Brain Performance Enhancement for Military Operators

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ABSTRACT

Performance of military operators depends on both physical and cognitive aspects. Enhancement of operator performance should therefore address both the body and the brain. This paper focuses on the latter. We provide an extended list of areas where neuroscientific knowledge may be important like training and mental healthcare. We zoom-in on the relevance of neuroergonomics and Brain Machine Interfaces (BMIs) and present recent data from our lab. Up till today, the majority of applied neuroscience research is aimed at assisting people with medical limitations, and not at performance enhancement for healthy users. Knowledge transfer from patient orientated applications to military brain performance enhancement offers major opportunities, for example in the design and evaluation of new systems. We foresee that the first applications of BMIs will be available for workstation operators in high-risk environments. Future research should be focussed on three transitions: 1) from clinical and patient apparatus to applications and equipment for healthy users, 2) from lab (or controlled) environments to the field, and 3) from fundamental knowledge to operational applications.

1.0 INTRODUCTION

Traditionally, human performance enhancement focuses on the improvement of the physical performance, and not so much on the cognitive abilities of the human. However, in current military operations cognitive tasks such as information gathering and interpretation, decision making, communication with civilians (with or without (remote) language support), and operation of complex equipment are required throughout all ranks and levels. Apart from physical fitness, cognitive fitness has become a prerequisite to complete mission essential tasks. This makes enhancing cognitive or brain performance a relevant issue.

Apart from mission essential tasks, cognitive performance is also critical in the interaction with systems. In this respect, understanding the cognitive state and capabilities of the individual soldier becomes increasingly important to build the required 'intelligent' systems (see Figure 1). There are large individual differences and these should be taken into account in operational deployment and the design and use of operational systems. In the last decade, the contribution of neuroscience has grown, based on the conviction that the human brain is the basis for both cognitive tasks (perception, planning, decision making) and for physical performance (grasping, aiming, pointing). Since the brain also controls processes throughout the body, and our body interacts in turn with our brain, brain performance is also relevant with respect to physical performance. Important steps forward have been made in fundamental neuroscientific knowledge. Knowledge on the structure and functioning of the brain grows every day.

Figure 1: Examples of humanization of the interface; intelligent systems ("virtual assistants") that look and behave like human beings, and that are required to have a better understanding of the human partner's cognitive and emotional state and capabilities.

From the perspective of biology, brain performance enhancement through pharmacological and later on possibly through genetic/stem-cell measures will significantly improve neurocognitive abilities. Today we see a lot of activities directed to optimise the biochemistry of the brain and biochemical signalling. For example, the well-described mental state of flow with all its positive effects seems to be connected with the activity of the substance Anandamide, probably the transport vehicle for endorphins through the blood-brain barrier. Most of these activities arouse from observing unexpected side effects of medication to patients with psychiatric diseases, but only are enabled by major advances in understanding human biochemistry. This paper however, does not sketch the biological perspective but follows a Human Factors Engineering approach (see [1] in this issue for a complementary view). It consists of several parts. First, we reflect on the potential contributions of neuroscientific knowledge to the military domain and in particular on the areas neuroergonomics and Brain-Machine Interfaces (BMI). We zoom-in on neuroergonomics and BMI applications and report the latest data from our lab on the use of brain signals to improve human-system symbiosis. Finally, we discuss the way forward and the (specific) challenges and opportunities.

Figure 2: Example of the risk of perceptual and cognitive overload.

2.0 MILITARY RELEVANCE OF NEUROSCIENTIFIC KNOWLEDGE

Neuroscientific knowledge can potentially contribute to several military issues. In some areas, this contribution will be minor, but in others it may actually be essential to make progress towards human-system symbiosis [2]. We give the following list as an indication of the scope rather than as a complete overview. We will discuss the first four in more detail in the next sections.

- **System design**. Neuroscientific knowledge can have an important contribution in the design phase of military systems (as far as user cognition is relevant for the system at hand). Traditionally, the cognitive sciences have made major contributions to this area, mainly by providing models of functions like perception, memory, and motor skills that help optimise system design. Example include design considerations such as colour use, symbol size, and menu structures. Neuroscientific knowledge on user aspects such as attention, engagement, and workload can expand the set of existing system design guidelines.
- **System evaluation**. Besides improving system design, neuroscientific research tools (e.g., neuro-imaging) can also be used to evaluate systems by testing the extent to which various known brain areas and signals are involved while the system is being used. Neuro-imaging may therefore help determine whether and to what extent systems stimulate the relevant brain regions optimally involved in a particular task. The advantage of neuroscientific measuring methods is that they help us understand variables that cannot be determined by behavioural measurement.
- **Direct communication**. People working in challenging environments and at the edge of their physical and cognitive abilities such as military operators are a major thrust for ergonomic innovation (see Figure 2). Developments in human system integration have proven to be of great importance in supporting mission essential tasks in high-risk environments. In situations where an operator has literally a shortage of eyes and hands, direct communication between operator and system without the user's sensory or motor system but based on brain signals, can be considered as an additional communication channel between user and system.[1]

[1] Please note that communication can also be from system to user, for instance cochlear implants for the hearing impaired and electrodes for deep brain stimulation for people suffering from tremors.

- **System adaptation**. Sensory or cognitive overload is an eminent risk for operators in information rich environments. One of the solutions to this risk is to implement a system that adjusts the information presentation (e.g., postpone messages) or the task allocation (e.g., take over tasks from the user) to the user's current capabilities. To accomplish this, such an adaptive system needs information on the present state of the user, for example on visual attention, task engagement, or cognitive load. Brain signals may be valuable indicators of operator state, adding to existing physiological indicators such as heart-rate variability. Another possibility is that brain signals may indicate rare but threatening situations such as pilot spatial disorientation[2]. An advantage of neural measures is that they can add vital information to sometimes less reliable behavioural measures. For example, we can use eye movement technology to determine what someone is looking at, but not whether that person is actually perceiving the visual information or attending to music playing on thee radio or planning an action. By measuring brain signals in the visual cortex, we may be able to determine the focus of someone's attention. A step beyond identifying the locus of attention is distilling information about the objects an operator has seen. Recently, neurocognitive researchers have been able to accurately identify which of two objects a respondent had been looking at, for instance a horse or a cow, a bird or a butterfly, based on twenty seconds of fMRI data (for an overview see [3]).
- **Personnel selection**. Neural indicators may help to assess and predict the extend to which an individual is able to cope with stressful environments, high information loads, etc.
- **Training**. Most aspects of training are related to the brain and its plasticity. Measuring this plasticity and changes in the brain can help to improve training methods in general and an individual's training schedule in particular. With respect to the latter, indicators such as learning state and rate of progress (novice / expert) are useful. To sketch a picture of recent neuroscientific progress: Neuroscientists showed that they were able to predict whether or not a respondent would remember a specific word based on fMRI patterns only. A topic gaining relevance to military performance is the emerging scientific field of neuroplasticity. The term refers to the brain's ability to change its physiological structure and function, in particular by expanding or strengthening circuits that are used, and by shrinking or weakening those that are rarely engaged. The science of neuroplasticity has mostly documented brain changes that reflect physical experience and input from the outside world. Recently also the change in response to purely internal, mental signals has been investigated by EEG [4] and fMRI by probing Buddhist long term meditators. Early work from the 1970s and 1980s probing Transcendental Meditation practitioners already revealed dramatic increase in synchronicity and activity of brain waves through EEG measurements, but could not correlate it to physiological changes in the brain. These findings allow for new types of mental training to improve or even aquire mission critical abilities.
- **Resilience and mental healthcare**. Neuroscientific knowledge could also help to protect military personnel against brain-related stressors (resulting in a better preparation for deployment), or help to recovery after stressful experiences. Neurofeedback can be considered as direct communication between brain and system. However, the aim here is not to communicate messages or to control a machine, but to train producing (or suppressing) brain signals themselves in order to improve well-being. Neurofeedback is already considered a valuable tool in treating for instance depression, sleep disorders, and post traumatic stress disorder.
- **Cognitive performance**. Neurofeedback and other neuroscientific techniques can also be employed to increase cognitive performance, concentration and mental fitness in general.

[2] Please note that this is a hypothetical example. As far as we know, no brain signal correlates of Spatial Disorientation have been identified yet.

- **Information operation**. A niche application with military relevance is to employ the superior pattern recognition capacities of the human brain to analyse large amounts of visual imagery like satellite images at high speed and select relevant images or detect changes over time.
- **Rehabilitation**. After deployment, neuroscientific knowledge can also contribute to physical (and mental) healthcare, e.g. through knowledge on neural recovery, to support people with reduced sensory, motor, or cognitive functions and to treat mental disorders. The use of BMIs in motor revalidation is currently investigated by for instance the EU project TOBI (Tools for brain-computer interaction). The idea is to give feedback to the responses of motor neurons as to keep them active even though the body is (currently) not responding.

Of the list above, we will zoom-in on the first four bullets: system design, system evaluation, direct communication, and system adaptation. The first two of these are also known under the designation, neuroergonomics, while the latter two are considered as Brain Machine interfaces (BMI) or Brain Computer interfaces (BCI).

2.1 Neuroergonomics: system design and evaluation

Recently, more and more automation has been made available to the human. However, a possible downside can be the increasing information complexity and volume, and an increasing autonomy of technical systems with out-of-the-loop, situational awareness and vigilance problems as a result. To cope with these issues, human factors engineering is essential. We should keep the human as central focal point of the design process, to prevent human error and major consequences after system implementation. Neuroergonomics is an emerging field that combines neuroscience with human-system interaction studies in order to evaluate how well a technology matches human capabilities and limitations. The term neuroergonomics was first coined by Raja Parasuraman [5]. Parasuraman explains the aim of the field in the following words: "*to use the discoveries of human brain and physiological functioning both to inform the design of technologies in the workplace and home, and to provide new training methods that enhance performance, expand capabilities, and optimize the fit between people and technology*". An illustrative example is the recent research on cell phone use during driving [6, 7, 8] and brain-imaging results that indicates that even the hands-free or voice activated use of a mobile phone is as dangerous as being under the influence of alcohol during driving. The listening-and-drive mode produced a 37% decrease in activity in the parietal lobe, which is associated spatial processing, critical for navigation. Activity also decreased in the occipital lobe, which processes visual information [9].

2.2 Brain Machine Interfaces: direct communication and system adaptation

Brain Machine Interfaces (BMIs) enable direct communication between the user's brain or nervous system and a machine without involving the motor system. BMIs are an embryonic technology but remarkable accomplishments have been reported in the last decade, for example in the ability to use single trial EEG measurements [10] and apply BMIs in fast control processes [11].

BMIs can be roughly divided in active, reactive and passive BMIs [12]. With active or reactive BMIs, users consciously operate a machine handsfree. In active BMIs, they do this for example by imagining left versus right hand movements which the computer then can decode as the desired direction of a cursor on a screen or of a vehicle[3]. In reactive BMIs, users are presented with different kinds of so-called probe stimuli (e.g. images or differently pitched tones) that elicit certain detectable brain signals whenever attention is consciously focused on them. As in active BMIs, reactive BMIs allow the communication of messages without the use of the motor system. An advantage of active over reactive is the independence of probe stimuli; an advantage of reactive over active is the speed of communication due to the relatively clear brain signals even without training of the user. A special application of reactive BMIs lies in image

[3] To date, motor imagery has been the most commonly used task. However, eventually other cognitive tasks may prove to be more effective [203].

classification [13]. Since the (human) brain is still notably better in certain kind of image recognition or classification tasks than computer algorithms, one can make use of this capability by presenting the brain with large sets of very quickly presented images where the human has to pay attention to a certain target. Instead of, or in addition to, pressing a button, brain signals can be used to speed up the classification task. The third kind of BMIs is called passive. Passive BMIs are not intended to control machines but to enhance human-system interaction and/or inform the user about his/her state. These BMIs do not require mental effort or consciously generated brain signals, but use spontaneously, 'automatically' generated signals that arise when doing a certain task. Passive BMIs can monitor aspects such as (visual) attention, engagement, drowsiness or mental workload and initiate proper action such as issue a warning, adapt the information presentation or allocate tasks differently between user and system. Also, errors can be recognized and corrected [14].

The ultimate goal is the use of these passive BMIs to create a symbiotic relation between human and machine in a closed-loop system, which continually optimizes its performance. Extended research has already been done in the field of Augmented Cognition, which aims to compensate for temporal limitations in human information processing [15].

3.0 BMI DEVELOPMENTS AT TNO

In this section, we will discuss a reactive BMI and two kinds of passive BMIs (one to monitor errors and one to monitor workload) from our lab.

3.1 Handsfree navigation

The traditional application domain for handsfree navigation BMIs is for severally disabled people who lack the motor capabilities to communicate. In this domain, active BMIs are the principal choice because users can devote large parts of their cognitive resources to the navigation task. For military applications, the advantage of handsfree navigation is evident, but operators will certainly not be in a situation where they can easily devote cognitive resources to the navigation task only. For example, brain-based applications may be introduced to navigate a remotely operated vehicle more intuitively than via complicated control devices while the user is engaged in cognitively demanding tasks such as surveillance or ordnance disposal. Thus we should look for interfaces that benefit from the handsfree aspect but also require acceptable cognitive effort. Therefore, our principal choice is for reactive or passive BMIs. Ultimately, a BMI should be able to recognize the brain’s desire to navigate somewhere, so that the user does not have to plan and execute the appropriate motor commands to control a complex interface.

Many reactive BMIs are based on Event Related Potentials (ERPs), especially the P300 ERP. The P300 is a positive peak in EEG that occurs approximately 300 ms after presentation of an attended 'target' stimulus, presented within a sequence of other ignored 'distracter' stimuli. Because users can choose for themselves which of the presented stimuli is the target to attend to, and because the P300 can relatively easily be detected, this signal has often been used to drive BMIs. A well-known example is the P300 speller in which rows and columns of a matrix consisting of letters are sequentially flashed in random order [16]. Every time the row or column is flashed that contains the symbol that the user wants to spell, a P300 occurs. In this way, users can spell directly with their brain. Other P300 based BCIs have been designed to control a robot wheelchair [17], to switch devices on or off in a virtual room [18] and to stop a virtual car [19].

As far as we know, all P300 BMIs up to date have used visual or auditory stimuli to elicit P300s. However, for military purposes tactile stimuli can be an interesting alternative. These stimuli can be delivered by tactors that are hidden under the user's clothes, making the ‘stealthy’. Using tactile stimuli will also keep the eyes and ears of the user free, and these are often primarily required to ensure the soldier's performance and safety. Tactors applied around the waist have proven to be successful as navigation display [20], and may therefore be a natural choice for designing an intuitive BMI for navigation.

In a series of experiments, we asked participants to focus on one of several tactors around the waist (Figure 3) that vibrated in random order with or without corresponding visual stimuli on a monitor. The idea is that in this way they can communicate a desired direction of movement: a P300 occurring after the tactor on the navel vibrated means 'I want to go forward' and after the tactor on the left side 'I want to go left'. In the first experiment, we demonstrated that these kind of stimuli indeed elicited P300s and that they can be at least as strong as visual P300s [21]. Off-line classification showed that a classification model can successfully pick out the target direction from the distracters after only one presentation of each, though performance increases with more presentations (Figure 4). Also, we found that presenting stimuli bimodally (in the tactile and visual modality) increases the performance of the BMI. This indicates that tactile stimuli are also powerful enough to add to the traditional visual BMIs. We suspect that this advantage may be even larger when the visual and tactile stimuli are more in congruence than in our experiment (i.e., perceived at the same location in space rather than on the waist and on a screen). In subsequent experiments, we tested several spatial and temporal parameters of a tactile BMI where participants received online feedback. Findings include that from a P300 point of view, two, four and six tactors are equally suitable [22] and that the time between the start of the stimuli could be at almost twice as short in comparison to the experiments before (376 ms instead of 626 ms) without loosing any classification accuracy.

Figure 3: Participant showing the tactile vest and EEG cap used in the experiment.

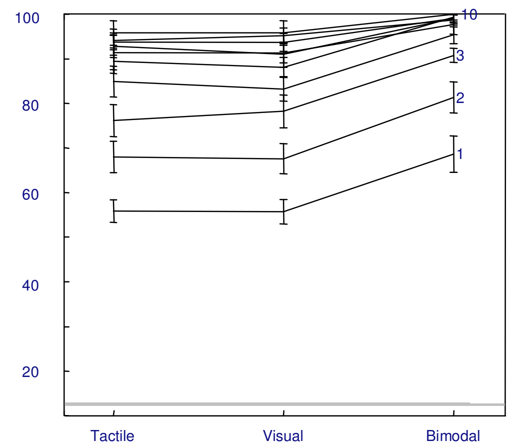

Figure ???: Classification performance (percentage correct) as a function of stimulus modality (tactile, visual, bimodal) and the number of stimulus presentations (1-10). The grey line indicates chance performance.

3.2 Error correction

Although the cognitive mechanisms underlying human error detection processes are not yet fully understood, various EEG studies [23, 24, 25] have shown that human error detection is associated with typical patterns in the EEG signal, so-called error potentials. In general, these error potentials can be observed whenever the actual outcome of an action does not match the intended outcome. The exact structure of error potentials depends on the type of error. On the one hand, the machine may commit an error (for example when wrongly interpreting a user intention due to restricted information); on the other hand, errors may occur due to erroneous behaviour of the user (for example when accidentally pressing a wrong button). We call these machine errors and self-generated errors, respectively. Error potentials provide us with information that is not directly observable from the 'outside' and could be used by BMIs to quickly detect and possibly correct errors without disturbing and requiring any effort of the user. Some studies showed that BMIs can indeed detect single machine errors [12] and self-generated errors [26].

As alluded to in the previous section, tactile interfaces started to attract the attention in the field of human-machine interaction. Van Erp [20] pointed out various advantages of tactile interfaces. These include their potential to lower cognitive workload in other modalities and their ability to intuitively direct a user's attention (a proverbial tap-on-the-shoulder). Because of the increasing importance of tactile interfaces in human-machine systems, it is of interest to determine whether error potentials similar to the ones found in the visual and auditory domain are observable for tactile stimuli. There exists only one study [27] that indicates that self generated error potentials can be elicited in the tactile domain. We explored the EEG patterns related to error processing in the tactile modality for both, self-generated and machine errors [28].

Subjects were asked to move a tactile cursor to a tactile target. Cursor and target were presented using the tactile display as described in the previous section. The target was continuously vibrating with on- and off times of 100 ms. The cursor was presented for 400 ms. Subsequently, subjects were presented with a visual cue indicating a movement direction (clockwise or counter clockwise). By pressing an 'accept' button or a 'reject' button they could either make the cursor move in the desired direction or not. In some conditions, the machine committed an error by moving the opposite direction of that indicated by the user. In other conditions, the visual cues were made more difficult to interpret, such that the users made relatively many errors. Figure 5 shows the averaged error potentials as found in this study. Interestingly, for self-generated errors, EEG traces between correct and erroneous trials already start to differ before the button has been pressed, indicating that the brain is aware it has initiated an erroneous movement before it is executed. This could potentially be very valuable information to be used by a BMI. Mean classification rate for both types of errors was around 70%, albeit with relatively many false alarms. This can most probably be improved by providing the classification model with more training data.

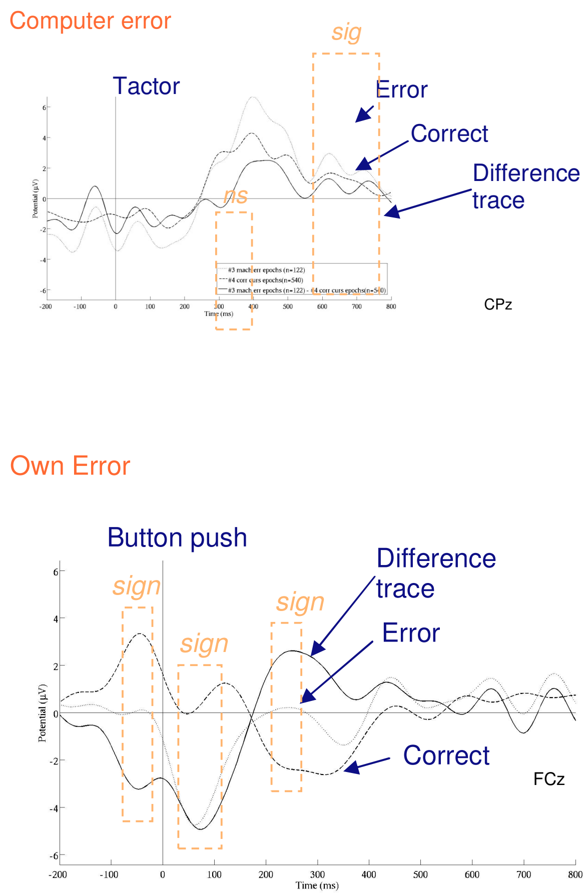

Figure 5: Tactile error related EEG signals.

3.3 Operator State and adaptive interfaces

The ability to continuously monitor workload in a real-world environment would have important implications for the design of human machine interfaces as well as the real-time online improvement of interaction between humans and machines. For example, based on an online measure of operator state, one could adjust the task allocation between operator and machine during high workload, let the automatic pilot take over control during pilot spatial disorientation, or send a baggage inspector for a break when their visual attention is too low. Several studies showed that different frequency bands in the EEG power spectrum vary with workload [29, 30, 31], fatigue [32, 33, 34], or visual attention [35, 36].

NIRS (Near Infrared Spectroscopy) is a less investigated brain imaging technique that measures the relative concentration of oxyhemoglobin and deoxyhemoglobin within the cortex. There are indications that workload affects NIRS signals as well [37, 38]. Since EEG and NIRS measure different physiological signals and are susceptible to different noise sources, it is possible that a combination of both techniques will enhance our ability to distinguish between different levels of workload online. We investigated the effect of different workload levels on EEG and NIRS, and evaluated whether using both signals in a classification model will improve offline workload identification.

Workload was varied using the n-back task [39]. Ten subjects viewed a screen on which letters were presented successively. Their task was to indicate by button press whether or not the current letter was the same as the one presented just before (1-back) or the one before that (2-back). In the 0-back condition subjects judged whether the letter is an 'x' or not. EEG and NIRS signals were recorded simultaneously (Figure 6).

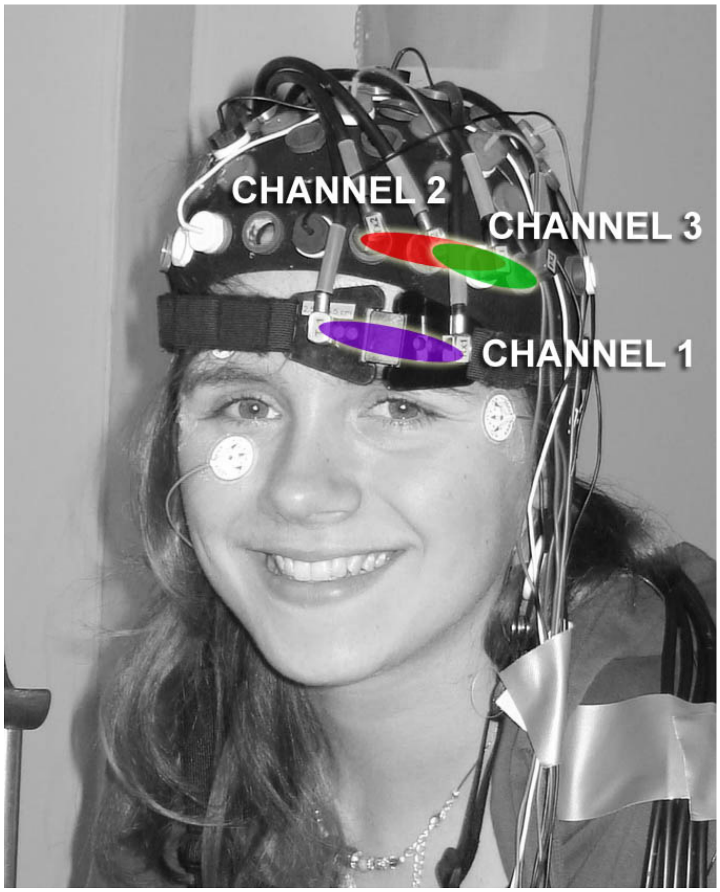

Figure 6: Participant wearing a cap that contains both EEG and NIRS sensors. The three NIRS sensors are indicated by the three ovals.

Preliminary analyses (see also Figure 7) show that the EEG recordings generally resulted in good classification between the 2-back and both the 1-back (70.8%) and the 0-back (73.3%) conditions, but NIRS not (53.5% and 61.3%, respectively). Also, combining EEG and NIRS (56.5% and 61.1%, respectively) did not improve the classification results compared to EEG alone. The limited performance of NIRS as workload indicator may be due to the fact that we have not yet developed classifiers specifically for NIRS signals but used EEG classifiers for the both the EEG and the NIRS data. Further analyses should reveal whether NIRS signals can add to EEG in classifying levels of workload.

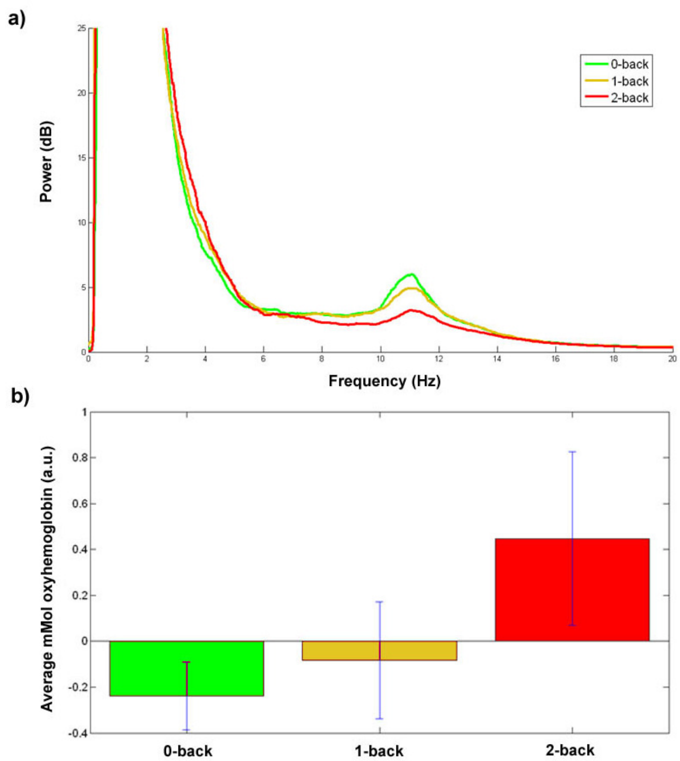

Figure 7: Example result for one participant in the workload study. Effect of task difficulty on the EEG power spectrum is given in panel a) and on the oxyhemoglobin level in panel b).

4.0 CONCLUSIONS

We argued that current military operations not only challenge the physical capabilities of soldiers, but also their cognitive abilities. Performance enhancement should therefore also be focussed on cognitive performance and thus the brain. Or as Parasurman and Wilson [40] put it: to examine behaviour and the mind at work, one should study what makes work possible – the brain. The scientific discipline that studies the brain is neuroscience, and hence we should identify neuroscientific knowledge that is of relevance to the military domain. We have given an extended list of the possible neuroscientific contributions and zoomed-in in more detail to neuroergonomics and BMIs. Until today, the majority of applied neuroscience research is aimed at assisting people who suffer from a physical, perceptual or cognitive challenge and not at performance enhancement for healthy users. This situation opens up opportunities for spin-off and spin-in between advanced (military) Human System Interaction knowledge and the accomplishments in neurotechnology for patients. Currently, there is inadequate structural knowledge development[4] for military specific fields while fundamental knowledge has limited value for applications, especially in the military domain. Several new challenges arise: how to build an application that is fast, accurate, easy to use, and that can be operated in strenuous environments and based on sensor systems (EEG, NIRS, or others) that are preferably portable, easy to don, and non-obtrusive. Also, low bitrates may be acceptable for patient applications, but may be of less interest to healthy users [41]. These issues add to challenges that have to be dealt with in applications for patients such as large differences between individuals and even BCI illiteracy. From a military perspective, knowledge development should

[4] Several NATO countries have started research programs or feasibility studies into this matter, amongst others the UK, the US, Canada, Germany and the Netherlands.

focus on three transitions: 1) from clinical and patient applications to applications for healthy users, 2) from lab (or controlled) environments to the field, and 3) from fundamental knowledge to operational applications. These transitions will also involve ethical issues. Everyone will agree that personality, free will and mental abilities are interwoven with brain function, which become more important if we shift from therapeutic BMIs towards enhancement BMIs (see Figure 8). Therapeutic BMIs focus on people with degraded functioning (for example as a result of a stroke), while enhancement BMIs focus on expanding the capacities of normal functioning individuals which is an important difference from an ethical point of view, especially when medical risks are involved as with invasive sensor systems.

In conclusion

- Neuroscientific knowledge can contribute to the military domain in designing and evaluating equipment (neuroergonomics), selection and training of personnel, increasing resilience and in user system communication (BMI).
- Recent developments in neuroergonomics are concerned with the neural basis of cognitive functions (such as perception and decision making) and of physical performance (such as grasping and aiming). These developments are essential new ways to cope with increasing problems in human–system integration.
- BMIs carry with them the expectation of the future, they are among us and are here to stay. Tens of thousands of individuals already use a BMI for different therapeutic applications. Still, these BMIs are one-way tools to either actively send signals from the brain to a technical system or v.v. (including cochlear implants and deep brain stimulation for people suffering from tremors). Especially non-invasive BMIs are not yet capable of transferring information-bearing signals into the brain. Thus, pure interactive brain-machine communication is not viable yet[5].
- Generally speaking, one could say that as BMI qualities improve, the application of BMIs will no longer be limited to patients. Instead, the field may gain momentum at the moment the military, gaming, entertainment, and other industries get fully involved and BMIs will become available to an exponentially increasing set of patients and non-patient groups.
- We foresee that the first applications of BMIs will be passive systems for workstation operators in high-risk environments. Active systems still are still too slow in terms of precise intentional information transfer. In recent years, major steps have been accomplished in passive BMIs in lab environments for instance to implement adaptive automation. Also, applications for workstation operators do not depend on the development of wearable (sensor) systems.
- The thrust from technology with enablers like advanced materials, nanotechnology, microintegration etc. will open up possibilities to contact the brain in a more effective and gentle way, therewith paving the way for broader application of neurotechnology in the military domain.

[5] For healthy users, one could consider to use the peripheral nervous system to establish communication from system to the brain therewith bypassing the human senses with their shortcomings but without needing to contact the brain directly.


Chippen in de Baja Beach Club

Betalen met geld in een club is vaak onhandig en ook een chippas werkt niet optimaal. Daarom heeft de Baja Beach Club in Rotterdam iets nieuws bedacht: de onderhuidse chip.

Een onderhuids dranktegoed

Figure 8: Trends over the past few decades clearly show that technology and systems are coming closer to the human body and are nowadays often worn on the body. Next generation interfaces for healthy users may be partly inside the body. This step has already been taken for special patient groups. Although ethical questions will certainly play a role in this process, applications for healthy users are based on implanted chips are on the market, like VeriChip (Delray Beach, FL) implants to pay for drinks in a discotheques (picture from Baja Beach Club, Rotterdam, The Netherlands; www.baja.nl).

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