., 2005, 2006).

An increase in task demands, as well as time-on-task, increases frontal theta and decreases parietal alpha activity (Sauseng et al., 2005). Attention demands of a task have been related to alpha activity (Ward, 2003).
The changes have also been linked to accuracy of performance (Slobounov et al., 2000). Time-pressure affects EEG spectra (Slobounov et al., 2000), but the effect of learning on EEG metrics is less clear (Fairclough et al., 2005). Sleep deprivation increases both alpha and theta activity in frontal areas (Cajochen et al., 2001). Both multitasking and lack of sleep increase brain workload, which is seen as changes of EEG spectra.

Event-related brain activity (ERP), also measured with EEG, is the result of very small changes in electrical voltages that are triggered by the neural responses of specific groups of nerve cells to different sensory stimuli, motor or cognitive events. Concerning the use of ERPs to study the interactions between brain activity and cognition, the P300 is the most commonly measured response. It occurs approximately 300ms after an event has been presented to a subject. The P300 component has been shown to be sensitive to information-processing resources of the brain (Ullsperger et al., 2001).

As the recording of ERPs requires study setups with external stimuli, time-locked to the task, and the use of several stimulus strings in order to accurately detect the response, ERP studies are mostly done in laboratory settings.

Eye movements generate electrical activity that can also be measured with an EEG recording device, electro-oculography (EOG). In EEG analysis, activity due to eye movements has to be distinguished from brain-based activity. In these situations it is treated as an artefact. EOG recordings alone can also be performed for gaining objective data on vigilance. Saccadic eye movements measured with EOG, while a person is following a target on a computer screen visually, are sensitive to fatigue caused by prolonged time awake (Hirvonen et al., 2010). EOG has also been used in field settings for the detection of slow-wave sleep, unintentional sleep (Virkkala et al., 2007) and sleepiness (Fabbri et al., 2009).

The physiological state of the autonomous nervous system which regulates cardiovascular responses is also affected by vigilance, sleepiness and overall stress (arousal) levels. Measuring heart rate variation (HRV) has been used to study the effects of sleep deprivation which leads to increased sympathetic and decreased parasympathetic tone of the autonomic nervous system (Zhong et al., 2005). Heart rate variation (HRV) is also affected by the level of mental effort (Mulder, 1992). HRV measures react to both physical and mental workload.

Cardiovascular and brain physiology interact. Thus, systems that measure simultaneously the responses of both the autonomic and central nervous system during task performance may provide usable combinations of outcome measures on the effects of cognitive task load level and its changes (Hancock and Szalma, 2007) on both human physiology and cognition.

Linking sleep, cognition and neurophysiology

The role of sleep in promoting learning cannot be underestimated (see review by Maquet, 2001). Sleep is essential for brain plasticity and restoration of energy resources (Hairston and Knight, 2004). EEG theta and alpha activity increase during performance of more demanding tasks in sleep deprivation (Smulders et al., 1997). With extended wakefulness and increasing sleepiness, the P300 amplitude to auditory stimuli decreases rapidly (Gosselin et al., 2005). A decrease in P300 amplitudes during sleep debt has been suggested to denote less available cognitive resources (Smith et al., 2002) and a prolonged P300 latency to indicate a slowing down of cognitive processing.

During sleep our brain further processes things that we have recently learned and experienced and our long-term memory databank is upgraded (Hairston and Knight, 2004). During rapid-eye-movement sleep (REM), reactivation of memory processes and upgrading of long-term memory with new information and knowledge takes place (Maquet, 2001). Sleep deprivation can be caused by inadequate sleep, poor sleep quality, extended wakefulness and restricted sleep. It has been estimated that the extension of wakefulness to more than 20 hours leads to an escalation of performance impairment (McCauley et al., 2009).
There is often a need to maintain performance at a high level for long periods of time. This results in a time-on-task effect, which gradually causes increasing fatigue and raises the risk of attention lapses and human error. Sleep restriction enhances the adverse effects of long working hours on task performance. Recovery from cumulative sleep loss appears to require more time than recovery from acute sleep loss (Axelson et al., 2008). Recovery of subjective sleepiness occurs earlier than recovery from physiologic sleepiness (Lamond et al., 2007).

In our own studies, a gradual decline in the ability to carry out demanding multitasking was seen in healthy young men under the age of 30 who had been exposed to restricted sleep of 4 hours on 5 consecutive days. There was clear individual variation in the extent of worsening of their performance. Recovery to baseline multitasking capacity, measured before sleep restriction (when the vigilance of the subject was estimated as normal), was not complete after two nights of normal length sleep (Haavisto et al., 2010).

**Estimating overall brain load**

At the Brain and Work Research Centre (BWRC) we have developed a computerized test battery with which both the information load and the number of tasks to be performed as well as the task presentation speed (work pace), can be modified (Sallinen et al., 2008). We have then investigated how information derived from the EEG spectrum can be used as an indicator of overall brain load. This was done by combining physiological measurements in time synchrony with the cognitive task and then manipulating 1) external factors: the difficulty and thus mental load of the computerized tests; and 2) internal factors (sleep pressure) burdening the subject. Our studies show that changes in EEG spectra, namely the frontal theta/parietal alpha ratio, correlate with the effects of both internal and external factors burdening the subject. As the EEG spectrum also reacts to changes in the cognitive demand of the task from low to high, it offers an objective means to estimate the overall physiological state of the brain (Holm et al., 2009).

Time-synchronization of neurophysiologic metrics with computerized tasks makes it possible to study the interactions between brain physiologic state, task demands and cognitive performance, as well as any environmental factors (such as noise) present. The EEG frontal theta/parietal alpha ratio increased systematically with increasing task demands and also with increased time awake. The ratio returned to baseline after a good night’s sleep (Holm et al., 2009). The change in the ratio was more pronounced in sleep-deprived subjects. As this EEG metric increases both due to increased task demands and sleep pressure and returns to baseline after a good night’s sleep, it could be used to optimize both the mental workload of a learning task and time spent at learning. It could also give feedback to individuals on when a break is needed to prevent mental overload or fatigue and help in estimating when adequate recovery has been achieved.

The fact that the EEG frontal theta/parietal alpha ratio increased with time awake indicated that a subject had to put more effort into performing the task by mobilization of further brain resources. This is done at the expense of both behavioural and physiological well-being. (Hockey, 1997). The energy metabolism of the brain is affected by sleep pressure and time-on-task, suggesting that changes in the ratio also reflect energy consumption.

The same level of brain load can be caused by different loading factors. A high external load, such as demanding work, caused a temporary loading effect that is comparable to what would be obtained by the gradual increase of sleep pressure due to increased time spent awake. It is also possible that, when the internal physiologic state of a subject is not optimal, cognitive overload situations may develop faster in high-workload conditions compared to low task demands. It should also be kept in mind that tasks of low mental demand can be demanding on vigilance. A person can become fatigued when a task is perceived as monotonous. It is all about balancing doing, surveillance, reacting and idling.
An increase in either internal or external factors, or both, narrows the gap between task demands and available resources. When EEG metrics indicate unhealthy brain loading, a more detailed analysis of causes, both external (such as task demands, environmental information load, learning methods) and internal, individual related factors, should be carried out. Overall mental load is influenced also by a person’s cognitive capacity, aptitude, skills and motivation. An environment can either promote good work flow and performance and learning or, for example, consist of distracting sensory stimuli hampering concentration and attention and thus having a negative, burdening effect on performance.

**Neuroergonomics: promoting the well-being of the learning brain**

During a demanding and cognitively challenging project the neural networks of our brain change their electrical activity level: the brain consumes more energy, and chemical neurotransmitter levels and their ratios change. Our adaptive brain can thus increase its working power when needed. Working in a high-gear mode cannot continue forever. Ultimately, a limit will be reached where the extra resources of our brain have been used up and returning to a recovery and resting mode is needed.

The overactive and overloaded brain is ‘short-sighted’ and does not necessarily understand that enough is enough. This is due to the fact that the brain adapts to the heightened level of activity required by the external or internal demands. Our brain can also become addicted to overworking which, in the end, results in a declining learning curve. A person can be unaware of the fact that continuing to work or study does not, after a certain point of mental loading of the brain has been reached, promote mastering a new skill. A person whose brain is ‘high’ from doing does not feel the need to sleep, eat or do something else. Downgrading can cause withdrawal symptoms, such as a feeling of emptiness, anxiety or a depressive mood.

The wisdom, ‘a healthy brain and mind in a healthy body’, stated by the Greek physician Hippocrates, founder of medicine, still holds true. Interdisciplinary research on learning and cognitive neurophysiology can be used to adjust tasks and learning situations to match the resources and capabilities of an individual learner. New approaches for balancing doing and idling with learning are possible. Kujala and Näätänen (2010) have recently discussed the adaptive brain from the neurophysiologic perspective.

The gut-brain and neuro-humoral axis link together physiological, metabolic and hormonal phenomena, neurotransmitters and immunological functions of brain, mind and body. Current health technology devices are capable of measuring large numbers of physiologic parameters of autonomic and central nervous system dynamics. The challenge for the near future is to find suitable combinations of different metrics that are both feasible and accurate enough for evaluating an individual’s mental and physiologic performance, as well as the still-available resources. For layman use, in self-monitoring and feedback on how to best optimize one’s learning sessions, EEG and HRV are currently the most promising methodological approaches in terms of user-friendliness.

An estimation of the overall neurophysiologic state of the brain can, in the near future, be measured with a compact, wearable device in both naturalistic field, clinical and laboratory settings. This enables monitoring brain physiology in both daily life and work in learners of different ages. Current cognitive neurophysiologic metrics provide new tools to be used to promote further development of learning environments and tailor them to meet individual needs, while optimizing them to take into account both mental as well as physiologic human factors. Also, the usability of modern information technology and social media applications of learning and their effects on individuals can be studied with a holistic approach.

**References**
