Validation of MobileMe
– a psychophysiological recording system –
from a motion sickness perspective

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– a psychophysiological recording system –
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Summary

Motion sickness, a generic term including for example car sickness, sea sickness and space sickness, is a condition that occurs when the human body is exposed to movements that do not match the perceived sense of balance. Drugs that restrain motion sickness exist, but they often cause drowsiness and are therefore not suitable for usage in military and civil professional fields. Prevention of motion sickness without affecting mental capacity is highly wanted, since risks for accidents in the transport industry and deterioration of soldier performance could be reduced.

Research has shown that changes in certain physiological variables, for example heart rate, can reveal early stages of motion sickness prior to perception of any motion sickness symptoms. Mechanisms behind motion sickness, such as causes and how it develops, can be examined by studying these particular physiological variables. Different methods and equipments for measuring these variables exist, for example a newly developed portable system, MobileMe (BioSentient® Inc, Houston, USA). However, if MobileMe is to be used in medical research, a validation, i.e. an examination of whether the equipment measures what it is intended to measure, should be performed.

This thesis includes a validation of the MobileMe system, divided into two parts. First a laboratory study, including four subjects exposed to different conditions, was conducted. Simultaneous measurements with MobileMe and a reference equipment produced data used as input for statistical analysis. Results of the analysis showed that MobileMe could be considered valid in controlled environments, and this result was used as basis for a field study, where the suitability of the equipment for usage in tougher environments was examined. The field study was conducted onboard a combat boat and included six subjects. Apart from the examination of the MobileMe system, motion sickness symptoms and different rating scales were examined during the field study.

Results from the two studies showed that MobileMe was valid, and suitable for usage in field studies. The laboratory study showed that the measurements produced by the equipment were correct, and the field study proved durability of MobileMe in tougher environments. As a consequence, MobileMe will be used by the Swedish Defence Research Agency (FOI) for motion sickness studies, and by the Faculty of Health Sciences, Linköping University, for rehabilitation research.
Sammanfattning

Rörelsesjuka, ett samlingsbegrepp som innefattar bland annat åksjuka, sjösjuka och rymdsjuka, är ett tillstånd som kan inträffa till exempel då kroppen utsätts för rörelser som inte matchar vad som uppfattas av balanssinnet. Läkemedel mot rörelsesjuka finns tillgängliga, men de medför dåsighet och lämpar sig därför inte för användning i militär- och civilyrkessammanhang. Att kunna förebygga rörelsesjuka utan att påverka mental förmåga är något som det finns ett stort intresse av, då olycksrisker inom transportsektorn och prestationsförsämring hos soldater därmed skulle kunna minska.

Forskning har visat att förändringar av olika fysiologiska mått, till exempel hjärtfrekvens, kan påvisa tidiga stadier av rörelsesjuka innan den upplevs av den som håller på att bli rörelsesjuk. Mekanismer bakom rörelsesjuka, vad som orsakar den och hur den utvecklas, kan studeras genom att studera just dessa fysiologiska mått. Olika metoder och utrustning finns för att mäta dessa mått, bland annat ett nyutvecklat trådlöst bärbart system, MobileMe, utvecklat av BioSentient® Inc (Houston, USA). För att denna utrustning skall kunna användas i medicinsk forskning så krävs dock en validering, dvs en utförlig undersökning om den korrekt mäter de mått den är avsedd att mäta.


Resultaten från de två studierna visade att MobileMe-utrustningen är valid, samt att den är lämplig att använda för fältstudier. Labstudien visade att de mått som utrustningen producerar är korrekta och fältstudien visar på god tålighet för tuffare miljöer. En följd av resultatet av denna studie är att MobileMe kommer att användas av Totalförsvarets forskningsinstitut (FOI) för rörelsesjukesjukestudier, samt av Hälsouniversitetet i Linköping inom rehabiliteringsforskning.
Preface

This thesis was conducted from October 2005 until March 2006 as the final step in the master's programme of engineering at the Institute of Technology, Linköping University, Sweden. Most of the work took place at Rehabilitation Medicine, Department of Neuroscience and Locomotion at the Faculty of Health Sciences, Linköping University, in collaboration with the Swedish Defence Research Agency.

There are a number of people that have helped us during our work with this thesis. First, we would like to thank our examiner, Göran Salerud, for introducing this particular thesis proposal to us.

Torbjörn Falkmer and Joakim Dahlman, our supervisors, provided us with tough but fair continuous feedback that secured any possible quality of our work. They also helped us with everything from biostatistics to coffee machine instructions.

We would also like to thank Staffan Nählinder, for lending us the Vitaport 2 equipment, and providing us technical support around it. Furthermore, Lars-Håkan Thorell provided us with highly appreciated knowledge about the world of skin conductance. Raj Mandavilli, developer of the MobileMe system, and Karl Arrington, developer of the ViewPoint EyeTracker®, helped us with numerous things concerning their equipments. They kindly accepted our whining about software updates and provided us with quick and reliable support.

Special thanks goes out to Bjarne Widheden and the happy sailors Capt. Lars Bellini and Capt. Claes Berg of the Combat boat #886 who took us, and the poor subjects, for the boat rides of our lives. All the participating subjects, who voluntarily exposed themselves to our measurements, also deserve a big thank you.

Last, but not least, thanks to friends, lovers and families.

Linköping, March 2006

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This thesis examines the validity of MobileMe, a digital recording system used for measurements of physiological variables. To determine validity in both controlled and uncontrolled environments, two studies were performed. The first one was conducted in a laboratory setting and the second one was a field study. The field study focused on analysing the suitability of MobileMe for measuring motion sickness symptoms. Furthermore, studies of eye movements, and a comparison of motion sickness rating scales, were conducted during the field study.

1.1 Background
Motion sickness is a condition which occurs when the body is exposed to real or apparent motion stimulation that is unfamiliar or inconsistent with previous experiences (Benson, 1988). Development of methods for detecting motion sickness at early stages is a research field of interest. Motion sickness is known to deteriorate performance (Dahlman & Falkmer, 2005), and could therefore be a problem in for example the transportation industry and in military applications, where environments inducing motion sickness are common.

In the field of psychophysiology, conclusions are drawn about how psychological events affect bodily processes, based on measurements of physiological responses. The measured variables could be blood flow or electrical activity in the brain, various autonomic responses, or internal secretion of different hormones (Backs & Boucsein, 2000). Early stages of motion sickness can be discovered by studying certain
psychophysiological variables, such as heart rate and skin conductance (Cowings, Suter, Toscano, Kamiya, & Naifeh, 1986; Johnson & Jongkees, 1974). The ability to measure these autonomic variables accurately, both in controlled and uncontrolled environments, is crucial when to receive valid data that can be used for learning more about motion sickness. Cowings et al. (1990) considered examining multiple autonomic responses to be the best way for characterizing motion sickness. Preferably, this is done with one single measurement equipment and there are not many existing cost-effective portable equipments designed for this purpose.

A common way of measuring physiological variables is to use some kind of ambulatory recording system. Such a system is the AFS-2, an analogue system that records data on magnetic tapes. AFS-2 has been developed and used by the National Aeronautics and Space Administration (NASA) for about 15 years, for aerospace purposes. A commercial offspring of the AFS-2, MobileMe, made by BioSentient® Inc. (Houston, USA), is a newly developed digital recording system. It is portable and wireless, and therefore beneficial in field studies, for example at sea. The system is capable of measuring electrical activity of the heart (ECG), blood volume pulse (BVP), skin conductance (SCL), respiration rate and skin temperature. Details about the MobileMe equipment are presented in chapter 3.1.

MobileMe is a system originally designed for biofeedback monitoring and has not yet been tested for validity, which means that it is not assured that MobileMe produces correct measurements. The equipment has to undergo validity tests before it can be used properly in research, including clinical studies. The validation is done by comparing the measurements from MobileMe with data from a reference equipment. In this study, a digital recorder called Vitaport 2, made by TEMEC® Instruments B.V. (Kerkrade, The Netherlands), is used as reference equipment. If the system turns out to be valid, it is intended to be used by the Swedish Defence Research Agency (FOI) for motion sickness research, and this research would be extensively facilitated. This project is a co-operation between Linköping University and FOI, which means that MobileMe later on can be used for research and clinical applications in other areas, such as pain coping and stress measurements.

Studies of eye movements and motion sickness have been conducted, for example, regarding if forced fixations affect the level of perceived motion sickness (Flanagan, May, & Dobie, 2004). However, no research on fixation duration changes during onset of motion sickness has been found in available resources. Furthermore, current research has been focusing on laboratory studies. This thesis examines if there are any notable changes in fixation durations during onset of motion sickness in uncontrolled environments, i.e. in the field.
Subjective ratings of motion sickness can be obtained using questionnaires concerning different motion sickness symptoms. These questionnaires are often composed of several questions, which mean that the answering time can be quite long, around one minute. The ideal case would be to get a quick motion sickness rating from only one question, but this demands a thoroughly worked out question and scale. In the field study, it was investigated whether the Borg CR10 (Borg & Borg, 2001) scale could be used as a one-question motion sickness rating scale. The Borg scale is a rating scale which has mainly been used for subjective rating of aches and pain, in clinical applications.

1.2 Purpose

Two studies were performed and presented within this report. The aim of the laboratory study was to determine whether the MobileMe equipment could be considered valid and, hence, useful for research purposes. The first hypothesis was stated as following:

1.1 The MobileMe equipment can produce valid measurements in controlled environments.

For the field study, the main purpose was to assess whether MobileMe could be considered valid in uncontrolled environments. Further purposes were to determine whether MobileMe could detect early symptoms of motion sickness, and to study changes in visual fixation patterns, using an eye tracker, during motion sickness stimulation. The hypotheses for the field study were:

2.1 Based on a positive result from the first study, the MobileMe equipment can be used for monitoring physiological variables in the field.
2.2 Based on a verification of hypothesis 1.1, and occurrence of motion sickness, it is possible to verify the autonomic responses which would eventually build up to perceived motion sickness.
2.3 Longer fixation durations and reduced number of fixated objects precedes the onset of acute motion sickness.
2.4 The Borg CR10 scale is useable for rating severity of perceived motion sickness.

1.3 Delimitations

The laboratory study was limited to validation of only two of the five variables that MobileMe is capable of measuring. The chosen variables were electrocardiography (ECG) and skin conductance level (SCL).
In the field study, tests were conducted aboard a sea vessel, which represented an uncontrolled environment. No reference equipment was used in the field study, since implementation of the field study depended on a successful laboratory study.

### 1.4 Outline

To facilitate the reading, each chapter begins with a short summary of its content. A theoretical framework for this thesis is presented in chapter 2. Chapter 3 consists of descriptions of the technical equipment that were used for data acquisition in the studies.

Since the thesis consists of two separate studies, the rest of the report is divided into two parts, with similar dispositions. First, the method is presented, followed by the results and a discussion concerning the method and the results. Furthermore, conclusions are presented separately for each study. The laboratory study is presented in the first part and the second part covers the field study.

A reference list and appendices finalizes the thesis.
This chapter presents the basic theory for autonomic responses in general and responses to motion sickness in particular. The five physiological variables measured by MobileMe are briefly explained.

### 2.1 Autonomic nervous system

The autonomic nervous system (ANS) is the part of the central nervous system (CNS), which accounts for the non-volitional functions of our bodies. Autonomic nerves control smooth muscles, cardiac muscles, secretory epithelia and glands. There are three divisions of the ANS: the sympathetic, parasympathetic and enteric divisions. The sympathetic and parasympathetic parts of the system, which both have their origins in the CNS, are the two major efferent pathways, except from those controlling skeletal muscles (Boron & Boulpaep, 2003). Most organs receive innervations from both the sympathetic and parasympathetic divisions and the two work together to increase or decrease activity (Tortora & Grabowski, 2003). Increase of sympathetic function occurs, for example, under conditions of stress, fear, excitement or physical activity, while the parasympathetic division is more active when conditions like eating or relaxing are dominant (Boron & Boulpaep, 2003).

The enteric division of the ANS is a system of afferent neurons, interneurons and motor neurons that surrounds and controls the gastrointestinal (GI) tract. It can function as a separate and independent nervous system, but is often controlled by the CNS via sympathetic and parasympathetic fibres (Boron & Boulpaep, 2003).
During physical or emotional stress, the sympathetic division dominates over the parasympathetic division (Tortora & Grabowski, 2003). The entire sympathetic division is activated together and has a uniform effect on all target organs. This effect is in contrast to that of the parasympathetic division, which typically functions in a more discrete, organ-specific, and reflexive manner. In response to fear, exercise, and other types of stress, the sympathetic division produces a massive and coordinated output to all end organs simultaneously, and parasympathetic output ceases. This type of sympathetic output is used to prepare the body for life-threatening situations - the so-called fight-or-flight response (Boron & Boulpaep, 2003). Sympathetic responses include a wide range of activations, as well as inhibition of processes that are not essential for meeting the stressful situation. Heart rate, cardiac contractility, blood pressure and ventilation of the lungs increase. Blood vessels that supply the kidneys, skin and gastrointestinal tract constrict, which decreases blood flow through these tissues, whereas blood vessels supplying skeletal muscles dilate (Tortora & Grabowski, 2003).

The ANS maintains physiological parameters within an optimal range by means of feedback loops made up of sensors, afferent fibres, central autonomic control centres, and effector systems. These feedback loops achieve homeostasis – the condition of equilibrium in the body’s internal environment - by monitoring input from visceral receptors and adjusting the output of both the sympathetic and parasympathetic divisions. A system relying solely on feedback could produce a response that is delayed with respect to the stimulus and therefore the ANS also reacts to anticipation of future activity, so-called feed-forward stimulation. (Boron & Boulpaep, 2003)

### 2.1.1 Heart rate

One of the most frequently recorded measurements in the field of psychophysiology is heart rate (Backs & Boucsein, 2000). The average normal heart rate is 75 beats/min, but varies from 60 to 100 beats/min. Adults have lower heart rate than children and physically fit individuals have lower heart rate than untrained individuals. Increased body temperature, as occurs during a fever or strenuous exercise, causes an increase in heart rate (Tortora & Grabowski, 2003).

A normal heart rate is fairly regular, though slightly faster during inspiration than expiration, the so-called *respiratory sinus arrhythmia* (Berntson et al., 1997). Autonomic regulation of heart rate originates from the cardiovascular centre in the brain stem. The cardiovascular centre increases or decreases the frequency of nerve impulses in both the sympathetic and parasympathetic branches of the ANS. Adjustments of heart rate are important in the control of blood supply to working
tissues. There are also anticipatory increases in heart rate, especially in competitive situations, which are controlled by the ANS. An increase in sympathetic stimulation increases heart rate, whereas an increase in parasympathetic stimulation decreases heart rate. Proprioceptors that monitor the position of limbs and muscles regulate the heart rate as physical activity changes. The quick rise in heart rate at the onset of physical activity is due to proprioceptive input. Other sensory receptors that provide input to the cardiovascular centre include chemoreceptors, which monitor chemical changes in the blood, and baroreceptors, which monitor stretching caused by blood pressure in major arteries and veins (Tortora & Grabowski, 2003).

Heart rate can be used as an indicator of physical, as well as mental strain (Backs & Boucsein, 2000). Individuals display considerable variation in their cardiovascular reactions to stressful stimuli but there are some general responses. Heart rate typically increases as mental workload increases and decreases as mental workload decreases (Hugdahl, 1995). However, heart rate does not provide diagnostic information about the source of mental workload since heart rate is also affected by physical demands that may be independent of mental workload (Backs & Boucsein, 2000).

Heart rate is usually derived from electrocardiogram (ECG), which is a recording from electrodes on the skin of electric currents generated by the action potentials of the cardiac muscle cells. When the heart muscle contracts, an action potential is triggered, which changes the polarity of the cell membranes. This depolarization of cell membranes starts at the base of the heart, continues over the atria and finally spreads the contraction into the ventricles. Potentials generated in the heart propagate to the body surface and the changes in potential on the skin surface reflect the propagation of cardiac muscle cell contraction. In ECG recordings, the notations P, Q, R, S and T denote the various phases in the electrical activity of the heart (Hugdahl, 1995; Jacobsson, 1995). Figure 1 shows the recording of one cardiac cycle (one heartbeat) with markings of the different phases and their corresponding notations.
2.1.2 Skin conductance

Psychological stimulation induces changes in skin resistance. These changes are due to activation of sudomotor nerves – nerves from the sympathetic division of the autonomic nervous system that stimulate the sweat glands to activity (Benson, 1988). Sweat glands are distributed throughout the skin with only a few exceptions such as the nail beds and eardrums. They are most numerous in the skin of the forehead, palms and soles. The density can be as high as 450 per square centimetre in the palms. Perspiration usually occurs first on the forehead and scalp, extends to the face and the rest of the body, and occurs last on the palms and soles. Under conditions of emotional stress, however, the palms, soles and axillae (arm pit) are the first surfaces to sweat (Tortora & Grabowski, 2003).

Activation of sweat glands can be measured by attaching two cutaneous electrodes to the palms, volar surfaces of the fingers or forehead. Resistance is then recorded by applying a weak current and measuring the resistance of the skin to the current passing between the electrodes. When measuring physiological responses, conductance, rather than resistance, is the measure of choice. Conductance is the reciprocal of resistance – the amount of current that would flow through the medium given a particular resistance. Recording units for skin conductance are micro siemens (µS) or micro mho (µmho). The electrical properties of the sweat glands and the skin can be regarded as that of a population of resistors in parallel. Skin conductance levels are, hence, linearly related to the number of active sweat glands. (Hugdahl, 1995) This implies a relation between skin conductance and surface area of the electrodes. Increased electrode area results in higher conductance levels (Bouscein, 1992).

Electrodermal activity (EDA) is a common term for all electrical phenomena in skin, active as well as passive. Electrodermal methods with exosomatic reading use an
external current applied to the skin. In measurements with direct current (DC) and constant voltage, EDA is recorded directly in skin conductance units. Electrodermal activity is categorized as either tonic (slow changing) phenomena or phasic (fast changing) phenomena and the corresponding skin conductance measurements are skin conductance level (SCL) and skin conductance response (SCR), respectively (Bouscein, 1992).

The normal variation for tonic changes in skin conductance is 1-30 µS per cm², but there are large individual differences (Hudgahl, 1995). Activation of sweat glands by some sort of stimulation leads to a quick rise in skin conductance level to peak values and then a much slower recovery towards pre-stimulation level (Bouscein, 1992).

Absolute measurements of skin conductance should be made at temperatures as constant as possible, since sweat gland activity is closely related to thermoregulatory functions of the body (Hudgahl, 1995). Most researchers use the volar surfaces of the fingers for electrodermal readings. Bouscein (1992) recommend the medial or distal phalanges of the index and middle finger, since sites for SCL measurements should be free from scarring and large enough for electrode fixing. An example of electrode placements on the medial phalanges can be seen in figure 2.

![Figure 2. Schematic figure of SCL electrode placement on the medial phalanges.](image)

Electrodermal activity reflects sympathetic activity and is thus a measure of arousal (Hudgahl, 1995). It is a sensitive indicator of changes in cognitive and emotional state and has frequently been used in the assessment of psychiatric disorders and brain damage.
2.1.3 Respiration rate

The basic rhythm of respiration is controlled by the respiratory centre in the brain stem. In the basic rhythm of breathing, inspiration lasts for about two seconds and expiration lasts for about three seconds. During normal, quiet breathing, inspiration is an active process - the diaphragm and intercostal muscles contract - whereas expiration occurs passively when the inspiratory muscles relax. In forceful breathing, internal intercostal and abdominal muscles contract which decreases the size of the thoracic cavity and causes expiration. The rhythm of respiration can be modified in response to input from brain regions or receptors in the peripheral nervous system. Respiration patterns can, to some extent, be altered voluntarily. However, the respiratory system is very sensitive to changes in the levels of CO₂ and O₂ in body fluids and the ability to control breathing is limited when there is build-up of CO₂ and H⁺ in the body. Chemoreceptors monitor levels of CO₂, H⁺ and O₂ and provide input to the respiratory centre. Physical activity increases depth and rate of breathing even before changes in O₂, CO₂ and H⁺ concentration occur. These quick changes in respiratory effort are due to input from proprioceptors. Other factors that contribute to regulation of respiration are anticipation of activity or emotional anxiety, which increase the rate and depth of ventilation. An increase in body temperature increases respiration rate and a decrease in body temperature decreases respiration rate. Sudden cold stimulus or sudden severe pain cause temporary apnoea, an absence of breathing. Changes in blood pressure have some small effects on respiration. (Tortora & Grabowski, 2003)

Psychophysiological recordings of respiration may be obtained by attaching a strain gauge around the chest or abdomen, which records the expansion and reduction in circumference during inspiration and expiration. Respiration rate can also be measured using a capnometer or a thermistor in the nose. Capnometers use infrared light to measure expired CO₂. Concentration of CO₂ in the air changes with the respiratory cycle and can, hence, be used for respiratory monitoring. Thermistors are used in a similar way, monitoring changes in air temperature instead of CO₂ concentration (Hugdahl, 1995).

2.1.4 Blood volume pulse

The cardiovascular centre that helps regulate heart rate also controls feedback systems that regulate blood pressure and blood flow to specific tissues. Input is received both from higher brain regions and from sensory receptors. During physical activity, nerve impulses are sent to the cardiovascular centre resulting in vasodilation - increase in blood vessel diameter - of skin blood vessels. Since vasomotor activity is controlled by the sympathetic nervous system, the blood volume pulse (BVP) measurements can display changes in sympathetic arousal. An increase in BVP amplitude indicates
decreased sympathetic arousal and greater blood flow to the peripheral vessels (Tortora & Grabowski, 2003).

Blood volume estimations can be done with different types of plethysmographs. For peripheral blood flow measurements photoplethysmography (PPG) is often used (Mendelson, 1992). A photoplethysmograph is a non-invasive transducer, which measures the relative changes of blood volume in the tissue. The waveform obtained from the PPG sensor represents the blood volume pulse. BVP is a relative measurement of the peak-to-peak values in the PPG signal. The phenomenon behind PPG recordings is the attenuation of incident light, usually infrared (IR) light, done by haemoglobin in the blood (Farmer, 1997). Absorption of IR light in the tissue reflects the concentration of haemoglobin and hence the blood volume. The photoplethysmographic signal tracks changes in light absorbance as the blood pulses (Mendelson, 1992). Transmission sensors measure the amount of light that passes through the tissue, while reflectance sensors measure the amount of light that is reflected back to the probe (Farmer, 1997). Possible sites for sensor attachment are fingertips, ear lobes or toes for transmission sensors and forehead, fingers or temples for reflection sensors (Mendelson, 1992). Other methods of estimating blood volume pulse or volume flow are impedance plethysmography and Doppler flowmetry (Hugdahl, 1995).

Impedance plethysmography is the indirect assessment of blood volume changes in any part of the body by measurement of its electrical impedance. Blood volume changes in any part of the body are reflected inversely in the electrical impedance of the body segment (Jindal, 1986).

Doppler flowmetry is a non-invasive, continuous measure of microcirculatory blood flow. The principle of this method is to measure the Doppler shift - the frequency change that light undergoes when reflected by moving objects, such as red blood cells (Assous, Humeau, Tartas, Abraham, & L’Huillier, 2005).

**2.1.5 Body temperature**

Despite wide fluctuations in environmental temperature, homeostatic mechanisms maintain the internal body temperature near 37°C. *Core temperature* is the temperature in body structures deep to the skin and subcutaneous layer. *Shell temperature* is the temperature near the body surface – in the skin and subcutaneous layer. Depending on environmental temperature, shell temperature is 1-6°C lower than core temperature. Body temperature is regulated by signals from thermoreceptors in the skin and mucous membranes and in the hypothalamus. If core
temperature declines, mechanisms that conserve heat and increase heat production act to raise the body temperature to normal (Tortora & Grabowski, 2003).

It is well known that body temperature changes with physical strain. However, there are also small changes in shell temperature with mental or emotional strain. Core temperature is not a suitable measure for short-term changes, but finger temperature may instead be used as an indicator of mental strain (Backs & Boucsein, 2000). When sympathetic arousal occurs, vasoconstriction in dermis decreases blood flow and temperature, which is why shell temperature readings can be seen as a measurement of ANS activity (Bio-medical, 2005). Relaxing increases skin temperature, whereas stressful environments will cause decreases in skin temperature (Backs & Boucsein, 2000).

### 2.2 Eye movements

Moving the eye from one point to another is a way of moving the visual attention of the brain from one particular point to another. Generally, attention is used for focusing mental capacities on selections of the sensory input, allowing the mind to successfully process the stimulus of interest. Visual attention can thus be described as the attention gathered by the ocular sensory system, i.e. the eyes. Tracking and studying eye movements is a way of following a visual attention path of a subject, producing insight into what captures the viewer’s attention. It is also a way of studying the origins of the underlying causes of involuntarily eye movements, i.e. which phenomena makes the eyes move in ways controlled by the autonomic parts of the nervous system (Duchowski, 2003).

There are four basic eye movement responses. These are saccades, fixations, smooth pursuits and nystagmus. Saccades are the most rapid eye movements, used for shifting the focus from one fixation to another. They can be both voluntarily and reflexively executed, and can range in duration from about 10 – 100 ms, making the executor virtually blind during the saccade (Duchowski, 2003).

When the focus of the eyes is stabilized on a stationary object of interest, a fixation occurs. How long a fixation normally lasts is not unified, for example Hugdahl (1995) propose that a fixation lasts between 250 and 1000 ms, while Duchowski (2003) says that 150 – 600 ms is the normal duration range. During a fixation, the eye is not completely still. Different kinds of micro eye movements, e.g. drift and tremor, characterize fixations. Micro eye movements are used for controlling focus of the fovea, and making sure that the retinal sensor cells are not too much exposed to gaze input (Duchowski, 2003).
Smooth pursuits are slow movements, involved in tracking moving targets (Duchowski, 2003), and nystagmus are continuous oscillations of the eyes, preventing images to remain stationary on the retina (Hugdahl, 1995).

### 2.3 Motion sickness

Motion sickness is a generic term describing a group of common nausea syndromes (Keinan, Freidland, Vitzhaky, & Moran, 1981), which occurs when an individual is exposed to unfamiliar motion stimuli (Benson, 1988). Various forms of the malady are usually named after the environment or vehicle that induces symptoms (Benson, 1988), sea-, car- and airsickness are the most commonly experienced examples (Oman, 1991). Motion sickness is characterized primarily by nausea, vomiting, pallor and cold sweating. Other symptoms are reported, but in general these occur more variably. Symptoms are triggered by real or apparent motion stimuli of which the individual has no previous sensory motor experience (Benson, 1988; Oman, 1991). Motion sickness is seen as a consequence of the inability to adapt to certain types of motion (Keinan et al., 1981).

#### 2.3.1 Symptoms

According to Benson (1988), the development of motion sickness follows an orderly sequence where the earliest symptom usually is the sensation of ‘stomach awareness’. If exposure to the provocative motion continues, well-being deteriorates quite quickly with the appearance of nausea, pallor and sweating. In most individuals nausea increases in intensity and culminates in vomiting or retching. Other symptoms such as increased salivation, feeling of bodily warmth, alterations of respiratory rhythm by sighing and yawning, hyperventilation and headache are commonly associated with the early stages of development of nausea, though more infrequently observed. Drowsiness is another important symptom associated with exposure to unfamiliar motion, even if not necessarily an integral part of the motion sickness syndrome. The timescale for onset of the various symptoms is determined primarily by the intensity of the stimulus and the susceptibility of the individual.

#### 2.3.2 Causes

Whenever the central nervous system receives unexpected or unfamiliar sensory information concerning the orientation and movement of the body, motion sickness typically results (Oman, 1991). Situations where visual cues to motion are not matched by the usual pattern of vestibular and proprioceptive cues to body acceleration result in an overflow of neural activity to centres that produce motion symptoms (Keinan et al., 1981; Oman, 1991). Motion sickness is often said to be induced by overstimulation of the inner ear equilibrium organs, the vestibular system (Keinan et al., 1981). The receptor organs for equilibrium are called the vestibular
apparatus, which include the saccule, utricule, and semicircular ducts (Boron & Boulpaep, 2003). Portions of the vestibular system are known to play a significant role in the genesis of motion sickness as they are required for susceptibility (Oman, 1991). Only those individuals who lack a functional vestibular system are truly immune (Benson, 1988). The most common physical stimulus for motion sickness is low frequency, nonvolitional motion, but symptoms can also be induced by purely visual stimuli without a changing force environment (Oman, 1991). Since symptoms can be evoked as much by the absence of expected motion as by the presence of unfamiliar motion, overstimulation of the vestibular organs is not the only possible cause of motion sickness (Benson, 1988).

2.3.3 Sensory conflict theory
One widely accepted theory of how motion sickness is induced is the sensory conflict or neural mismatch hypothesis. The sensory conflict hypothesis states that in all situations where motion sickness is induced, there is a conflict between the sensory information provided by those receptor systems, which transduce the motion stimuli and the anticipated sensory signals (Benson, 1988; Oman, 1991). When exposed to movement, the body expects certain visual or proprioceptive confirmations to match the signal from the equilibrium organs. Motion sickness symptoms are provoked when there is a mismatch between the visual input and vestibular input (Hu, Grant, Stern, & Koch, 1991). The hypothesis is a unifying concept, which permits explanation of why sickness should occur in some motion environments and not in others. The sensory conflict theory also explains the basic features of adaptation since the body will learn what responses can be expected in different motion environments (Benson, 1988).

2.3.4 Susceptibility
Motion sickness is a normal response to an unfamiliar motion environment (Benson, 1988) and virtually everyone is susceptible to some degree, provided that the stimulus is appropriate and last long enough (Oman, 1991). An individual’s future susceptibility to motion sickness can be predicted from previously experienced reaction to motion stimuli (Keinan et al., 1981). There are considerable differences between individuals in their susceptibility to the condition and the incidence of sickness in a particular motion environment is affected by a number of factors such as the frequency, intensity and duration of the motion (Benson, 1988). However, individuals who are able to anticipate incoming sensory cues, for example drivers of cars and pilots of aircrafts, are usually not susceptible to motion sickness even though they experience the same motion as their passengers (Oman, 1991). There is also the phenomenon of adaptation, where individuals with prolonged exposure to sickness inducing motion develop immunity to the sickness. These examples emphasize that
motion sickness cannot result simply from vestibular overstimulation (Benson, 1988; Oman, 1991).

### 2.3.5 Detrimental effects

Motion sickness has been shown to affect performance of a wide variety of tasks (Benson, 1988), and methods whereby the detrimental effects of motion sickness might be minimized are highly desirable. Most of the existing treatments are rather impractical when unrestricted activity and optimal levels of performance are required (Keinan et al., 1981). Anti-motion sickness drugs can cause drowsiness as a side-effect, and other approaches for reducing symptoms often involve lying down as an attempt to minimize motion cue conflict. These types of treatments are not suitable for certain occupational groups i.e. aircrews on duty. In the long run, adaptation to the provocative environment is considered the best approach in dealing with motion sickness (Benson, 1988). Under certain circumstances, it could be an advantage in being able to screen for individuals with high susceptibility to motion sickness and, hence, employ selection procedures in order to minimize the debilitating effect of a moving environment. Various studies have also shown that concentrating on a specific task, i.e. getting distracted from the motions, reduces the probability to become sick. When relaxing and becoming more attentive to bodily sensations, the appearance of symptoms and signs of motion sickness are more likely to appear (Benson, 1988).

### 2.4 Physiological responses to motion sickness

Changes in ANS activity associated with motion sickness can be categorized as a stress response. There are general changes in the autonomic responses of e.g. heart rate (HR), skin conductance level (SCL), respiration rate (RR), and blood volume pulse (BVP) during exposure to motion sickness stimuli (Cowings et al., 1986). Activation is mediated by the sympathetic division of the ANS in response to changes in the motion environment (Himi et al., 2004). The four ANS variables above represent different aspects of the ANS and previous research has shown them to change as a function of stimulus intensity. Heart rate, skin conductance level, respiration rate, and blood volume pulse are all easily measured and have therefore been used in several studies of motion sickness (Cowings et al., 1990; Cowings et al., 1986; Stout, Toscano, & Cowings, 1995). Other physiological responses are frequently monitored through recordings of electrogastrogram (EGG) and electrocardiogram (ECG).

Different types of motion sickness stimuli e.g. rotating chair, oscillating video or rotating optokinetic drum have been used in studies of ANS responses. Both vestibular and visual stimulation induce the physiological responses associated with motion sickness (Himi et al., 2004). All types of motion sickness stimulation induce
much stronger ANS responses than other common stressors, such as mental arithmetic or cold pressor (Cowings et al., 1990).

The general, autonomic responses when exposed to motion sickness stimulation are:

- *Increase in heart rate*, with immediate recovery when stimulation stops. Susceptibility to motion sickness affects the acceleration of heart rate. (Cowings et al., 1986)

- *Gradually increased skin conductance level*, with slow recovery (Wan, Hu, & Wang, 2003). Marked activity of the sweat glands can be detected prior to any noticeable awareness of motion sickness and can thus be considered an early symptom. (Johnson & Jongkees, 1974). When SCL is used for monitoring motion sickness symptoms, care should be taken to control additional contaminating factors such as ambient temperature, motor activity, anxiety and psychosocial stimulation. (Warwick-Evans et al., 1987).

- *Decreased blood volume pulse*, for high susceptibles as motion sickness develops. Peripheral blood flow decreases as motion sickness stimulation progresses (Cowings et al., 1986; Himi et al., 2004). The pallor seen in subjects that experience motion sickness is caused by vasoconstriction of cutaneous vessels (Benson, 1988).

- *Respiration rate increases* with the onset of motion stimuli and then decreases to pre-test levels a few minutes after stimulation has stopped (Cowings et al., 1986). Some reports have shown that nausea-inducing motion results in hyperventilation (Johnson & Jongkees, 1974). Since increased CO₂ concentration in the blood facilitates the vomiting reflex, it is possible that an increase in the respiratory cycle, which decreases blood CO₂, prevents nausea (Himi et al., 2004).

- *Augmented gastric tachyarrhythmia* which is measured as an increased electrogastrogram (EGG) activity (Hu et al., 1991). Himi et al. (2004) suggest that gastric motility changes precede the sensation of nausea.

- *Reduction of mean successive differences in R-R intervals* (derived from ECG) which indicates a decrease in parasympathetic activity (Gianaros et al., 2003; Hu et al., 1991)

- *Changes of eye movement patterns* such as elicitation of nystagmus are occurring during motion sickness stimuli (Flanagan et al., 2004). However, Quarck et al. (2000) state that eye movements are not involved in either occurrence or development of motion sickness. Flanagan et al. (2004) presents results describing that forced fixation produces less perception of experienced motion sickness, compared to no restriction of eye movements.
During the first minutes of motion stimuli, the subjects often show elevated levels of all physiological variables even though they are not experiencing symptoms of motion sickness. These higher response levels are due to the startle reflex, a temporary response, which sets in when the body experiences novel stimulation, and not motion sickness symptoms (Cowings et al., 1990).

There are distinct inter-individual differences in autonomic response profiles when exposed to motion sickness stimuli. The intra-individual responses, however, are highly reproducible and each individual can therefore be expected to show similar ANS responses in repeated motion sickness tests (Cowings et al., 1990; Stout et al., 1995).

Monitoring of ANS variables is usually accompanied by a measurement of perceived sickness severity. A frequently used scale is the symptom diagnostic scale developed by Miller and Graybiel (1970), which yields a numerical value, the so-called malaise score, from subjective ratings of different symptoms. The symptom diagnostic scale is described in chapter 8.2.1. Stout et al. (1995) reported that changes in malaise scores are significantly related to changes in heart rate (HR), respiration rate (RR) and blood volume pulse (BVP). As the level of malaise increases, HR and RR also increase, whereas BVP decreases. This result differs from the measures obtained by Hu et al. (1991) where there was no significant relation between HR and severity of symptoms. With the use of a slightly different rating scale Himi et al. (2004) found an increase in the mean HR for subjects reporting nausea.

A number of studies have shown that SCL recorded at palmar finger sites is significantly correlated to severity of motion sickness (Hu et al., 1991; Wan et al., 2003; Warwick-Evans et al., 1987).

Correlations are derived by comparing autonomic responses from subjects reporting high malaise scores with responses from subjects who are exposed to the same motion sickness stimuli, but do not experience nausea (Himi et al., 2004). Physiological response levels can be used to objectively describe severe malaise. Simultaneous examination of multiple ANS responses along with subjective reports of malaise level is considered the most accurate way of characterizing motion sickness (Cowings et al., 1990).

Motion sickness represents an instance of sympathetic and parasympathetic activation of the autonomic nervous system (Stout et al., 1995). Changes in autonomic responses are due to a combination of both an increase in sympathetic activation and a decrease in parasympathetic activation (Gianaros et al., 2003; Hu et al., 1991). It has been suggested that the symptoms mediated by the sympathetic nervous system could be
defensive reactions against the sensation of nausea (Himi et al., 2004; Wan et al., 2003).
This chapter gives a brief explanation of the two main equipments used in the first and second study. MobileMe is the digital recording equipment that is to be validated in the first study. In the second study, measurements were taken with both MobileMe and the ViewPoint EyeTracker® system.

### 3.1 MobileMe

MobileMe is a system for measuring physiological variables controlled by the autonomic nervous system (ANS). Its predecessor is a similar equipment called AFS-2 (Autogenic Feedback System 2), which has been used by NASA for autogenic feedback training (AFT). The AFT system developed by NASA is a system for biofeedback training used by astronauts in their training for decreasing levels of space sickness, which is a form of motion sickness (Ames, 2005). AFT is a procedure that enables subjects to control their own motion sickness symptoms, by training to control the physiological variables that are most responsive to motion sickness stimulation. Following training, subjects display reduced autonomic nervous system response magnitude and this is correlated with increased tolerance to motion sickness stimulation (Stout et al., 1995). Other types of biofeedback training have been tested, mostly in the USA, as treatment for different compliances, such as migraine and high blood pressure. For some sickness states, involving certain types of muscle paralysis or tension, biofeedback training has turned out to be a successful treatment (Nationalencyklopedin, 2005).
MobileMe has the same functionality as AFS-2, but is more light-weight and uses PC-based software instead of magnetic tapes for storing data. The development of MobileMe is a way of making the concept of these systems, including biofeedback training, available for commercialization (Ames, 2005). Since MobileMe mostly consists of standard parts from other manufacturers, for example the sensor parts are supplied by Thought Technology Ltd. (Montreal, Canada), the system can be seen as more cost-effective than AFS-2.

The MobileMe system can be seen as consisting of three parts:

1. SentientMonitor, software running on a stationary PC or a laptop. The program is used for real-time monitoring and data analysis. Raw data signals and derived parameters are presented graphically, as seen in figure 3, which enables the use of MobileMe for biofeedback training.

2. A garment with sewn-on channels for electrodes and sensor leads. A belt is included in the garment, containing a receiver box for signals from the electrodes and sensors. A picture of the described part can be seen in figure 4.

3. A portable PC, made by OQO (San Francisco, USA), that connects the sensor system to the SentientMonitor software via MobileMe software and a wireless network. The unit collects data from the receiver box and processes data itself, which makes it possible to use the MobileMe system without using the SentientMonitor software. The OQO computer can be seen in figure 4.

Along with the hardware, a manual is included. It consists of a binder, including detailed instructions on how to set up and start monitoring with the equipment.
Figure 3. *SentientMonitor* real-time monitoring display (1)

Figure 4. The MobileMe garment (2) and the OQO computer (3) mounted on a subject
As shown in figure 4, a belt is included in the garment. The portable PC and the receiver for sensor signals are placed in the belt and connected to each other via USB-interface.

Up to 30 MobileMe units can be used, connected to the same wireless network. Real-time data from all units connected to the network can be collected into SentientMonitor, running on a stationary PC or laptop. This makes it possible to monitor and compare real-time data from several subjects at the same time.

The system is delivered with the possibility to measure five variables and can be extended to handle additional parameters. Standard parameters are heart rate (via electrocardiography, ECG), blood volume pulse, respiration rate, skin temperature and skin conductance.

### 3.1.1 ECG

ECG is measured by a three-electrode lead placed on the chest just below the left and right clavicles (distally) and on the left lower part of the thorax. The negative (yellow) electrode is placed below the right clavicle, the ground electrode (black) below the left clavicle and the positive (blue) electrode is placed on the lower left side of the chest. An algorithm within the MobileMe software calculates heart rate, via differentiation of ECG sequence and R-wave detection. Either ECG or heart rate real-time data can be presented in SentientMonitor.

### 3.1.2 Blood volume pulse

A probe is placed on the ring finger on the left hand for measuring blood volume pulse, BVP. The probe uses photoplethysmography (PPG) for measuring this variable. The PPG sensor consists of an IR-diode placed beside a photodiode. The photodiode receives only the IR-light that has been back-scattered in the illuminated tissue. The amount of back-scattered light varies with the blood volume of the finger, and by processing of the photodiode signal, a relative measurement of blood volume in the tissue can be received.

### 3.1.3 Skin temperature

On the little finger of the left hand a small temperature transducer is placed for measuring skin temperature. The transducer is a thermistor with an accuracy of ±1.0° C.

### 3.1.4 Skin conductance level

Two disposable electrodes, smaller than the ECG electrodes, are placed on the index and middle fingers of the left hand for measuring skin conductance level. A small
potential, $\approx 0.5$ V, is induced between the electrodes, and the current is measured. Ohm’s law gives a measurement of skin resistance, which is the inverse of conductance. The upper layer of epidermis, which mostly contains of dead skin cells, can be seen as an isolator, but sweat glands are penetrating the layer and gives, when activated, ability for currents to travel through the skin. Skin conductance is therefore linear with the number of activated sweat glands (Hugdahl, 1995).

### 3.1.5 Respiration

A strain gauge, attached to the garment, measures the chest expansion. Both chest expansion and respiration rate can be presented as real-time data by SentientMonitor.

### 3.2 ViewPoint EyeTracker® system

The eye tracker used in the field study is the ViewPoint EyeTracker® system, by Arrington Research Inc. (Scottsdale, USA). The system consists of the eye tracker hardware and a software package. The software package includes programs for controlling the eye tracker, analyzing of data, and also a software development kit (SDK) for integrating the eye tracking system into other applications. The equipment can be used with contact lenses and eye glasses, and also on either left or right eye. Binocular mounting, i.e. detecting movements of left and right eyes at the same time, is also possible, but not used in this report.

![Figure 5. ViewPoint EyeTracker®](image)

The eye tracker is of video-based pupil, or corneal, reflection type, and consists of tracking sensors mounted on a lightweight spectacle-style frame, see figure 5. The sensors are one forward pointing camera recording the visual field, the so-called scene camera, one IR light emitting diode (LED) and a CCD array, sensitive to light in the IR spectrum. The IR-LED is transmitting light to the eye and the reflected light is detected by the CCD array, which is pointing in the same direction as the diode. The IR light does not disturb the vision of the subject and the camera signal is used to detect the position of the pupil. Camera data is transferred to the software via a video capturing card mounted in the computer running the eye tracking program.
The software is able to detect and store several parameters derived from the recorded pupil position. Among those are gaze position, pupil size, ocular torsion, delta time, total time, blink rates and fixation durations. When data is recorded, there is an option for the user to record pupil position and several other parameters, only, or to concurrently record the video signal from the scene camera (the forward pointing camera) and the data parameters. Both types of data can be analyzed in the software used for data analysis and, for example, the point of gaze can directly be seen in the movie recorded by the scene camera. The data analysis software makes it possible for the user to step forward in the scene movie, frame by frame, together with an included point of gaze, making it possible to visually analyze what the subject actually was looking at.
~ Part one ~

The laboratory study
The first study was conducted in a laboratory setting to ensure that the conditions for the study were as repeatable as possible. The aim of the study was to investigate the validity of the MobileMe equipment. The study consisted of four parts, all conducted in the same laboratory at Rehabilitation Medicine, Department of Neuroscience and Locomotion at Linköping University. The first and fourth parts were baseline conditions, the second part was a mental stress condition, whereas the condition in the third part varied. The first two subjects performed the Multi Attribute Task Battery (MATB) computer program, with escalating task difficulty to increase mental workload, in the second and third parts. The last two subjects were also using MATB in the second part, but in the third part they were using a bicycle ergometer to increase the physical workload.

### 4.1 Validity

DePoy & Gitlin (1999) describes four types of instrument validity; content validity, criterion validity, predictive validity and construct validity.

- **Content validity** is a systematic method based on descriptive procedures and testing against all aspects of the case by construction of specific items. This method is the most basic type of validation since it is intended to describe the degree of how the instrument *appears* to reflect the content of the area of interest.
- **Criterion validity** is based on a correlation between the current test and another instrument or proven method. The method or instrument used as reference must have been proven valid and reliable for this kind of validation. The correlation becomes a measurement for how precise the examined instrument measures the idea compared to the reference instrument.

- **Predictive validity** is used when the purpose of the instrument is to predict or determine the occurrence of a specific behaviour or an event. A correlation coefficient can be measured between the predicted values and the instruments results.

- **Construct validity** is based on the theoretical outcome of a test and the examined instruments measurements. This method is the most complex and requires extensive knowledge of the nature of the area of interest.

For this study, criterion validity was the method of interest. A system proven to be valid, called Vitaport 2 was used as reference equipment. It was used simultaneously with the MobileMe system, measuring the same variables.

In this laboratory study, only two out of five possible physiological variables of the MobileMe system were taken into consideration. MobileMe consists of standard parts, e.g. sensors, each produced by well-known manufacturers, such as Thought Technology Ltd., and the validation was done to assess whether the parts are working together as expected. Hence, this study was a validation of the MobileMe system as a whole, making an assumption that the system would still be valid, even if all of its features were not examined, legitimate.

### 4.2 Examined physiological variables

Electrocardiogram (ECG) and skin conductance level (SCL) were the chosen variables, since they both have definite response to ANS stimuli. Furthermore, several studies (Cowings et al., 1986; Gianaros et al., 2003; Himi et al., 2004; Hu et al., 1991; Wan et al., 2003) have already been done concerning these variables and their relations to motion sickness, which is a research area that MobileMe is intended to be used in. SCL is, for example, very sensitive to early ANS motion sickness responses. From the ECG signal, several other variables can be calculated, for example heart rate, heart rate variability and RR interval. These variables have been widely studied together with motion sickness, making ECG and SCL eligible for the validation in this study.

Furthermore, both SCL and ECG are sensitive to different kinds of stress, and are by that fairly easy to elevate and reduce, by presenting stressing or relaxing tasks to a subject. The possibility of controlling the responses was an important demand, based on the fact that a range of levels was to be investigated within the validation.
4.3 **Materials**

Materials used in this laboratory study were MobileMe, the reference equipment Vitaport 2, questionnaires, a bicycle ergometer and Multi Attribute Task Battery (MATB) software. MobileMe and Vitaport 2 were connected to the subject simultaneously during the entire test session. In the second part, and for some subjects also in the third part, MATB was utilized to increase the level of mental stress. The bicycle ergometer was used to increase physical stress to the subjects attending that certain part of the study. After each measurement, the subject was given a questionnaire concerning experiences of the tests.

4.3.1 **MobileMe**

MobileMe is a digital real-time monitoring system, originally designed for biofeedback training. Made by BioSentient® Inc. (Houston, USA), it is a further development of a NASA system used for monitoring astronauts on space missions. Details about MobileMe can be found in chapter 3.1.

4.3.2 **Vitaport 2**

Vitaport 2 is a modular high-performance digital recording system which has been widely used in research (Braun et al., 2002; Foerster, Thielgen, Fuchs, Hornig, & Fahrenberg, 2002; Jörg, Jock, Boucsein, & Schäfer, 2004). It consists of one main unit, optional number of analogue units and one recording unit. The main unit includes a high precision amplification system and a 32 bit 68xxx-type processor. It also includes one serial port (RS232), which allows Vitaport 2 to be controlled by an external computer, a two-row display with buttons for basic controlling, inputs for EDA measurement and marker events and a power button. The storage unit, which can be a flash disk or a small sized hard drive, connects to the main unit with a PC-card interface. Maximum storage capacity is 512 MB of data. Up to eight analogue units can be connected to the main unit and different types of units can be used depending on the input signals. For this study, one analogue unit is used, which gives the system a weight of 750 grams and a size of 9 x 15 x 4.5 cm. (Jain, Martens, Mutz, K., & Stephan, 1996)

Filter adjustments and other channel settings are programmable through the serial port, which also can be used for data transfer. The storage unit can be transferred to a computer for further data analysis. In this study, a 512 MB compact flash-type card was used via a PC-card adapter as storage unit. For data analysis, the storage card was transferred to a laptop PC for data processing. The unit was, in all four parts of this study, set to measure SCL in 16 Hz and ECG in 256 Hz. The ECG signal was filtered with a bandpass filter with cut-off frequencies 0.5 Hz and 40.1 Hz. No other variables were recorded with Vitaport 2.
4.3.3 Multi attribute task battery (MATB) software

MATB is a concept developed by NASA (Comstock & Arnegard, 1992) and is widely used for performance studies and research involving mental stress. The system consists of modules, including subtasks, that can be put together to form a stress-inducing computer program suitable for the present study. The difficulty of each subtask can be adjusted by changing specific parameters in a separate file. After each session performance scores are presented in an ASCII format text file. Performance scores were not used at all in this study since the performance of the equipment, rather than the individual, was of interest. One test leader observed the subject during the MATB tests to make sure that he or she was performing the task properly. An implementation of the MATB concept can be seen in figure 7. This is a simplified version of the MATB software, which in its complete form has five subtasks and provides the possibility of testing additional capacities.
MATB was the preferred method since it is capable of inducing different levels of stress to subjects in an easy way. The tests are performed at a computer workstation, which makes the subject relatively stationary and thereby decreasing movement artefacts in ANS data. Only two of the MATB subtasks, shown in figure 7, the tracking task (upper right) and the sorting task (lower left), were running during the tests in order to avoid large movements of the subject’s right arm. This was decided since pre-tests had shown that extensive arm movements gave rise to artefacts in the ECG signal. Furthermore, the subject could not use the left hand during the tasks since the BVP, skin temperature and SCL sensors were all attached to the left hand. Wilson and Russell (2003) utilized the MATB software, in studies of mental workload, with two different task difficulties and one baseline situation where the subject merely watched the static MATB screen. A similar experimental design was used in this study.

4.3.4 Ergometer
In this study, it was desirable to force the subjects’ physiological responses to increase in order to see that the MobileMe equipment could handle large as well as small input
data values. There are several possible methods for inducing elevated levels of the chosen physiological variables. Physical exercise or various methods that induce stress can be used for this purpose. A bicycle ergometer was used in this study to increase the physiological responses further from what the above discussed mental stressor was expected to show.

Ergometers are used in physiology studies to measure how different types of muscle work affect the body. In bicycle ergometers, the force needed to pedal can be adjusted by electrical or mechanical brakes, which enable precise measurements of load and amount of work done. Ergometers often have built-in systems for monitoring heart rate, ECG and blood pressure. In this study, however, a bicycle ergometer was only used for exercise purposes, in order to increase the subject’s heart rate and skin conductance level. The exercise tests produce a tougher environment for the MobileMe equipment and if it produces accurate measurements in these types of tests as well, MobileMe could be considered capable of being used for a wider range of purposes.

### 4.3.5 Questionnaires

For all four parts of the study, a questionnaire was handed out to the subjects, following the practical part. The four questionnaires had similar dispositions, and were all given in paper format. They were combinations of multi-answer and written-answer questions, the latter were used to get detailed information about other answers. Multi-answer questions were graded in seven levels, as recommended by Charlton (2002). The questionnaires were designed to give subjective measurements of some aspects of the study, for example experienced differences between the MATB-parts. The questionnaires can be found in appendices 1-5.

The first questionnaire consisted of seven questions concerning the age and sex of the subject, if the subject had taken any medication up to 24 hours before the test session and finally questions concerning the experience of the MobileMe and Vitaport 2 equipments. The questions in this first questionnaire also aimed to investigate the comfort of the equipments.

Questionnaire number two was an extension of the first, with additional questions concerning the experience of the stress-inducing MATB software. Subjects were asked to provide subjective estimates of their mental workload. Since the first and second parts were conducted following each other questions about medication and age was removed. All questionnaires were marked with a number to make it possible to link together the questionnaires answered by a certain subject.
There were two versions of the third questionnaire. For the first two subjects, the third questionnaire included the same questions as the second, but with additional questions concerning the comparison between the second and third part. Since stress levels were increased from the second part to the third part, it was eligible to get a measurement of the experienced stress levels. For the third and fourth subjects, those who attended the bicycle ergometer tests, the third questionnaire was based on the second one, but with questions about the experience of the cycling instead of questions about the MATB task.

The fourth questionnaire included nine questions and had the same design as the first, except that the questions about age and medication were removed. Since the first and forth part were baseline tests, additional questions were added to give comparative estimates of relaxation.

4.4 Electrode placement
MobileMe and Vitaport 2 were connected to the subject for simultaneous measurements. This setup gave, for each of the variables, one value from MobileMe and one reference value from Vitaport 2 at every point in time. It would have been optimal to use the same electrodes for both equipments, but due to the instrumentation, this was not possible. Instead, double sets of electrodes placed close together were used for recordings of both variables. Since two equipments were used at the same time, with separate electrodes, much effort prior to the experiments was made to figure out the best electrode placements when measuring with double sets.

4.4.1 ECG measurements
As mentioned, the subjects wore double sets of electrodes, to enable measurements of the same responses at the same time with different equipments.
Pre-tests with ECG data from two similar equipments showed that there were no observable problems when measuring ECG with double sets of electrodes.

First, the electrode pairs were placed horizontally, where the three electrodes to the left in each electrode pair were connected to one of the equipments and the three on the right were connected to the other equipment. This set-up gave good ECG signals for baseline measurements, but when the subject moved one or both arms artefacts appeared in the ECG signal. Especially MobileMe proved to be sensitive to movements of the lateral electrodes. There were also movement artefacts in Vitaport 2 ECG data, but they were much smaller, since Vitaport 2 uses bandpass filtering that restrains the artefact components. This electrode placement was rejected because of the large movement artefacts in MobileMe ECG data and a vertical placement of the electrode pairs was employed instead. The three uppermost electrodes were
Laboratory study – Method

connected to Vitaport 2 and the other three to MobileMe, as shown in figure 8. This placement gave smaller movement artefacts since all electrodes had a more medial placement and were not as much disturbed by arm movements as with the previous electrode attachment point.

Figure 8. Schematic figure of the ECG electrode placements, where MM denotes MobileMe and VP denotes Vitaport 2

4.4.2 SCL measurements

Before the decision of where to place the SCL electrodes was made, alternative placements were tested. In the MobileMe manual, it is suggested that the electrodes should be placed on the inside of the lower left arm. Pre-tests with two MobileMe systems, with two pairs of electrodes placed at the suggested spot, showed considerable differences in values between the pairs, even if the electrodes were placed as tightly as possible. There are large variations of sweat gland densities in this particular skin area, where skin with high density of sweat glands (palms) meets the skin of the arm. Electrode placement on the lower arm was, thus, rejected.

SCL is often measured between the medial phalanxes of the index and middle fingers (Bouscein, 1992). It is measured by inducing a small voltage between two electrodes and measuring the current. The current is either DC or AC, depending on if the induced voltage is direct or alternate. Vitaport 2 was originally set to measure SCL
Laboratory study – Method

with AC, and not by DC. Pre-tests with four electrodes at the medial and proximal phalanges of the index and middle fingers were conducted to examine which possible lead gave the most accurate measurements. When measuring SCL between the fingers, an AC component from Vitaport 2 became visible in MobileMe data, which indicated that the equipments disturbed each other. After these pre-tests, Vitaport 2 settings were changed to measure with DC instead of AC, since MobileMe is measuring SCL with DC and it was preferred that the two equipments used the same measuring techniques when validity tests were performed.

The optimal solution would have been to measure SCL on the same tissue at the same time with two equipments, but this was not possible due to the fact that measurements had to be performed with different electrode pairs. SCL is a measure of the activation of sweat glands in the skin underneath the electrodes. The four electrodes covered different skin surfaces, with different sweat gland densities, and would, hence, not give the exact same SCL measurements. Still, the values, ignoring baseline differences, followed each other, which made it legitimate to say that the sweat glands on the index and middle fingers were activated at the same rate and quantity. This assumption was also based on the fact that the sweat glands of the index and middle fingers are innervated by the same sympathetic nerve (Bouscein, 1992). Hence, the SCL measurements were decided to be conducted on separate fingers, as seen in figure 9.

![Figure 9. Placement of SCL electrodes measurements with double sets of electrodes.](image)

### 4.5 Subjects

Four subjects were participating in the study. Brief information about the subjects can be found in table 1. Subjects were recruited from public advertisements posted at
Linköping University. Participation was voluntary and the subjects gave their informed consent before the test session. Prior to the study, interviews were conducted to ensure that the participants were in good general health.

<table>
<thead>
<tr>
<th>Table 1. Subject information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
</tbody>
</table>

Since data was recorded simultaneously with two instruments, each subject was its own control. By using the individual as its own control, inter-individual variability that increases error variance and decreases statistical power could be minimized (Backs & Boucsein, 2000). This makes the study feasible with only one subject, since its focus lies on responses from the instruments rather than on physical responses from the subjects. However, to make sure that the equipment is capable of measuring different ranges of values, two different setups were used in the study. These included different kinds of stressors, with two subjects attending each setup.

### 4.6 Procedure

Prior to the first part, the subject was given written instructions (see appendix 6) handed out by the test leaders. Each part of the study was fully explained before written consent was obtained from each subject. Subjects could at any time ask the test leaders questions. The subjects were asked questions concerning their mood and general state of health, which was then noted in a test protocol.

MobileMe is designed to measure ECG via a three electrode lead as described in chapter 3.1.1, and Vitaport 2 was therefore set up to measure ECG via the same configuration. The ECG electrodes were placed close together in pairs at the three attachment points. After careful cleaning of the skin with preparation gel (Skinpure, Nihon Kohden Corp.) and alcohol, ECG electrodes were attached to the chest as described in figure 8. The electrodes used in this study were disposable pre-gelled Ag/AgCl electrodes (Ambu® Blue Sensor P). The subject was then fitted with the MobileMe garment and wires were attached to the ECG electrodes. The impedance between the electrodes was measured to ensure sufficient electrical contact between the electrodes and the skin surface. High impedance was associated with increased noise in the ECG signal. Impedance levels below 5 kΩ were desirable, though levels below 10 kΩ were considered sufficient.
For SCL measurements smaller Ag/AgCl electrodes (Bio-Medical Instruments, GS-27) were used, attached to the medial and proximal phalanges of the index and middle fingers of the left hand. No pre-treatment was used for the SCL measurements, as stated by Bouscein (1992). Electrodes placed on the index finger were used for measurements with Vitaport 2 and electrodes on the middle finger were connected to MobileMe as seen in figure 9. When electrodes had been properly placed, the rest of the MobileMe system was fitted to the subject.

The total duration of the test was no more than two hours for each subject. Subjects were connected to MobileMe and Vitaport 2 during the entire session. For all parts, recording of data was conducted for about two minutes.

4.6.1 Baseline 1
The purpose of the first part of the study was to collect baseline data from a subject in a resting state. The subject was instructed to sit down and relax in order to get as stable physiological responses as possible. Subjects were placed in front of the MATB computer, with a blank screen, to avoid transportation between first and second parts. When responses were reasonably stable, data was collected simultaneously with the two recording equipments. Following every part of the study, data was transferred from the measuring equipments and stored at an external computer for later analysis.

4.6.2 Low stress
When data from the first part was properly received, the second part of the study began. This part was conducted in the same way for all four subjects. The subject was instructed to begin using the MATB computer program, which for this part was set to give the subject a low level of mental stress. ANS responses of heart rate and skin conductance were expected to show elevated levels during low or moderate stress stimuli compared to those from baseline tests.

4.6.3 Increased stress
The third part was conducted directly following the first and second parts. For the two first attending subjects, the procedure for this part was similar to the previous one, except that the task difficulty in the MATB program was higher. The third and fourth subjects were, instead of performing MATB, riding a bicycle ergometer, set to increase the subjects’ physical stress. A verbal task, consisting of counting down from different numbers in steps of seven, was held for all four subjects. This task was added to increase the level of mental stress further for the two first subjects, since only two of the MATB subtasks were running, and to make the last two subjects not only physically stressed, but also mentally stressed. Speaking, or even thinking about verbalizing, is known to increase heart rate and SCL (Buck & Miller, 1969).
The higher mental and physical workload was expected to elevate ANS responses further from the second part for all subjects. For a discussion about stressors, see chapter 6.2.4.

4.6.4 Baseline 2
Due to the fact that the subjects could feel some amount of stress even at the first baseline part, for example due to unfamiliarity to the measuring equipments, a second baseline test was held. This test was conducted after the third part, but did not start until the subject was relaxed. Responses from those subjects that had conducted the ergometer test in the previous part were expected to show higher second baseline ANS responses than those from the first two parts, even if they were relaxed.

4.7 Data analysis
Raw data from the different parts of the studies was collected as text files in ASCII-format. Since sample rate varied between variables, data files were of different sizes, which made data processing necessary. When data files were of the desired format, statistical methods could be applied. All data synchronization and processing was conducted in Matlab (Mathworks Inc., version R14 for Windows), and all statistical calculations using SPSS (SPSS Inc., version 12.0.1 for Windows).

4.7.1 Synchronization and processing
A problem when using two measuring equipments is synchronization. When comparing simultaneously recorded data from two equipments, it is necessary to know the time lag between the data series, since it is not certain that data acquisition started at exactly the same time. When the time lag is known, it is easy to adjust one of the data series so it becomes synchronized with the other.

Both MobileMe and Vitaport 2 present their data in ASCII text files including time stamps. Unfortunately, timestamps from MobileMe data files are received from the computer system clock, which only has a time resolution of one second. With sample rates of at least 32 Hz in MobileMe-data this makes synchronizing using timestamps difficult, since all samples collected during one second has the same time stamp. Data files from Vitaport 2 contains, for each sample, not only time stamp in seconds, but also time from start of data collection to when the sample was taken. This makes it possible to give an exact point in time when each sample was collected, which is not possible in MobileMe data. Therefore, synchronization could not be done just by comparing time stamps in data files.

It is possible to set time marks (events) with MobileMe software and by pushing a button on the Vitaport 2 device, but trying to synchronize them this way is not
practically possible, due to the structure of events and timestamps in MobileMe. This fact, together with the above described, made it necessary to develop another method for synchronizing.

The synchronization problem was instead solved by calculating cross-correlation coefficients between ECG-data from MobileMe and Vitaport 2. Correlation coefficients were expected to be highest when the two data sets were shifted so that they corresponded in time. The difference in number of samples, the time lag, for the highest correlation could in this way be calculated, and it was used to time-shift the data sets so that they corresponded in every point in time. All data series were then visually inspected to ensure correct synchronization. This method makes the synchronization of start of data acquisition less important.

The difference in number of samples could not directly be used for synchronization of SCL data, since sample rate for the two variables were different (256 Hz for ECG and 32 Hz (16 Hz from Vitaport 2) for SCL). Downsampling of SCL data sets to equal sample rate was also performed to make analysis and rearrangements easier. The sample rate was set to 16 Hz, since that was the actual sample rate of SCL in Vitaport 2 and it could not be adjusted to a higher rate. ECG data sample rate was kept at 256 Hz for the statistical analysis. The time lag for SCL data was calculated by dividing the ECG lag by 16, since the difference in sample rates was 256Hz / 16Hz = 16, and rounding it to nearest integer.

The recording time for each subject in each part was about two minutes, which gave expected raw data lengths of \( \approx 31\,000 \) samples (ECG) and \( \approx 1\,900 \) samples (SCL). Synchronization, as described above, was made on SCL and ECG data from every subject. The synchronized data sets, one for each situation and subject i.e. a total of 32 data sets, were then written to disk as delimited ASCII-files, making it possible to import them into SPSS. Each data set contained data from both MobileMe and Vitaport 2.

Matlab scripts were developed to calculate heart rate variability (HRV) from MobileMe ECG data. The heart rate algorithm in the MobileMe software calculates average heart rate over a fixed number of seconds. To obtain HRV data, it is preferable to have heart rate data calculated from each heart beat rather than average heart rates over a few seconds. These calculations were made by R-peak detection in the ECG signal and heart rate data was then derived from each R-R interval.
4.7.2 Statistical analysis

Pearson correlation is a method that provides a measurement of linearity between two data series. It is often used to study possible associations between data variables, but can also be used for different types of validation, as described in chapter 4.1. The method leads to a correlation coefficient, \( r \), which is a number between \(-1\) and \(1\). A correlation coefficient of \( r = -1 \) marks total reversed proportionality, whereas \( r = 1 \) is total proportionality and \( r = 0 \) is no measurable correlation at all. (Altman, 1991)

The purpose for this study was to determine whether MobileMe was capable of producing valid measurements in a laboratory setting. For this study, validity is said to be confirmed if the correlation between data from MobileMe and Vitaport 2 is higher than 0.8. This statement is valid for both ECG and SCL data. For the final conclusion, if MobileMe is valid or not, a significance level of 0.05 was set. Partial significance requirements for the 32 partial correlations levels were calculated with application of the Bonferroni correction. Bonferroni correction is used to determine partial significance levels, \( \alpha_p \), from a total significance level, \( \alpha_t \), and a number of partial significance levels, \( c \), with the following relation:

\[
\alpha_p = \frac{\alpha_t}{c}
\]

With \( \alpha_t = 0.05 \) and \( c = 32 \), the partial significance level requirement for each correlation was calculated as

\[
\alpha_p = \frac{0.05}{32} < 0.0015
\]

The following chapter presents the results from the first study. For each situation, correlation coefficients between MobileMe data and Vitaport 2 data were consistently high. All correlation coefficients presented in the following chapters are significant at the 0.001 level. Due to errors in data acquisition, small parts of the Vitaport 2 data were removed, at various points, from two of the data sets. A total of about 0.15% of the data was removed from the third subject’s low stress situation and the same amount of data was removed from the fourth subject’s baseline 1.

5.1 Baseline 1

Correlation coefficients from the first baseline part are presented in table 2.

<table>
<thead>
<tr>
<th>Subject</th>
<th>ECG</th>
<th>SCL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.961 (N=30 951)</td>
<td>0.997 (N=1 943)</td>
</tr>
<tr>
<td>2</td>
<td>0.958 (N=29 915)</td>
<td>0.809 (N=1 946)</td>
</tr>
<tr>
<td>3</td>
<td>0.961 (N=32 226)</td>
<td>1.000 (N=2 017)</td>
</tr>
<tr>
<td>4</td>
<td>0.903 (N=31 449)</td>
<td>0.995 (N=1 946)</td>
</tr>
</tbody>
</table>

The correlations are consistently very high, with some exceptions. For example, the SCL measurements from the second subject gave $r=0.809$, which differs notably from
the other correlations. The variance can be explained by individual differences between SCL responses from the index and middle fingers.

Table 3 is presenting heart rate median and SCL mean from the MobileMe equipment.

**Table 3. Median and mean values from MobileMe at the first baseline measurements**

<table>
<thead>
<tr>
<th>Subject</th>
<th>Heart rate median (BPM)</th>
<th>SCL mean (µSiemens)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>69</td>
<td>2.87</td>
</tr>
<tr>
<td>2</td>
<td>63</td>
<td>3.07</td>
</tr>
<tr>
<td>3</td>
<td>78</td>
<td>10.3</td>
</tr>
<tr>
<td>4</td>
<td>75</td>
<td>5.15</td>
</tr>
</tbody>
</table>

It is noticeable that both the heart rate and SCL is at low levels, especially for the two first subjects. Since the only point of interest, when it comes to variations of the SCL mean, is intra-individual differences, the high SCL mean of subject 3 is nothing to take further notice about.

About two seconds of synchronized ECG data from MobileMe and Vitaport 2, from subject 4, can be seen in figure 10. This example shows a very high correlation where the only difference is a small scaling factor between the two data series. The suppression of peaks in the ECG signal from Vitaport 2 is due to the bandpass filtering, described in chapter 4.3.2.
Figure 10. Example of MobileMe and Vitaport 2 ECG data from subject 4 during the first baseline measurements

5.2 Low stress

Table 3 is presenting the correlation coefficients from the second part of the study, where the subjects were using the MATB program set at low stress level. Here, all the correlation coefficients are well above 0.9.

<table>
<thead>
<tr>
<th>Subject</th>
<th>ECG</th>
<th>SCL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.969 (N=30 974)</td>
<td>0.980 (N=1 955)</td>
</tr>
<tr>
<td>2</td>
<td>0.961 (N=29 938)</td>
<td>0.927 (N=1 929)</td>
</tr>
<tr>
<td>3</td>
<td>0.958 (N=32 289)</td>
<td>0.999 (N=2 019)</td>
</tr>
<tr>
<td>4</td>
<td>0.972 (N=31 161)</td>
<td>0.994 (N=1 929)</td>
</tr>
</tbody>
</table>

When it comes to median and mean levels in the second part, an expected increase of SCL mean levels can clearly be seen, but there was no observable increase in heart rate, which can be seen when comparing heart rate values in table 3 and table 5.
Table 5. Median and mean values from MobileMe at the low stress measurements

<table>
<thead>
<tr>
<th>Subject</th>
<th>Heart rate median (BPM)</th>
<th>SCL mean (µSiemens)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>71</td>
<td>13.2</td>
</tr>
<tr>
<td>2</td>
<td>60</td>
<td>12.2</td>
</tr>
<tr>
<td>3</td>
<td>71</td>
<td>11.9</td>
</tr>
<tr>
<td>4</td>
<td>69</td>
<td>18.8</td>
</tr>
</tbody>
</table>

Since the subjects remained stationary between the first and second part, and because the mental workload was set at a low level and large changes in heart rate were not expected. The three latter subjects even had a slight reduction of heart rate, which could be explained since they seemed a bit stressed at the beginning of the first part of the study.

An example of skin conductance measurements from the second part is shown in figure 11.

![Image of graph showing SCL from MobileMe and Vitaport 2](image_url)

Figure 11. Example of MobileMe and Vitaport 2 SCL data from subject 4 exposed to a low level mental stressor.
A difference in level can be seen and a small scaling factor is also noticeable, but these differences are not affecting the linearity and, hence, do not affect the correlation either.

5.3 Increased stress

In the third part, the first two subjects were performing the same task as in the second part, but with higher stress level and an added verbal task. The two last subjects were using a bicycle ergometer to increase heart rate and were exposed to the same verbal task as the first two. Using an ergometer increased the rate of motion artefacts in the data, especially in the ECG data. However, since the measurements sites were nearly the same for both equipments, artefacts were expected to appear at the same rate and relative amplitude. Since all correlations of table 6 are high, this expectation can be stated as confirmed.

<table>
<thead>
<tr>
<th>Subject</th>
<th>ECG</th>
<th>SCL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.960 (N=30 957)</td>
<td>0.948 (N=2 040)</td>
</tr>
<tr>
<td>2</td>
<td>0.941 (N=29 511)</td>
<td>0.917 (N=1 900)</td>
</tr>
<tr>
<td>3</td>
<td>0.966 (N=31 007)</td>
<td>0.991 (N=1 929)</td>
</tr>
<tr>
<td>4</td>
<td>0.938 (N=32 050)</td>
<td>0.960 (N=2 008)</td>
</tr>
</tbody>
</table>

Heart rate medians and mean skin conductance levels, seen in table 7 are showing the difference between the subjects that used the ergometer and those who only used MATB as a stress inducer. Skin conductance levels were for all four subjects increased from the second part, which was as expected. Likewise, heart rate levels were increased but not as much for subjects 1 and 2 as for subjects 3 and 4. This was also highly expected since the physical strain of subjects 1 and 2 was almost none.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Heart rate median (BPM)</th>
<th>SCL mean (µSiemens)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>85</td>
<td>13.2</td>
</tr>
<tr>
<td>2</td>
<td>70</td>
<td>22.5</td>
</tr>
<tr>
<td>3</td>
<td>165</td>
<td>15.3</td>
</tr>
<tr>
<td>4</td>
<td>144</td>
<td>31.1</td>
</tr>
</tbody>
</table>

An example of ECG data from a subject exposed to both mental and physical stress is presented in figure 12.
The entire measurement data set resulted in a median heart rate of 144 beats per minute. It is clearly seen that the typical waveform of an ECG signal is somewhat distorted compared to the one showed in figure 10, due to the higher heart rate. Small artefacts can be seen as the presence of higher frequencies at some intervals of the example. Figure 12 is only presenting MobileMe data, but the artefacts are also present in Vitaport 2 data. However, they are suppressed due to the bandpass filtering of Vitaport 2 data.

### 5.4 Baseline 2

About ten minutes after the second stress part, when the subjects seemed relaxed, a second baseline measurement was conducted. These baseline data gave high correlation coefficients between MobileMe and Vitaport 2, as seen in table 8.

<table>
<thead>
<tr>
<th>Subject</th>
<th>ECG</th>
<th>SCL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.972 (N=30 965)</td>
<td>0.937 (N=1 976)</td>
</tr>
<tr>
<td>2</td>
<td>0.957 (N=29 924)</td>
<td>0.998 (N=2 010)</td>
</tr>
<tr>
<td>3</td>
<td>0.959 (N=32 242)</td>
<td>0.994 (N=2 015)</td>
</tr>
<tr>
<td>4</td>
<td>0.962 (N=31 862)</td>
<td>0.997 (N=1 978)</td>
</tr>
</tbody>
</table>

Heart rate medians and SCL means for the fourth part, shown in table 9, were at the expected values, i.e. at about same levels as the first baseline part. Subject 3 had a slightly elevated heart rate in the second baseline, compared to the first baseline,
which could be due to slow recovery from the much higher heart rate in the ergometer test.

Table 9. Median and mean values from MobileMe at the second baseline measurements

<table>
<thead>
<tr>
<th>Subject</th>
<th>Heart rate median (BPM)</th>
<th>SCL mean (µSiemens)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>68</td>
<td>3.44</td>
</tr>
<tr>
<td>2</td>
<td>60</td>
<td>7.23</td>
</tr>
<tr>
<td>3</td>
<td>84</td>
<td>7.50</td>
</tr>
<tr>
<td>4</td>
<td>75</td>
<td>6.48</td>
</tr>
</tbody>
</table>

Figure 13 is showing a summary of all heart rate medians and SCL means. The high heart rate medians of subjects 3 and 4 are clearly seen and the progressions of the SCL means, from the different parts, are just as expected, except from an unexpected increase for subject 1 in the second part. The raise is possibly due to a sympathetic arousal at the start of the MATB task, or caused by individual characteristics in the SCL responses for subject 1.

Figure 13. Heart rate median and SCL mean from all parts and subjects

5.5 Other variables

Even if the validation results of the first study were based on the ECG and SCL variables, responses from the other three variables, respiration rate (RR), blood volume pulse (BVP) and skin temperature, measured by MobileMe were also investigated. Furthermore, heart rate variability, that is how the heart rate varies over time, is examined in the following chapter.
The periodicity of heart rate shown in figure 14 is due to respiratory sinus arrhythmia. Comparisons of the heart rate variability (HRV) curve with respiration measurements, such as in figure 15, show that HRV increases during inspiration and decreases during expiration. It is also noticeable that the periodicity of the HRV is the same as for the respiration rate. Respiratory sinus arrhythmia is most apparent in baseline situations and the amplitude of the HRV decreases with increased heart rate. Recordings from ergometer situations, where heart rate is about 150 beats/min, as seen in figure 16, show much less variability in heart rate than those from baseline measurements.

Figure 14. Heart rate variability from subject 3 attending the first baseline part

Figure 15. Respiration curve from subject 3 attending the first baseline part
Figure 16. Heart rate variability from subject 3 attending the ergometer part

Figure 17 shows an example of a blood volume pulse measurement, taken from subject 3 attending the second baseline measurement. The heartbeats are clearly seen as the peaks of the curve, and a low frequency is also visible, originating from respiration. When inhaling, the baseline of the BVP is increasing, and when exhaling, the BVP baseline is decreasing.

Figure 17. Blood volume pulse from subject 3 attending the first baseline part

Skin temperature is the examined variable with least variation over time. The temperature level readings in this study depended strongly on what the subjects were doing prior to the study, if they were coming in from the cold or already had been indoors for a while. No predictions about skin temperature changes during the
different parts of the study were made, and therefore the variable was not further studied.

5.6 Questionnaires

After each part of the study, a questionnaire was handed to the subjects, with questions regarding the experiences of the stress tests and the MobileMe equipment. A further description of the questionnaires can be found in chapter 4.3.5. Since this study was conducted with only four subjects, no statistical analysis was made on the results from the questionnaires. They were only used to obtain indications of how the subjects felt during the tests and what they thought about the equipment.

All subjects experienced a higher stress in the third part compared to the second part, as seen in table 10.

Table 10. Ratings, graded 1-7, from the questionnaires comparing the second and third parts

<table>
<thead>
<tr>
<th>Subject</th>
<th>Stress level</th>
<th>Mental strain</th>
<th>Physical strain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2\textsuperscript{nd} part</td>
<td>3\textsuperscript{rd} part</td>
<td>2\textsuperscript{nd} part</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

Furthermore, it can be seen in table 10 that no subject experienced any physical strain during any MATB test, but all subjects attending the ergometer tests experienced them as both physically and mentally stressful.

Table 11. Ratings from the questionnaires comparing the first and fourth parts

<table>
<thead>
<tr>
<th>Subject</th>
<th>Most relaxing baseline part</th>
<th>Finger electrode awareness (1-7)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1\textsuperscript{st} part</td>
<td>4\textsuperscript{th} part</td>
</tr>
<tr>
<td>1</td>
<td>No difference</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>4\textsuperscript{th} part</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>No difference</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>1\textsuperscript{st} part</td>
<td>5</td>
</tr>
</tbody>
</table>

There were no differences in experienced relaxation between the first and second baseline tests for all subjects. However, there was a difference in the experience of the equipment between the first and second baseline, in that the subjects were less aware of the finger electrodes and sensors at the last baseline part, as seen in table 11. The
lower level of distraction was possibly due to habituation to the electrodes and sensors.

5.7 Hypothesis verification

The hypothesis for the laboratory study was that the MobileMe equipment is valid. All calculated correlation coefficients between MobileMe data and Vitaport 2 data were higher than 0.8, which together with the statement of chapter 4.7.2 verifies the hypothesis. The verification is strengthened by the fact that only one out of 32 correlations was below 0.9, and that all correlations were significant at the 0.001 level.
The following chapter includes a discussion about the method and the results concerning the laboratory study. Furthermore, the usability of the MobileMe equipment is discussed.

### 6.1 MobileMe

MobileMe is developed as a system for biofeedback monitoring. It has characteristics applicable to other tasks than those used in this study. The manuals belonging to the system are only describing how to set up the system for monitoring and are not presenting any technical details. There are specifications, but only for the sensor modules. Moreover, the focus in the SentientMonitor software is to present real-time data in a clear and legible way, and not on processing and storing data. Information about units for the variables are not presented anywhere in the software, despite the large, clear graphs. Still, getting a good view of the variables made it easier to carry out the study, since it was possible to monitor the subject in real-time and start recording data whenever it was found suitable. The method for setting events is one of the features that are not yet fully developed. However, promises from the manufacturer have been made, concerning the event setting feature, which is going to be updated in a newer version of the SentientMonitor software. Marking events in data log files could have made data synchronizing easier, but the lack of this feature did not complicate it to a large extent.
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Figure 18. OQO computer.

The structure of the MobileMe system is modular, and at least one part can be considered redundant. The small OQO computer, figure 18, which is transferring data wirelessly from the subject to the SentientMonitor software, could perhaps be replaced by a less advanced PDA, which could reduce the costs of the system. On the other hand, if there is no need or not possible for wireless real-time monitoring, and large data series is to be recorded, it is very useful to have the storage capabilities and flexibility of a PC. A drawback of the fact that the system consists of several modules is that it demands knowledge of the operator about all parts, if errors occur in the system. The modularity simplifies in many ways rough troubleshooting. However, since the modules themselves are advanced, demands on the operator’s knowledge increases if module replacement is not possible.

The included software is developed continuously and therefore it is not certain that the software used in the study is the latest and, by that, the most functional one. This statement, that the software included in the tested system is not the latest, produces a limitation stating that it is only one specific version of the software that is tested for validity. However, since software development is considered not to remove general features of a system, and since the data used for the study is produced by only a sub-part of the software, this assumption is negligible. This means that it is reasonable to claim that if the tested version of the system is valid, smaller changes in the software do not make the system invalid. If major software changes occur, then it should be considered whether or not to conduct complementary tests for determining validity. On the other hand, if major hardware changes are presented by the manufacturer, and if they are intended to be used instead of the previous hardware, new validity
studies must be considered. New versions of the garments are developed continuously but their changes can be considered not to affect the validity of the system.

6.2 Method discussion
One of the main advantages of the used method was the possibility to use each subject as its own control. However, there was no possibility to measure with two equipments at the exact same sites, only to measure at adjacent sites. Hence, the physiological responses did not have the same origin, and the measured values were therefore not expected to be exactly the same.

If it not would have been possible to use the subject as its own control, there would have been no other choice than to employ some kind of repeated measurements method. Repeated measurements require greater demands on repeatability of environmental conditions, as well as of the subject’s physiological state. However, repeated measurements would have given the chance to place the electrodes at the same sites for each measurement. Still, it is more advantageous to measure at the same point in time, with tightly placed electrodes, than to try to repeat all test conditions at different times and measure at the same sites.

6.2.1 Reference equipment
For the validation, Vitaport 2 was used as the reference equipment. An alternative would have been to instead use the AFS-2, an analogue recording system used by NASA for biofeedback training of their astronauts. This would perhaps have been the most obvious choice of reference, since AFS-2 and MobileMe are constructed in similar ways, and since MobileMe to some degree is a further development of the AFS-2.

A research proposal had been sent to the NASA ethics committee concerning the use of AFS-2 for this study and further research regarding physiological responses to motion sickness. However, the research proposal had not yet come up for consideration at the start of this project and the AFS-2 equipment could therefore not be used as reference. Furthermore, the AFS-2 system demands calibration and since it is analogue, processing of recorded data to a preferred digital format would have required a vast amount of work. The focus of the study would then have been on processing of AFS-2 data, which would have overshadowed the preferred focus, to test MobileMe for validity. The reference equipment used in the study, Vitaport 2, is portable, and easy to start using. Furthermore, Vitaport 2 is a digital system, and its data files are in the same format as the MobileMe data files, which require no extensive processing prior to statistical analysis of the recorded data.
6.2.2 Questionnaires

The questionnaires used in the study could have been designed differently in order to be more informative for the validation. For example, there could have been a decreased number of, and more comprehensive, questions about the experience of MobileMe. Since there were only four subjects participating in the study, the questionnaires were not expected to provide a basis for any conclusions about the general experience of the MobileMe equipment. If this was to be assessed, a much larger group of subjects would have had to participate in the validation study.

6.2.3 Validation variables

The choice of investigated ANS responses, that is the SCL and ECG measures, depended on several factors. It could have been possible to conduct a validation study of all five parameters available on MobileMe, but probably too time-consuming. Even though the assumption, that the whole system is valid even if only two out of five variables are investigated, is well-founded, there is always a risk that some of the parts not investigated are malfunctioning.

It could have been practically possible to choose any two out of the five available variables. For example, blood volume pulse could have been chosen instead of skin conductance level. Neither BVP nor SCL can be measured at the same site at the same time, but BVP has the disadvantage of being more sensitive to disturbances. For example, even if the BVP measurement site is completely still, artefacts can be seen when the subject is mentally stressed. Heart rate can be derived from a BVP signal, and it could therefore have been a replacement for ECG as a source for heart rate data. This would, however, have made the ergometer part of the study very difficult, since the movement of the subject during the test would make BVP data heavily distorted, due to its sensitivity to motion of the measurement site. Furthermore, an algorithm that calculates heart rate from an ECG signal can be made more independent of individual waveform differences than a BVP heart rate algorithm.

Skin surface temperature is another variable that might have been chosen, but it has very small changes in time, and it is difficult to change the temperature response to desired levels. Respiration rate is a variable that is easy to measure, but it is very sensitive to speech and it is also under voluntary control, making it not completely ANS controlled.

6.2.4 Stressors

The Multi Attribute Task Battery, MATB, was the chosen mental stressor for this study. Other examples of stressors that trigger sympathetic activation are speech tests, the cold pressor test and the Stroop task. The cold pressor test consists of immersing
Laboratory study – Discussion

one arm into cold water, whereas the Stroop task includes asking subjects of the ink colour of a written word. The word is written in a certain colour, and the background has another colour. To make it even more stressful, the word itself describes a third colour. Especially these two tests are well-known to induce stress to subjects (Hugdahl, 1995).

The cold pressor test could have provided more comparable responses from the four subjects, since it would have been easy to create equal conditions for the subjects, by controlling water temperature and immersion time. This could be considered as an advantage over the MATB stressor, where the subject has the ability to put more or less effort into the task, despite a constant task difficulty. In this study, the goal of using stressors was to produce different levels of the physiological responses, and there was, hence, no need for an equal stress level among the subjects. Furthermore, the cold pressor test is rather painful to the subject and there could be a risk working with water close to the recording equipments.

Another possible stressor that was discussed at the early stages of the study was motion sickness stimulation. This particular stressor was of interest since the MobileMe equipment is intended to be used for motion sickness research. The available stimulus was a motion platform, with six degrees of freedom, producing a low frequency movement similar to the motion of a sea vessel. However, it was decided that a method where the subject moves as little as possible would make the data acquisition easier and more controllable.

When the subjects were using the bicycle ergometer, smaller movements of the measurement sites were inevitable. These movements were expected to induce artefacts to the signals, and studying the size and number of the artefacts was considered a part of the validation of the MobileMe equipment. Ergometer tests have the drawback that despite having the same adjustment of load, subjects could experience varying physical strain depending on pedalling rate and physical fitness. Heart rate could, hence, differ between subjects. The exact physiological responses were, however, not crucial for the validation as long as there was an elevation of heart rate during the ergometer test. A treadmill could have been used instead, but due to availability of a bicycle ergometer, and that a running subject would induce larger and increased number of artefacts in the signals, a possible use of a treadmill was rejected.

6.2.5 Statistical analysis

The statistical method used, correlation analysis, only gives a measurement of linearity between two data series. It can therefore not detect any scaling factors or
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level differences between the data series. Despite this, correlation is a sufficient method both for SCL and ECG measurements. When it comes to ANS SCL responses, they could not be expected to be exactly the same, in absolute level, due to the electrode placement. Correlation is also sufficient for ECG measuring, since it is only the waveforms of the signals that produce usable data, and not the absolute level of the signal. Also, in possible upcoming usage of MobileMe, primarily heart rate calculations are to be done, making knowledge of the peak levels of the ECG signal unnecessary. Heart rate calculations are often done by detecting the QRS complex, which is a certain part of the waveform. It is known that the Vitaport 2 uses bandpass filtering of the ECG signal, which can lead to slight depression of certain parts of the waveform, mainly the R wave.

When calculating correlation coefficients, data from the different parts, subjects and variables were separated, making a total of 32 correlations. This is a large number of partial results, which requires very low significance levels to make the hypothesis securely verified. It would have been possible to merge the data sets from the different parts, and also different subjects, which would have reduced the number of correlation coefficients. However, when using several correlations, the conditions that produced a low correlation can directly be isolated and examined.

Pearson correlation is based on an assumption of normally distributed data. Since there was such large number of samples for each correlation analysis, in this study, the data could be considered to have approximately normal distribution. To further ensure that both SCL and ECG data had normal distribution, Kolmogorov-Smirnov tests were made on a subset of both SCL and ECG data. These tests showed that the assumption of normal distribution of the data sets was legitimate.

If another method would have been used, for example comparing means and standard deviations, consideration about levels would have been taken, and therefore the results would depend on levels and/or scaling. Possible results would then not have reflected the stated assumptions, and drawing conclusions about the validity would have been almost impossible.

If any of the correlations would have turned out to be below the stated validity limit, a further investigation to determine the causes would have been proposed. A slight decrease of a correlation, if it occurred in SCL data, could have been explained by individual differences of SCL responses between the subjects’ index and middle fingers. For ECG data, an erroneous correlation would have been indicating either loss of data, producing partially unsynchronized data files, or malfunction of the equipment. A further investigation of erroneous correlations would have included extensive analyses of data files from both MobileMe and Vitaport 2. Furthermore, the
experimental setup and the particular experiment would have been examined to find out if any external influence, not caused by the recording equipment, could have affected the results.

6.3 Result discussion

For the different parts of the study, different levels of the physiological responses were desired. Heart rate levels were expected to increase between the first, second and third parts for all subjects, since the stress levels were increasing. For almost all subjects, this was the case. However, two subjects showed a slight decrease in HR between the first and second part, possibly due to physical stress prior to the first baseline part. The total amount of low-level ECG data was thus increased, but the desired range of levels was covered by data from other subjects. The subjects attending the bicycle ergometer parts had an increase of about 50% in HR levels between the second and third parts, producing the high-HR ECG data, just as expected.

SCL levels were also expected to increase between the first, second and third parts, due to increased stress levels. Calculating SCL means from the different subjects and parts and comparing them showed that the levels turned out to be approximately as expected. Due to individual differences, the absolute increase varied between subjects, but the relative increase was almost the same for all subjects, apart from one, which had no increase between second and third part.

Since the correlations presented in chapter 5 are rounded, very high correlations can be interpreted as perfect (= 1) even if they only are close to 1. All correlations are, in principle, well above the stated validity limit, and the significance level, according to the Bonferroni correction, is 0.0015, making the main hypothesis strongly verified.

One of the aims of this study was to investigate validity at different input levels, which could be interpreted as an equal variance of input data, from baseline level to maximum level, was desired. Since only two out of four subjects were exposed to physical stress, there were less ECG data from high HR levels. The variance of SCL data was approximately the same over the different levels, with an increase in number of baseline levels. The larger amount of low-HR ECG data could further be explained by the observation that prediction of HR levels turned out to be more difficult than expected, and especially HR levels of the second MATB parts were not at all as high as expected. If the second MATB part was removed, and all subjects were attending the bicycle ergometer part, equal amounts of ECG data from all HR levels could more strongly have been expected. Both ECG and SCL would also have a more equal variance of data over the desired interval if only one baseline part had been
conducted. The last baseline could, hence, be considered unnecessary, since the first baseline part already had given baseline level data. But, when studying physiological processes, data from a second baseline, following a stress part, is interesting to investigate. Since the study is an investigation of the validity of a recording system, where the result is based on correlation coefficients for different levels of data, it could have been discussed whether correlations were needed to be calculated for the second baseline, when similar data already had been recorded.
The results from the laboratory study concluded that the MobileMe recording system was valid in controlled environments. The heart rate and skin conductance responses measured by MobileMe were significantly correlated with measurements from a reference equipment, which produced sufficient basis for stating that the whole MobileMe equipment was valid. Blood volume pulse and ECG measurements were, however, sensitive to large movements and this should be taken into consideration in further research. Since the validation was successful, an investigation of the ability of MobileMe to measure in field environments was conducted, i.e. the field study in this thesis.
~ Part two ~

The field study
In the second study, the purpose was to investigate if the MobileMe equipment was suitable for motion sickness studies in the field, and to study visual fixation pattern changes during motion stimulation. The first part of this report concluded that MobileMe produced valid data in laboratory settings and it was therefore eligible to see how the equipment could handle uncontrolled environments.

*Figure 19. The Combat boat 90 #886, the boat used in the field study.*
The tests were conducted on board a sea vessel, the Swedish amphibious corps Combat boat 90, as shown in figure 19. Physiological data and eye movements were recorded continuously with the MobileMe recording equipment and the ViewPoint eye-tracker. The tests were conducted until the subject voluntarily cancelled the test or when the test was cancelled by the test leaders. During the test, the subject was using a distraction task, in order to stay occupied. Every fourth minute, the distraction task was aborted and the subject answered an electronic questionnaire concerning the level of perceived motion sickness.

### 8.1 Examined physiological variables

Before the onset of motion sickness, several physiological responses are known to change, as a reaction to the processes that occur in the body prior to perceived motion sickness (Benson, 1988). The physiological variables measured by MobileMe include some of the most studied motion sickness responses, making the equipment a suitable tool for this area of interest, as stated in chapter 1.1. A summary of the characteristics of the particular responses are presented in chapter 2.4. Most of the previous research has been conducted in laboratory settings, and it is therefore uncertain which of the responses that are most suitable and easiest to record when an uncontrolled environment affects the subject, the equipment and, hence, the results. One of the purposes with this study was to verify if the above mentioned expected changes of physiological responses could be measured with the MobileMe equipment during a field study.

As stated in chapter 2.4, forced eye fixations can decrease the level of perceived motion sickness. One part of this study was to investigate if there are any signs of a backward relationship, i.e. if fixation durations increase prior to the onset of perceived motion sickness. This can either be an autonomous reaction, or, when the onset of perceived motion sickness is close, a conscious increase of fixation durations, performed to restrain nausea.

### 8.2 Subjective ratings of motion sickness

Subjective ratings of the severity of motion sickness were obtained using two different scales.

#### 8.2.1 Symptom diagnostic scale

The symptom diagnostic scale is based on subjective ratings of the severity of a number of motion sickness symptoms. Symptoms included in the diagnostic criteria are categorized as minimal, minor, major or pathognomonic where the different categories correspond to different points (Graybiel, Wood, Miller, & Cramer, 1968;
Miller & Graybiel, 1970). The five cardinal symptoms of motion sickness; nausea, pallor, cold sweating, increased salivation and drowsiness are all included in the diagnostic criteria. There are also additional qualifying symptoms, which are associated with motion sickness but not as strongly as the cardinal symptoms mentioned above. Diagnostic criteria for the scale can be found in table 12.

Table 12. Diagnostic categorization of different symptoms of acute motion sickness

<table>
<thead>
<tr>
<th>Category</th>
<th>Pathognomonic</th>
<th>Major</th>
<th>Minor</th>
<th>Minimal</th>
<th>AQS*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nausea syndrome</td>
<td>Vomiting</td>
<td>Nausea II, III</td>
<td>Nausea I</td>
<td>Stomach discomfort II</td>
<td>Stomach awareness I</td>
</tr>
<tr>
<td>Pallor</td>
<td>III</td>
<td>II</td>
<td>I</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sweating</td>
<td>III</td>
<td>II</td>
<td>I</td>
<td>Increased warmth I, II</td>
<td></td>
</tr>
<tr>
<td>Increased salivation</td>
<td>III</td>
<td>II</td>
<td>I</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drowsiness</td>
<td>III</td>
<td>II</td>
<td>I</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Headache</td>
<td></td>
<td></td>
<td></td>
<td>I, II</td>
<td></td>
</tr>
<tr>
<td>Dizziness</td>
<td></td>
<td></td>
<td></td>
<td>I, II</td>
<td></td>
</tr>
</tbody>
</table>

*AQS = Additional qualifying symptoms.
†III = severe, II = moderate, I = slight.

Included in the additional qualifying symptom category are; increased warmth, dizziness, stomach awareness and headache. There are two levels of increased warmth, dizziness and headache; slight (I) or moderate (II). However, both levels render the same number of points. For the symptoms associated with nausea syndrome, stomach awareness is defined as a feeling which draws attention to the epigastric area, but is not uncomfortable. Stomach discomfort is defined as a feeling of distress which is more than awareness but short of nausea (Graybiel et al., 1968). Stomach awareness can be rated as slight, whereas stomach discomfort has the level moderate. Remaining symptoms of motion sickness are pallor, sweating, increased salivation and nausea, which can be described as slight (I), moderate (II) or severe (III).

In practice, the symptom diagnostic scale consists of a number of questions concerning severity of each symptom. Points for each symptom are obtained through subjective ratings using a questionnaire or by observing the subject. Adding the points for all answers yields a numerical score, the so-called malaise score, corresponding to
the subject’s perceived motion sickness (Graybiel et al., 1968; Miller & Graybiel, 1970), as seen in table 13.

**Table 13. Levels of severity identified by total points score**

<table>
<thead>
<tr>
<th>Frank sickness</th>
<th>Severe malaise</th>
<th>Moderate malaise A</th>
<th>Moderate malaise B</th>
<th>Slight malaise</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 16 points</td>
<td>8-15 points</td>
<td>5-7 points</td>
<td>3-4 points</td>
<td>1-2 points</td>
</tr>
</tbody>
</table>

The symptom diagnostic scale, developed by Graybiel et al. (1968), has been widely used in studies involving motion sickness producing devices in the laboratory and in evaluating air sickness and sea sickness (Cowings et al., 1990; Hu et al., 1991; Quarck et al., 2000; Stout et al., 1995; Warwick-Evans et al., 1987). Graybiel et al. (1968) state that modifications in scoring may be required to better suit the purpose of the study. Appendix 7 lists the questions included in the symptom diagnostic scale and the points for each answer. In this study, questions 11 and 12 were omitted since only the early stages of motion sickness were of interest.

### 8.2.2 Borg scale

The Borg scale (Borg & Borg, 2001) is a verbally level-anchored ratio scale, also called category rating (CR) scale, which means that verbal anchors are describing the answerable levels of the scale. It has, for example, been used as a method for scaling sensory perceptions, experiences and emotions, and its primary use has been in clinical diagnosis of aches and pain and in determination of perceived exertion. The scale is based on one question, which asks the subject to grade its sensation of a certain state, for example pain. The scale begins at 0, which for the answering subject corresponds to no sensation at all, of the current question. Maximum grade corresponds to the level above the strongest experienced sensation of the symptom described by the question. The maximum level is not represented by any numerical value; the highest numerical value is instead described by the strongest sensation the subject has ever experienced. The value of the highest grade depends on which type of scale that is used, if the CR10 or CR100 is used. The only difference between the two types is the numerical range, CR10 ranges from 0 to 10 while CR100 ranges from 0 to 100. An example of the Borg CR10 scale is presented in figure 20.
Figure 20. CR10 scale.

### 8.3 Materials

Material used in this field study was the MobileMe digital recording equipment, the ViewPoint EyeTracker® system, a distraction task, and an electronic questionnaire used to determine the subjects' perceived motion sickness. All tests were conducted below deck, in a closed cabin, and there was no risk for any equipment being exposed to water. However, the equipment was exposed to engine vibrations, boat movement, and other uncontrollable variables, such as changes in air humidity and temperature. Determining how the equipment was affected by these variables, called confounding variables, was a part of the purpose of this study.

#### 8.3.1 MobileMe

A detailed description of the MobileMe equipment can be found in chapter 3.1. In this study, all variables were measured and investigated.

#### 8.3.2 ViewPoint EyeTracker®

The ViewPoint EyeTracker® is a lightweight video-based system that is easy to use and includes monitor software, capable of logging eye movements. In this study, the eye tracker was used to detect fixations and fixation durations. These variables are based on output data from a fixation duration algorithm (Bjällmark & Larsson, 2005), and by visual inspection of eye tracker data in the ViewPoint data analysis software. The eye tracker is further described in chapter 3.2.
8.3.3 Distraction task

A distraction task, consisting of a software program running on a laptop computer, was introduced to the subject before the start of the test. The task was of pattern recognition-type and produced ratings on how well the subject could distinguish a certain type of picture from a set of similar pictures. At the start of the task, a grid with 20 images was shown. The pictures were encircled arrows, and only one out of the 20 pictures had all arrows pointing in the same direction. The task was to find the particular image where all three arrows were in the same direction, and to click on that image as fast as possible. When an image was selected, the program was signalling whether the selected image was right or wrong, followed by a restart of the task, to keep the subject constantly occupied during the trials. The clickable image grid, as seen in figure 21 was shown for a specified number of seconds, and if the subject had not chosen an image when the grid was removed, a sign signalling that there has been a time out was shown, and the task restarted with a new picture grid.

The distraction task was integrated with the electronic questionnaire described in chapter 8.3.4. Every fourth minute of the running time for the distraction task, the questionnaire was presented. When the questionnaire was fully answered, the distraction task started over again.

The task was also designed to get a rating on the subjects’ ability to perform a mentally demanding test. The program produced log files including response times for each round, the selected image, and the correct image. Ratings on performance could be calculated, or described, by data from the log files. For this study, the purpose of
using this task was mainly to keep the subjects occupied and to keep them from taking deliberate counter-measures against possible motion sickness, such as fixating on a stationary object or shutting their eyes.

### 8.3.4 Questionnaire

The questionnaire included both the symptom diagnostic scale and the Borg CR10 scale described in chapter 8.2. In this field study, the question connected to the Borg CR10 scale was: How much nausea are you feeling?

### 8.4 Subjects

Six subjects, aged 22 to 30 were participating in the study. Data for all subjects are presented in table 14.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age</th>
<th>Sex</th>
<th>Eye-tracker</th>
<th>Test trial</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25</td>
<td>Female</td>
<td></td>
<td>I</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>Female</td>
<td>X</td>
<td>I</td>
</tr>
<tr>
<td>3</td>
<td>22</td>
<td>Male</td>
<td></td>
<td>II</td>
</tr>
<tr>
<td>4</td>
<td>22</td>
<td>Male</td>
<td>X</td>
<td>II</td>
</tr>
<tr>
<td>5</td>
<td>22</td>
<td>Female</td>
<td></td>
<td>III</td>
</tr>
<tr>
<td>6</td>
<td>24</td>
<td>Female</td>
<td>X</td>
<td>III</td>
</tr>
</tbody>
</table>

Subjects were recruited from Chalmers University of Technology and from the National Institute for Working Life, both located in Göteborg, where the study was performed. Participation was voluntary and all procedures and anticipated discomforts or risks were explained to the subjects before written consent was obtained. Prior to the study, interviews were conducted to ensure that the participants did not have any vestibular disorders and were in good general health. Subjects susceptible to sea sickness were sought for, since one of the purposes was to measure physiological responses at the onset of motion sickness. The subjects were also informed that they could not take anti-motion sickness medications or antihistamines within 24 hours prior to the start of tests.

### 8.5 Procedure

The field study was emanating from the Älvsborg amphibious regiment, located in the outer part of the port of Göteborg. The outcome of the study was highly sea state dependent, since heavy sea can be expected to induce motion sickness easier than calm sea.
Field study - Method

On arrival, the subject was given information (see appendix 8) about the purpose of the study by the test leaders and was then asked to give written consent to participate. Further, questions were asked regarding the subject’s perceived physical status. The subject was then fitted with the MobileMe equipment as described in chapter 4.6, with one exception. Since no reference equipment was used in this study, skin conductance level (SCL) was measured between the medial phalanges of the index and middle finger.

Before boarding the vessel, the subject was briefed on the procedure, given a chance to ask questions and also reminded of the possibility to abort the test at any time, without giving any reason for it. When subjects and test leaders had boarded the combat boat, the eye-tracker was mounted on one of the two subjects attending the same trial. As soon as the MobileMe equipment was ready to record physiological data, the eye-tracker was calibrated, followed by the start of the tests. The subjects were told to begin using the distraction/questionnaire program, and at the same time all data acquisition began. During the whole test, the subjects were sealed off visually from the outside world, to remove all stationary outer points of reference, such as the horizon. Noise from the boat engine made it necessary for the subjects to wear active ear protectors during the whole trial.

When the test was cancelled, either by the subject or the test leaders, all data acquisition was stopped, the distraction/questionnaire program was closed and some parts of the equipment was removed from the subject. Data acquisition was conducted for no more than 60 minutes. When the boat returned to the harbour, all equipment was removed from the subject, and if the subject experienced motion sickness, he or she was asked to report severity of residual symptoms.

8.6 Data analysis

The purpose of the data analysis was to produce results, based on the recorded data, to make it possible to either confirm or reject each of the four hypotheses stated in chapter 1.2. MobileMe and ViewPoint data was recorded with the same computer, running both the SentientMonitor and the ViewPoint software. MobileMe data was also recorded by the OQO computers, if the wireless data transmission should fail. When data from all equipments were synchronized, statistical methods and data processing could be applied. Data processing was conducted in Matlab (Mathworks Inc., version R14 for Windows) and statistical analyses were made in SPSS (SPSS Inc., version 12.0.1 for Windows).

Because of expected divergence among subjects in their responses to motion stimulation and differences in test conditions for the three test trials, the parts
concerning motion sickness were regarded as explorative studies. Hence, the results from each subject were treated as separate case studies.

8.6.1 Synchronization

All data files, including log files from the distraction/questionnaire program, included one or more time stamps. All time stamp resolutions, except for data recorded by the eye-tracker, were seconds, making synchronization in less than one second virtually impossible. Since expected length of data series was about 45 minutes, and mean values from several minutes of data were to be calculated, synchronization within one second was seen as sufficient.

The method used to synchronize data was based on comparison of the system clock of all computers involved in data recording. One of the computers was chosen as reference, and for the other computers, a lag to the reference system clock was noticed. A translation sheet was then compiled, including time differences between data files, in different formats such as seconds and samples. When data from specific time intervals was to be used for calculations, time limits were fetched from the translation sheet.

8.6.2 Data processing

The recorded data had to be processed to get the specific variables used as input for statistical analyses. To be able to study changes of the variables over time, compared to the malaise score, mean values of the variables were calculated. The whole measuring time was split into intervals, derived from when the electronic questionnaires began. Start time for each interval was set to two minutes before a questionnaire began, since the interval between the questionnaires was set to four minutes. Stop time for an interval, except for the last, was the time for the sample prior to the start time for the following interval. Hence, mean values for each variable were calculated from data with a questionnaire in the middle of the time interval.

All raw data from the measuring equipments were not suitable for the mean calculations and statistical analyses. Table 15 is describing the variables that were processed prior to the mean value calculations and the statistical analyses. SCL and skin temperature raw data were not processed and are therefore not included in table 15.
Table 15. Processed data formats and their corresponding raw data formats.

<table>
<thead>
<tr>
<th>Raw data format</th>
<th>Processed data format</th>
</tr>
</thead>
<tbody>
<tr>
<td>BVP signal</td>
<td>Relative peak-to-peak values</td>
</tr>
<tr>
<td>ECG</td>
<td>Heart rate</td>
</tr>
<tr>
<td>Resp. signal</td>
<td>Respiration rate</td>
</tr>
<tr>
<td>ViewPoint data</td>
<td>Fixation durations</td>
</tr>
<tr>
<td>Performance data</td>
<td># Correct answers/minute</td>
</tr>
<tr>
<td>Questionnaire data</td>
<td>Malaise score + Borg scale</td>
</tr>
</tbody>
</table>

BVP, ECG and the respiration signal were processed using Matlab scripts, designed specifically for this study. Comparisons were made of results from the real-time HR, RR and BVP algorithms included in the MobileMe software, with results from the Matlab scripts. The real-time algorithms proved less stable and would give larger number of unreasonable values, which could be due to detection of noise.

Fixation durations were calculated using an algorithm designed by Bjällmark & Larsson (2005), whereas performance and questionnaire data was manually analysed.

8.6.3 Validation of MobileMe

To assess whether the MobileMe equipment could be used for monitoring physiological variables in the field, a visual inspection of data from all variables was done. Limits of acceptance were based on the appearance of MobileMe data recorded in the laboratory study. Hence, data from the field study were validated against data from the laboratory study. The visual inspection consisted of three parts, of which one was searching for artefacts, induced by the environment onboard a moving boat. Remaining parts of the inspection included examination of waveforms of the ECG, BVP and respiration signal, to conclude if they resembled expected waveforms, and concluding whether SCL and skin temperature data were within reasonable ranges. Reference ranges and waveforms were derived from the results of the first study in this report, which consisted of MobileMe measurements in a controlled laboratory environment.

8.6.4 Autonomic responses and motion sickness

Verification of autonomic responses associated with motion sickness demands the occurrence of perceived motion sickness. Occurrence was determined by the malaise score, derived from the electronic questionnaire. Motion sickness was defined as reaching *frank sickness* on the symptom diagnostic scale described in chapter 8.2.1. If any of the malaise scores for a subject exceeded 16, the particular subject was said to have reached the motion sickness threshold. When this was the case, mean values for each variable were correlated with the malaise score, using Spearman’s Rho (Altman,
1991) as correlation method. Significant correlations, with $p<0.05$, were used as basis for any possible hypothesis verification. Since five parameters were recorded for each subject, the Bonferroni correction was applied as described in chapter 4.7.2.

The conditions for the three trials were expected to be different, both in motion stimulation and in environmental conditions, such as temperature. This was one of the reasons why the result from each subject was treated as a case study and no inter-individual comparisons were done. The responses would not have been expected to be comparable even if the conditions would have been exactly the same for all subjects, because of the large inter-individual differences in the autonomic responses to motion sickness, see chapter 2.4.

### 8.6.5 Fixation durations and motion sickness
As described in chapter 2.4, the level of perceived motion sickness could be decreased if a subject were forced to fixate on a stationary object. To determine any relationship between longer fixation durations and perceived motion sickness, correlation coefficients for each subject that used the eye-tracker, were calculated. As with the previous analysis, Spearman’s Rho was the correlation method. This method was used since the malaise score not could be considered normally distributed, and since there was a small number of data pairs.

### 8.6.6 Evaluation of the Borg CR10 scale
The design of the questionnaire software made it easy to incorporate an implementation of the Borg CR10 scale, described in chapter 8.2.2, following the questions of the malaise score questionnaire. To assess the usability of the Borg CR10 scale, for rating severity of perceived motion sickness, each subject rated their motion sickness in two different ways. Since this analysis was an evaluation, the Borg scale data from all subjects were merged to increase the statistical power. Spearman’s Rho was used as correlation method, since data both from the Borg scale and the malaise score could not be considered normally distributed. A correlation coefficient above 0.8 was considered as sufficient for hypothesis verification.
The following chapter presents the results from the second study. The outline of this chapter is based on the order in which the four hypotheses are presented in chapter 1.2.

The motion sickness stimulation was not of the desired intensity, due to disadvantageous weather conditions with poor visibility and calm sea. In order to induce motion sickness, the crew were asked to make provocative motions by turning sharply back and forth, when surroundings permitted. However, this became possible only in the last trial, due to fog during the first two trials. Since the boat crew followed three different predetermined routes, the test sessions were of different length. The lengths of data acquisition, along with test conditions, for each of the three trials are given in table 16.

\[
\begin{array}{cccc}
\text{Trial} & \text{Weather} & \text{Sea state*} & \text{Provocative motion} & \text{Time of day} & \text{Length} \\
\hline
I & \text{Dense fog} & 1 & & 9 \text{ am} & 59 \text{ min} \\
II & \text{Fog} & 1 & & 1 \text{ pm} & 45 \text{ min} \\
III & \text{Mist} & 1 & X & 3 \text{ pm} & 25 \text{ min} \\
\end{array}
\]

* World Meteorological Organization Sea State Code (see Appendix 9)
Performance scores were calculated for each questionnaire interval. For all subjects, no significant correlations were found between performance and malaise scores.

9.1 Validation of MobileMe

Data losses in the wireless transmission of MobileMe data from the OQO computers made the data files recorded by SentientMonitor useless. Instead, MobileMe data recorded by the OQO computers were used for the evaluation.

Visual inspections of all data were performed as described in chapter 8.6.3. Very few artefacts were discovered in the signals, despite the uncontrolled environment. The BVP signal showed the largest and most frequent artefacts, which was also the case in the laboratory study. One of the BVP signals, from subject 2, was so heavily distorted that the typical waveform could not be distinguished at all. All of the other physiological variables gave signals with no noticeable artefacts. Furthermore, waveforms of the BVP, ECG and respiration signals were examined, and there were distinct resemblances with the expected waveforms. Skin temperature and SCL were not waveform examined, since no periodicity was expected. When determining whether these variables were within acceptable ranges, artefacts were ignored. A comparison of SCL and temperature measurements from the laboratory and field study can be found in table 17.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Laboratory study</th>
<th>Field study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skin temperature</td>
<td>25.1 – 35.7</td>
<td>13.0 – 34.9</td>
</tr>
<tr>
<td>SCL [µS]</td>
<td>2.58 – 36.2</td>
<td>1.32 – 37.9</td>
</tr>
</tbody>
</table>

The ranges were somewhat larger in the field study which can be explained by the confounding variables, principally temperature differences.

Examples of all physiological variables measured by MobileMe are presented in figure 22 to figure 26 below.
Figure 22. ECG signal where all parts of the waveform are clearly visible.

Figure 23. Example of SCL data from a 16 minute interval.

Figure 24. Respiration data where increased relative thoracic expansion corresponds to inspiration.
Figure 25. Example of BVP data with the distinct features of the photoplethysmographic signal clearly visible.

Figure 26. Example of temperature data.

9.1.1 Hypothesis verification

Based on the results above, hypothesis 2.1, stating that the MobileMe equipment can be used for monitoring physiological variables in the field, was verified.

9.2 Autonomic responses

Only subjects that experienced motion sickness were of interest for the verification of autonomic responses to motion sickness. Subject 4 and 5 scored 16 points or higher on the symptom diagnostic scale, which corresponded to *frank sickness*. These two subjects were included in the analysis of early symptoms of motion sickness.

Subject 4 answered ten questionnaires, which gave ten data points for correlation analysis of physiological responses with malaise score. Subject 5 only answered five questionnaires, due to a shorter route. With only five data points, the power was too low for a statistical analysis and the results, from this subject, are instead presented as observed tendencies.
9.2.1 Subject 4
For this subject, two correlations were significant (each with \( p < 0.01 \)). There were no other significant correlations that verified expected autonomic responses. Figure 27 and figure 28 show the significant correlations from subject 4.

**Figure 27.** Scatter plot of mean peak to peak values from the BVP signal versus malaise scores obtained from the symptom diagnostic scale.

A decrease in BVP amplitude is accompanied by an increase in malaise score, i.e. perceived motion sickness (\( \rho = -0.95 \)), which can be seen in figure 27. Furthermore, SCL level increased, as subject 4 experienced more motion sickness, according to malaise score (\( \rho = 0.86 \)). This relationship can be seen in figure 28.

**Figure 28.** Scatter plot of mean SCL values for each questionnaire interval versus malaise scores.
9.2.2 Subject 5
Subject 5 showed tendencies of correlation between SCL level and malaise score during the test, but there were no other observed tendencies. Figure 29 shows that as subject 5 experienced increased motion sickness, the SCL level also increased. However, this result could not be statistically tested as there were only five samples.

![Figure 29. Scatter plot of mean SCL values versus malaise scores where a tendency towards positive correlation can be seen.]

9.2.3 Hypothesis verification
Since only two of the subjects experienced motion sickness and few of their physiological responses correlated with malaise scores as expected, hypothesis 2.2, stating that it would be possible to verify the autonomic responses which would eventually build up to perceived motion sickness, could not be verified.

9.3 Fixation duration
Of the three subjects wearing the eye-tracker, only subject 4 experienced motion sickness. For this subject, there was no significant correlation between fixation duration and malaise score.

9.3.1 Hypothesis verification
Hypothesis 2.3, concerning motion sickness and fixation durations could not be verified.

9.4 Evaluation of the Borg CR10 scale
Subjects 1 and 2 were omitted since neither of them showed any tendencies of motion sickness, and since none of them scored more than 0 on the Borg scale.
The Spearman correlation between Borg CR10 scale and the symptom diagnostic scale was \( \rho = 0.84 \), significant at the 0.01 level. Figure 30 shows a scatter plot of Borg scale versus malaise scores, where the positive correlation between the two scales can be seen.

![Figure 30. Scatter plot of Borg scale values versus malaise scores obtained from the symptom diagnostic scale.](image)

### 9.4.1 Hypothesis verification

As hypothesis 2.4 states, the Borg CR10 scale is useable for rating severity of perceived motion sickness.
The following chapter discusses the method and the results from the field study. First there is a discussion concerning the design of the experiment and the materials and methods used. Thereafter the different results are discussed in the order they are presented in chapter 10.

### 10.1 Method discussion

The main purpose of this study was to assess whether MobileMe could be considered suitable for field studies, and the test procedure was designed from these prerequisites. Focus was on determining if the MobileMe equipment could produce adequate measurements in uncontrolled environments and the verification of autonomic responses was thus of subordinate importance. If the focus had been on physiological responses to motion sickness, more effort would have been put into selecting highly susceptible subjects and waiting for appropriate weather conditions, to ensure the proper prerequisites for developing motion sickness.

There would have been an advantage in having a larger number of subjects to choose from and to thoroughly investigate their previous experiences of motion sickness, especially sea sickness. Then, it would have been possible to select only high susceptibles to participate in the study. In the advertisements, people highly susceptible to motion sickness were sought for, but it is not certain whether the subjects that attended the tests actually were high susceptibles, since they were not asked about their previous motion sickness experiences and no test for susceptibility
was performed, as a screening procedure. Furthermore, there was limited possibility to choose the day and time for the experiments and it would have been better, from a motion sickness perspective, to await more provocative conditions, regarding sea state and visibility. The routes were not designed for this experiment in particular, but part of the daily training exercises. However, the method used in the field study was sufficient for the evaluation of MobileMe as a recording system in uncontrolled environments. The most important thing was to expose the equipment to confounding elements, e.g. vibrations, common in transport vehicles.

If the purpose of the field study would have been to draw general conclusions concerning physiological responses to motion sickness, a much larger number of subjects would have been needed and care should have been taken to create as comparable test conditions as possible.

10.1.1 Uncontrolled environment
When performing field studies there is always some influence of the surroundings. Several environmental parameters, like ambient temperature and humidity, are difficult, or even impossible, to control, which can influence the results. These confounding variables should be taken into consideration when measurements are made in uncontrolled environments.

It is difficult to determine when the motion sickness stimulation actually begins when boats are used as motion stimulation. In most previous studies, conducted in laboratory settings, there has been control of when the stimulation started and also a possibility to gradually increase the intensity of the stimulation. However, the uncontrolled motion stimulation, which the subjects experienced during the trials in this study, has the advantage of being very close to the reality of working at sea. Boat crews and soldiers under transportation would experience similar types of conditions during their daily work. Performing tests in real environments brings high ecological validity, a concept that refers to the extent to which the context of a study matches the context of the actual use of the system. Furthermore, high ecological validity makes it reasonable to suppose that results of a study are representative of actual usage, and that contextual differences unlikely affect any conclusions (Usability, 2006).

10.1.2 Examined physiological variables
The five physiological variables measured by MobileMe are not the only biological processes affected by motion sickness. There are other variables that are as good as, or perhaps even better than those measured by MobileMe, for predicting or diagnosing motion sickness. One example is electrogastrogram (EGG), which has been widely
used in motion sickness studies, since there is a strong relation between motion sickness and epigastric phenomena. However, EGG is very sensitive to motion and would therefore not be suitable for measurements in moving environments.

10.1.3 Subjective ratings of perceived motion sickness

The symptom diagnostic scale was chosen as the main rating scale for perceived motion sickness, since it is a valid method used in several studies, see chapter 8.2.1. However, there are other scales previously used for motion sickness studies (Golding, 1992; Himi et al., 2004; Wertheim, Ooms, de Regt, & Wientjes, 1992), both simple one-question scales and scales based on ratings of several symptoms. One of these scales could have been used for obtaining subjective ratings of perceived motion sickness and, depending on how the scale was composed, may perhaps have given a different result.

A drawback with the chosen scale is the extensive questionnaire, which takes time to answer. There is a limitation in how often malaise scores can be obtained, since the questionnaire consists of 12 questions to answer. Obtaining enough samples for analysis is a common problem and a simple solution to that problem would be to present the questionnaire more often, in order to increase the number of data points. In previous studies, for example by Stout et al. (1995), the symptom diagnostic scale has been presented every fifth minute. To slightly increase the number of data points, the diagnostic questionnaire was presented every fourth minute in this study, but it could have been better to present it even more often. Furthermore, malaise scores can increase for other reasons than motion sickness e.g. drowsiness, headache and increased warmth, which do not necessarily have to be symptoms of motion sickness. Hence, if the motion sickness threshold is set too low, subjects that are merely getting warmer can be rated as motion sick even if the increased warmth is due to changes in the ambient temperature.

One problem associated with all types of subjective ratings is the possibility of subjects misunderstanding the questions or accidentally giving the wrong answer.

The question connected to the Borg CR10 scale is crucial for which information will be given by the subject. In this particular case, the Borg scale only resulted in a rating of how nauseous the subject felt. There was no possibility of detecting when the different symptoms of motion sickness first occur, which is possible when ratings of perceived motion sickness is obtained by letting the subject answer multiple questions. However, when the Borg scale has been properly introduced to the subject, its simplicity and ease of use is evident.
10.1.4 Data analysis

The evaluation of MobileMe was primarily done by visual inspection of the raw data signals. Hence, the results are based on subjective evaluations and there is no objective measurement of how well the equipment worked in the field study.

Heart rate (HR), blood volume pulse (BVP) and respiration rate (RR) were calculated using algorithms that included bandpass filtering, in order to extract the important features of the signals by noise reduction. However, too much filtering can remove important information in the signal and change the waveform. Therefore, careful weighing between detecting noise and losing breaths or heart beats had to be done in the design of algorithms. In the heart rate algorithm, large movement artefacts were sometimes detected as heart beats. With respiration rate it was even more difficult, since breathing mainly is under voluntary control. When the respiratory rhythm is uneven, there are difficulties defining what can actually be considered a breath. However, since only mean values of HR, BVP and RR, over several minutes, were used in the data analyses, small errors, such as a few extra beats or one or two skipped beats, would not have any significant influence on the result.

Algorithms for calculating HR, BVP and RR exist both in SentientMonitor and in the MobileMe software running on the OQO computers, and these algorithms could have been used instead of the Matlab scripts created especially for this study. Using the included algorithms would perhaps have been better for the evaluation of the entire MobileMe system since the algorithms are a part of MobileMe. It might also have been better for the validation in the laboratory study to use the HR algorithm included in MobileMe, instead of making the HR calculations separately. However, the software included in the MobileMe system is developed continuously and, hence, the HR algorithms were different in the laboratory and the field study. Further improvements of the software are expected and an evaluation of the quality of raw data was therefore considered most important for the overall validation.

The fixation algorithm used for calculation of fixation durations has been optimized, and validated, for another eye tracking system, but assumed to work for the ViewPoint EyeTracker®, as well. This assumption was made after pre-test comparisons of results from the fixation algorithm with frame-by-frame analysis of ViewPoint movie files. Another possibility, for generating fixation durations, would have been to use the fixation algorithm included in the ViewPoint software. Generating fixation durations this way could perhaps have given a different result. However, in the ViewPoint algorithm, there is less control of the classification of eye movements and especially of what is considered a fixation. In the chosen algorithm,
developed by Bjällmark and Larsson (2005), thresholds for minimum fixation duration and maximum eye movement during a fixation can be adjusted.

10.2 Result discussion

In the field study, the main purpose was to determine if the MobileMe system could be used for measurements in uncontrolled environments, in this case represented by a small combat boat. The boat was moving in different ways for the different tests, making the provocative motion differ between pairs of subjects. As stated in table 16, only the third test part included extensive provocative motion, with sharp turns and fast boat movements. However, this was not so crucial for the main focus of the field study, but hypotheses 2.2 and 2.3, concerning autonomic responses during motion sickness build-up, became harder to verify. This was due to different sea sickness susceptibilities among the subjects, and different levels of provocative boat movements. Only 33% of the subjects were rated as sea sick, determined by a score of 16 points or higher on the symptoms diagnostics scale, others showed either tendencies towards sea sickness, or no symptoms at all. Ideally, for hypothesis 2.2 and 2.3, all subjects should have experienced motion sickness. A rougher sea state would perhaps have produced more motion sickness among subjects, but for this study, there were no possibilities of waiting for certain weather conditions. Provocative boat movements could practically have been induced in all three tests, but heavy fog and educational tasks among the boat crew stopped that. However, there are problems associated with prolonged exposure to extensive motion stimulation. The autonomic responses, connected to motion sickness, could eventually be suppressed by the strictly physical compensation to stay upright. Compensatory movements could cause deterioration of performance and artefacts in the measurements. Furthermore, more provocative motion could result in earlier terminations of the tests, due to rapid progress of motion sickness, which in its turn would have resulted in fewer malaise scores from the questionnaires, and by that a loss of statistical power. Shorter intervals between questionnaires could have been a possibility for solving this, if tests would have been terminated earlier than they were.

Since the three test trials were of different lengths, with the longest about twice the length of the shortest, and that questionnaires were presented with the same frequency, the number of malaise scores varied from 5 to 13 between all subjects. This affected the statistical power, but with the method used and as described above, it was not possible to predict the length of the data acquisition and, hence, the number of questionnaires. The different lengths of data series affected only the outcome of hypotheses 2.2 and 2.3, not 2.1 and 2.4.
10.2.1 Validation of MobileMe

As described in chapter 9, an appreciable amount of data was lost in the wireless transmission between the OQO computers and the SentientMonitor computer. The evaluation of MobileMe data was therefore conducted on data recorded by the OQO computers. More than 50 percent of the data was lost, compared to less than one percent loss in the laboratory study. The causes for data losses were not further examined when the field study was performed, since data was stored on the OQO computers just for the occasion of interrupts or failures in the wireless transmission. It is not clear what the source of error was, but it is conceivable that the combat boat’s radar system could have disturbed the wireless network used by MobileMe. Marine radars utilizes the 2-4 GHz frequency band, and the MobileMe wireless network uses 2.4 GHz as base frequency, which increases the possibility of the boat radar as source of the errors.

The loss of reliable wireless data transmission means that real-time monitoring of data was impossible and only post-processing of data was possible. This can be seen as a notable shortage in the MobileMe system, and that the system may not be suitable for marine research. However, since data was successfully recorded by the OQO computers, and that no real-time monitoring was necessary for the outcome of the field study, the loss of wireless transmission was not seen as an evidential basis for a hypothesis rejection.

To determine the quality of the MobileMe recordings, visual inspections of the data were performed on all data series. Data ranges were compared to those from the lab study, and waveforms and any artefacts were examined. SCL and skin temperature were not exactly in the same ranges as in the lab study, but this was not expected. Confounding variables, especially ambient temperature and air humidity was expected to affect these variables, and for example the skin temperature range was displaced downwards on the temperature scale due to lower ambient temperature. The temperature increased gradually in the cabin, during each test session, as soon as the boat engine was running. Hence, the estimated ambient temperature differed between approximately 5°C and 15°C.

As previously discussed, there is no definitive measurement of the outcome of a visual inspection; it is only a subjective decision. However, the visible differences between the waveforms from the lab study and the field study was so negligible that no measurement was seen as needed. The amount of artefacts was also comparable to that from the lab study. For certain subjects’ BVP data, it was difficult to separate artefacts from actual waveforms, since BVP is the most sensitive of all the measured variables, as seen in the lab study. However, for most of the subjects, characteristics of
the BVP signal were clearly distinguishable, which makes occasional artefacts negligible.

10.2.2 Autonomic responses
Perceived motion sickness was described by the malaise score derived from questionnaire answers, received from the subjects each fourth minute during the test trials. With the method used, only two of the six subjects, subjects 4 and 5, were rated as motion sick, and only two of the variables recorded from these subjects presented significant correlations with the malaise scores. Other subjects showed tendencies toward motion sickness, but no correlations were significant. Subjects 5 and 6, who attended test trial III experienced provocative motion directly at the start of the trial, causing possible startle effects in the autonomic responses. The provocative motion diminished after a few minutes, and for subject 6, a steady decrease of SCL level during the whole test trial can clearly be seen. However, for subject 5 SCL level steadily increased until termination of the test. For both subjects, heart rate levels increased at the start, and decreased when the provocative motion was diminished. This could conclude that responses depended on initial conditions, and that start of the provocative motion preferably could have been smoother than it was in test trial III. However, increased heart rate at the beginning of the test trial could also have been caused by anticipatory effects, which in its turns caused by nervousness about the experiment, or other psychological factors.

For subjects 1, 2 and 3, there were no expectations of significant correlations between responses and malaise score, since none of them showed any tendencies at all of perceived motion sickness. Subject 4 however, scored enough on the susceptibility scale to be rated as motion sick, even if test trial II did not include any heavy provocative motion. Results also showed that there were expected significant correlations between malaise score and motion sickness responses for subject 4. Hence, the differences in malaise scores, and also in motion sickness responses, between subjects 3 and 4, could be explained by an individual difference in motion sickness susceptibility.

To be able to verify hypothesis 2.2, concerning motion sickness responses, larger number of significant correlations would have been needed. This would have been a possibility if either provocative motion would have been more controlled, and more similar between test trials, or if subjects would have been more susceptible to motion sickness.
10.2.3 Eye movements
The aim of this part of the study was to determine any possible relationship between fixation durations and perceived motion sickness. Perceived motion sickness was once again determined by the malaise score. It was originally planned that all subjects should be using eye trackers, but it turned out that it was too power consuming for the electrical system of the combat boat to provide two eye tracking systems with power at the same time. Therefore, only one of the subjects attending each test trial could wear an eye tracker. Only one of the eye tracker subjects experienced enough motion sickness to be included in the statistical analysis of eye tracking data. This case, subject 4, did not show any significant correlation between fixation durations and malaise score, which made it clear that hypothesis 2.3 could not be verified. It is possible that the distraction task did affect the eye movements of that extent that the motion sickness responses would have been suppressed. A different distraction task, perhaps with less visual activity demands on the subject, could have made the fixation duration variable more sensitive to motion sickness.

If a more extensive eye movement examination is to be performed, it is recommended that a more accurate calibration of the eye tracker, than in this study, is done. However, an exact calibration was not needed in this study, since information on where the subject’s glance was placed, was of less importance for the hypothesis verification. The calibration of the eye tracker did not affect the recording of the glance position, which fixation durations mainly were derived from. Furthermore, videos of what the subject was looking at, was recorded in this study, but due to calibration errors, they did not produce any further results or information.

10.2.4 Evaluation of the Borg CR10 scale
High (rho>0.8) significant correlation between the Borg scale and the malaise scores was a sufficient result for a verification of hypothesis 2.4. However, this result does only show that the Borg scale is useable in this particular application, it does not conclude that the Borg scale can be used for general motion sickness rating. The rating question of the Borg scale could have been designed in another way and possibly affected the outcome of this part of the study.

Subjects 1 and 2 were excluded in the statistical analysis of questionnaire ratings, since they did not score any rating higher than 0 on the Borg scale. Furthermore, all other subjects had one or more malaise scores that were higher than 8, which was described as severe malaise in the definition of the scale, see table 13. It could therefore be stated that all subjects, except 1 and 2, showed tendencies towards perceived motion sickness. Hence, their questionnaire scores could be included in the comparison of the rating scales.
MobileMe is useable for recording physiological data in uncontrolled environments. The quality of raw data was comparable to that from the laboratory study. However, blood volume pulse (BVP) and skin temperature were variables sensitive to confounding variables that occurred during the field study. This study could not confirm changes of the physiological variables expected when subjects experienced perceived motion sickness. Further, this study could not confirm any relationship between eye movements and perceived motion sickness. Finally, it was stated that the Borg scale, in this study, could produce a rating that gave a measurement of perceived motion sickness.

If further research including MobileMe is to be done using similar methods as in this study, the following changes are proposed:

- To increase statistical power in the motion sickness responses part, increased number of data points is recommended. This can be created by selecting a larger number of subjects highly susceptible to motion sickness, and presenting malaise score questionnaires more often. Laboratory studies can be conducted prior to field studies, to verify motion sickness susceptibility by examining autonomic responses when subjects are exposed to controlled motion sickness stimulation.
- A validation of the built-in BVP and HR algorithms should be performed.
- If an eye-tracker is intended to be used, care should be taken when calibrating, to ensure quality of movie data for point of gaze analyses.
- Skin temperature and BVP should be considered not to be used in field studies, due to their high sensitivity to confounding variables.


List of appendices:

Appendix 1. Questionnaire 1
Appendix 2. Questionnaire 2
Appendix 3. Questionnaire 3, MATB
Appendix 4. Questionnaire 3, ergometer
Appendix 5. Questionnaire 4
Appendix 6. Information, laboratory study
Appendix 7. Motion sickness rating questions
Appendix 8. Information, field study
Appendix 9. Sea state table
Enkät studie 1, del 1


Exempel:
Tyckte du att det här försöket var roligt?

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nej, det var sådär det roligaste jag varit med om</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Jag är Man ( )
   Kvinna ( )

2. Jag är ________ år gammal

3. Har du tagit någon form av medicin under de senaste 24 timmarna? Ja ( )
   Nej ( )

   Om ja, vilken medicin var det? ____________________________

   För hur många timmar sedan tog du medicinen? 0-3 ( ) 4-7 ( ) 8-24 ( )

Nedan följer frågor angående utrustningarna och din upplevelse av dem.

4. Tänkte du på att du hade fingerelektroderna på dig?

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nej, jag glömde att de alls fanns där Ja, till och från Ja, jag tänkte på dom hela tiden</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. Tänkte du på att du hade bröstelektroderna på dig?

<table>
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<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nej, jag glömde att de alls fanns där Ja, till och från Ja, jag tänkte på dom hela tiden</td>
<td></td>
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</tbody>
</table>
### Appendix 1

6. Stördes din andning av bandet som satt runt bröstkorgen?

<table>
<thead>
<tr>
<th></th>
<th>1</th>
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<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nej, det märktes inte att bandet satt där</td>
<td>Ja, det kändes att bandet satt runt bröstet</td>
<td>Ja, det gjorde andningen mycket svårare</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7. Stördes du av resten av utrustningen?

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nej, jag tänkte inte på att jag hade den på mig</td>
<td>Ja, jag tänkte på den ibland</td>
<td>Ja, jag kunde inte tänka på något annat än att den störde.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Om du svarat 4 eller högre på fråga 6, vad var det som störde dig?

---

8. Är det något du vill tillägga angående din upplevelse av mätutrustningarna?

---

---

---

Tack för din medverkan!
Enkät studie 1, del 2


1. Jag är Man ( )
   Kvinnan ( )

Nedan följer frågor angående mätutrustningarna och din upplevelse av dem.

2. Tänkte du på att du hade fingerelektroderna på dig?

   1 2 3 4 5 6 7
   Nej, jag glömde att de alls fanns där
   Ja, till och från
   Ja, jag tänkte på dom hela tiden

3. Tänkte du på att du hade bröstelektroderna på dig?

   1 2 3 4 5 6 7
   Nej, jag glömde att de alls fanns där
   Ja, till och från
   Ja, jag tänkte på dom hela tiden

4. Stördes din andning av bandet som satt runt bröstkorgen?

   1 2 3 4 5 6 7
   Nej, det märktes inte att bandet satt där
   Ja, det kändes att bandet satt runt bröstet
   Ja, det gjorde andningen mycket svårare

5. Påverkades du av att du var tvungen att hålla vänsterhanden helt stilla?

   1 2 3 4 5 6 7
   Nej, det var inga problem med att hålla handen stilla
   Ja, det påverkade koncentrationen en aning
   Ja, det gjorde det mycket svårare att genomföra försöket
Appendix 2

6. Stördes du av resten av utrustningen?

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
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<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nej, jag tänkte inte på att jag hade den på mig</td>
<td>Ja, jag tänkte på den ibland</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Ja, jag kunde inte tänka på något annat än att den störde.</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

Om du svarat 4 eller högre på fråga 6, vad var det som störde dig?

7. Är det något du vill tillägga angående din upplevelse av mätutrustningarna?

Nedan följer frågor angående stressprogrammet och dina upplevelser av det.

8. Upplevde du försöket som mentalt ansträngande?

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nej, inte alls</td>
<td>Från och till</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ja, det var mycket ansträngande</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

9. Kände du dig stressad under försöket?

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nej, jag blev inte stressad</td>
<td>Ja, jag tyckte det var aningen stressigt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ja, jag tyckte det var jättestressigt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

10. Upplevde du försöket som fysiskt krävande (blev du andfådd, trött i armen av musklickande, etc.)?

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nej, inte alls</td>
<td>Ja, det var ganska krävande</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ja, det var mycket krävande</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
11. Är det något du vill tillägga angående din upplevelse av stressprogrammet?

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

Tack för din medverkan!
Questionnaire 3, MATB

Enkät studie 1, del 3

1. Jag är Man (  )
   Kvinna (  )

Nedan följer frågor angående mätutrustningarna och upplevelsen av dem.

2. Tänkte du på att du hade fingerelektroderna på dig?
   1  2  3  4  5  6  7
   Nej, jag glömde att de alls fanns där
   Ja, till och från
   Ja, jag tänkte på dom hela tiden

3. Tänkte du på att du hade bröstelektroderna på dig?
   1  2  3  4  5  6  7
   Nej, jag glömde att de alls fanns där
   Ja, till och från
   Ja, jag tänkte på dom hela tiden

4. Stördes din andning av bandet som satt runt bröstkorgen?
   1  2  3  4  5  6  7
   Nej, det märktes inte att bandet satt där
   Ja, det kändes att bandet satt runt bröstet
   Ja, det gjorde andningen mycket svårare

5. Påverkades du av att du var tvungen att hålla vänsterhanden helt stilla?
   1  2  3  4  5  6  7
   Nej, det var inga problem med att hålla handen stilla
   Ja, det påverkade koncentrationen en aning
   Ja, det gjorde det mycket svårare att genomföra försöket
Appendix 3

6. Stördes du av resten av utrustningen?

1 2 3 4 5 6 7
Nej, jag tänkte inte på att jag hade den på mig      Ja, jag tänkte på den ibland      Ja, jag kunde inte tänka på något annat än att den störde.

Om du svarat 4 eller högre på fråga 6, vad var det som störde dig?

________________________________________________________________________

7. Är det något du vill tillägga angående din upplevelse av mätutrustningarna?

________________________________________________________________________

________________________________________________________________________

Nedan följer frågor angående stressprogrammet och din upplevelse av det.

8. Upplevde du försöket som mentalt ansträngande?

1 2 3 4 5 6 7
Nej, inte alls      Från och till      Ja, det var mycket ansträngande

9. Kände du dig stressad under försöket?

1 2 3 4 5 6 7
Nej, jag blev inte stressad      Ja, jag tyckte det var aningen stressigt      Ja, jag tyckte det var jättestressigt

10. Upplevde du försöket som fysiskt krävande (blev du andfådd, trött i armen av musklickande, etc.)?

1 2 3 4 5 6 7
Nej, inte alls      Ja, det var ganska krävande      Ja, det var mycket krävande
11. Är det något du vill tillägga angående din upplevelse av stressprogrammet?


Nedan följer frågor angående jämförelse av andra och tredje delen av försöket, det vill säga de båda försöken med stressprogrammet.

12. Vilket av försöken upplevde du som mest mentalt ansträngande?

1. ( ) Andra försöket  2. ( ) Tredje försöket  3. ( ) De var lika ansträngande

13. Vilket av försöken upplevde du som mest stressigt?

1. ( ) Andra försöket  2. ( ) Tredje försöket  3. ( ) De var lika stressiga

14. Vilket av försöken upplevde du som mest fysiskt ansträngande?

1. ( ) Andra försöket  2. ( ) Tredje försöket  3. ( ) De var lika ansträngande

15. Är det något du vill tillägga angående jämförelse mellan andra och tredje försöken?


Tack för din medverkan!
Questionnaire 3, ergometer

Enkät studie 1, del 3

1. Jag är  Man (  )
   Kvinna (  )

Nedan följer frågor angående mätutrustningarna och upplevelsen av dem.

2. Tänkte du på att du hade fingerelektroderna på dig?

   1 Nej, jag glömde att de alls fanns där   2 3 4 5 6 7 Ja, till och från
   Ja, jag tänkte på dom hela tiden

3. Tänkte du på att du hade bröstelektroderna på dig?

   1 Nej, jag glömde att de alls fanns där   2 3 4 5 6 7 Ja, till och från
   Ja, jag tänkte på dom hela tiden

4. Stördes din andning av bandet som satt runt bröstkorgen?

   1 Nej, det märktes inte att bandet satt där   2 3 4 5 6 7 Ja, det kändes att bandet satt runt bröstet
   Ja, det gjorde andningen mycket svårare

5. Påverkades du av att du var tvungen att hålla vänsterhanden helt stilla?

   1 Nej, det var inga problem med att hålla handen stilla   2 3 4 5 6 7 Ja, det påverkade koncentrationen en aning
   Ja, det gjorde det mycket avräre att genomföra försök
6. Stördes du av resten av utrustningen?

<table>
<thead>
<tr>
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<th>3</th>
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</table>

Om du svarat 4 eller högre på fråga 6, vad var det som störde dig?


7. Är det något du vill tillägga angående din upplevelse av mätutrustningarna?


---

*Nedan följer frågor angående stressprogrammet och din upplevelse av det.*

8. Upplevde du försöket som mentalt ansträngande?

<table>
<thead>
<tr>
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<th>3</th>
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<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nej, inte alls</td>
<td>Från och till</td>
<td>Ja, det var mycket ansträngande</td>
<td></td>
<td></td>
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</table>

9. Kände du dig stressad under försöket?

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<tr>
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<th>6</th>
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<tbody>
<tr>
<td>Nej, jag blev inte stressad</td>
<td>Ja, jag tyckte det var aningen stressigt</td>
<td>Ja, jag tyckte det var jättestressigt</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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10. Upplevde du försöket som fysiskt krävande (blev du andfådd, trött i armen av musklickande, etc.)?

<table>
<thead>
<tr>
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<th>4</th>
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<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nej, inte alls</td>
<td>Ja, det var ganska krävande</td>
<td>Ja, det var mycket krävande</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
11. Är det något du vill tillägga angående din upplevelse av stressprogrammet?


Nedan följer frågor angående jämförelse av andra och tredje delen av försöket, det vill säga de båda försöken med stressprogrammet.

12. Vilket av försöken upplevde du som mest mentalt ansträngande?

1. (  ) Andra försöket  
2. (  ) Tredje försöket  
3. (  ) De var lika ansträngande

13. Vilket av försöken upplevde du som mest stressigt?

1. (  ) Andra försöket  
2. (  ) Tredje försöket  
3. (  ) De var lika stressiga

14. Vilket av försöken upplevde du som mest fysiskt ansträngande?

1. (  ) Andra försöket  
2. (  ) Tredje försöket  
3. (  ) De var lika ansträngande

15. Är det något du vill tillägga angående jämförelse mellan andra och tredje försöken?


Tack för din medverkan!
**Enkät studie 1, del 4**


1. Jag är **Man** ( )
   **Kvinna** ( )

**Nedan följer frågor angående mätutrustningarna och upplevelsen av dem.**

2. Tänkte du på att du hade fingerelektroderna på dig?

   1 2 3 4 5 6 7
   Nej, jag glömde att de alls fanns där  
   Ja, till och från dom  
   Ja, jag tänkte på dom hela tiden

3. Tänkte du på att du hade bröstelektroderna på dig?

   1 2 3 4 5 6 7
   Nej, jag glömde att de alls fanns där  
   Ja, till och från dom  
   Ja, jag tänkte på dom hela tiden

4. Stördes din andning av bandet som satt runt bröstkorgen?

   1 2 3 4 5 6 7
   Nej, det märktes inte att bandet satt där  
   Ja, det kändes att bandet satt runt bröstet  
   Ja, det gjorde andningen mycket svårare

6. Stördes du av resten av utrustningen?

   1 2 3 4 5 6 7
   Nej, jag tänkte inte på att jag hade den på mig  
   Ja, jag tänkte på den ibland  
   Ja, jag kunde inte tänka på något annat än att den störde.
Appendix 5

Om du svarat 4 eller högre på fråga 6, vad var det som störde dig?

________________________________________________________________________

________________________________________________________________________

7. Är det något du vill tillägga angående din upplevelse av mätutrustningarna?

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

Nedan följer frågor angående jämförelse av första och fjärde delen av försöket, det vill säga de båda avslappningsdelarna.

8. I vilket av försöken kände du dig mest avslappnad?

1. ( ) Första försöket 2. ( ) Fjärde försöket 3. ( ) Det var ingen skillnad

9. Är det något du vill tillägga angående jämförelse mellan första och fjärde försöken?

________________________________________________________________________

________________________________________________________________________

________________________________________________________________________

Tack för din medverkan!
Information, laboratory study

Beskrivning
Vi är mycket tacksamma att du vill ställa upp som försöksperson i vår studie. Vi som utför försöken heter Anna Sjörs och Ulf Almqvist och dessa försök ingår som en del av vårt examensarbete vid Linköpings tekniska högskola. Nedan följer lite information om vad som kommer att hända på försöksdagen.

Syfte
Det här försöket går ut på att undersöka giltighet och stabilitet hos MobileMe, en utrustning som mäter fem fysiologiska variabler. Vi vill alltså kontrollera så att utrustningen ger korrekta värden och att den ger konsekventa mätresultat vid upprepade mätningar. Till vår hjälp har vi också en annan mätutrustning kallad Vitaport 2 som används som referens.

Utrustning

Utförande

Vi kommer sedan att be dig ta på en tröja där sladdar till elektroderna finns fastsatta. En termometer kommer att tejpas på ditt vänstra lillfinger och en blodvolymsmätare tejpas fast på ditt vänstra ringfinger. För att mäta andningsfrekvensen fästs ett band runt bröstkorgen, ovanpå tröjan. Du kommer även att få bära ett vadderat bälte med

Studien är indelat i fyra försök. Alla försöken kommer att utföras under samma dag, med några minuters mellanrum.

**Försök 1**
I första försöket vill vi mäta din hjärtfrequens och svettutsändring i vila. Du kommer då att få sätta dig till rätta och vi kommer att be dig att vara så stilla som möjligt och koppla av. Försöket kommer att pågå i ungefär tio minuter och efteråt kommer du att få svara på en enkät om dina upplevelser av försöket.

**Försök 2**

**Försök 3**
I tredje försöket kommer du att få cykla på en träningsscykel. Försöket kommer att pågå i ungefär 20 minuter och efteråt kommer du att få svara på en enkät om dina upplevelser av försöken.

**Försök 4**
Sista försöket kommer att utföras ungefär en kvart efter det tredje försöket. Detta är också ett viloförsök och utförs på samma sätt som det första försöket.

**Övrigt**
**Hitta till oss**

Försöken utförs på smärt- och rehabcentrum som ligger på Brigadgatan 22, Garnisonsområdet i Linköping. Karta finns bifogad.

Om du har några frågor så går det bra att kontakta oss på telefonnummer 013-221583 eller:
Anna Sjörs
annsj745@student.liu.se
0739-773087

Ulf Almqvist
ulfal241@student.liu.se
0733-266609

Ansvarig för försöken är:
Med. Dr. Torbjörn Falkmer
INR, Institutionen för nervsystem och rörelseorgan
Hälsouniversitetet, Linköping
# Motion sickness rating questions

*Table of questions asked in the symptom diagnostic scale and their corresponding points.*

<table>
<thead>
<tr>
<th>Question</th>
<th>None</th>
<th>Slight (I)</th>
<th>Moderate (II)</th>
<th>Severe (III)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Are you feeling warmer?</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>n/a</td>
</tr>
<tr>
<td>2. Do you have any dizziness?</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>n/a</td>
</tr>
<tr>
<td>3. Do you have a headache?</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>n/a</td>
</tr>
<tr>
<td>4. Are you drowsy?</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>5. Are you salivating more?</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>6. Do you have facial pallor?</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>7. Are you sweating?</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>8. Do you feel stomach awareness?</td>
<td>0</td>
<td>1</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>9. Do you have stomach discomfort?</td>
<td>0</td>
<td>n/a</td>
<td>2</td>
<td>n/a</td>
</tr>
<tr>
<td>10. Do you have any nausea?</td>
<td>0</td>
<td>4</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>11. Have you vomited today?</td>
<td>No</td>
<td>0</td>
<td>Yes</td>
<td>16</td>
</tr>
<tr>
<td>12. How many times did you vomit?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Information, field study

Information fältstudie

Vi är mycket tacksamma att du vill ställa upp som försöksperson i vår studie. Vi som utför försöken heter Anna Sjörs och Ulf Almqvist och dessa försök ingår som en del av vårt examensarbete vid Linköpings tekniska högskola. Nedan följer lite information om vad som kommer att hända på försöksdagen.

**Syfte**


Under försöken kommer hälften av försökspersonerna att utrustas med en blickregistreringsutrustning som mäter ögonrörelser och registrerar vad man tittar på. Detta görs för att se om ögats rörelsemönster ändras när man utsätts för båtens rörelser.

**Utrustning**

MobileMe-utrustningen använder måtinstrument som tejpas eller klistras fast på huden och alla mätningar görs non-invasivt, d.v.s. utanpå kroppen (inga sprutor, nålar eller andra ingrepp används). Vi kommer att mäta puls, svettning, andningsfrekvens, temperatur samt blodflöde i fingret.


Det kommer att ges tillfälle för dig att bekanta dig med utrustningen innan försöken sätter igång. De båda utrustningarna är helt ofarliga.
**Utförande**

Det första som händer när du kommer till försöksstillfället är att försöksledarna ger en kort genomgång av försöket och visar utrustningen som kommer att användas. Du kan när som helst under försöksperioden ställa frågor till försöksledarna och skulle du vilja avbryta försöket kan du göra det när som helst och ändå erhålla full ersättning.

Innan ombordstigning kommer elektroder att klister på ditt vänstra pek- och långfinger samt på din bröstkorg. Dessa är likadana elektroder som används vid läkarundersökningar för att mäta EKG. Du kommer att bära elektroderna på dig under hela försöktiden. Klistret från elektroderna kan i sällsynta fall orsaka klåda och rodnad och vi avlägsnar dessa om du upplever obehag.


För dig som ska utrustas med eye-trackern så tas den på och kalibreras ombord på båten strax innan försöket sätter igång.

Under försöket får du sitta framför en bärbar dator och utföra en enkel uppgift (inte någon intelligensmätning, problemlösningsuppgift eller liknande).


**Övrigt**

Tid och plats

Försöken kommer utföras på gamla AMF 4 på Käringberget i Göteborg. För att komma till försöksplatsen, ta spårvagn nr 11 mot Saltholmen och kliv av vid Käringberget. Mer detaljerad information om tid för förmiddags- respektive eftermiddagsförsöken meddelas senare.

Om du har några frågor så går det bra att kontakta oss på telefonnummer 013-221583 eller:

Anna Sjörs
annsj745@student.liu.se
0739-773087

Ulf Almqvist
ulfal241@student.liu.se
0733-266609
# Sea state table

*Table of the World Meteorological Organization Sea State Code*

<table>
<thead>
<tr>
<th>Sea state</th>
<th>Code Description</th>
<th>Average Wave Heights (feet)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Sea like a mirror; calm</td>
<td>None</td>
</tr>
<tr>
<td>1</td>
<td>Smooth sea; ripples, no foam</td>
<td>0 - 0.3</td>
</tr>
<tr>
<td>2</td>
<td>Slight sea; small wavelets</td>
<td>0.3 - 1.7</td>
</tr>
<tr>
<td>3</td>
<td>Moderate sea; large wavelets, crests begin to break</td>
<td>1.7 - 4</td>
</tr>
<tr>
<td>4</td>
<td>Rough sea; moderate waves, many crests break, whitecaps</td>
<td>4 - 8</td>
</tr>
<tr>
<td>5</td>
<td>Very rough sea; waves heap up, forming foam streaks</td>
<td>8 - 13</td>
</tr>
<tr>
<td>6</td>
<td>High sea; sea begins to roll, forming very definite foam streaks and considerable spray</td>
<td>13 - 20</td>
</tr>
<tr>
<td>7</td>
<td>Very high sea; very big, steep waves with wind-driven overhanging crests, sea surface whitens due to dense coverage with foam</td>
<td>20 - 30</td>
</tr>
<tr>
<td>8</td>
<td>Mountainous seas; very high-rolling breaking waves, sea surface foam-covered</td>
<td>30 - 45</td>
</tr>
<tr>
<td>9</td>
<td>Mountainous seas; air filled with foam, sea surface white with spray</td>
<td>45 and greater</td>
</tr>
</tbody>
</table>
MobileMe is a recently developed system for monitoring and recording physiological variables. It is wireless, and can therefore be suitable for field research, for example when measuring motion sickness symptoms.

The aim of this thesis was to conclude whether the MobileMe recording system was valid for research studies. A validation study, consisting of two parts and including 10 subjects, was performed. The first part was a laboratory study, where data from MobileMe and a reference equipment were compared. A field study was also performed, onboard a combat boat, to determine the equipment’s validity in uncontrolled environments. Furthermore, the field study included an investigation of motion sickness symptoms, and provided data for evaluation of motion sickness rating scales.

Statistical results from the laboratory study, and results from evaluation of data from the field study, showed that MobileMe was valid in both controlled and uncontrolled environments.