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Neuroscience for selection and training of resilient military personnel

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Summary

The defense is confronted with a high competition on the labor market and a substantial scarcity of personnel. If we are able to enhance and maintain resilience and performance of personnel by proper selection procedures or mental training we expect to increase the return on investment of military education, training and operation, that is: troops will operate more successfully with more endurance during military missions. However, at present the defense needs more knowledge concerning the selection and training of personnel that is capable and motivated (resilient) to cope with stressful operations in threatening environments. The current report goes into a neuroscientific approach. We provide an overview of applications for selection and neurofeedback-training of EEG (electro-encephalogram) and the hemodynamic response as measured by fMRI (functional magnetic resonance imaging) or NIRS (near-infrared spectrometry). These types of brain signals can be measured non-invasively, and, in the case of EEG and NIRS, are portable and relatively cheap. We have systematically searched for EEG and hemodynamic (NIRS and fMRI) predictors of military performance under extreme conditions such that a more concrete idea can be formed of the relatively short-term (im)possibilities of neuroscientific applications in selection and neurofeedback training. Our literature search pointed out that for some possible predictors of military performance, there is a rapidly growing body of evidence for measurable neural correlates. This holds especially for personality traits as defined by the Five Factor and Eysencks neuroticism-extraversion model, as well as for stress reactions. Neurofeedback-training has recently been shown to be effective in some cases, but solid research is still needed to investigate whether it can enhance mental resilience. It would be optimal to provide feedback directly over those brain processes that have been shown to determine military performance. It is argued that this will be possible only with the aid of synthetic environments (simulation, virtual reality, gaming) that maximally mimic real military situations.

Contents

Foreword

The military occupation exposes its members to a wide range of stressors. Combat-related stressors are the most obvious and extreme ones, gaining the most attention, but military operations in the post–Cold War era entail a wide range of other challenges and potential stress factors. In addition, the numbers of peacekeeping, peacemaking, humanitarian, and other kinds of operations have increased dramatically, while deployments are more frequent and longer in duration than in times past. This in turn has resulted in more training exercises, planning sessions, and equipment inspections in preparation for deployment. All of these factors add to the workload and pace of operations. During and after missions, performance, well being, and health of military personnel may therefore be reduced considerably, not only due to the workload and pace of operations, but also due to typical deployment stressors, such as sleep deprivation, danger, ambiguity, boredom, isolation, restrictions, culture shock, etc. Acute stress reactions and sometimes even more chronic conditions, like depression and post-traumatic stress dysfunction (PTSD) may appear. This may hamper operational effectiveness and threaten the uphold of our military ambition level.

The defense is confronted with a high competition on the labor market and a substantial scarcity of personnel. If we are able to maintain or enhance performance, endurance, and resilience of personnel by proper selection procedures or mental training we expect to increase the return on investment of military education, training and operation, that is: troops will operate more successfully with more endurance during military missions (e.g. Uruzgan). However, at present the defense needs more knowledge concerning the selection and training of personnel that is capable and motivated (resilient) to cope with stressful operations in threatening environments. The current report goes into a neuroscientific approach.

1 Introduction

Military operations do not only involve the physical capabilities of military personnel, but also their cognitive and mental capabilities. Since the brain is the seat of these capabilities, studying the brain seems a straightforward way of increasing our knowledge about cognitive and mental processes such that human performance can be enhanced. Several recent reports stressed the importance of neuroscience for the military (Kruse, 2007; van Erp et al., 2009; Reschke et al., 2009; Wiebe, 2006; Committee on Opportunities in Neuroscience for Future Army Applications & National Research Council, 2009). The (military) fields of application suggested in these reports include system design, mental state monitoring, mental health care, rehabilitation, Brain-Computer Interfaces, selection and training. Here we will focus on selection - using neuroscientific knowledge in order to select the most suitable candidates for a specific task or training schedule, and training - more specifically, neurofeedback training. In contrast to the above mentioned reports, this report provides more details of relevant scientific findings, including references to scientific journals such that a more concrete idea can be formed about the relatively short-term (im)possibilities of neuroscientific applications in selection and neurofeedback training. The overview is not only relevant for the military domain but also for other domains involving people who work under stressful, risky and extreme circumstances where stakes are high, such as rescue workers and fire fighters.

1.1 Selection

Recently, Willem Verbeke, professor at the Faculty of Business Economics of the Erasmus University in Rotterdam, appeared in the media arguing that a brainscan will be a standard procedure when applying for a job within 5 years (ANP, Pauw en Witteman 24-02-09). Verbeke stated that “a brainscan reflects precisely who you are” which would be helpful in choosing the right person for a particular job. Even though most neuroscientists would definitely not agree to the statements by Verbeke, research starts to accumulate relating individual patterns of brain activation and anatomy to personality characteristics and psychological disorders.

For the selection part of this report, we searched for recent studies describing neural correlates of properties that are important when carrying out highly demanding military tasks and missions. Examples of these properties are stress resilience and emotional stability. Neural correlates of these could potentially be applied for selection. For selection purposes one would ideally like to simply test the candidates’ performance in extreme environments and under extreme conditions that are similar to the ones where they will be working. Environments and circumstances that are less harsh will likely fail to distinguish between the top most suitable individuals and others with average abilities (Paulus et al., 2009). However, testing people under extreme conditions raises practical and ethical problems. Thus, other predictors of performance would be useful. Tools that are commonly used to try and predict performance under harsh conditions are psychological questionnaires. However, reliable (neuro)physiological indicators of properties of interest have several advantages over questionnaires and other kinds of verbal tools. First, the ability to report about experienced emotions varies substantially between subjects (Sander et al. 2005).

Furthermore, (neuro)-physiological state is harder to manipulate than behavior (Picard, 2001). This is essential when tests are used for the purpose of selection, where candidates could bias their responses in the desired direction. Hartmann et al. (2003) examined the predictive validity of several tests in Norwegian Naval Special Forces candidates. While they only found a weak correlation between personality scales and performance, a Rorschach approach (which is much less transparent to the participants) did a better job. Hartmann et al. (2003) and Paulus et al. (2009) conclude that it is important to use tests that do not enable individuals to identify the desired response. Additional advantages of (neuro)physiological variables for continuous measurement of mental state are that one does not need to rely on distorted retrospective reports and there is no need to disrupt an operator performing his or her task in order to ask questions.

1.2 Neurofeedback training

(Neuro)physiological markers of essential traits of military personnel could be helpful in evaluating the effect of training paradigms. However, we here want to explore whether neuroscientific knowledge could also be helpful in developing other ways of training, more in specific, whether or not neurofeedback could be a useful intervention in training. In a neurofeedback training paradigm the user learns to modulate brain signals through online (visual or auditory) information of what these brain signals look like. The idea is that neurofeedback helps to change certain characteristics of the brain signals, which again leads to improvement of behavior and skills or to the recovery of a mental or physical disorder. Even though many claims about neurofeedback that can be found in papers and on the internet are not based on solid scientific evidence, studies of higher quality started to appear over the last few years. From a review paper by Heinrich et al. (2007) it becomes clear that training certain brain signals of healthy participants can indeed specifically alter brain signals and behavior as well. Particular advantages of neurofeedback training are its self-controlled nature and the independence of verbal skills.

1.3 Scope and overview

Due to the abundance of relevant publications, a limit in scope of the literature overview is necessary. Firstly, we will limit ourselves to neurophysiological variables. However, it is important to keep in mind that (the addition of) other physiological variables - such as heart rate variability and skin conductance - could be of vital importance to improve validity of markers and to improve training results (e.g. Taylor et al., 2007; Russo et al., 2005b; Shephard & Kosslyn, 2005). Furthermore, we exclude the chemical component of neural processes in our review though these could potentially be of importance in selection and intervention (e.g. Dautzenberger & Hauger, 2002; Koob, 1999; Haas & Canli, 2008). We will focus on two types of brain signals: EEG (electro-encephalogram) and the hemodynamic response as measured by fMRI (functional magnetic resonance imaging) or NIRS (near-infrared spectrometry). These types of brain signals can be measured non-invasively, and, in the case of EEG and NIRS, are portable and relatively cheap.

We start our review with a short description of EEG and fMRI/NIRS. This is followed by an inventory of characteristics that are of vital importance for military personnel or first responders on a mission. We then search the literature for possible neural correlates of the identified characteristics. These correlates could be helpful for selection purposes. In the subsequent section, we look at the possible application of neurofeedback as a training paradigm. Conclusions and a discussion on possible research avenues for TNO follow.

2 EEG and the hemodynamic response (NIRS, fMRI)

EEG is recorded as a set of weak time-varying differences in voltage between electrodes in contact with the scalp and a reference electrode attached somewhere on the head or body. These small voltage differences are produced by the activity of neurons. There are some limits to the signals that can be measured. The signal origin must be close to the skull, meaning EEG originates mainly in the outer layer of the brain known as the cerebral cortex, a 4-5 mm thick highly folded brain region responsible for activities such as movement initiation, conscious awareness of sensation, language, and higher-order cognitive functions. Only large groups of neurons in a particular layer of the cortex which are aligned and firing in concert can contribute to EEG signals; otherwise the current is not strong enough to be detected or opposite charges cancel out. This collective signal is attenuated and spatially smeared as it is conducted through the cerebral spinal fluid, meninges, and highly resistive skull. This means that the spatial accuracy of the signal is low.

However, EEG has a high temporal resolution. Roughly two aspects of EEG can be analyzed. Firstly, the (positive and negative) peaks in the signal after an event (event related potentials or ERPs) provide information about the brain's processing of external stimuli. Secondly, one can examine spectral aspects, e.g. how strongly certain wave frequencies are present in the data. In general, these frequencies provide information about the general state of (part of) the brain.

Table 1 summarizes groups of frequencies in which EEG has been divided together with their approximate location and behavioral correlates in healthy adults (adapted from wikipedia, http://en.wikipedia.org/wiki/ Electroencephalography).

Table 1 EEG frequencies.

Name	**Freq. (Hz)**	**Location**	**Correlates**
delta	up to 4	frontally	Slow wave sleep.
theta	4-7		Drowsiness or arousal, idling, meditation (Aftanas & Golosheykin, 2005), short-term memory tasks (Vertes, 2005).
alpha	8-12	posterior regions of head, central sites at rest	Relaxed, closed eyes, idling (Hari & Samelin, 1997, Pfurtscheller & Klimesch, 1992) or top-down suppression of activity (Klimesch et al., 2007).
mu	12-16	sensorimotor cortex	Negatively correlated with (mental simulation of) motor activity.
beta	12-30	most evident frontally	Alert/working, active, busy or anxious thinking, active concentration.
gamma	30-100		Certain cognitive or motor functions.

Figure 1 MRI scanner.

The hemodynamic response is based on the distribution of oxygen in the brain. When a brain area is activated, metabolic activity increases, leading to a brief increase in the amount of deoxyhemoglobin and a decrease in oxyhemoglobin after around 2 s in the immediate vicinity of the activated neurons. This stimulates the increase of blood flow to a wider area, which causes oxyhemoglobin levels to begin to increase to a peak at about 5 s and then slowly decline over about 5 – 10 s after neural activity returns to normal. This hemodynamic response is measured in fMRI through placing the head in a strong magnetic field which causes atoms to align (see Figure 1 for a picture of an MRI scanner). Perturbations in atomic spin alignment after radio pulses of specific frequencies are used to identify changes in blood oxygenation levels. The hemodynamic respons is measured in NIRS (Figure 2) by projecting two different wavelengths of light that are differentially absorbed by oxyhemoglobin and deoxyhemoglobin into the head using a laser or light-emitting diode. The amount of light that reaches a receiver several centimeters away through a diffusion process can thus be used to measure relative changes in oxygenated and deoxygenated blood within a ‘banana-shaped’ area of the cortex lying between the transmitter and receptor.

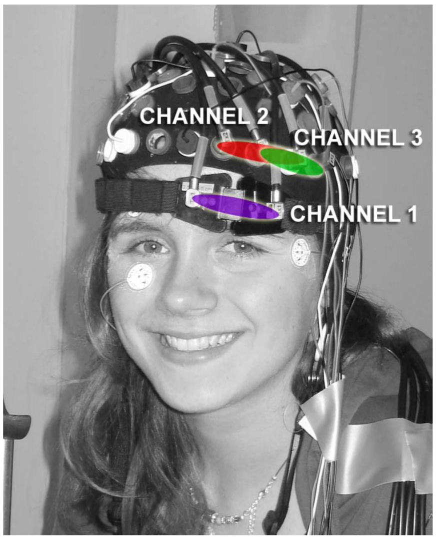
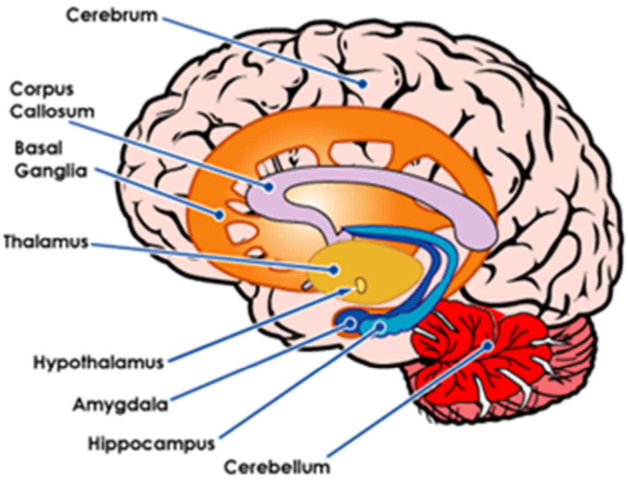


Figure 2 Combined NIRS and EEG setup at TNO Soesterberg. The channels indicate NIRS channels consisting of transmitters and receivers.

Partly due to the inherently slow physiological response, temporal resolution of fMRI and NIRS is limited. However, spatial resolution is relatively high. Which areas of the brain become active and the level of activity informs us about the specific neural

processes that are going on. Figure 3 shows the location of most of the brain regions mentioned later, for example the neurobiological substrates of social cognition (amygdala, fusiform gyrus, superior temporal sulcus: Pinkham et al.,2008) and brain regions involved in emotion processes (amygdala, hippocampus, insula, hypothalamus, cingulate gyrus, fusiform gyrus, prefrontal cortex: Hamann & Canli 2004). In neuroscientific studies of emotion the limbic system plays an important role. This term denotes a set of interconnected brain regions, including the hypothalamus, hippocampus, amygdala, olfactory bulb, septum, other small structures, parts of the thalamus and cerebral cortex (Kalat, 1992).

The tools to measure brain activity as described above are non-invasive and do not present any risk to person that is recorded. While EEG and NIRS are portable and relatively cheap, fMRI is not. However, since fMRI measures the same signal as NIRS, results of fMRI studies are relevant when planning studies with NIRS.
One should note though that NIRS can only record from the cortex whereas with fMRI, processes in any location of the brain can be studied.



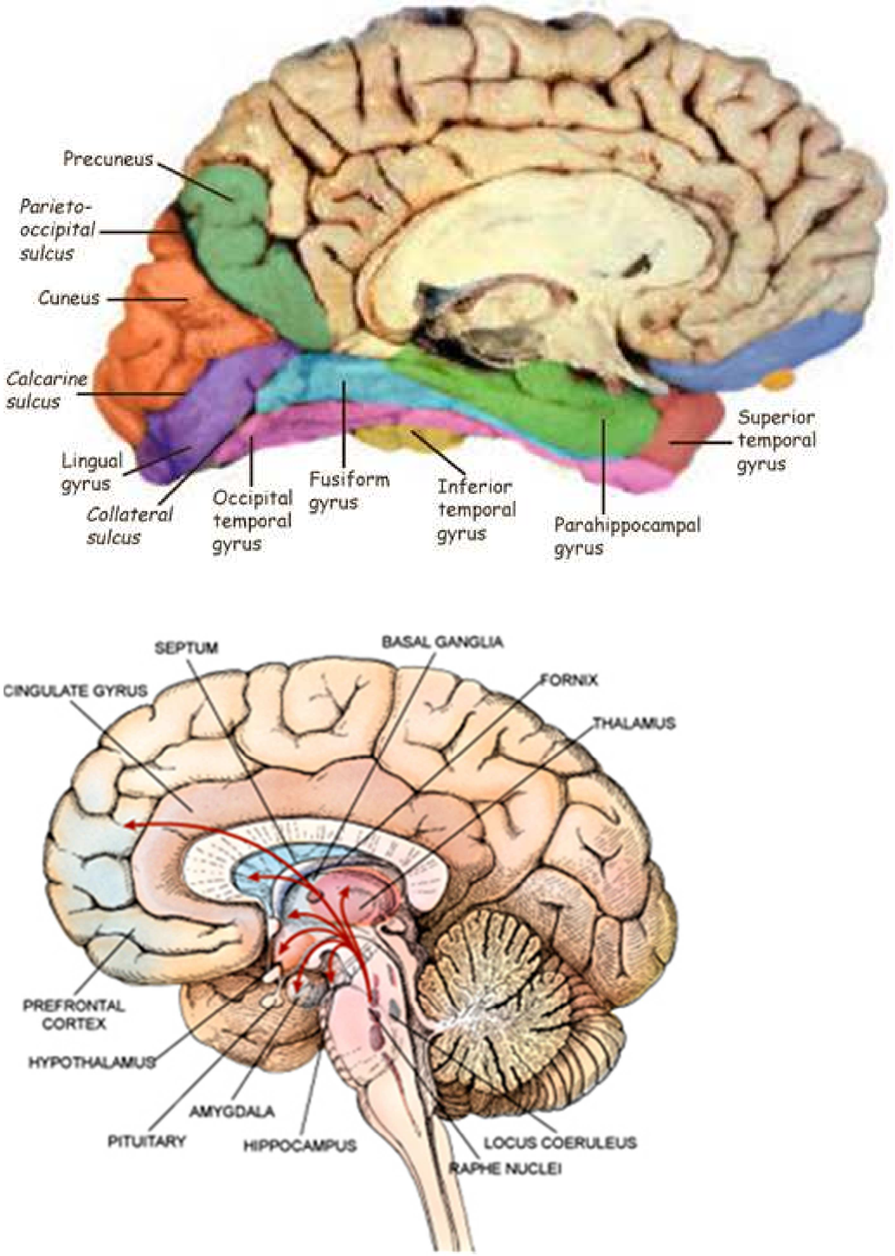


Figure 3 Overview relevant brain regions.

3 Predictors of performance in extreme military circumstances

Optimal performance can be defined as the degree to which individuals achieve a desired outcome when completing goal-oriented tasks (Paulus et al., 2009). Optimal performance is determined by internal (personal) factors, such as knowledge, skills, (transient) states of the individual, and (stable) personality traits, as well as external factors in the environment (rewards, resources, threats, etc.). External factors affect optimal performance not only directly, but also by influencing the transient internal factors, such as stress or arousal. For example, Bartone et al. (1998, 2009) identified six external factors underlying operational stress in the military (isolation, ambiguity, powerlessness, boredom, danger and workload).
In the present study, we focus on competences and personality traits.
Personality traits are stable and unchanging personal characteristics, such as extraversion or neuroticism, that contribute to individual optimal performance.
As argued by Paulus et al. (2009), it will be difficult or impossible to find one set of predictors of optimal performance under all kinds of extreme military conditions, since they will depend on the specific task, environment and circumstances. However, it seems reasonable to expect that there are some personality characteristics and competences that are in general essential in high-demand military missions. Using a range of different techniques, several studies examined predictors or correlates of optimal performance under military mission (like) circumstances.

From Bartone et al. (1998, 2009) we learn that resilience against stress may be one factor of importance. Resilience against stress is proposed to be determined by ‘hardiness’ (Kobasa, 1979), that is, a strong commitment to self, a vigorous attitude toward the environment, a sense of meaningfulness, and an internal locus of control.
Taylor et al. (2006; 2007) examined the factors that affect the degree to which individuals successfully completed one of the most challenging military training programs called Basic underwater demolition/SEAL training (BUD/S). This was done by questioning BUD/S trainers. Besides physical strength and endurance, factors that popped up were ‘mental toughness’, ‘will to win’, ‘emotional stability’ and ‘team orientation’.
Hartmann et al. (2003) found that ‘stress tolerance’, ‘reality testing’, ‘cognition’ and ‘social adjustment’ as measured by a Rorschach test predicted pass/fail results in the training of Norwegian Naval Special Forces candidates.
Palinkas et al. (2000) examined factors that influenced performance and behavior of individuals during Antarctic wintering-over expeditions between 1963 and 1974. Significant positive predictors of performance besides extent of military service were low levels of neuroticism, high levels of extraversion and conscientiousness and a low desire for affection from others.

Together, these studies mention a range of characteristics that are of importance for optimal military performance. We proceeded this literature review by searching for a combination of the word 'brain', at least one of the words 'EEG', 'fMRI' or 'NIRS', and one by one, each of the characteristics . Only literature after 1970 was concerned. Hardiness, mental toughness, will to win, team orientation, stress tolerance and desire for affection did not result in useful references.

However, resilience, emotional stability, social adjustment, reality testing, conscientiousness, neuroticism and extraversion did. Stress even resulted in 565 hits. Of these, only hits after 2005 were scanned (300 hits).

Personality traits studied in the context of neuroscience (and other disciplines) often originate from one of two influential descriptive personality models: Eysencks extraversion-neuroticism model (Eysenck, 1947) and the five factor personality model (Costa & McCrae, 1985) with the five factors being conscientiousness, neuroticism, extraversion, openness and agreeableness (the ‘Big Five’).
Thus, many of the studies about three of the characteristics that we identified above, conscientiousness, neuroticism, and extraversion, do not deal with them in isolation, but together with the other personality factors. A summarized description of the five personality characteristics as given by Wikipedia (http://en.wikipedia.org/wiki/Big_Five_ personality_traits) is the following:

Conscientiousness - (efficient/organized vs. easy-going/careless). A tendency to show self-discipline, act dutifully, and aim for achievement; planned rather than spontaneous behavior.
Neuroticism - (sensitive/nervous vs. secure/confident). A tendency to experience unpleasant emotions easily, such as anger, anxiety, depression, or vulnerability.
Extraversion - (outgoing/energetic vs. shy/withdrawn). Energy, positive emotions, urgency, and the tendency to seek stimulation in the company of others.
Openness - (inventive/curious vs. cautious/conservative). Appreciation for art, emotion, adventure, unusual ideas, curiosity, and variety of experience.
Agreeableness - (friendly/compassionate vs. competitive/outspoken). A tendency to be compassionate and cooperative rather than suspicious and antagonistic towards others.

In the following section, the literature is briefly described per keyword: emotional stability, social adjustment, reality testing, neuroticism, extraversion, conscientiousness, and stress. Since relevant results found through the keyword resilience were also found through the other keywords used, there is no separate resilience subheading.

4 Neural correlates of predictors

4.1 Emotional stability

A number of (f)MRI studies investigated psychiatric disorders involving emotional instability (borderline personality disorder, depression and schizophrenia). For our purpose, these are mainly relevant if they can be generalized to milder forms of emotional instability as found in healthy individuals. There are strong indications that depression is related to the failure to regulate the response of the limbic system (including the amygdala) to negative stimuli (Johnstone et al., 2007; Anand et al., 2005). For borderline patients, Koenigsberg et al. (2009) found a greater activity in the amygdala and primary visual processing regions when negative relative to positive emotional pictures are viewed compared to healthy controls. In a review paper, Aleman and Kahn (2005) attribute reduced emotional expression and deficits in recognizing emotions in schizophrenics to a downsized amygdala and reduced interconnectivity with the prefrontal cortex.

Curtis and Cicchetti (2007) hypothesized that positive emotionality and increased emotion regulation ability associated with resilient functioning would be reflected in relatively stronger left frontal activity. This was confirmed in EEG recordings of maltreated and nonmaltreated children.
In a large scale EEG study where subjects were required to perform a difficult internal counting task and push buttons at appropriate times, Pavlenko and Konareva (2000) found several correlates between ERPs and personality characteristics. These included negative correlations between the readiness potential and psychoticism indices and between contingent negative variation (CNV) and emotional stability.

4.2 Social adjustment

Pinkham et al. (2008) refer to the amygdala, fusiform gyrus and superior temporal sulcus as constituting the neurobiological substrates of social cognition.
Indeed, they found in an fMRI study that this network is more activated in non-paranoid schizo-phrenics and healthy controls when rating a face untrustworthy rather than trustworthy while paranoid schizophrenics did not show a difference. Greater activation of this social cognitive network when rating untrustworthy faces was correlated with social functioning (or social adjustment).

Hofmann (2006) recorded EEG alpha from participants who were at rest or preparing an impromptu speech task. High self-monitors (people who strongly adjust their self-presentation to social situations) showed lower cortical activity in frontal and parietal scalp regions than low self-monitors during the preparation task, whereas there was no difference between the personality types during rest.

4.3 Reality testing

Impaired reality testing (distinguishing between what was perceived from the outside world and what was self-generated) occurs in a range of psychiatric conditions and psychological states. For schizophrenics, this impairment seems to correlate with abnormalities in activity of the Medial Prefrontal Cortex (MPFC; Simons et al., 2006; Taylor et al., 2007; Vinogradov et al., 2008). In healthy individuals, activity in regions including the MPFC is associated with attributing a presented image to having imagined that before while activity in visual processing regions correspond to attributing a presented image to having perceived it before (Kensinger & Schacter, 2006). All of the studies mentioned used fMRI to record brain activity.

4.4 Neuroticism

Several fMRI studies show correlations between neuroticism on the one hand, and brain reactivity to (perceived, remembered or expected) emotional stimuli on the other hand (Haas et al., 2008; Hooker et al., 2008; Kumari et al., 2007; Canli et al., 2001; Canli et al., 2004; Jimura et al., 2009; Chan et al., 2008). Implicated brain regions mentioned in these studies are the medial prefrontal cortex, temporal pole, right superior parietal cortex, amygdala, hippocampus, anterior and posterior cingulate, superior/middle temp gyrus, precuneus, putamen, thalamus and the middle occipital gyrus. Of these, the medial prefrontal cortex, the temporal pole and the right superior parietal cortex can potentially be recorded from by (cheap and portable) EEG or NIRS equipment. Haas et al. (2008) found neuroticism to be correlated with stronger activity in the medial prefrontal cortex throughout blocks of sad facial expressions as compared to happy or neutral faces. Similarly, Jimura et al. (2009) found that temporal pole activation during viewing sad but not happy facial expressions correlated with neuroticism. Chan et al. (2008) showed a positive correlation between activitation in the right superior parietal cortex and neuroticism scores when categorizing and memorizing negative words, and a negative correlation when retrieving those words. An exception to fMRI studies investigating correlates with neuroticism using emotional stimuli is Eisenberger et al. (2005). They used a task in which participants detected oddball stimuli within standard stimuli and found neuroticism to be correlated with increased activity in the dorsal anterior cingulate cortex (an area associated with discrepancy detection). Interestingly, they reported that neural correlates of neuroticism predicted a relevant behavioral outcome (interoceptive accuracy) better than self-reports.

A review paper by Haas and Canli (2008) discusses differences in neural substrates for emotional memory between individuals, their correlation with personality and how they are likely to result in more or less vulnerability for emotional memory related disorders such as depression, generalized anxiety disorder and PTSD. They focus on the amygdala (which cannot be recorded from by NIRS or EEG equipment, but the prefrontal cortex is also mentioned as probably involved). On the one hand, amygdala activity when attending to emotional stimuli correlates with the retention of these stimuli, and on the other hand it correlates with extraversion and neuroticism scores. This between-subject variation likely governs variability in the extent to which emotional memories are facilitated in some individuals but not in others.

Several studies found EEG spectral correlates with neuroticism when EEG was measured at rest (Chi et al., 2005; Hosseini et al., 2007; Jaušovec & Jaušovec, 2007; Knyazev et al., 2003; Razoumnikova, 2004; Schmidtke & Heller, 2004). Neuroticism was found to be negatively correlated with theta (Chi et al., 2005), negatively with delta and positively with alpha (Knyazev et al., 2003). Schmidtke and Heller (2004) reported a positive correlation between neuroticism and right posterior activity which seems inconsistent with Hagemann et al. (1999) who suggested that a greater activation of the left temporal cortex increases susceptibility to experience negative emotions. Mcfarlane et al. (2005) studied a large population of non-clinical subjects. They found that neuroticism increased with early life stress, and that the power in the beta, theta, alpha and delta decreased with early life stress. There was also a (negative) correlation between early life stress and the size of the N2 amplitude, an ERP elicited by an auditory oddball stimulus (a stimulus that differs from its context stimuli).

4.5 Extraversion

fMRI studies also show that extraversion is correlated to brain activity (Hutcherson et al., 2008; Hooker et al., 2008; Kumari et al., 2004; Canli et al., 2001; Canli et al., 2004, Eisenberger et al., 2005). Implicated brain regions include the dorsolateral prefrontal cortex, ventral striatum, amygdala, anterior cingulate and the thalamus. Hutcherson et al. (2008), Hooker et al. (2008) and Canli et al. (2001, 2004) all showed that brain responses to emotional stimuli are associated with the level of extraversion. Participants in Kumari et al. (2004) performed an ‘n-back’ memory task. Extraversion correlated positively to a change in fMRI signal from rest to the highest memory load condition in the dorsolateral prefrontal cortex and the anterior cingulate cortex. A relatively low activity during rest in the thalamus and Broca’s area for extraverts confirmed the hypothesized difference in general cortical arousal between extraverts and introverts. Using a task in which participants detected oddball stimuli within standard stimuli, Eisenberger et al. (2005) found extraversion to be correlated with activity in the lateral and medial frontoparietal networks (areas implicated in task-focused or self-focused controlled processes).

Several studies found EEG spectral correlates with extraversion when EEG was measured at rest (Craig et al., 2009; Hosseini et al., 2007; Jaušovec & Jaušovec, 2007; Knyazev et al., 2003; Razoumnikova, 2004; Tran et al., 2006). Extraversion was found to be associated positively to delta (Knyazev et al., 2003; Tran et al., 2006) and negatively to alpha (Knyazev et al., 2003) at rest. Consistent with the negative relation between extraversion and alpha, Craig et al. (2009) reported cortical underarousal to contribute to low emotional intelligence, where extraversion contributes to emotional intelligence. However, when participants were performing tasks, Fink and colleagues found cortical activation to be low for extraverts compared to introverts. This was the case for judging facial emotions, performing a cognitive task (Fink, 2005) and performing a memory task (4-8 Hz) (Fink et al., 2005). The EEG results as summarized here seem at odds with the fMRI results as presented above.

4.6 Conscientiousness

Some of the EEG studies about neuroticism and extraversion as mentioned before, also found neural correlates of conscientiousness (Craig et al., 2009; Tran et al., 2006; Mcfarlane et al., 2005). Mcfarlane et al. (2005) reported not only higher levels of neuroticism with more early life stress but also lower levels of conscientiousness. As mentioned, early life stress correlated with lower power in the beta, theta, alpha and delta band and a smaller N2 amplitude. Not only extraversion, but also conscientiousness contributes to emotional intelligence (Craig et al., 2009) where cortical underarousal is correlated with low emotional intelligence.

4.7 Stress

Traditional theorists have conceived stressors as those factors posing a demand on the person. This means that reactions evoked in every day (working) situations that are challenging and require a certain amount of mental or physical effort can be considered to be stress reactions. However, in these situations people may also be enthusiastic, feel satisfied and happy when the task is completed successfully.
We are interested in stress as an undesirable state in which “environmental demands evoke an appraisal process in which perceived demand exceeds resources, and that results in undesirable physiological, psychological, behavioral, or social outcomes” (Salas et al., 1996). As stated in this definition, stress reactions will occur only when a person *thinks* he or she cannot cope with the situation.
This means that the occurrence of stress depends on stable (personality) characteristics, skills and (transient) states of the person on the one hand, and on the (working) environment, on the other. Stressed individuals often show inefficient behaviour, overreactivity and the incapacity to recover from work. They also suffer from a decreased well-being, sleeping problems, psychomatic complaints and increased health risks (Gaillard, 1993). As mentioned earlier, resilience to stress is supposed to be one of the essential characteristics of military personnel.
Our Scopus search resulted in an overwhelming amount of studies on this topic in the context of neuroscience. Note that not all studies define stress in the same way.

A number of ways has been used to induce different levels of stress for neuroscientific studies, such as having participants perform mental arithmetic (including negative social evaluation) (Dedovic et al., 2009ab; Wang et al., 2007) prepare a public speech (Wager et al., 2009), recall non-traumatic highly stressful events versus relaxing imagery (Sinha et al. 2004), perform a monetary incentive delay task (Vythilingam et al., 2009) and making participants feel socially excluded through a game (Masten et al., 2009). Also, individuals have been recorded during naturally occurring times with high and low stress (Lewis et al., 2007; Liston et al., 2009) such as caused by (non) examination periods. All of these studies indicated that limbic and prefrontal regions are involved in perception and modulation of stress (see also for reviews: Pruessner et al. 2010; Dedovic et al., 2009a).
Several studies report either higher or lower right (relative to left) prefrontal activity to be correlated with stress, in EEG (Lewis et al., 2007; Verona et al., 2009), fMRI (Masten et al., 2009; Wang et al., 2007) and NIRS (Tanida et al., 2007).
The different types of asymmetry may be caused by different types of stress, in particular whether it is accompanied by withdrawal or approach responses (Harmon-Jones et al., 2010).

A particular and severe type of stress-related dysfunction is PTSD (post-traumatic stress disorder) which may develop after experiencing a traumatic event. Diagnostic symptoms include re-experiencing the traumatic events through flashbacks or nightmares, avoidance of trauma-related stimuli and increased arousal reflected in sleep problems, anger and hypervigilance. Since military personnel has a relatively high chance of being exposed to traumatic events, PTSD is an important topic for the military. PTSD and its neural correlates are being studied extensively. From 2005 until January 2010 at least 33 journal papers were published about this topic. Most of them describe fMRI results. Shin and Liberzon (2010) published a review. They conclude that PTSD correlates with heightened amygdala activation in response to PTSD-relevant stimuli and that PTSD is associated with diminished responsivity in the rostral anterior cingulate cortex and the adjacent ventral medial prefrontal cortex. See for other reviews on the topic Van Boven et al. (2009); Habecker et al. (2009) and Francati et al. (2007).
For EEG, some studies did not find a difference in EEG between controls and PTSD patients (Shankman et al., 2008; Wolf et al., 1988) but a range of other studies did. Veltmeyer et al. (2006) found an altered cortical arousal as indexed by reduced alpha and increased theta/alpha. Similarly, Begic et al. (2001) and Chae et al. (2004) reported relatively strong theta and beta activity for PTSD patients.
In addition, ERP studies reveal differences between PTSD patients and healthy controls. Karl et al. (2006) reviews the effect of PTSD on the P300, an ERP that reflects attentional processing of a stimulus. The P300 can both be increased and decreased by PTSD, where relatively large P300 amplitudes are recorded when traumatic or inherently distinct stimuli are presented. Relatively low amplitudes are interpreted as a (resulting) lack of attention when processing other kinds of stimuli. Karl et al. (2006) also report alterations in amplitude and latency of other ERPs, such as the P50 and P200, which reflect changes in information processing to accompany PTSD as well. Galletly et al. (2008) reported an increased target N2 amplitude and latency for PTSD patients and a reduction of P300 amplitude for both auditory targets and non-targets.

Since stress basically is a response to certain threatening circumstances, it would be very helpful to be able to predict stress vulnerability (or its antipode resilience). This is especially so when one is interested in the response to extreme circumstances which is difficult to test, e.g. in the case of events eliciting PTSD.
Studies that 'only' examine (neural) differences between PTSD patients and healthy controls do not determine whether abnormalities represent acquired signs of the disorder or vulnerability factors that increase the risk of developing PTSD (Shin & Liberzon, 2010). Some authors explicitly studied stress vulnerability. Admon et al. (2009) recorded emotional and brain responses of 50 a priori healthy new recruits before and after entering service (including the experience of stressful events). Amygdala reactivity before entering service predicted an increase in stress symptoms. Furthermore, increased hippocampal responsiveness to stress-related stimuli after service correlated with stress symptoms. They conclude that the likelihood to develop stress symptoms may depend on the interplay between amygdala predisposing reactivity and hippocampal plasticity. Through a combat related twin study Gilbertson et al. (2002) found evidence for a reduced hippocampus to be a predisposing factor to develop PTSD and not a consequence. Another route to predicting stress vulnerability by neural markers is through measuring the neural correlates of personality characteristics that render an individual susceptible to stress.

For example, high neuroticism scores correlate with the susceptibility of developing PTSD (Stein et al., 2007; Chan et al., 2008). As described before, neuroticism is correlated with certain brain indices (e.g. increased amygdala and insula activation when processing emotional stimuli) which could function as markers for stress vulnerability. This corresponds with the above mentioned findings of Admon et al. (2009) and the idea that amygdala activity facilitates the consolidation of traumatic memories (McIntyre et al., 2003).

4.8 Note on gender

Over the whole range of reviewed literature in this section 'Neural correlates of predictors', studies popped up that showed interactions between brain signals (in response to certain (emotional) tasks) and gender (e.g. Hamann & Canli, 2004; Curtis & Cicchetti, 2007; Jaušovec & Jaušovec, 2007; Tran et al., 2006; Razoumnikova, 2004; Fink et al., 2005, Wang et al., 2007; Yang et al., 2007; Stark et al., 2006; Tops et al. 2006). Stark et al. (2006) and Tops et al. (2006) suggest that for stress, this interaction is caused through differential effects of stress hormone cortisol on the prefrontal cortex. In any case, the possible effect of gender should be taken into account when applying or studying the neural correlates of selection criteria.

5 Neurofeedback

With neurofeedback, individuals receive direct feedback about their own brain signals with the goal of learning to modulate these. Usually feedback is provided through visual or auditory stimuli, sometimes in the form of a game or a movie that only continues playing when the desired brain signals are being generated.
The idea is that neurofeedback helps to change certain characteristics of the brain signals, e.g. as identified by research on neural correlates of behavior or disorders, which again leads to changes in this behavior or to the recovery of the disorder (but see Egner et al. (2004) for reasons of caution for this assumption). In principle, all different kinds of techniques to measure brain signals could be used for neurofeedback, such as fMRI (Weiskopf et al., 2003) and NIRS (Obrig et al., 2000; Toomin et al., 2004; Coben & Padolsky, 2007). However, the most popular technique is EEG. Different characteristics of EEG signals have been fed back to the users, such as EEG rhythms or frequencies (Lubar & Shouse, 1976; Tozzo et al., 1988) and slow cortical potentials (Birbaumer et al., 1992; Strehl et al. 2006ab). Special advantages of neurofeedback would be the active role of the individual him or herself and the reduced reliance on talking capabilities and medication.

There is no doubt that individuals are able to modulate certain types of brain signals with help of feedback (Birbaumer et al., 1992; Birbaumer, 2006; Lubar & Shouse, 1976; Weiskopf et al., 2003; Heinrich et al., 2007). However, many studies on neuro-feedback as an effective treatment are based on case studies and lack proper control groups. Still, there are quite some neurofeedback clinics around claiming to be able to treat a range of problems from burn-out to whiplash (see e.g. http://www.eegbiofeedback.nl/index.php). Over the last few years, studies of higher quality started to appear. From a critical review paper by Heinrich et al. (2007) it becomes clear that training EEG frequencies and slow cortical potentials of healthy participants indeed specifically affects behavior. For the treatment of ADHD and epilepsy, there are strong indications of positive effects. The latter is recently confirmed through a meta-analysis by Tan et al. (2009). Recent studies published in solid scientific journals indicate that EEG neurofeedback can improve certain types of memory (Keizer et al., 2010a; Vernon et al., 2003), intelligence (Keizer et al., 2010b), attention (Egner & Gruzelier, 2001; Egner & Gruzelier, 2004) and mood (Raymond et al., 2005). These studies all involved healthy individuals.

With respect to problems that are of particular relevance to military personnel, several authors claim that neurofeedback can reduce symptoms of PTSD (Peniston & Kulkolsky, 1991; Peniston et al. 1993; Hammond, 2005; 2006), anxiety (Kerson et al., 2009) and depression (Rosenfeld, 2000; Hammond, 2005; Paquette et al., 2009). However, up till now, there is a lack of solid (double-blind, placebo controlled) research on the effects of neurofeedback with respect to PTSD symptoms.

A possible alley to exploit neurofeedback to prevent stress-related symptoms is to use it to enhance meditation or relaxation techniques. Several studies indicate neural correlates both in EEG and fMRI for (mindfulness) meditation (Davidson et al., 2003; Lagopoulos et al., 2009; Goldin et al., 2009; Lazar et al., 2000) that are partly in line with the research on neural correlates of stress.

However, a Scopus search on 'neurofeedback and meditation' as well as 'neurofeedback and mindfulness' did not result in any hits. A search on 'neurofeedback and relaxation' did. Egner et al. (2002) report that a neurofeedback training that aimed at increasing theta over alpha has been used as a therapeutic relaxation technique. Even though they found that this type of neurofeedback indeed modified brain signals, the self-reported relaxation effect was as high as that of a group who received fake neurofeedback. Similarly, Batty et al. (2006) found that alpha-theta neurofeedback did not result in a stronger susceptibility for hypnosis than muscle relaxation and self-hypnosis training. However, this kind of lack of effect could also have been caused by the particular dependent variable that was chosen as also suggested by Egner and Gruzelier (2003). Egner and Gruzelier trained individuals (conservatoire students) with alpha-theta neurofeedback as they did in their 2002 study, and compared the students’ EEG and music performance (as rated by single-blind experts) to the EEG and music performance of students trained on other neurofeedback protocols or having received other treatment.
The first group performed better and the improvements were correlated with the effect size in EEG.

6 Conclusions and discussion

6.1 Selection

Our literature search pointed out that for some possible predictors of military performance, there is a rapidly growing body of evidence for measurable neural correlates. This holds especially for personality traits as defined by the Five Factor and Eysencks neuroticism-extraversion model, as well as for stress reactions. Lately, PTSD has been studied frequently. Many of these studies focus on neural differences between patients and healthy individuals, which leaves the question unanswered as to whether these differences were present before developing PTSD. However, there are also studies pointing out neural correlates that can help to determine an individual's vulnerability to develop PTSD, as well as correlates of PTSD risk factors.

Traditionally, neuroscientific research on higher cognitive functions relied heavily on repeated measures designs, where one examines differences in brain signals between tasks or states within a person. Individual variation was considered as noise. However, for selection purposes, measurable differences between individuals are required (where individual differences can also lie in how a person's brain signals respond to different tasks or states). As reviewed in this manuscript, recent studies now provide solid evidence for correlations between inter-individual variations or differences in specific brain signals and certain personality traits (Hamann & Canli, 2004).

Relatively well understood and consistent are the results of fMRI studies on neuroticism (see section 5.4). This is particularly interesting, because not only is neuroticism mentioned as a general predictor of performance under extreme circumstances (Palinkas et al., 2000), it has also been shown to predict the likelihood of developing PTSD (Stein et al., 2007; Chan et al., 2008).

Not all knowledge on the correlation between individual characteristics and brain signals mentioned in this review are as advanced as the one described in the previous paragraph. Correlates of some characteristics (like emotional stability, social adjustment and reality testing) have been examined in rather isolated studies, where some results appear to conflict. In addition, it should be clear that, as with any measure predicting a persons' performance in future situations, it is impossible to achieve a neuroscientific indicator that will do a perfect job. However, as described in the introduction and confirmed by results scattered through this review, neurophysiological measures have certain advantages over other tools and could be a valuable addition to conventional tools.

We structured this literature review by first identifying essential characteristics of military personnel on a mission and then searching for possible neural correlates. Although for now we opted for a global search using words like emotional stability as literature search terms, it is important to further verify that the meaning or definition of these concepts in neuroscientific studies matches with what is of interest for the military. This should also be kept in mind when reading neuroscientific studies that focus on the pathological side of these characteristics rather than correlates within healthy individuals.

6.2 Another neuroscientific to selection

Paulus et al. (2009) describe an alternative to our followed approach of how to possibly harness neuroscience for selection purposes. They suppose that hardly anything is known about the underlying neurobiology of individual characteristics underlying optimal performance. Therefore they propose a preliminary neural modelof optimal performance. This model involves a system that processes the interoceptive effects exerted by extreme circumstances (notably the insula and the anterior cingulate cortex). Information from this system is processed by systems that 1) monitor value and salience (orbitofrontal cortex and amygdala), 2) are important for evaluating reward (ventral striatum/extended amygdala) and 3) are critical for cognitive control processes (anterior cingulate cortex). The (anterior) insula would also be responsible for generating a predictive model of how the body will feel. The idea is that optimal performers have developed an internal body state that is appropriate for its context and associated with the appropriate level to act, whereas sub-optimal performers receive interoceptive information that is too strong or too weak resulting in a mismatch between experienced body state and the necessary action to maintain homeostasis. Paulus et al. (2009) propose that assessment of these different neural systems could be used as indicators of training status or preparedness. A comprehensive general neural model of optimal performance such as (the extended version of) this is desirable, though for now this particular one is still too crude to be able to apply it soon.

6.3 Neurofeedback training

Neurofeedback should concern specifically those brain processes that are critical for military performance. Modulating and controlling these will hopefully lead to the desired behavioral aspects that are required for enhancing performance under high-demand military missions. This is the case when there exists a strong relationship between military task performance and a certain personal characteristic, such as stress tolerance at one hand, and between this characteristic and a the neural correlate to be modulated by feedback at the other.

At present, there is no overwhelming bulk of solid evidence yet that neurofeedback can be particularly useful to train skills especially useful for military personnel on a mission. However, given the recent achievements in neurofeedback and brain-computer interface research, as well as the existence of neural correlates of e.g. stress (vulnerability) as described in this manuscript, we (and others; e.g. Gruzelier, 2009; Sokhadze et al., 2007) think there is potential for neurofeedback to help prevent and treat PTSD as well as improve relaxation and attention in the military.

6.4 Possible research avenues

In general, selection on the basis of resilience to stress (including PTSD) seems promising. On the one hand, stress resilience is clearly relevant for military personnel and other professionals working under extreme conditions, and on the other hand, there are quite some (consistent) studies pointing out the neural correlates. Neurofeedback could possibly help to reduce stress or to train stress resilience (and improve other skills or characteristics). In the area of neurofeedback, much work remains to be done.

The positive side of this is that it is still relatively easy to perform solid studies that clearly fill a gap in our knowledge about the effectiveness of neurofeedback, and as argued above, positive results are not unlikely. Especially important in future neurofeedback studies is that one or more suitable control groups are included. Finally, we would like to point out that, when studying (the neural correlates or training of) higher cognitive functions or characteristics, it is important to define these well. It would be preferable to use existing definitions for which validated tools exist, such as the personality characteristics as defined by Eysenck or the Five Factor model. This makes use of and comparison between other studies easier.

We here reviewed studies about neural correlates of characteristics that are relevant to military performance. Given the diversity of the possible factors that contribute to military performance and resilience, both qualitatively and quantitatively, batteries or combinations of such elementary measures may suffice in predicting or training military performance. Another, daring line of research could focus on finding a more general neural correlate of military performance. Individuals differing with respect to (proven) military performance could be compared with respect to brain signals, at rest or during performance of military-like tasks in Virtual Reality (VR) that include the real complexities and higher-order combinations of task-elements that are specific for military operations. Chances of success are probably modest, but with advancements in methods and techniques it may be possible.

Also when neural correlates of separate, relevant characteristics are considered (e.g. experience of stress), VR could be a powerful addition. It allows for creating and presenting stimuli and tasks in a controlled way that are relatively close to the world that one is interested in. A special case in which Virtual Reality may be particularly useful is in treating stress disorders such as PTSD and training stress resilience. Virtual Reality allows for mimicking stressful military circumstances. This way subjects who have experienced a fearfull incident could receive a pleasant counter-intervention in a similar VR environment in order to prevent the development of stress reactions This may be a window of opportunity to for non-invasive techniques to be used safely in humans to prevent the return of fear and thus enhance mental resilience. Through neural (and other physiological) correlates, stress level can be monitored online by a therapist, by the individual him/herself (neurofeedback) or even automatically, allowing for a suitable down or upregulation of stresslevel in the virtual environment.

Some other possible research avenues for TNO (Defense and Security, Soesterberg) logically follow from current and earlier projects. There is expertise in (the use of) VR, and the first study investigating EEG and other physiological responses to stress as induced by a VR environment has been conducted (Brouwer et al., 2011). TNO has a NIRS apparatus available and has some experience working with it. Since NIRS technology for measuring brain signals is relatively new, there is still a lot to be studied and TNO could relatively easily gain a headstart in research and applications using this tool. Research on neuroscience for military personnel could be or is already embedded in current related programs. These are V811 (Biostress), V812 (Health Monitoring), V707 (Soldier performance), V801 (Effective Instruction and Training), and V1117 (Mental resilience).
In 2010, a so-called Kraamkamerproject about the relation between learning effectiveness and neurofeedback of EEG gamma frequency was carried out.

In addition, TNO is involved in the 6-year SmartMix program Braingain about Brain-Computer Interfaces. This work is coordinated by the University of Nijmegen.
One project within this program, that is particularly interesting in this context, is *Self-modification of brain activity by feedback and training*. Workpackages of this project include: stress-reduction skills, concentration training, identifying markers for EEG/fMRI, mindfulness and concentration.

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15. ABSTRACT (MAXIMUM 200 WORDS (1044 BYTE))

The defense needs more knowledge concerning the selection and training of personnel that is capable and resilient to cope with stressful operations in threatening environments. In this connection, this report provides an overview of applications for selection and neurofeedback-training of EEG and the hemodynamic response as measured by fMRI or NIRS. We have systematically searched for EEG and hemodynamic predictors of military performance under extreme conditions such that a more concrete idea can be formed of the relatively short-term (im)possibilities of neuroscientific applications in selection and neurofeedback training. Our literature search pointed out that for some possible predictors of military performance, there is a rapidly growing body of evidence for measurable neural correlates. This holds especially for personality traits as defined by the Five Factor and Eysencks neuroticism-extraversion model, as well as for stress reactions. Neurofeedback-training has recently been shown effective in some cases, but solid research is still needed to investigate whether it can enhance mental resilience. It would be optimal to provide feedback directly over those brain processes that have been shown to determine military performance. It is argued that this will be possible only with the aid of synthetic environments that maximally mimic real military situations

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