INFORMATION SOCIETY TECHNOLOGIES (IST) PROGRAMME

SENSATION
507231

Report on methods and classification of stress, inattention and emotional states

In relation to Deliverable No.		**D1.1.2**	
SubProject No.	**SP1**	SubProject Title	**Stages definition, classification criteria and tools**
Workpackage No.	**WP1.1**	Workpackage Title	**Physiological states and their transitions**
Activity No.	**A1.1.4**	Activity Title	**Stress, inattention and emotional states and criteria classification**
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Status		**Final**	
File Name:		**SENS_KI_SP1_WP1.1_D1.1.2_Final.doc**	
Project start date and duration		**01 January 2004, 48 Months**	
Reference period		**From 01 January to 30 August 2004**	

List of abbreviations

ACTH	Adrenocorticotropic hormone
BP	Blood pressure
CATS	Cognitive Activation Theory of Stress
EEG	Electroencephalogram
EMG	Electromyogram
EOG	Electrooculogram
ERP	Event related potential
GAS	General Adaptation Syndrome
HPA	Hypothalamic-pituitary-adrenal axis
HF	High frequency
HR	Heart rate
HRV	Heart rate variability
LF	Low frequency
PNS	Parasympathetic nervous system
SAM	Sympathetic-adrenal-medullary axis
SNS	Sympathetic nervous system
VLF	Very low frequency

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Executive summary

This deliverable is part of Sub project 1 and summarizes the results of activity 1.1.4 (WP1.1). It includes a literature review on stress, emotional states related to stress (such as negative mood, anxiety/depressive symptoms, fatigue and effort), monotony and inattention. The focus of the review is on the understanding of the states (e.g. definition and measurement) and how these states are related to physiological and behavioral markers with relevance to SENSATION (e.g. heart rate, blood pressure, EEG, eye behavior etc.), as well as to sleep/wakefulness transition. The deliverable ends with recommendations of how the states should be measured in naturalistic conditions, as well as what should be improved to make the methods more feasible. An early draft of the report was distributed to 23 experts, both within SENSATION and external, for comments. The conclusion is that there are many well-established physiological markers for the measurement of stress and emotion and the selection of the "best" one would depend on the question of the study. It is not possible to establish cut-off or critical values for the physiological markers since the individual variations in baseline levels and reactivity patterns are very large. Clinical values are irrelevant and the main purpose should be to study changes from resting or from normal activity. A general recommendation is to use multi-sensorial systems and record several parameters simultaneously. However, a simple method to measure stress in real life situations would be to use a wrist monitor that records heart rate, activity and subjective emotional ratings related to stress. Another recommendation is to use 24-hour recordings, and in particular to make recordings during sleep and rest. Elevated physiological stress levels during rest and sleep impairs the recovery process and increases the risk for development of chronic stress. The development of improved methods to measure eye behavior (gaze, eye closure, head position) provides good possibilities to study inattention in situations such as driving and control room work. Studies on physiological correlates of fatigue and effort show rather inconsistent results, however, heart rate variability and facial EMG activity have been suggested as promising candidates. Monotony should be regarded as an exposure variable (or a stressor) that causes fatigue, sleepiness and inattention, and should be measured with observation methods and task analysis.

1. Introduction

Sleep loss, excessive fatigue, stress and inattention constitute a common public health problem in our society. Sleep disorders, such as insomnia, chronic insufficient sleep and snoring, roughly affects 20% of the population. Stress and emotional related disorders, such as burnout or moderate depression, also affects many people and are common causes to sick leave in many European countries. In addition, a significant percentage of severe traffic and industrial accidents, as well as minor everyday errors, seem to be caused by severe sleepiness and fatigue (due to involuntary sleep attacks) or by prolonged inattention (Brookhuis, De Waard, Fairclough, 2003, Reason, 1990). Although disturbed sleep, fatigue/sleepiness and stress are acknowledged as important predictors to accidents, errors and many diseases, there are many methodological problems that make it difficult to measure these states in clinical and natural (e.g. workplace) situations. For example, the physiological methods are often expensive and obtrusive, and it is often not possible to make meaningful real-time monitoring. In practice, one often has to rely on subjective methods, such as questionnaires, because of the methodological difficulties associated with physiological measurements.

SENSATION aims to explore a wide range of micro and nano sensor technologies, with the aim to achieve unobtrusive, cost-effective, real-time monitoring, detection and prediction of human physiological state in relation to wakefulness, fatigue and stress anytime, everywhere and for everybody. 17 micro sensors and 2 nano sensors are developed within SENSATION for this reason - they include brain monitoring, autonomic functions sensors, eye characteristics and activity; all wirelessly integrated through a body/local/wide area network. These sensors are combined into medical systems for medical diagnosis and treatment, but will also be integrated in systems for detection and prediction of sleepiness at the work place. Thus, one of the goals of SENSATION is to improve and develop physiological recording methods so it will be more feasible to measure sleep, sleepiness and stress in natural situations.

2. Aim of the report

This deliverable is part of Sub project (SP) 1. One of the major tasks of SP1 is to define physiological states, such as sleep, wakefulness, sleepiness, stress, and inattention, and to describe the characteristics and classification systems of transitions between those states.

The aim of this activity is to make a literature review on stress, emotional states related to stress (such as negative mood, anxiety/depressive symptoms, fatigue and effort), and inattention. The overview will include information about (1) the understanding of these states – definition and measurement, (2) how these states are related to physiological and behavioral sensors with relevance to SENSATION, and (3) how these states are related to sleep/wakefulness transitions.

An early draft of the report was distributed to 23 experts, of which 10 were involved in SENSATION. The task of the expert's was to make an "informal" review and suggest improvements. The present report ends with recommendations on how the states should be measured, as well as what should be improved to make the methods more feasible. It should be pointed out that deliverable 1.1.1 (Criteria and algorithms for physiological states and their transitions) deals with classification of sleep and transitions between sleep, sleepiness and high alertness.

Stress, emotional states and inattention are often closely connected to sleep and sleepiness. Stress and emotional reactions may be both causes and consequences of disturbed sleep, or at least mediate the effect of not getting good sleep. A high stress level may mask an underlying high level of sleepiness. Thus, it is often advantageous and necessary to measure sleep, stress and attention more or less simultaneously, in order to understand the relation to health and safety.

Stress, attention and emotional responses may from a physiological point of view be regarded as "on-off" phenomena, and classification will focus mainly on the characteristics of the onset process. Thus, in contrast to sleep, stress, emotion and inattention has no standardized classification or scoring system. There is no "gold standard" on how to measure these states, although there are many well-established markers (subjective, behavioral and physiological) of the processes. However, critical criteria (i.e. cut-off scores) are lacking and usually an onset is characterized by a predicted change, such as an increase in heart rate for stress, but the inter-individual variations are large. A problem is the non-specificity of the physiological stress markers – an increase may also appear for exciting and emotionally pleasant activities. Hence, subjective emotional ratings play a key role in the measurement of stress. Moreover, fluctuation in physiological markers of stress and attention are multi-factorial and the influence of extraneous factors is large. It is often difficult to establish reference values for the biological indicators of stress. If there are reference values, they usually relate to clinical diagnoses (e.g. a blood pressure above 160/90 mmHg is a criterion for hypertension) and not to variations in stress.

The selection of biological markers will also depend on contextual factors and what is feasible to measure, in particular in naturalistic studies. The strategy to handle these constraints is to use a mix of various indicators (subjective, physiological and behavioral) and to evaluate the pattern of the responses, preferably across repeated measures.

There exists vast research on stress, emotion and attention and the aim of the present report is to make a brief summary of the knowledge relevant for SENSATION. The focus is on normal persons and normal (non-pathological) states, and physiological markers. This means that research on neuroendocrinology has been eliminated, with a few exceptions. The underlying physiological mechanism for regulation of stress, emotion and attention has a lot in common. The section of stress is larger than the other sections and covers basic physiological response patterns, which also are relevant for the understanding of emotions and attention.

3. Stress and emotional states

3.1 What is stress?

Stress is an important concept in life sciences and contributes to the development of heart and cerebrovascular disease, hypertension, peptic ulcer, inflammatory bowel diseases, musculoskeletal disorders, absenteeism from work, negative emotional reactions and reduced work productivity (Baker & Karasek, 2000). Prolonged stress, or very intense stress, can also influence performance and may impair attention and memory (McEwen & Sapolsky, 1995), and can contribute to human errors and accidents. Stress is, however, a somewhat vague term and several definitions are available. It is a complex process involving social, psychological and physiological elements.

According to psychological theories stress is determined by "the balance between the perceived demands from the environment and the individual's resources to meet those demands" (Frankenhaeuser, 1986; Lundberg, 1995). A recent paper by Ursin and Eriksen (2004) presents the Cognitive Activation Theory of Stress (CATS), which emphasizes the cognitive processes and neurophysiological activation and arousal. According to CATS the term “stress” includes four aspects; the stress stimuli, the experience of stress, the non-specific general physiological (alarm) stress response, and the experience of the stress response. The physiological stress response depends on the individual’s appraisal (evaluation) of the stress situation. The appraisal phase is characterized by two stages: (1) the primary phase is associated with the detection of the stressor and its consequences – e.g. if the stressor is harmful, threatening or challenging. (2) The secondary appraisal involves how the stressor should be counteracted and determines the coping strategies (Kalimo, Lindström, & Smith, 1997). If coping is ineffective, prolonged stress may occur that give rise to functional damage (Cox, 1978). Ursin and Eriksen (2004) propose that the level of the physiological (alarm) response depends on the expectancy of the outcome of the stress stimuli and the specific responses available for coping. Thus, expectation of a positive outcome has an arousal lowering effects, whereas uncertainty or lack of predictability of the outcome produces a strong physiological arousal (stress response). According to CATS ill effects occur only when there is lack of adequate coping, which can results in feelings of helplessness and hopelessness.

The stress process involves three related components: (1) stressor; an environmental condition or psychosocial factor that results in stress, (2) strain; a short term physiological, psychological or behavioral manifestation of stress, and (3) a modifier; an individual characteristic such as a coping style or social support that may reduce or increase the individual’s stress response (Baker & Karasek, 2000). Stressors can be divided into several groups based on their character: physical versus social or psychological, duration (acute versus chronic) and intensity (although it is difficult to estimate the intensity of a stressor – however, abnormally high intensive stressors may have direct damaging effects). In real life, many stressors are mixed and act in concert (Pacak & McCarty, 2000). Many experts regard psychological factors as the most potent stimuli for the physiological stress response (Mason, 1968). Typical and frequently occurring stressors are noise, time pressure, difficult and novel performance tasks, high work pace and social conflicts.

3.2 Physiological stress theory

The basis of the physiological stress model has its roots in the work by Cannon and Selye. Cannon (1914) developed the “fight-flight” concept, which linked emotional expressions such as fear to physiological changes in the periphery. He emphasized the activation of the sympathetic adrenal medullary (SAM) system in such situations, irrespective of whether the emergency reaction was “fight” or “flight”. The markers of the fight-flight response are the catecholamines epinephrine and norepinephrine, which increases when stress appears, and other physiological indicators associated with the autonomic nervous system. Thus, the SAM system is activated when the individual is challenged in its control of the environment, or is threatened, and this defense reaction prepares the body for battle or escape (Lundberg, 2000). Epinephrine is also related to mental effort and cognitive performance. Under normal levels of stress increased epinephrine is associated with improved performance (Lundberg, 2000). In fact, several studies show that stress, but only up to a certain level, improve performance, e.g. on selective attention tasks (Chajut & Algom, 2003).

Selye proposed the General Adaptation Syndrome (GAS, McCarty & Pacak, 2000) that reflects the physiological changes following adverse emotional stimulation, i.e. prolonged stress. GAS consisted of three phases – an alarm phase, a resistance phase and an exhaustion phase – and the bodily stress response was proposed to be non-specific irrespective of the stressor. The hypothalamic-pituitary-adrenal (HPA) axis has a central part of Selye’s formulation of GAS. Activation of the HPA system is associated with release of the hormones

ACTH and cortisol. The activation of HPA and SAM leads to increased arousal, which means that energy is mobilized and aids the body in the physical fight or flight. Energy is mobilized to the brain, heart and to the muscles, and at the same time the blood flow to the muscles and gastrointestinal system is reduced. The energy mobilization, resulting in an elevated blood concentration of glucose and free fatty lipids, is given priority and anabolism is down regulated (Theorell, 2000). The anabolic processes is central to the body's defense of all organ systems that need constant rebuilding and restoration. The reduced anabolism associated with prolonged stress is likely to be of great importance for stress related disease development.

When the body is exposed to stress, a rapid alarm phase starts. However, the alarm phase is an essential and necessary physiological phase, and although it may be an unpleasant experience, it is not associated with illness or disease (Ursin & Eriksen, 2004). If stress exposure persists over time, the second stage of GAS develops – the resistance phase. During this phase, the organism achieves a state of increased adaptation towards the stressor but would be more susceptible to deleterious effects due to regulatory disturbances (e.g. problems to maintain homeostasis) of the biological stress systems (McCarty & Pacak, 2000). If the stress exposure continues and perhaps increase in intensity, the organism would enter the third phase – exhaustion. This stage is triggered by depletion of energy stores, when the stress regulatory systems are worn out.

Selye's proposed non-specific stress response has been criticized in later research. Recent animal studies show that stressors have different neuroendocrine profiles (McCarty & Pacak, 2000). Mason (1968) questioned the one-dimensional stress concept and emphasized the physiological balance between energy providing "catabolic" processes and regenerative "anabolic" process (Karasek, Russel, & Theorell, 1982). Thus a large energy mobilization may be relatively harmless for the body if the subsequent anabolic processes can increase their compensatory recovery.

The classical markers for acute stress are cortisol, epinephrine, heart rate and blood pressure, which will increase rapidly to stress exposure. Epinephrine is regarded as maybe the best indicator of the intensity of the stressor. However, a disadvantage with epinephrine, heart rate and blood pressure is that these measures will not reflect the emotional value of the stressor and are rather non-specific. Also activation associated with positive mood and pleasant activities will increase the levels of these measures. It has been proposed by some experts (Lundberg & Frankenhaeuser, 1980), that cortisol is a better marker if the emotional value is of interest. According to their theory, increased cortisol levels should be associated with inability to cope, lack of control of the stress situations, and depressive mood (Peters et al., 1998). The empirical evidence for this hypothesis is so far limited.

Ambulatory blood pressure is regarded as one of the most feasible markers of acute stress in natural conditions, in particular if one wants to relate physiological responses to subjective perception of stress (Pickering, 2000). However, it is important to have control over activity and posture, which can have a great impact on the results. In a study of various activities it was found that walking increased systolic blood pressure with 12 mm Hg. Being at a meeting produced an increase of 20 mmHg and talking in the telephone increased systolic blood pressure with 10 mmHg. Sleep decreased systolic blood pressure with 10 mmHg (Pickering, 2000).

An interesting stress measure is the fluctuation of heart rate over time. Heart rate variability (HRV) measures frequency fluctuations across time and reflects the autonomic balance, i.e. whether it is the sympathetic nervous system (SNS) or the parasympathetic nervous system

(PNS) that is dominating. Stress usually causes a decrease in HRV. A decrease in HRV, in particular the 0.1 Hz component, is associated with increased mental effort (Mulder, 1992) and some researchers interpret this measure as an objective indicator of mental fatigue.

HRV can be measured as the standard deviation of the mean heart rate across time. However, a more sophisticated analysis is to analyze variability using power spectral analysis. Spectral analysis in the frequency domain enables a crude separation between vagal (PNS related) and sympathetic cardiac control to be made (van Amelsvoort, Schouten, Mann, Swenne, & Kok, 2000). The high frequency component (HF, 0.15-0.4 Hz) is mainly related to respiratory influences and solely controlled by PNS. There is also a low frequency component (LF, 0.04-0.15 Hz) and a very low frequency component (VLF, =0.04 Hz), which are controlled by both SNS and PNS. Some studies have also analyzed the LF/HF ratio and observed that an increase is associated with mental stress (Sloan et al., 1994). HRV is an important clinical measure and a strong predictor of mortality after an acute myocardial infarction (Task Force, 1996). It is important to control for physical activity, posture, breathing and speech, which will affect the variability components (Bernardi et al., 2000).

The integrated long-term recordings of respiratory sinus arrhythmia (RSA) may provide a new insight to the stress evaluation during work and recovery (Beauchaine, 2001). Non-linear analyses of the HRV are useful in the stress related cardiovascular risk analyses and improve the possibility to study the complexity between different physiological signals (Richman & Moorman, 2000).

3.3 Acute stress responses

Activation or arousal of the stress systems leads to a cluster of behavioral and physiological changes that are remarkably consistent (Chrousos, 1998). The stress response related to behavioral adaptation includes increased alertness and vigilance, improved cognition and focused attention, and inhibition of vegetative functions, such as appetite, feeding and reproductive function. The stress response related to physical adaptation aims at promoting an adaptive redirection of energy to the body sites where they are needed most, increased cardiovascular activity (elevated heart rate and blood pressure), increased respiratory rate and intermediate metabolism – all work in concert to promote availability of vital substrates.

Table 1 presents an overview of the acute physiological stress responses, particularly electrophysiological parameters. Electrical brain activity (measured with EEG) shows a desynchronized pattern during stress and strong excited emotions (e.g. fear) and beta frequencies are dominating (Lindsley, 1952). In a relaxed, non-stressful state, the EEG contains a mix of beta and alpha activity. Mental stress can also contribute to increased muscle tension, reflected in elevated EMG activity particularly in the trapezius muscle (Lundberg, 2002). Electrodermal measures such as skin conductance level and spontaneous fluctuations are well known indicators of activation (arousal) and may therefore show increased levels during stress (Andreassi, 2000). Some eye measures may show associations with stress. For example, pupil dilatation and increased blinking frequency has been observed in studies of stress (Andreassi, 2000). A general observation is that the correlations between physiological stress measures are rather weak and that the individual variability is high. However, within an individual the stress response is usually fairly consistent, even when the stressor differs (Levine, 1986).

The stress markers can also be influenced by other factors. For example, physical activity is associated with increased levels irrespective of the mental stress level. Heart rate and blood pressure are influenced by posture. Other factors that can influence the obtained results are caffeine, alcohol, some medications and circadian rhythm (most hormones demonstrate clear time of day variations).

3.4 Chronic stress responses

The acute stress response is no problem as long as the stress activation can be shut off when stress terminates. Thus, periods of rest and recovery are very important for the consequences of stress. McEwan and Seeman (1999) described four possible situations that may cause chronic stress: (1) too frequent stress exposure, (2) failure to habituate to repeated exposure of the same kind of stressor, (3) inability to shut off the stress response, despite that stress has terminated, and (4) situations that cause regulatory disturbances of the stress system. Thus, it is of great importance to differentiate between acute and chronic stress.

Table 1: Responses to acute and chronic stress*

	Acute stress (alarm phase)	**Chronic stress (resistance phase and exhaustion phase)**
Heart rate	Increase	Elevated levels throughout the 24h day
Blood pressure	Increase	Elevated levels throughout the 24h day
HRV	Decrease (particularly for LF)	? (the LF/HF ratio may be changed due to changed autonomic balance)
Electrodermal activity	Increase	?
EEG desynchronization	Increase	Probably no effect
EMG activity	Increase	? (possibly elevated levels throughout the 24h day but the pattern is depending on the stressor)
Epinephrine (SAM activity)	Increase	No effect (maybe elevated levels throughout the 24h day)
Cortisol (HPA activity)	Increase	Both increase and decrease possible (a changed diurnal variation is also possible)
Anabolic markers (e.g. testosterone, growth hormone)	No effect	Decrease

*the table is simplified and should be interpreted with caution, ?=the effect is unknown or inconsistent

However, the chronic stress response is much less studied and the existing results seem more inconsistent compared with findings associated with the acute stress response. Table 1 presents an attempt to make a crude and simple overview of the physiological response pattern associated with chronic stress. Chronic stress refers to the resistance phase and to the exhaustion phase according to Selye's stress model (referring to GAS). There are many question marks due to the lack of appropriate studies (the effect is unknown) and/or inconsistent findings between studies.

One problem is that there is no definition of chronic stress. For example, should a stressful month be labeled as a chronic stress situation? Most experts would probably refer to longer time periods with stress exposure in order to define it as a chronic stress situation. With respect to the physiological responses one could expect that chronic stress should result in hyperarousal, e.g. elevated levels of heart rate, blood pressure, cortisol etc, which is observed in depressive and anxiety disorders (Grings & Dawson, 1978). There is some evidence supporting this hypothesis. Some studies on prolonged occupational stress show that high job strain (characterized by high work demands and effort, and low control and reward) is associated with elevated blood pressure (Theorell, Ahlberg-Hulten, Jodko, Sigala & de la Torre, 1993; Pickering, 2000; Steptoe, Siegrist, Kirschbaum & Marmot, 2004). However, what is perhaps more interesting is that the elevated levels not only occur during work, but also during free time and sleep. Thus, chronic stress seems to result in elevated levels throughout the 24h period and not only during work. The reason for this could be difficulties to shut off the stress activation systems. Similar findings have been obtained in studies of extended periods with overtime work. Rissler (1977) observed that during a period of intense overtime, epinephrine increased in the evening after work.

However, the physiological stress marker that has been mostly studied in connection with chronic stress is cortisol (Melamed, Ugarten, Shirom, Kahana, Lerman & Froom, 1999). The results for this marker are somewhat inconsistent, and some studies suggest that chronic stress may be associated with decreased cortisol levels (a state of hypoarousal) instead of the expected increase (Yehuda, 1997; Zarkovic et al., 2003). For example, subjects that score high on burnout have showed decreased morning cortisol (Pruessner, Hellhammer & Kirschbaum, 1999). It has been hypothesized that the decrease in cortisol may be related to subjective feelings of exhaustion. There are also studies showing that the temporal pattern of cortisol changes during chronic stress situations (Rosmond, Dallman, & Björntorp, 1998). Chronic stress may also be reflected in markers of the immune system. For example a study by Grossi and coworkers showed enhanced inflammatory responses (higher levels of TNF-alpha) in a high burnout group (Grossi, Perski, Evengård, Blomkvist & Orth-Gomér, 2003).

It has also been suggested that the analyses of temporal changes in the balance between SAM system and the HPA axis may enhance the characterization of stress responses and stress related illnesses (Nicolaidis, 2002). Another interesting issue is whether chronic stress affects the acute stress response. It may be possible that the acute stress response becomes weaker after chronic stress exposure (Kristenson et al., 1998).

3.5 Sleep and stress

Disturbed sleep is probably one of the most sensitive markers of stress. Stress is also regarded as the most frequent cause of short-term insomnia, although it has seldom been documented with polysomnographic recordings (Roehrs, Zorick & Roth, 1989). For example, occupational stress is a common predictor of disturbed sleep (Kalimo, Tenkanen, Härmä, Poppius & Heinsalmi, 2000; Åkerstedt, Knutsson, Westerholm, Theorell, Alfredsson & Kecklund, 2002) and even some of the questionnaires on occupational stress include questions of sleep complaints. Also, studies on anticipatory stress have shown associations with disturbed sleep, e.g. reduced amounts of slow wave sleep (Torsvall & Åkerstedt, 1988a; Kecklund & Åkerstedt, 2004). The mechanism seems to involve elevated physiological activation at bedtime and during the night. Hyperarousal is also a common observation among many insomniacs and their negative attitude to sleep may act as a chronic stressor for these individuals (Vgontzas, Bixler, & Kales, 2000). Interestingly, some measures of chronic stress, such as burnout, seem to consistently be associated with self-reported sleep disturbances

(Melamed et al, 1999; Grossi et al, 2003). Although studies on physiological sleep and chronic stress state, such as burnout, are rare, preliminary findings of a study by Söderström et al (2002) showed that a high burnout score was associated with a higher frequency of micro-arousals (indicating more sleep fragmentation), as well as elevated heart rate.

It has also been suggested that disturbed sleep may cause stress (Van Reeth, Weibel, Spiegel, Leproult, Dugovic & Maccari, 2000). The evidence for this relation is relatively limited, although some studies have shown that sleep deprivation results in elevated evening cortisol, which may indicate immediate effects on the HPA-axis (Leproult, Copinschi, Buxton, Van Cauter, 1997; Spiegel, Leproult van Cauter, 1999).

3.6 Stress and emotion

The psychological model of stress emphasizes the appraisal of the environment as a critical factor. When the conditions of the environment are appraised as threatening we react with negative emotion and this emotional response may contribute to the physiological changes (Feldman et al, 1999). Thus, the emotion component of the stress process may influence disease onset and progression. Therefore, rating scales measuring emotions and mood have often been used within stress research since they reflect the subjective response to stress exposure.

The relation between emotions, mood and bodily responses can be regarded as subtle and the importance of emotions for physiological responses is controversial. A large number of studies have investigated the correlation between physiological indicators and stress related emotions such as anxiety, tension and negative affect (Thayer, 1989; Watson, Clark & Tellegen, 1988). The physiological markers that have been studied most in studies of emotions and mood are heart rate, blood pressure, electrodermal responses, and muscle tension reflected in EMG measures, EOG measures and EEG measures. A general observation is that the correlations between physiological arousal and emotions are inconsistent and weak, and it is difficult to draw any conclusions of the available studies (Mueller, 1992; Watson & Pennebaker, 1989). Feldman et al (1999) showed in a meta-study that the contribution of negative emotion to acute stressors was limited for cardiovascular responses.

Among the emotional states, fear, anxiety and depression have received a lot of attention. Fear is closely associated with activation of the autonomic nervous system, particularly the sympathetic branch, including elevated heart rate, increased blood pressure and epinephrine levels (Öhman, 2000). The typical fear related behaviors are anxiety, freezing, increased vigilance, and intense focusing on the threatening situation. However, at the first stage, when the fear-eliciting stimulus is attended, heart rate often decelerates.

Depression and anxiety symptoms often coincide and are associated with hyperarousal (Negrao & Gold, 2000). However, a subtype of depression, labeled “atypical depression”, shows the opposite pattern – hypoarousal – and is associated with a pathological inactivation of the stress mediators.

Although most studies have measured cardiovascular variables and hormones, some interesting findings have been observed with respect to EMG. Levenson et al (1990) and Dimberg (1990) have shown that the facial EMG response is a general component of the emotional reaction, which also could differentiate between emotions. For example, the corrugator muscle seems to be active in several negative emotions such as fear, anger and sadness.

Ambulatory blood pressure and heart rate monitoring is one of the best methods for the study of emotions, mood and physiology in real life. It is relatively easy to relate blood pressure to subject's perception through diary entries. In most studies, the relations between mood and cardiovascular parameters have been rather modest, with ratings of stress being the most predictive (Shapiro, Jamner, & Goldstein, 1997). A study by Shimomitsu and Theorell (1996) investigated the intra-individual variability and showed that about one fourth of the subjects had no significant relation at all between blood pressure and emotional reports. The most common emotional reports, which showed significant correlations with blood pressure, were "calm" (negative association), "hectic"(positive association) and "tense" (positive association).

4. Fatigue, effort and monotony

Fatigue is a multidimensional state that is closely associated with stress and attention. The dimensions of fatigue usually include a physical component, a mental component and a sleep related component referring to sleepiness (Åhsberg, Gamberale, & Kjellberg, 1997). One may also divide fatigue into acute responses and chronic responses (Craig & Cooper, 1992). For SENSATION, mental fatigue and sleepiness is probably the most relevant fatigue dimension. Thus, mental fatigue and sleepiness can be regarded as a consequence of severe or sustained stress and are important mediators of the relation between stress and performance. However, the present report will focus mainly on mental fatigue since sleepiness is covered by other reports.

Mental fatigue mainly refers to lack of energy and motivational aspects and can be regarded as a consequence of high mental workload and lack of resources due to mental task execution. It warns for the increasing risk of performance failure (Veldhuizen et al, 2003). It has been more difficult to find reliable physiological indicators of mental fatigue. However, a recent study has shown that facial EMG activity (of the corrugator and frontalis muscles) is a sensitive measure of mental fatigue (Veldhuizen, Gaillard, & de Vries, 2003). EMG activity decreased across the workday, but increased within a test period. The latter was interpreted as reflecting increased effort mobilization to maintain performance. They also found that subjects who scored high on emotional exhaustion had a lower level of EMG activity throughout the workday. Thus, the exhausted subjects were unable to mobilize extra energy.

There are also other studies that have linked muscle activity to fatigue effects. For example, Wilkinson (1962) found a strong relation between muscle tension and task performance in sleep-deprived subjects. Those subjects who showed the largest increase in muscle tension were able to maintain performance at an acceptable level, whereas those who had a small increase in muscle tension showed a larger performance decrement. Sleepiness related fatigue have shown relatively strong covariation with EEG indices – increased sleepiness is associated with increased theta and alpha activity (Lal & Craig, 2001; Åkerstedt & Gillberg, 1990) – and EOG indices – increased sleepiness is associated with, for example, slow eye closure (Van Orden, Jung, & Makeig, 2000). Among the EOG measures, slow eye movement (SEM, 0.1-0.6 Hz) is considered to be one of the best indicators of sleepiness. SEM usually appears when alpha activity (as an indicator of EEG recorded sleepiness) breaks up and the individual begins to "drift off" (Åkerstedt, 1990). SEM usually increases strongly prior to dozing off (Torsvall & Åkerstedt, 1988b).

It should also be mentioned that mental fatigue is often measured with standardized performance tasks, e.g. vigilance tasks or reaction time tasks (Craig & Cooper, 1992). The main outcome of this research is that performance deteriorates (longer response times, more lapses) when fatigue increases. However, performance testing can only be viewed as an indirect measure of mental fatigue. For example, increased mental fatigue can be compensated by increased mental effort if the individual is motivated. The extra effort will protect performance and maintain it at an acceptable level. The willingness to mobilize extra effort may also depend on the type of task. When faced with a boring and monotonous task, the individual may be reluctant to increase effort, in particular if motivation is reduced (Hockey, 1997).

Mental effort has been described as energy mobilization and represents a compensatory strategy to protect performance in the presence of increased fatigue due to increased task demands or psychological stressors (Fairclough & Houston, 2004; Hockey, 1997). Objective indicators of mental effort are muscle tension (see above), increased epinephrine (Lundberg, 2000), decreased blood glucose level (Fairclough & Houston, 2004) and decreased HRV (Aasman, Mulder & Mulder, 1987; Meijman, 1997). In HRV, the 0.1 Hz component has been regarded as being sensitive for mental effort, although some studies suggest that the measure may not reflect compensatory effort in all situations (Fairclough & Houston, 2004).

Monotony and boredom is often associated with fatigue and effort. According to the stress-strain model, monotony can be regarded as a stressor, whereas fatigue reflects the strain (the response of the stressor). Effort should be regarded as a mediator that may influence the fatigue response. In this context boredom is an aversive emotional response to an environment that is perceived as monotonous, and have been associated with reduced industrial work productivity and performance (Davies, Shackleton, & Parasuraman, 1982; O'Hanlon, 1981). Boredom is highly situation-specific and is immediately reversible when the situation changes and becomes more stimulating (O'Hanlon, 1981).

Monotony is usually defined with reference to the sensory stimulation that is present in a specific situation. A monotonous situation is characterized by low variation and lack of alerting stimulation (Thiffault & Bergeron, 2003). Monotony is an “exposure” variable that can be quantified through observation and task analysis. It is not possible or meaningful to measure monotony with subjective methods or physiological markers. However, since there are probably individual differences in the tolerance to monotonous situations, physiological and subjective responses of monotony exposure would still be relevant to study. Thus, monotony should be an important modifier of the relation between fatigue/sleepiness and accidents/performance errors. A typical monotonous and boring situation is when the demands for sustained attention are high but little information is conveyed. Hence, monotony can be regarded as a source of task-induced fatigue that contributes to performance deterioration and “strengthen” the fatigue response. Monotony is considered to be a critical factor in transportation, especially during uneventful motorway driving, but also in monitoring of industrial processes.

If the individual at the same time is exposed to other fatigue or sleepiness contributing factors, such as sleep loss or night work, the monotony induced increase in fatigue may have dramatic consequences and increase performance decrement. On the other hand, if the individual is alert (no sleep loss, daytime work) before the monotonous situation starts, the effect on performance may be relatively weak and the reached fatigue level will be moderate. The individual’s response to monotony is usually to mobilize extra energy through effort, at least if motivation is high. This can be very stressful and the cost for the increased effort may result in increased autonomic activation, e.g. decreased HRV and increased muscle tension. In this context monotony (or boredom) can be regarded as a stressor. However, compensatory effort may only be mobilized for a relatively short time, if the fatigue level is high, and when the extra effort process terminates the arousal level will decrease and physiological signs of sleepiness (reflected in EEG and EOG activity) will appear.

5. Inattention

All kinds of performance demand attention. To learn or to develop a complex skill, to perceive and to voluntary recall something, there is always an attention component. Attention serves the goal of accurate and speedy perception and action, as well as the maintenance of information processing over time (Parasuraman, 2000). Thus, attention is very important for human behavior in almost all situations. For example, a temporary lapse of attention (inattention) can lead to very negative consequences if you drive a vehicle or in job settings, which require monitoring of information displays in order to detect signals that require some action to be taken (Nachreiner & Hänecke, 1992).

Attention can be classified into three main components (Parasuraman, 2000). The first component is labeled "selection" and serves coherent and goal-directed behavior – one selects one or a few stimuli of the environment to attend to. The second component is labeled "control" and refers to coordination of activities and managing information-processing activities in the brain. The third component is labeled "vigilance" or sustained attention and ensures that goals are maintained over time.

In everyday life attention also refers to the ability to focus mental processes (concentration) and to work on several tasks that at the same time requires monitoring, concentration and action (divided attention). The attentional control mode is closely related to working memory and has limited capacity – it is slow, sequential, effortful and difficult to sustain for more than brief periods (Kahneman, 1973). Thus, attention can be seen as a capacity limited resource that needs to be allocated to ongoing events. Tasks that consume virtually no attentional resources – those that run mechanically or unconsciously – are supposed to be "automatic" opposed to "controlled" processes (Segalowitz, Velinkoja, Storrie-Baker, 1994). Posner describes the attentional process in three steps: (1) orientation of attention (both covert – without eye movements – and overt), (2) engagement of the target, and (3) disengagement from the target (e.g. Posner & Petersen, 1990). Inattention can occur in each of these steps. For example, the subject might remain focused on the previous stimuli (lack of disengagement), or did not pay attention to a novel critical stimulus (lack of orientation).

The research field of attention is huge and it is not possible to cover the entire field in this report. The vigilance component is the most relevant for SENSATION and will be the focus of this section, although attentional control also has shown severe impairment due to sleep loss (Jones & Harrison, 2001).

Vigilance refers to tasks that require detection of infrequent and unpredictable events over long periods of time. The typical vigilance task is a long lasting, monotonous and non-stimulating, and has low probability of critical events. Reaction time tasks are also classical within attention and vigilance research (Nachreiner & Hänecke, 1992), although they differ from the classical vigilance tasks in two ways. In a reaction time task the individual should respond to all stimuli as fast as possible, whereas in the vigilance task the individual should only respond to certain target stimuli. Furthermore, in a reaction time task speed is the key measure, whereas "detection rate" (reduced vigilance means more misses) is the key measure in a vigilance task. The quality of this attention component is fragile and the decline over time is well known (Parasuraman, Warm, & See, 2000). This decline is known as the vigilance decrement. Thus, inattention is often expressed as lapses in vigilance research. A lapse is a lack of response (an error) or an extended response time to a specific stimulus. Lapses often appear in clusters and result in increased performance variability. The vigilance decrement is strongly determined by variations in sleepiness (Dinges & Kribbs, 1991).

In the literature vigilance and arousal have been used interchangeably and refers to a general state of wakefulness that also could be labeled alertness. Cortical arousal, measured with EEG, is believed to be a determinant of vigilance. Indeed, studies measuring spontaneous EEG and event-related potentials (ERPs) have shown changes (decreased arousal) that parallel the vigilance decrement (Parasuraman et al., 2000). ERPs are considered to be a very good research tool in attention research if one wants to study specific neural and cognitive processes associated with inattention (Luck & Girelli, 2000). ERP components can roughly be divided into two categories: early exogenous and late endogenous components. Vigilance studies often focus on the endogenous, usually P3, component, since it is related to conscious perception of an eliciting stimulus (Koelga, Verbaten, van Leeuwen, Kenemans, Kemner & Sjouw, 1992). However, the correlation between time-induced changes in ERPs and vigilance performance is regarded to be low or moderate. This suggests that performance deterioration is probably not associated with an increase in difficulty to discriminate between targets and non-targets, but rather with a decrease in effort (and maybe motivation) or lack of resources allocated to the task. Thus, the vigilance decrement is probably due to lack of effort rather than to cognitive disability (Grier, Warm, Dember, Matthews, Galinsky & Parasuraman, 2003).

However, there are also studies showing that the vigilance decrement can depend on other factors than physiological sleep (Nachreiner & Hänecke, 1992). This was nicely demonstrated in a sleep deprivation study by Gillberg & Åkerstedt (1998), which found that more than half of the misses showed no association with EEG and EOG recorded sleepiness. The authors suggested that inattention could be a likely cause to these misses. For example, an inattention-related miss was characterized by inadequate (eye) tracking of the critical stimuli or by strong movements during the test. However, a small fraction of the misses occurred despite that EEG implied an alert state and the individual was tracking the stimuli. Hence, failures to respond in vigilance tasks may appear for several reasons and are not only due to sleepiness. In addition, task characteristics (such as event rate), situational factors (such as time of day and environmental conditions) and individual factors (such as age and motivation) also have a strong influence on the performance of vigilance tasks, and may not be mediated by waking arousal (Kjellberg, 1977a, 1977b, 1977c).

Recent development of methods that measure eye behavior (e.g. gaze and eye closure) and head position make it possible to monitor attention in natural conditions, such as driving. For example, it is possible to monitor that a driver's attention is not drawn from the road, except for brief periods, due to distraction (Bekiaris & Nikolaou, 2002). In working life studies, attention is often measured with some performance task that may be repeated a few times across the critical period (e.g. in the beginning and at end of a work shift). Poor performance is interpreted as an indicator of low attention during work. In addition, EEG and EOG may be recorded in parallel to the performance tests. As previously mentioned, inattention (or the level of attention) is indicated by performance measures, such as response speed and occurrence of errors. Although it is difficult to measure physiological indicators reliably in "active" work situations, it can be an indirect measure of the attention level. For example, if the EEG and EOG demonstrate signs of sleepiness one may assume that inattention can occur, although performance on vigilance or reaction time tasks may not be impaired. The lack of attention impairment on the performance task may be related to the subject's use of extra effort as a compensatory strategy during the performance test. However, the mobilization of extra effort is a limited compensatory resource that is efficient only on short-term tasks. Thus, EEG and EOG related signs of sleepiness could give a more correct description of the subject's attention level at work than the results of the performance tasks.

6. Recommendations for the measurement of stress, emotion, and inattention in natural conditions

There are many well-established physiological markers for the measurement of stress and emotions and the selection of the "best" one will depend on the question of the study.
Heart rate and blood pressure are frequently used markers of acute stress that are feasible and easy to use in most situations, and permits longitudinal (ambulatory) recordings. The response is also relatively easy to interpret – increased stress is associated with increased levels. However, it is important to simultaneously monitor physical activity and body posture and eliminate their contribution to the results in order to get a "pure" and reliable stress measure. If HRV analysis will be made one may also need to record respiration for control purpose. However, the selection of suitable physiological parameters will depend on the question that should be studied and contextual factors. For example, if the studied group has musculoskeletal disorders, or the stressor includes repetitive work movement, EMG would be a feasible marker to record. Although biochemical parameters (stress and anabolic hormones) are not the scope of SENSATION, they should not be excluded in the study of stress. In particular, biochemical variables (such as cortisol and testosterone, which can be measured in saliva) would probably be preferred, rather than autonomic variables, in the study of chronic stress (Kelly, 2001). In general it is a good strategy to measure several parameters simultaneously and examine the fluctuations over time. The overall level of a certain physiological marker does not always discriminate between low and high stress situation, rather it is the profiles over time that seem to reflect the differences.

This argues for the use of multi-sensorial systems that record several parameters at the same time. However, even though extraneous factors such activity is controlled for, it is not possible to draw any conclusions of an individual's stress state based on only physiological recordings. As mentioned earlier, the physiological measures of stress and emotional states indicate the non-specific neurophysiological activation of the body and give no information of the emotional value. This means that an elevated level may also occur during pleasant and non-stressful activities. Thus, it is important to get information of the subjective emotional experiences of the situation. Usually this is obtained through paper and pen instruments, although recently, hand-held computers have been introduced as recording device for ratings. We suggest that one should continue along this line and develop measurement systems that also can record subjective ratings and other behavioral events in connection with physiological recordings.

One of the simplest ways to measure stress would be to use a wrist monitor (e.g. actigraph or actiwatch) that records heart rate, wrist activity and with the possibility to make ratings. In addition, wrist activity can also be used for quantification of sleep length and awakenings.

It is also advantageous to make physiological recordings during sleep. Sleep offers a relatively standardized recording situation that eliminates most of the influences due to physical activity and posture. Elevated neurophysiological activation during rest and sleep is probably one of the best indicators of chronic stress and indicates problems to shut off the energy mobilization (stress) systems. Disturbed sleep impairs the recovery after stress exposure and is likely to be a risk factor for the development of chronic stress, and possibly stress related diseases. Moreover, elevated physiological activation during sleep could act as a potent sleep disturbance factor. However, it is very important that the recording methods of activation related physiology don't disturb sleep.

It may also be relevant to record stress in studies where the main focus is on sleepiness or fatigue. For example, lack of physiological sleepiness may depend on high physiological activation or stress. If one only measures sleepiness indicators such as EEG and EOG and obtains no increase of significance, one could draw the false conclusion that sleepiness is not a critical factor in this situation. However, the lack of manifest signs of sleepiness may be related to elevated stress that masks the physiological sleep tendency. Except for stress, physical activity is also a common masking factor. Hence, the underlying latent sleepiness level could be high but will not became manifest until stress or activity is eliminated or decreased. This means that sleepiness actually can be a critical factor, at least in situations when stress or activity is low. Due to non-feasible recording methods these kind of multi-physiological measurement have so far been difficult to do in the field. However, the integrated approach of SENSATION makes it possible to record markers of both stress/activation and sleepiness at the same time and study their inter-relations.

The development of improved methods to record eye behavior has great relevance to attention. Information about gaze, eye closure and head position offers good possibilities to track the individual's ability to attend to relevant information, e.g. during driving tasks. In the lab, measures of eye behavior could be combined with electrophysiological indicators, such as ERP recordings, in order to study the neurophysiological correlates of inattention.

In conclusion, the available methods for measuring physiological markers of stress, emotions and inattention in natural conditions today have several limitations. The methods are often quite obtrusive and it is often not possible to record more than a few markers at one time. Thus, development of better sensors and multi-sensorial systems that provide robust measures would facilitate the recordings of physiological and behavioral processes in studies of stress, emotional states and inattention in naturalistic conditions.

7. Conclusions

• There are many well-established physiological markers for the measurement of stress and emotional states, e.g. heart rate, HRV, blood pressure, respiration, EMG activity and electro dermal activity (e.g. skin conductance). However, there is no "gold" standard methodology and each marker has its pros and cons. Table 2 presents a list of markers and their sensitivity to stress and emotional states.

Table 2: Physiological markers and their suitability as indicators of stress and emotional states.

	EEG	EOG	HR	HRV	BP	EMG	Activity[1]
Stress	-	-	X	X	X	X	X
Negative emotions (e.g. anxiety, tension)	-	-	X	-	X	X	X
Mental fatigue/effort	X	X	-	X	-	X	X
Inattention	X	X	-	-	-	-	-
Sleepiness	X	X	-	-	-	-	X

[1]=as a control variable for physical activity, x=feasible marker of the state, -=not a "first hand" choice of marker of a state (however, may be of interest for research purposes)

• With respect to accuracy of measurement each parameter has its established levels of accuracy, which simply means adherence to standard measurement routines.
• With respect to cut-off or critical values all measures for field use are relative and very individual. Clinical criteria are irrelevant since the main purpose of field measures of stress is to indicate change from resting or from normal activity.
• It is very important to have an independent measure of physical activity as a control variable. Physical activity can be measured with for example a wrist or leg sensor. Even moderate levels of physical activity can cause elevated physiological activation when stress is low. Thus, lack of control of physical activity would cause a lot of "false" alarms in stress detection systems.
• EEG and EOG measures may in some situations be interesting markers of stress and emotional states; however, sensitivity in general for these states is relatively limited.
• The selection of markers will depend on the question of the study, the characteristics of the stressor (e.g. physical versus mental) and the emotion in question, and whether acute or chronic responses are of interest. Thus, it is not possible to propose a standardized methodology that works in all situations.
• The physiological markers of stress and emotional states are relatively non-specific and increased activation can also occur during pleasant activities. Thus, it is important to collect subjective ratings in order to get reliable detection of these states.
• A general recommendation is to use a multi-sensorial approach and record several markers simultaneously. The inclusion of several physiological markers increases the sensitivity and specificity of the measurement and would improve the detection of critical events.
• In some natural life situations it may not be feasible to record more than one or two markers. The measurement strategy of such a situation would be to record heart rate (which does not interfere with daily life activities), activity (in order to control for physical activity) and subjective emotional ratings.
• It is recommendable to use 24-hour recordings, and in particular to make recordings during sleep and rest. Sleep offers a well-controlled measurement situation with limited influence of extraneous factors such as posture and physical activity. Elevated physiological activation

during sleep may also indicate a chronic state and suggests links to impaired recovery and disturbed sleep.

- Methods that measure eye behavior (gaze, eye blinks and eye closure) and head position provides good possibilities to study certain aspects of inattention in situations such as driving and control room work. In addition, eye behavior markers are also good indicators of sleepiness.
- Studies on physiological correlates of mental fatigue and mental effort show rather inconsistent results, however, HRV and facial EMG activity seem to correspond relatively well with subjective and behavioral indices. In addition, EEG and EOG may also be important markers, since it can be difficult to separate mental fatigue/effort from sleepiness in real life studies.
- Event-related potentials (ERP) can in laboratory situations be a valuable marker of certain aspects of inattention, in particular when the underlying neurophysiological processes are of interest. However, in real life studies ERP lack feasibility and will be difficult to perform.
- Monotony should be regarded as an exposure variable (or a stressor) that causes fatigue, sleepiness, stress and inattention. Thus, monotony could be measured with task analysis and observation methods.

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9. Acknowledgement

The authors would like to thank the following experts for their valuable comments on an early draft of the present report.

Anna Anund	National Institute for Road and Transport Research (VTI), Sweden
John Axelsson	National Institute for Psychosocial Medicine (IPM), Stockholm, Sweden
Winnie Hoffman	Medcare B.V., Amsterdam, Netherlands
Mikko Härmä	Finnish Institute of Occupational Health (FIOH), Helsinki, Finland
Periklis Ktonas	University of Athens, Greece
Ulf Landström	National Institute for Working Life, Umeå, Sweden
Harri Lindholm	Finnish Institute of Occupational Health (FIOH), Helsinki, Finland
Ulf Lundberg	Department of Psychology, University of Stockholm, Sweden
Alain Muzet	Centre National de la Recherche Scientifique, Strasbourg, France
Jens Nilsson	National Institute for Psychosocial Medicine, Stockholm, Sweden
Thomas Penzel	Philips University, Marburg, Germany
Mikael Sallinen	Finnish Institute of Occupational Health (FIOH), Helsinki, Finland
Hans-Peter Søndergaard	National Institute for Psychosocial Medicine, Stockholm, Sweden
Patricia Tassi	Centre National de la Recherche Scientifique, Strasbourg, France
Töres Theorell	National Institute for Psychosocial Medicine (IPM), Stockholm, Sweden
Palle Ørbæk	National Institute of Occupational Health, Copenhagen, Denmark