MASTER'S THESIS

User Interface Design of a Cardiac Output Monitor

Redesign with focus on usability and displaying quantitative information

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Division Design & Human Factors
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden, 2010

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ABSTRACT IN ENGLISH

User Interface Design of a Cardiac Output Monitor
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The environment in emergency departments and intensive care units of hospitals is often stressful, and the staff must constantly take in large amounts of information. An increasing use of technology means that the staff must interact with highly advanced medical equipment, which is not always optimally designed for intuitive and efficient human-machine interaction. Already from the start of the development of medical equipment, it is important to include knowledge about the final users of the equipment in order to achieve optimal interaction. It is also advantageous to understand and apply information about the cognitive abilities that humans have, and what types of constraints are set up by the environment, to which the design must be adapted.

This thesis presents the theoretical background that is suitable for successful user-centered design, and it is applied to a specific case-study of a medical device. The device is the non-invasive ultrasonic cardiac output monitor USCOM. The interface was studied from a usability perspective, and redesigned to better suit the users' needs. Because the device can present large amounts of hemodynamic parameter values to the user, the focus of this thesis was also on enabling the user to make optimal use of this information. The task of examining cardiac output, the hospital environment, the intended users and the intended use were all examined in order to understand the usability demands of the device.

The outcome of the usability study is a set of usability guidelines and requirements, which have been illustrated by fictional screenshots of a redesigned user interface. The new interface has a different screen organization, modified functions and a design that better corresponds to the user and use needs. The most important potential usability issue that was found is the possibility of mistaking the patient's average parameter values for typical values. Furthermore, it is suggested that typical values are introduced to the interface, as they represent the most important means of user guidance. For future developments, it is recommended to also implement medical diagnosis 'decision trees' to the USCOM interface.

Keywords: Non-invasive ultrasound, cardiac output monitoring, usability, human-machine interaction, user experience design, cognitive ergonomics, Human Factors Engineering

SAMMANFATTNING PÅ SVENSKA

Användargränssnittsdesign för en hjärtminutvolymmonitor
– Ny utformning med fokus på användarvänlighet och visning av kvantitativ information

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Omgivningen på sjukhusavdelningar för akut- och intensivvård är ofta förknippad med en hög nivå av stress och personalen är tvingad att konstant ta in stora mängder av information. Ökande användande av teknologi medför att personalen måste interagera med avancerad medicinsk utrustning som inte alltid är optimalt utformad för intuitiv och effektiv människa-maskininteraktion. Redan från starten av utveckling av medicinteknik är det viktigt att inkludera kunskap om slutanvändarna av tekniken för att uppnå optimal interaktion. Det är fördelaktigt att förstå och applicera kunskap om de kognitiva förutsättningar vi människor besitter och vilka begränsningar som ställs upp av omgivningen, till vilka tekniken måste anpassas.

Detta examensarbete presenterar den teoretiska bakgrund som är lämplig att ha kunskap om för att kunna utveckla användarcentrerad design. Teorin är applicerad på en specifik användarvänlighetsstudie av en medicinteknisk produkt, en non-invasiv ultraljudsmonitor för avläsning av hjärtminutvolym, USCOM. Användargränssnittet studerades ur ett användarvänlighetsperspektiv och en ny utformning som är anpassad till användarnas behov presenterades. Efter som produkten kan visa stora mängder hemodynamikparametrar för användaren var visning av kvantitativ information också i fokus för utformningen. Uppgiften (att undersöka hjärtminutvolymen), sjukhusomgivningen, avsedda användare och avsedd användning undersöktes för att förstå de krav som ställs på produkten.

Resultatet från användarvänlighetsstudien är en lista av riktlinjer och krav för användarvänlighet, vilka illustrerats genom fiktiva skärmbilder av användargränssnittet med en ny utformning. Det nya gränssnittet är organiserat annorlunda, har något modifierade funktioner och en utformning som motsvarar användar- och användningsbehoven bättre. Det viktigaste potentiella användarvänlighetsproblemet som hittades är möjligheten att missuppfatta patientens genomsnittliga parametervärden för typiska värden. Typiska värden bör dessutom introduceras i gränssnittet då det är det bästa sättet att guida användaren. För framtida utvecklingsprojekt rekommenderas att implementera medicinska diagnostiska ”beslutsträd” i USCOM-gränssnittet.

Nyckelord: Minimalinvasivt ultraljud, övervakning av hjärtminutvolym, användarvänlighet, människa-maskininteraktion, kognitiv ergonomi

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APPENDICES

1 INTRODUCTION

This chapter is the introduction to the Master's Thesis User Interface Design of a Cardiac Output Monitor – Focus on Usability and Displaying Quantitative Information. The background for the thesis is followed by the scope, limits of the scope, a brief method description and presentation of the thesis questions. The organization of this thesis is then explained in the thesis outline.

1.1 BACKGROUND

The purpose of developing medical equipment is to improve patient health, which is done with great success in many areas. However, as medical technology is becoming increasingly complex and widespread, it is important to consider the potential areas for misuse and use errors, previously termed human errors. In order to reach good human-machine interaction for a successful outcome in healthcare, it is essential to work to prevent use errors and promote good usability[1] from the start point of the development, and not merely train the users of the equipment (FDA, 1997). Human Factors Engineering (HFE) is the "application of what we know about human capabilities and limitations to the design of equipment and devices in order to enable more productive, safe, and effective use" (Human Factors MD, 2010). Other terms closely related to HFE are Usability Engineering, Cognitive Ergonomics and User-Centered Design. These areas can help us understand *why* errors occur, and what we can do to *prevent* errors and discomfort in the interaction as well as improve the efficiency. It is cost-effective to invest in finding potential problem areas at the beginning of a product development process, as the cost of changing the product design increases in each step.

The company Uscom Ltd, Sydney, develops medical equipment for use in hospital environments with a mission to offer a machine providing non-invasive methods of monitoring heart function. The company's primary product is the USCOM 1A (UltraSonic Cardiac Output Monitor); a hemodynamic monitor for real time continuous measurement of cardiac output. The monitoring system is completely non-invasive and primarily used in intensive care units (ICUs), pediatrics and emergency departments (EDs). The USCOM 1A was released in 2002 and is protected by world-wide patents (Uscom Ltd, 2010).

Uscom Ltd is currently looking at ways of improving the user interface of the USCOM. (Because this thesis deals with the future versions of the device, the 1A will be left out of the name in most parts of the thesis.) This is why it was of interest to perform a usability study in order to investigate the level of performance of the human-machine interaction, and to develop the interface further. The compatibility between the human and the machine can be greatly enhanced by implementing knowledge and research on human cognitive psychology to the interface design (Gardiner & Christie, 1987), which is the focus for this thesis.

The USCOM calculates over 20 hemodynamic parameters that can be displayed to the user. This makes it an interesting product to study in terms of Human Factor Engineering. The

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[1] "Usability: The effectiveness, efficiency and satisfaction with which specified users can achieve specified goals in particular environments." (ISO, 1998)

usability of the device had not been formally investigated, and the human-machine interface had not changed significantly since the first version of the USCOM (Nick Schicht, personal communication, April 20, 2010).

A future step in the interface development of the USCOM is to help the user to interpret the displayed data further, for diagnosing patients and guiding treatment. Uscom Ltd additionally requested that research be made on this subject. The term 'quantitative information' in the thesis subtitle refers to this work, and is taken from Tufte's book Visual Display of Quantitative Information (2001, p. 191), on theory and practice in the design of data graphics.

1.2 SCOPE

There are two parts of this thesis. The first part investigates the level of usability of the USCOM. The goal for the usability study is to present a set of usability guidelines (with focus on software) to increase the quality of the human-machine interaction: target achievement, efficiency, safety and user satisfaction. The implementation of the guidelines is visualized by fictional screenshots of the interface.

The second part of this thesis focuses on research on how the interface can be developed to aid the user in decision making, by further interpreting the output visual data beyond the existing system. The term 'quantitative information' is used to highlight that the amount of information is vast; over 20 parameters of hemodynamic information can be displayed to the user. These parameters are of low usefulness if the user is unfamiliar with them and does not know how to make use of the information. Aside from cognitive ergonomics, which will be focused upon while studying the usability of the USCOM, also an assessment of the physical ergonomics of the device will be carried out.

The possible further user guidance development is in a research stage and some of the hemodynamic parameters that are involved in the possible data representations need more clinical research. The goal for the second part of this thesis is therefore to present possible quantitative information representations, and use useful theories to assist in future development. It does not aim at immediate implementation.

An additional goal for this thesis is to support Uscom Ltd by deepening the knowledge within the product development department of usability and Human Factors Engineering.

1.3 LIMITS OF SCOPE

The following limits to the scope of this thesis were identified:

- No investigation regarding the software programming for implementation of the redesign suggestions will be done, but it is assumed that there is sufficient support in the programming language to carry out the changes.
- The mechanical structure and electrical functioning of the USCOM will not be considered, but assumed to work properly.
- The USCOM requires training before being used in clinical settings, which is related to the nature of collecting the correct input data signal. Today, human senses are used to a large extent for determining the accuracy of the Doppler Flow profile, which constitutes a usability problem in itself. However, focus will not be on automating this procedure.

1.4 QUESTIONS

To ensure that the goals that were set up in the scope for this thesis are addressed, the following questions were posed:

- What are the usability needs of users of cardiac monitors?
- How should an interface of a cardiac monitor be built up in order to enhance the cognitive processes and promote the correct mental models of users?
- Which are the most important usability issues to deal with for the interface of the USCOM?
- How can large amounts of information be presented in a simple manner?

This thesis aims to answer the above questions during the course of the work.

1.5 GENERAL METHODOLOGY

This thesis project was based to a large degree on the product development process from a human-machine perspective presented in Bligård's paper "Utvecklingsprocessen ur ett människa-maskinperspektiv" (The development process from a human-machine perspective) (2010). It is an iterative process that involves data collecting, which was done through literature studies, user interviews and observations. Other methods that were used are different Human Factors Engineering methods to evaluate the quality of user interfaces.

The development process suggested by Bligård, as well as the work procedure and Human Factors methods that were employed, are described later in this thesis.

1.6 THESIS OUTLINE

The usability study constitutes the first part of this thesis, and focuses on how the user interface is built up today and how it can be redesigned and organized to better suit user needs. It aims to address the types of user problems that exist today and to minimize the risk of use errors and discomfort in usage. The latter part of this thesis concerns research and suggestions regarding further guidance to the user in interpreting the data to make diagnoses and treat medical conditions.

The target readers of this report are other students in the Product Development field and employees at Uscom Ltd. Hopefully it can serve as a guide for the development as well as an introduction support for new employees to the company.

To give an overview of the report and to simplify the process of reading selected parts, the thesis outline is described below.

Chapter 1: Introduction

The background for this thesis is followed by the scope, limits of the scope, a brief method description, presentation of the thesis questions and thesis outline.

Chapter 2: Cardiac Output Monitoring

In this chapter, the reader is introduced to the basics of cardiac output (CO) monitoring and Doppler technology, which is used in the USCOM. The chapter also includes information about hemodynamic parameter relations and so called 'Fluid challenges', used in hemodynamic monitoring.

Chapter 3: Theoretical framework

This chapter aims at explaining the nature of human-machine systems, and at supporting the reader with sufficient knowledge of the general theoretical framework that has formed the basis for the redesign of the USCOM. The last section describes the development process that was employed for this thesis project.

Chapter 4: Human Factors Engineering methods

This chapter presents and exemplifies the Human Factors Engineering methods that were used in this thesis project; for interface evaluations as well as different product development support methods.

Chapter 5: Description of Work Procedure

This chapter presents an overview of the work procedure that was employed for this thesis.

Chapter 6: Cardiac Output Monitor Market Analysis and Interface Comparison

This chapter briefly analyses the cardiac output (CO) monitor market and the main competitors to Uscom Ltd; discussed with focus on the systems' user interfaces. Also, interfaces of hospital equipment that the USCOM might work together with will be briefly discussed and compared.

Chapter 7: Needfinding

The first phase of the development process was the identification of usage needs that the USCOM must comply with. This chapter describes the needs that were found from studying the task, the user, and the environment that the device operates in.

Chapter 8: Usability Study

This chapter contains a deeper analysis of the user, task and interaction with the USCOM as well as the allocation of functions between human and machine. The physical ergonomics of the USCOM are also discussed. The needs that were found in the needfinding stage are in this chapter translated into usability requirements.

Chapter 9: Redesign of the USCOM

The first section in this chapter aims to summarize what the design aims at and the decisions that were made, and later in the chapter, a redesign suggestion of the USCOM is presented.

Chapter 10: Future Interface Design Solutions

In this chapter, research on the visual display of quantitative information and on the diagnosing procedure is presented. This is followed by future design recommendations for the USCOM.

Chapter 11: Discussion

This chapter contains the discussion of methods and this thesis project in general.

Chapter 12: Recommendations

The recommendations in this chapter concern the further development of the USCOM from a usability perspective, but also the most important factors for successful product development in general for Uscom Ltd. The recommendations are also addressed to thesis workers in similar projects.

Chapter 13: Conclusions

This chapter presents the main conclusions drawn in this thesis project.

2 CARDIAC OUTPUT MONITORING

In this chapter, the USCOM is presented and cardiac output (CO) and the reason for monitoring it (and other parameters that relate to how well the heart is functioning) are explained. The reader is also supported with background on Doppler technology as well as an explanation of hemodynamic parameter relations and so called 'Fluid challenges', used in hemodynamic monitoring.

2.1 PRESENTATION OF THE USCOM

The USCOM is an ultrasound cardiac output monitor that does not require any insertion of objects into the body (non-invasive). It is used by hospital staff to measure a patient's hemodynamic (blood forces) status. This is done both to diagnose patients and to know which steps to take next in treating patients. The user holds a transducer over the area of interest and the information is shown on a touch screen display, see Figure 1.

Figure 1. USCOM 1A. With permission from Uscom Ltd (2010).

The USCOM is the primary product of Uscom Ltd, incorporated in 1999 and listed on the Australian Stock Exchange in 2003. The first (and currently marketed) device, the USCOM 1A, was completed in 2002 and this was also the opening year for the Uscom Ltd Head Office in Sydney, Australia. Uscom Ltd has global marketing with a subsidiary in the U.S. and a registered place of business in the U.K. As at Jun 2009, Uscom Ltd had 19 employees and for the financial year 2009, it had a turnover of AU$1.9 million (Uscom Ltd, 2010).

The USCOM uses a hand held transducer that measures the stroke distance, or velocity time integral (vti), at the aortic or pulmonary valve with Continuous Wave Doppler. The Doppler Flow profile, from which CO is derived, is shown beat-to-beat on the monitor. The aortic and pulmonary valve diameters can be put in manually, or are calculated through a height-based algorithm. This allows for both right and left sided CO to be measured, and using the calculated diameter, there will be no influence of observational error between measurements. See Figure 2 for examples of right sided (Aortic Valve, AV) and left sided (Pulmonary Valve, PV) measurements. The USCOM can be used on patients of all ages, including neonates, and have no disposables. No major risks or complications are known; minor bruising can appear when measuring right ventricle CO on obese patients.

Further use descriptions of the USCOM are found in Chapter 1.

Figure 2. Left: USCOM CO measurement at the aortic valve, AV. Right: USCOM CO measurement at the pulmonary valve, PV. Note that the Doppler profiles on the USCOM monitor screen are above and under the 'baseline' for the AV and PV measurements respectively. With permission from Uscom Ltd (2010).

2.2 HEMODYNAMICS

Hemodynamics is the 'study of the forces involved in circulating blood through the body' (Taber's Cyclopedic Medical Dictionary, 2009). It is one important part of cardiovascular physiology and according to World Health Organization, cardiovascular diseases are the number one cause of death globally (WHO, 2009). In order to correctly diagnose patients with cardiovascular diseases and adequately administrate fluid and drugs, it is important to monitor the patient's hemodynamic status. Traditionally, only blood pressure (and not blood flow) has been used to assess hemodynamic status and as a result, trial and error has been used to a large extent for fluid and drug management of cardiovascular conditions, e.g. hypertension (high blood pressure) and heart failure (International Hemodynamic Society, 2000). CO monitors support clinicians with values of CO and other hemodynamic parameters to aid in decision making and treatment.

As reading support for this chapter, a list of used abbreviations is given in Table 1.

Table 1. Explanations of abbreviations.

Abbreviation	Interpretation	Explanation	Common unit
BP	Blood pressure	Consists of astolic (heart contraction) and diastolic (heart relaxation) pressure	mmHg
BSA	Body Surface Area	Estimated from height and weight	m^2
CI	Cardiac index	CO indexed with BSA	l/min/m^2
CO	Cardiac output	Volume of blood pumped by the heart in one minute	l/min
DpO_2	Peripheral Oxygen delivery	Oxygen delivered to the tissues per minute	ml/min
HR	Heart rate	Number of cardiac cycles per minute	bpm
MAP	Mean Arterial	Calculated from astolic and	mmHg

	Pressure	diastolic BP	
SpO_2	Peripheral Oxygen saturation	Percentage of hemoglobin binding sites occupied by oxygen	%
SV	Stroke volume	Volume of blood pumped by the heart in one beat	ml or cm^3
SVR	Systemic vascular resistance	Pressure against which the heart pumps	$Dyn*s/cm^5$ or $Mpa*s/m^3$
vti	Stroke distance	Distance the blood travels in one beat	cm

2.3 CARDIAC OUTPUT

Cardiac output (CO) is defined as 'the amount of blood discharged from the left or right ventricle [of the heart] per minute" (Venes, 2009). The amount of blood that is ejected from one of the ventricles of the heart in one contraction is called the stroke volume (SV). The SV multiplied by the heart rate (HR) is the cardiac output (Venes, 2009). For a 70kg person, normal values are around HR=70 and SV=70ml, giving a cardiac output of about 5 l/min (Rogers, 1999).

The heart's function in the body is to supply the body cells with oxygen, nutrients and chemicals, and to remove waste products. The heart has two ventricles, and the CO can be measured either at the aortic valve (AV) coming out of the left ventricle of the heart, or at the pulmonary valve (PV) out of the right ventricle. A simulated USCOM measurement of the CO at the AV and PV respectively is seen in Figure 3.

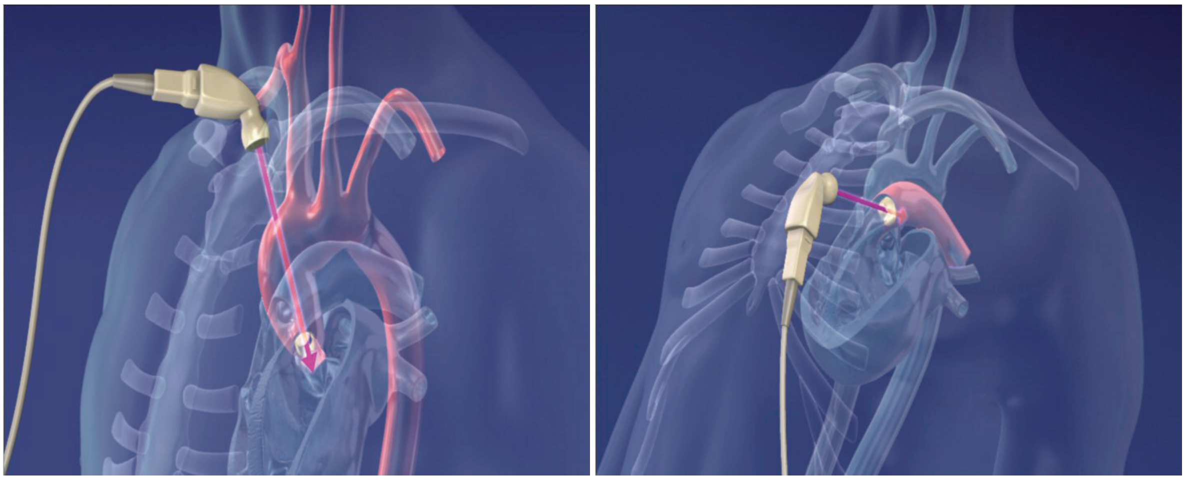

Figure 3. Left: CO measurement at the aortic valve. Right: CO measurement at the pulmonary valve. With permission from Uscom Ltd (2010).

In the USCOM, the blood stroke distance (also called velocity time integral, vti) is calculated from measuring the velocity of the blood across the outflow tract of either the AV or PV, using Continuous Doppler technology, explained in the next section. The flow area is calculated from the Outflow Tract Diameter (OTD), which is either derived from the patient's height (or weight, for small children), or inserted manually into the USCOM after doing an echocardiogram. The SV is the *flow area* multiplied by vti, and the CO is SV multiplied by HR, see Figure 4. To determine if the flow is normal, the Cardiac Index (CI) ($l/min/m^2$) is typically used as this measure is independent of patient size. CI is CO divided by Body Surface

Area (BSA) (estimated from the patient's height and weight). For an average adult at rest, a typical value of CI is 3.0 $l/m/m^2$ (Venes, 2009).

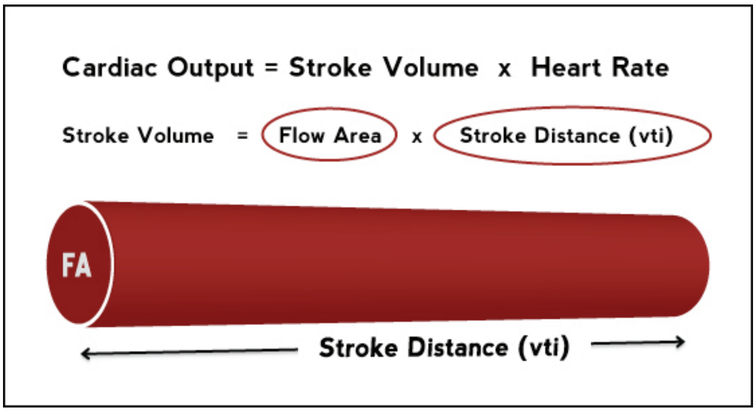

Figure 4. Cardiac output, modified from Uscom Ltd (2010).

The primary goal of CO monitoring is to allow the clinician to choose the appropriate treatment to maximize the amount of oxygen to the tissues and to know how effective the choice of treatment is. Hemoglobin is the "iron-containing pigment of red blood cells that carries oxygen from the lungs to the tissues" (Venes, 2009). If measurements of the patient's hemoglobin and oxygen saturation (SpO_2) levels are done, then the measurements can be combined with USCOM measurements to calculate the delivery of oxygen to the tissues (DpO_2).

2.4 CONTINUOUS WAVE DOPPLER ULTRASOUND

The USCOM uses Continuous Wave (CW) Doppler Ultrasound for measuring the velocities of the red blood cells. All the velocities that are picked up from the transmitting/receiving transducer (also called probe) are displayed on the USCOM screen, and constitute the Doppler Flow profiles, which are used for calculating the SV. Because the highest velocities in the arteries are found at the heart valves (as they are smaller than the arteries), the Doppler Flow profiles with the highest velocities are the ones that show the accurate SV.

Ultrasound is sound with frequencies over 20 kHz, so it exceeds the human audible spectrum. It does not travel through vacuum (and very poorly through air) (Shung, N.D), so gel must be applied to the transducer or directly on the patient before the measurement begins.

To calculate the blood cell velocities and to determine whether the blood is approaching or leaving the transducer, the Doppler Effect is utilized. The Doppler effect is a phenomenon where the observer of a sound source perceives a change in frequency depending on the velocity and direction of the sound source (and observer). The ultrasound transducer emits ultrasound of a certain frequency (for the USCOM, of 2.2 MHz) and as the soundwave meets the red blood cells coming towards the transducer, the wavelength is compressed and the frequency is elevated. The elevated ultrasound frequency is reflected back to the transducer and the difference in frequency is shown as a positive 'Doppler shift frequency'. For blood moving away from the transducer, the ultrasound frequency is lowered, resulting in a negative frequency shift.

Continuous Wave (CW) Doppler used by the USCOM is one of several types of ultrasonic Doppler flow approches; the others include Pulsed Wave (PW) Doppler, colour flow Doppler, power Doppler, etc. (Shung, N.D.) The CW transducer is made up of two elements which lay side by side; one continuously transmitting and the other continuously receiving, allowing for continuous blood flow velocity and direction measurements. CW Doppler measures all the velocities in its path, which can be displayed on a time line. Unfortunately, it is not possible to detect the origin of the measured area using CW Doppler. This problem can be alleviated using additional PW Doppler, where pulses of ultrasound are transmitted and received by the same element, so the pulses' time of flight can be analyzed to understand the place of origin. However, it is not possible to measure high velocities and depth at the same time, which makes it less suited for measuring high-velocity flow from cardiac valves (Shung, 2006).

The Doppler Flow profiles displayed on the USCOM are the Doppler shift frequencies, seen for the AV and PV respectively in Figure 5.

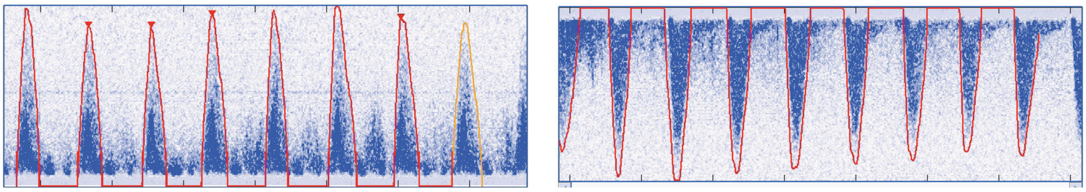

Figure 5. Examples of Doppler flow profiles. Left: a positive Doppler shift for the Aortic Valve, right: a negative Doppler shift for the Pulmonary valve.

The area of each profile represents the vti, the distance the blood travels in one beat. The AV profiles are shown as positive, above the x-axis, and PV profiles are shown as negative. This is due to the fact that when measuring the AV velocities from the suprasternal position (between the collar bones), the blood is approaching the transducer into the aorta, and for PV velocities from the parasternal intercostals position (between the ribs), the blood is flowing away from the transducer, into the pulmonary (lung) artery, creating a negative doppler shift.

The Doppler shift frequency lies in the human audible spectrum, so the signal is heard as a 'swooshing' sound when performing the examination with an USCOM. The perceived frequency of the shift is used by the operator as aid to determine whether the signal is satisfying or not. Other things to consider include the height (peak velocity) of the Doppler profiles, the correct profile has a triangular shape with a pointy top, and valve clicks might be observed as the valve opens and closes between systole and diastole. The ultrasound beam must be aimed to align as close as possible with the blood flow out of the observed tract, preferably with an angle between the flow and the beam of less than 20 degrees, for the calculations to be considered enough accurate. For an inexperienced user, it can be difficult to differentiate the AV flow from flow in the ascending aorta, which will always be slower than the flow right at the valve (Beverley Jacobson, personal communication, April 19, 2010).

2.5 HEMODYNAMIC PARAMETER RELATIONS

A range of medical conditions can be identified accurately if the relationships between the hemodynamic parameters are considered. For example, in a patient with sepsis (blood poisoning), the blood pressure can be very low even though CO is high. This is due to low SVR, so even if the heart is weakened from infection it still pumps more blood than normal because of the low resistance in the vascular system (Smith, N.D.).

However, BP depends on CO and SVR so if a patient's blood pressure is high, this can either be due to high CO, high SVR, or both (Smith, N.D.). This hemodynamic relationship can be better understood using an analogy with Ohms law. In an electrical circuit, the voltage, V, is generated from an electric current, I, over a resistance, R. In the cardiovascular system, these parameters are represented by BP, CO and SVR respectively, see Figure 6 (Smith, N.D.).

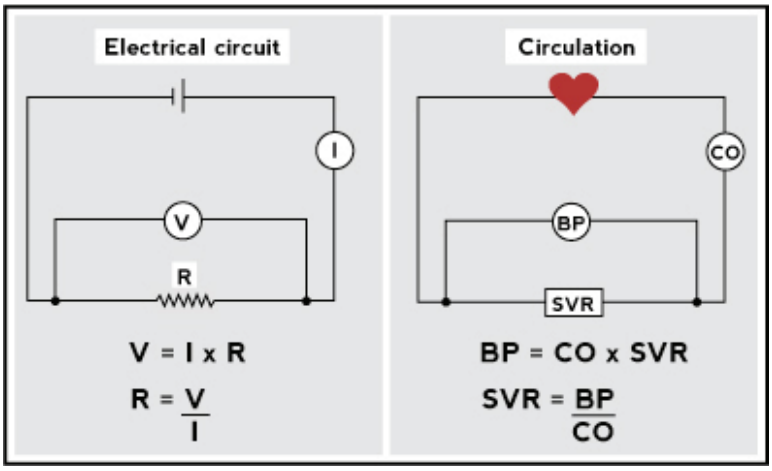

Figure 6. Ohms law and Hemodynamics analogy, modified from Smith (N.D.).

Currently, 17-20 parameters (depending on customer needs) can be displayed to the user of the USCOM. These are either direct measurements or derivations of other values. However, without understanding the meanings and relationships between the parameters, many of them are of little use to the operator. On the other hand, if clinicians can make use of the parameters, it can have a very positive impact on patient health. There is desire to guide users further in understanding and relating the different parameters, which will be dealt with in the later part of this thesis.

The hemodynamic parameters that the USCOM displays are listed in full in Appendix A.

2.6 FLUID CHALLENGES

To understand the different screens and options available in some of the cardiac output monitors on the market, some insight in cardiovascular management is necessary. For example, the term 'Fluid challenge', or 'Passive Leg Raising Test', needs an explanation.

As mentioned earlier, SV is the amount of blood in one stroke, and it depends on the Preload (the amount of blood in the ventricle immediately prior to the contraction of the heart), Contractility (the force with which the heart contracts) and Afterload (the forces the heart pressures against, essentially Systemic Vascular Resistance) (Smith, N.D.).

There is no easy way of measuring the Preload, but if SV is maximized, it is a good measure of the optimal value of Preload, according to classic work done by Frank and Starling. The Starling law states that "the energy of contraction of the ventricular muscle is a function of the length of the muscle fiber. Thus, if in a particular beat a ventricle is filled to a greater extent than the previous one, the next contraction would be more vigorous and a greater volume of blood (stroke volume) would be ejected" (Weichert et al. N.D.). The fluid challenge application of this law is seen in Figure 7.

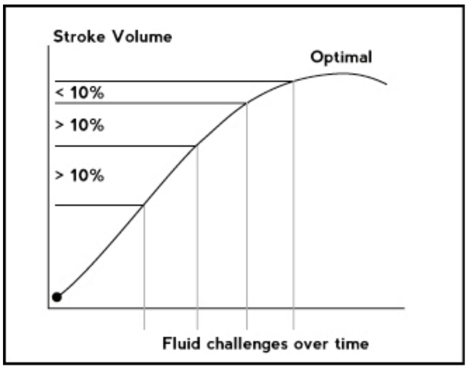

Figure 7. Fluid challenge application of the Frank-Starling law. Modified from USCOM (2010).

'Fluid challenges' are commonly performed in cardiovascular management, to optimize the fluids in the body. Fluid resuscitation can be life-saving but is also dangerous to overfill the patient with fluid, thus a Passive Leg Raising Test should first be made to determine if the patient is under- or overloaded. If the patient is underloaded, fluid might be administered, and if it is overloaded, vasodilators (widens the blood vessels) or diuretics might be used. The treatment is carried out until the peak of the Frank-Starling curve is reached, that is when the stroke volume has reached it's maximum and starts to fall. (Smith, N.D.) In practice, a stroke volume change of less than 5-10% indicates that the patient is unresponsive, and the challenge is terminated (Berkenstadt et al., 2001 & Smith, N.D.).

Finally, the contractility can be optimized by the use of inotropes, so by controlling the three different determinants for SV; preload, contractility and afterload; fluid and drug administration can be performed without the need of guesswork (Smith, N.D.)

The term stroke volume variation is sometimes used when performing Fluid challenges. However, the flow parameter Stroke Volume Variation, SVV, in the USCOM measures the difference between each heartbeat, and should not be confused with the variation in SV that occurs between before and after fluid has been administered.

3 THEORETICAL FRAMEWORK

This chapter aims at explaining the nature of human-machine systems, and to support the reader with sufficient knowledge of the general theoretical framework that has formed the basis for the redesign of the USCOM. The last section describes the development process that was employed for this thesis project.

3.1 HUMAN-MACHINE SYSTEMS

The nature of a system was formulated by Fredrich Hegel (1770-1831) as the following (Skyttner, 2006, p. 49):

- "The whole is larger than the sum of the parts
- The whole defines the nature of the parts
- The parts cannot be understood by studying the whole
- The parts are dynamically interrelated or interdependent."

There is an exchange of matter, energy or information between the parts of a system and there are system boundaries that differentiate which parts that belong to the system (Skyttner, 2006). The system boundaries can be physical, as for a machine or a person; social, as for a herd; or abstract, as rules (Bligård, 2010).

The purpose of creating a machine is to fulfill a goal that the human cannot achieve on its own, and the system where man and machine work together to fulfill the system goals, are called *human-machine systems,* or *human-technology systems* (Bligård, 2010; Osvalder & Ulfvengren, 2008). The term human-technology systems is used by Osvalder and Ulfvengren (2008) to illustrate that the theories apply to technological devices that are not traditionally seen as 'machines', i.e. alarm clocks or supervisory systems. However, in this text, the term *machine* will be used to cover all aspects of technological devices or systems. See a model of human-machine interaction in Figure 8.

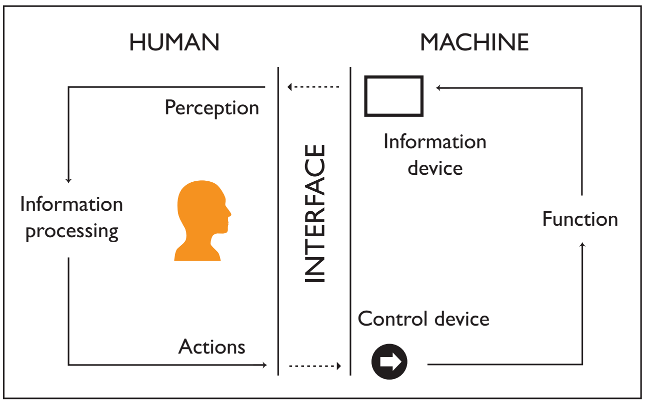

Figure 8. The model of a human-technology system. Information, matter, and/or energy are in a constant exchange between human and technology, under the influence of the surrounding environment. Modified from Chapanis (1965) cited in Osvalder and Ulfvengren (2008).

The *goal* for every human-machine system is to affect something; information, energy and/or material. To achieve this, the human-machine system usually needs to carry out one or several *tasks* in an optimal manner; it is important to consider all parts of the system that can influence the performance (Bligård, 2010).

3.2 USER AND USE

The *user* in a human-machine system is anyone that comes into contact with it, direct or indirect. The activity of acting in the same (larger) system as the machine is called *use*, while the direct interplay between the human and the machine is termed called *interaction*, which is hence part of the use. The activities that the manufacturer has developed the machine to perform are called the *intended use* and the use that leads to this is the *primary use*. Use that is not primary is for example the assembly, reparation, sale and recycling of the machine (Bligård, 2010).

The users of the machine can be divided into four roles (Janhager, 2005):

- Primary user – someone who uses the machine for its primary use, like the operator of a medical device or the patient that the device is used on.
- Secondary user – someone who uses the machine, but not for its primary use, like the assembler of a medical device.
- Co-user – a person who cooperates with a primary or secondary user, like a nurse who works together with the operator of a medical device.
- Side user – a person who is affected by the machine without direct influence on the use, like the patient in a bed in the same ward.

3.3 THE CONCEPT OF USABILITY

When the computer industry started recognizing the arising need for interfaces that are adapted to user needs, the term *user-friendliness* was used and is sometimes informally used. Human factors engineers and researchers have stepped away from this fuzzy term, that states that the user needs a 'friendly' machine, when the need is actually machine that does not stand in the user's way for reaching a the goal. Another inappropriate dimension of the term user-friendliness is that it implies that it can be measured on the same scale for all users, being more or less 'friendly'. However, all users are different, with different experiences, expectations and needs, and the term usability aims at addressing this issue, being a measurable term for each specified context (Nielsen, 1993). Usability is sometimes seen as pure common sense, but is still overlooked in a striking number of products on the market; a structured approach is needed to achieve a high degree of usability.

ISO (1998) defines usability as the following:

> "The effectiveness, efficiency and satisfaction with which specified users can achieve specified goals in particular environments."

In this definition, *effectiveness* refers to the extent to which the goal is achieved, while *efficiency* is a measure of how much effort that the goal achievement requires. *Satisfaction* refers to the degree of comfort that the user feels when using the machine, and also includes the level of acceptance from the user (Jordan, 1998).

The ISO definition explains the general meaning of usability, but is not detailed enough to be helpful for developing or assessing usability the human-machine system. To provide a deeper insight in the subject, a selection of usability models that have been developed are presented below.

3.3.1 Nielsen's model of usability

Nielsen (1993) identifies five factors that contribute to usability: learnability, efficiency of use, memorability, few and non-catastrophic errors, and subjective satisfaction.

He claims that for a machine to be successful in the human-machine system, it must first of all be accepted by the user. The level of acceptance depends on the combined levels of *practical acceptability* and *social acceptability*. Practical acceptability is related to factors such as usefulness, compatibility, and reliability, and can be high for a particular machine. However, if the social acceptability is low, the human is not motivated or lacks the necessary competence to use the machine; the level of acceptance will still be low (Nielsen, 1993).

The usefulness is the measure of how well the human-machine system as a whole can fulfill its intended system goals, and can be divided into two parts: *utility* and *usability* (Nielsen, 1993). See Figure 9 for an illustration of the relations between the above terms.

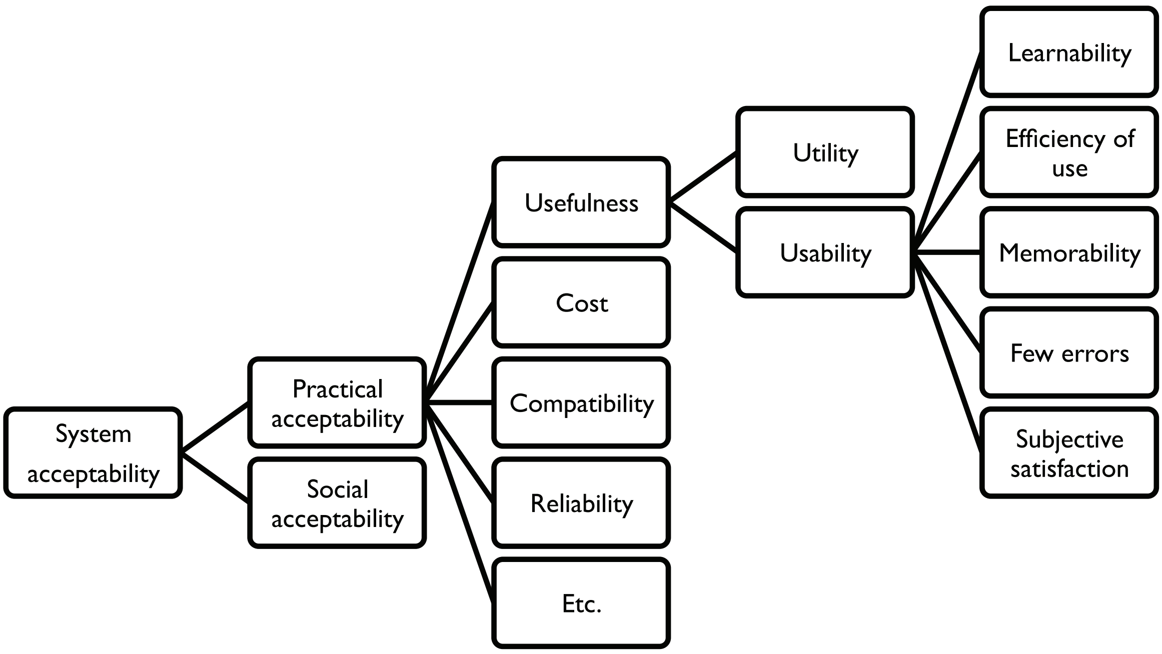

Figure 9. System acceptance model, modified from Nielsen (1993, p. 25).

Nielsen defines utility as the functionality of the machine and its ability to perform the intended tasks whereas usability is a measure of how well the machine helps the user to perform the intended task, i.e. a measure of the quality of the interaction.

3.3.2 Eason's model of usability

Eason (1984, cited in Leventhal & Barnes, 2008) divides the usability characteristics into three categories: system, task, and user characteristics.

System characteristics concerns the interface itself in terms of *ease of use*, *ease of learning* and *task match*. By task match, Eason refers to the extent to which information and functions matches the current need of the user, e.g. the lack of match between user and system for the task of writing an essay using game software.

Task characteristics concern what the user does with the system, which can be different from the intended use by the manufacturer. In Eason's model, these include *frequency* (how often the task is performed) and *openness* (the number of options available for a certain task).

User characteristics are those that the user brings into the interaction and include *knowledge*, *motivation*, and *discretion* (to which extent the user can choose to use more or less features of a system).

3.3.3 Jordan's model of usability

Jordan (1998) divides the usability into the components *guessability*, *learnability*, *experienced user performance*, *system potential* and *re-usability*. The *guessability* is related to how well first time users can complete a specified task, while *learnability* concerns the level of time and effort that a user, who is not an expert, requires in order to reach a desired level of competence in the interaction. In the previously described models, these two components can be said to be grouped under the terms *learnability* (Nielsen) and *ease of learning* (Eason) respectively.

The *experienced user performance* is a measure of the performance that is reached by experienced users in the interaction, and is important for products that are used frequently by the same user, while it may be of less importance for one-off users, e.g. for a tourist information display. *System potential* is closely related to the latter, as it describes the optimal performance that can be reached. These components are related to *efficiency of use* (Nielsen), and *easy to use* (Eason).

The component re-usability concerns the level of performance that a user reaches after using the machine after a relatively long period of absence, and responds to the memorability in Nielsen's model meanwhile it does not have a direct counterpart in Eason's model.

3.3.4 Usability models analysis

The usability models above have a lot of issues in common, such as the ease of learning and the potential that can be reached for different kinds of users. They are built up quite differently, however, and Nielsen's is the only model that explicitly mentions errors as a means of measuring the quality of the interaction. While Jordan and Nielsen focus on the larger context of system acceptability and performance and measuring the quality of the interaction, Eason's quite extensive model is rather causal, and implies that more or less focus on the different characteristics will influence the outcome. In Eason's model, the main indicator of usability is whether the system is used or not (Eason, 1984, cited in Leventhal & Barnes, 2008).

Leventhal and Barnes (2008) present a modified version of Eason's model, that introduces the variable *situational constraints*, which is not explicitly mentioned in any of the other models, although all methods mention the necessity of considering a specific user in a specific context. The *situational constraints* are exemplified by questions such as: "'Is the task ever done collaboratively?', 'Is the task done for entertainment?', and 'Is the task conducted in a hands-free setting or in some other way limited in terms of the user's modes of interaction?'" (Leventhal & Barnes, 2008, p. 34). This approach takes a causal view on the prerequisites for developing usable machine, and can be useful in the early stages of product development, while Nielsen's and Jordan's models, which focus on the result, might be more appropriate for considering and comparing different options and outcome.

One factor that is not mentioned in any of the models is the aesthetics of the machine. Although not a part of usabilitiy, it has an important relationship to both usability and functionality. Bligård (2010) has illustrated the balance of functionality (or utility in Nielsen's terms), usability and aesthetics that determines the success of a machine, see Figure 10 These three factors are not intrinsic qualities of the machine, but arise as a result of the relationships between the machine, the task and the environment.

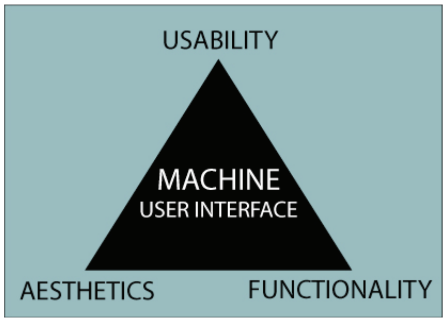

Figure 10. The balance between usability, aesthetics, and functionality must be considered for a successful human-machine system. (Bligård, 2010).

The functionality is the most concrete of these factors, while the usability can be considered as abstract and dependent on the environment to a larger extent. For a successful machine, the three factors should be optimized, without to much emphasis on either one, as the factors depend on each other. For example, changing the functionality can affect the usability positively, while optimizing the usability can affect the aesthetics in a negative manner. Note that the relation is not only negative, for example, studies have shown that users make less errors with machines with a more aesthetically pleasant interface (Norman, 2004, cited in Bligård, 2010).

For this thesis, the Nielsen model has formed the basis of the development, as the high-level approach is suitable for achieving measurable qualities of the interaction. However, all the models above have had influence and can be related to the methods that have been carried out. As an example, information was collected about the user, the task, the environment and technical solutions, which is not explicitly expressed in Nielsen's model while it does resemble the *characteristics* layout of the Eason approach.

It is important to note that usability (in Nielsen's terms and used in this thesis) does not refer directly to the quality of the function performed by medical equipment. For example, it does not measure how well a scalpel cuts or how well a blood pressure gauge measures blood pressure (Bligård, 2007, p.15), which would go under the term utility. Usability instead refers to how well the medical staff can make use of the functionality, e.g. how well they can understand what is displayed on the blood pressure display, or how well the scalpel fits the surgeon's hand (Bligård, 2007, p.15).

3.4 COGNITIVE PROCESSES

Weiten (2007, p. 13) defines *cognition* as "referring to the mental processes involved in acquiring knowledge". Gardiner and Christie (1987, p.57) explain *cognitive psychology* as "the study of knowledge and how people use it. It deals with how we gain information from the world, how it is represented and transformed as knowledge, how that information is stored, and how that knowledge is used to direct behavior".

Cognitive processes hence deal with how information is taken in through the human senses, are attended to or ignored, and are processed in the short- and long-term memory. It also includes the decision-making and response to the information (Osvalder and Ulfvengren, 2008). See Figure 11 for an illustration of the human information process. All elements of the information process take place simultaneously, either consciously or unconsciously. At the same time that information is attended to and processed, new stimuli is taken in by the different senses, and the quality of the cognitive process is affected by the load of simultaneous information. Human conscious cognitive capacity is limited, so pattern recognition, grouping, and rule of thumb decisions are often made in order to reduce the mental load and make decisions (Osvalder & Ulfvengren, 2008).

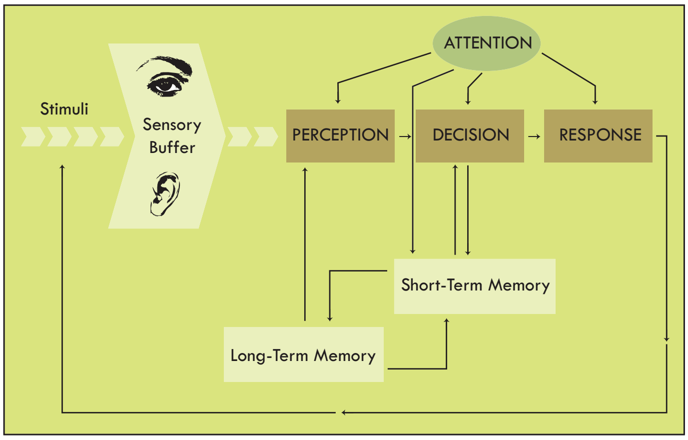

Figure 11. The human information process. Modified from Wickens et al. (2004, cited in Osvalder & Ulfvengren, 2008).

The cognitive processes depend, according to Rasmussen (1986), to a large extent on the human's previous experiences and ability to create *mental models* for new situations. A mental model is formed by freely combining different models, rules, and strategies that have worked in previous situations (Rasmussen, 1986). The idea that humans create a representation of the world that determine how we interact with it was first formulated by Craik in 1943, and has then developed over the years. Johnson-Laird (1983, p. 165) defined mental models as "structural analogues of the world", that make it possible for humans to reason without logic. They are not exact images or representations of the world, but only exact enough to allow for accurate predictions and actions according to Norman (1983, cited in Liu, 2009). Norman divided the concept of mental models into two types: *structural* and *functional*. Structural models are built from actually understanding the components of a system and their relationships. They allow for humans to predict the outcome of a series of action and *why* a system responds as it does. Functional models represents knowledge about *what to do*, but not why; e.g. knowing that the computer should be shut down before switched off. Expert users typically have more abstract and richer mental models whereas novice users have only developed real-time, more concrete models (Liu, 2009). It is important to remember that even though experts might have mental models that allow for deeper domain understanding and reasoning; in the interaction with new products, the experiences that the expert user has of similar products might influence the interaction negatively (Liu, 2009).

Users are not blank responders but interact with a system using previous knowledge and experiences that must be taken into consideration; many errors in human-machine interaction cannot be explained as random, or due to working memory limitations and lack of attention, but can only be accounted for by an incorrect mental model (Gardiner & Christie, 1987). However, even if a correct mental model of the interaction is well promoted, it is difficult to predict how humans will react in each encountered situation; memory load, stress factors and the environment also play a significant role for the result (Rasmussen, 1986).

The following chapters deal with important factors that determine the outcome of cognitive processes, such as the role of attention and perception, the intake by the human senses, and the human memory.

3.5 SENSATION, PERCEPTION AND ATTENTION

The first experimental psychologists that investigated sensation and perception called the subject *psychophysics* – "the study of how physical stimuli are translated into psychological experience" (Weiten, 2007, p. 130).

Sensation begins with a *stimulus* of the senses, and there is a limit to how little stimulus an organism can detect, the *absolute threshold*, a central concept in psychophysics. The human senses can be quite impressive, for example, under ideal conditions, a human can detect a candle flame seen at a distance of 48 km on a dark clear night, or feel the wing of a fly falling on his or her cheek from a distance of 1 centimeter (Galanter, 1962, in Weiten, 2007). The *just noticeable difference* is "the smallest difference in stimulus intensity that a specific sense can detect" (Weiten, 2007, p. 131) and tends to depend on the size of the initial stimulus. For example, a difference in one gram can be detectable for an initial weight of 50 grams, whereas for a weight of 500 grams, a difference of at least 10 grams is necessary for detection (Osvalder & Ulfvengren, 2008).

Perception is the "selection, organization and interpretation of sensory input" (Weiten, 2007, p. 130). Whereas the sensation involves the absorption of energy or sound waves, the perception deals with the organizing and the translation of the information into something meaningful, affected by previous experiences; the actual perception is not necessarily a "photo" of the environment, but an interpretation (Weiten, 2007).

Since the 1950's research has been carried out on the much questioned subject of *subliminal perception*, "the registration of sensory input without conscious awareness" (Weiten, 2007, p. 132), such as displaying hidden messages in films or music. Weiten (2007) claims that quite a number of recent studies show that perception without awareness *can* take place, but the effects of the subliminal stimuli are usually nearly as subliminal as the stimuli themselves. However, Weiten (2007) stresses that more research on the manipulative potential is needed.

What is certain is that the level of attention is critical to the encoding of memories. *Attention* "involves focusing awareness on a narrowed range of stimuli or events" (Weiten, 2007, p. 277) and is necessary for everyday functioning. Without filtering incoming information, we would not be able to for example, read a book or keep up a conversation. Scientists have debated over the years whether the filtration of sensory input that is attended to happens early, during sensory input, or late, after the brain has processed the meaning of the stimuli, and the probable answer is the latter. Consider the "cocktail phenomenon": you are at a party and involved in a conversation, filtering out the other conversations around you. However, if someone mentions your name, it is likely that you will register it (Weiten, 2007). Also, if you start monitoring the conversation in which you were mentioned, it is likely that you will struggle to keep up with the conversation you are involved in. People tend to think they are capable of multitasking, but research has shown that the human brain can only effectively handle one attention-consuming task at a time (Weiten, 2007), so "multitasking" is thought to consist of the action of switching attention back and forth between tasks, resulting in a poorer outcome for the main task in question, especially true if the information requires intake and response through the same sensory channel (Osvalder & Ulfvengren, 2008). Also, the capability of memory encoding is affected when paying attention to different tasks simultaneously (Weiten, 2007).

However, as discussed earlier, it is possible to carry out several tasks at the same time, even though they might not all receive the same level of attention. Osvalder and Ulfvengren (2008) describe two different strands of attention; *selective* and *divided*. Selective attention is described as the capacity to select where to optimize focus, for example when switching between the road, the mirrors and the speed dial when driving a car. Four factors determine the focus of attention: how strong the incoming signal is, what the individual expects to happen, the value of the information, and the level of effort to acquire the information that is needed. Divided attention refers to the capacity of a person to monitor several sources of information, which can be enhanced through experience and practice. The main factors that determine the outcome are the following three: mental effort and resource demand for the primary task, structural similarity of resources (which type of sensory response is required), and the individual's ability for task management.

3.6 THE HUMAN SENSES

Traditionally, the human senses are divided into *vision*, *hearing*, *touch*, *smell* and *taste*. In recent literature, however, there is no firm agreement among neurologists of the number of senses as the definitions of what constitutes a sense differ. One common addition to the five senses mentioned is the muscular sense, which comprises proprioception; the awareness of the body parts in space, and the kinaesthetic sense; information of movement in the joints. Another addition is the vestibular sense, or balance. The term *haptic* describes senses that have to do with both touch and bodily movement and so incorporates the tactile sense (touch) and the muscular sense. In this chapter, the visual, auditory (hearing), and haptic senses are presented in relation to design.

3.6.1 The visual sense

Visual perception is the result of the visual sense taking in information from the environment, and transforming it into a neural code (Schwartz, 2010). However, what people see is not simply a translation of the retinal stimuli (i.e. the image on the retina), but visual processing affects the outcome. For example, we unconsciously use cues for determining depth and distances, and if the cues are abnormally small or large, it will affect the perceived size and placement of another object (Osvalder & Ulfvengren, 2008). Other factors that determine the outcome are the abilities to adapt to darkness and to distinguish between colors.

The photoreceptors in the eye respond to light stimuli and are divided into rods (active in night time vision) and cones (day light vision). The rods mediate Scotopic vision, which is characterized by high dim light sensitivity but generates vision of low acuity and color discrimination, best performed by the Photopic vision, mediated by the cones. Interestingly enough, even though the Photopic vision might be seen as 'the best' human vision, a human's ability to detect a stimulus are much superior in the Scotopic vision state (Schwartz, 2010).

The cones are called long, medium and short wavelength cones, and mediate human trichromatic vision; i.e. three independent variables are sufficient to cover the human color vision, ideally able to distinguish over a million different colors (Stone, 2003). If one or two of the cone types are missing, color vision is reduced to less dimensions, dichromacy or monochromacy. The loss of all three reduces vision to purely scotopic. Many more men than women are dichromats, due to the fact that most common dichromatism forms are found in a gene located on the X chromosome and only one normal gene is necessary to achieve normal color vision. As men only have one X chromosome, it increases the probability of dichromatism (Goldstein, 2009).

Monochromism, true color blindness, is rare, and only affects around 10 people in a million (Legrand, 1957, cited in Goldstein, 2009), whereas the most common color deficiency, problems distinguishing red from green, is present in around 8 percent in the male population and around 0.4 percent in the female population (Birch, 2003). Another common deficiency is the problem distinguishing yellow from blue. It is not believed that ethnicity, geographic latitude and cultural development affect the numbers, whereas geographic and cultural isolation certainly has influence, as is the issue on certain islands (Birch, 2003).

In a range of situations, redundancy (i.e. additional information) in design is of essence, such as the consistent placement of the lights in traffic lights, enabling people with color deficiencies to determine which light is shown. It should also be noted that color deficiencies can sometimes be of advantage, an example being the ability of people with certain types of deficiencies to see through enemy camouflage in military operations due to a higher performance in distinguishing between different shades (Osvalder & Ulfvengren, 2008).

Vision is the dominant sense, and represents almost 80 percent of all sensory impressions. It has also been shown that it is the sense that humans rely on the most, especially of the information from the different senses are of the same nature, and it is extremely sensitive in detecting movements. Downsides of the vision sense nature is that it requires the human to turn around to take in all the information, and that it easily can be turned off, by closing the eyes (Osvalder & Ulfvengren, 2008).

The layout of an interface must properly mirror the "user's logical path through the application" (Cooper & Reimann, 2003, p. 231) considering that (in the Western world), the eye will scan from top to bottom and left to right. This will help the user to accurately accomplish goals and tasks and to speed up the process.

For design of visual presentation, Osvalder and Ulfvengren (2008) stress the need to consider the factors intensity, choice of color, strength of lighting, angle of vision and contrast.

3.6.2 The auditory sense

Hearing (the auditory sense) on the other hand, is always 'open', even in sleep, which makes sound advantageous for certain alarm systems. It is an important complement to the visual sense, and can be used to direct attention to visual information as well as warning us of dangers (Osvalder & Ulfvengren, 2008; Plack, 2005).

The auditory sense make use of the pressure fluctuations in the air around us, and the ears were developed to make use of more information and is an important means in communication. One in about six people is hearing impaired (Plack, 2005) and as we grow older, the auditory sense deteriorates, especially for higher frequencies (Osvalder & Ulfvengren, 2008).

Sound is used by humans, sometimes unconsciously, for feedback on actions, such as the sound from the keyboard when typing, or determining the quality of products, such as the noise form a closing car door, and is an important issue for product and interface design. Studies have shown that the sound experience also influences our perception of other qualities, for example can people's judgment of picture quality of a TV screen be affected by the quality of the sound (Osvalder & Ulfvengren, 2008). This phenomenon is termed synesthesia, and has only quite recently gained status in science (Sagiv, 2004). It describes "a condition in which stimulation in one sensory modality also gives rise to a sensation in a different modality. However, conditions involving different qualities within one modality (e.g. when the sight of letter shapes evokes color) are labeled synesthesia as well" (Sagiv, 2004, p. 3).

Important factors of sound to consider in design are according to Osvalder and Ulfvengren (2008) the loudness (amplitude), pitch (frequency) and location. The ability to determine the latter is enabled by the position of the human ears, which promote location determination to the sides, but is less apt in determining the location of sound sources above the ears.

3.6.3 The haptic sense

The haptic sense can be said to describe anything that has to do with touch or physical movement and hence covers a large part of the human-human or human-machine interaction. It allows us not only to communicate through touch and body gestures, but also to determine qualities of surfaces, making judgments of size, weight, temperatures and rotational movement of the material, etc. The haptic information can be transferred to the body in various ways, e.g. as friction, vibrations or forces (Osvalder & Ulfvengren, 2008).

Modern machine make use of haptics to a large extent, in applications such as flight and medical simulators and robots, computer video games and in interactivity in arts and design. Touch screens are nowadays common interfaces of telephones and other appliances.

Sometimes, the haptic influence in interaction is not consciously taken into consideration, such as the position of levers and controls. For example, you might not have to look at or listen to your stereo, to know the approximate volume level, as the position of a knob or lever informs you.

Haptics is advantageous as a source for information when other channels are overloaded, and is often used as a complement to visual information. Information that entails several of the senses, *multimodal,* sends the same message through the different senses for the information to come across faster, clearer and more easily noticed. When the functioning of one of the senses is low or absent, the information can be conveyed through more active stimuli of the other senses, which can be trained and sharpened for enhanced perception (Osvalder & Ulfvengren, 2008).

3.7 MEMORY

According to one of the most influential information-processing theories by Atkinson and Shiffrin (cited in Weiten, 2007), the information first passes through two temporary storage buffers, the sensory memory and short-term memory (STM) (or working memory). Finally, the information passes on to the long-term memory (LTM).

The sensory memory saves the original sensory information for a short period, usually less than a second. It can be illustrated by the lasting image of a flashlight moved around in the dark, perceived as for example a circle as opposed to a succession of individual points, as the blending of sensory afterimages creates a pattern.

The STM is a limited capacity that can store unrehearsed information for about 10-20 seconds. It was long believed that the storage capacity of the STM was 7±2 chunks of information, as introduced in George Miller's famous paper from 1956, "The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information" (cited in Weiten, 2007). However, more recent research (Cowan, 2005, cited in Weiten, 2007), shows that the number might have been overestimated, and the true number might be closer to 4±1. The "chunking" of information makes it possible to store large amounts of memory in the STM, as it is not single pieces of information that is referred to by the above numbers, but the chunks of familiar stimuli, stored as a single unit that is limited. Weiten (2007) demonstrates the concept of chunking with the following example: Asking a test subject to remember the sequence of 12 letters grouped in the following way:

FB-INB-CC-IAIB-M

might call for the test subject to remember each letter separately, which is too big a load for the STM. By grouping the letters into meaningful chunks, the test object will be much more likely to remember the letters:

FBI-NBC-CIA-IBM.

By rehearsing the information, such as reciting a phone number until one can dial it, the information in the STM could be saved forever. However, in reality, the rehearsal loop will eventually be broken when one is distracted. The loss of information from the STM is thought to depend not only on time-related decay of memory traces, but also on the interference from new incoming information (Weiten, 2007).

Once the information is stored in the LTM, it is thought to be stored there indefinitely, and the limitation is related to the *retrieval* process. There is no known limit to the capacity of the LTM, but it is clear that the quality of the information becomes less detailed and complete with time, and people sometimes are confident concerning the accuracy of their memories, that might be inaccurate. This is especially true for so called "flashbulb" memories, which signifies unusually vivid and detailed recollections of specific events, such as "what were you doing when you found out about the 9/11 terrorist attacks?" (Weiten, 2007).

It is believed that the levels of processing is related to different types of encoding, see Figure 12. The first level, structural, is related to the sensory memory, and is a shallow type of memory encoding. The second level, phonemic, is related to the processing of information stored in the STM, and involves the naming or saying of words (sometimes silently). The deepest level of information processing is the semantic encoding, where a meaning is associated with the information (Weiten, 2007).

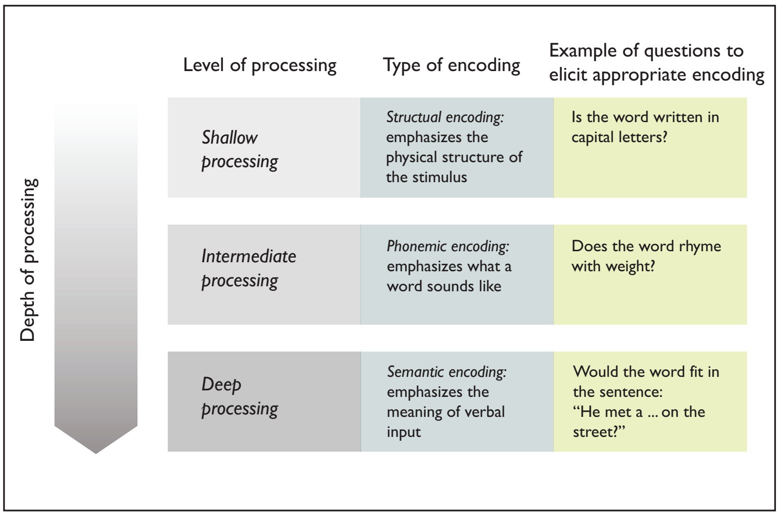

Figure 12. Levels of processing-theory, dividing the levels of processing into structural, phonemic and semantic encoding, on progressibely deeper levels of processing. Modified from Craik and Lockhart (1972) in Weiten (2007).

The levels-of-processing-theory and the partitioning of the memory into the different storages have been questioned over the last decades, and the sensory memory is sometimes viewed as "perceptual processes at work", rather than memory. Also, some researchers oppose to the division between STM and LTM, as both semantic encoding and interference effects, traditionally associated with the LTM, have been seen to influence also the STM. However, although alternative approaches are becoming increasingly influential, the dominant view is still the multiple storage model, which has had great influence on research, showing that that memory involves more than only storage, and how processing considerations influence memory (Weiten, 2007).

The organization of information in the memory depends on the type of information to be stored and many organizational structures have been presented to describe the mental representations in the human memory. It is believed that people spontaneously organize factual information in *clusters*, groups of similar or related items. Another way of organizing factual information is in *conceptual hierarchies*, for example, for the word sparrow, it is likely that the mind automatically groups it under the category of birds, which in turn is a subcategory of animals, etc.

Another way of explaining the organization of the memory is the formation of *schemas*, "an organized cluster of knowledge about a particular object or event abstracted from previous experience with the object or event" (Weiten, 2007, p. 288). The expectations on what to find or how a situation is usually carried out influences our memory of the event. Research has shown that people tend to remember things that fit into the schema above other things, but the opposite is also true (Weiten, 2007). Consider the situation of coming into a professor's room, where we probably expect to find shelves, books, a computer, papers and a desk and chair. Things that are not commonly found in the room are less likely to be remembered, and our memory can be falsely influenced by the schema, making us believe that we saw things that were not present. However, if something very unexpected, such as a slot machine, was found in the professor's room, the likeliness that we will remember this item is higher, as it strongly violates the schema.

Not all information fits into the organizations above and can be explained by e.g. semantic networks, which "consists of nodes representing concepts, joined together by pathways that link related concepts" (Weiten, 2007, p. 289). The length of the pathways between the concepts determine the likeliness of association. For example, the word 'bread' might be strongly associated with 'butter', increasing the probability of remembering the two words in combination, whereas for another person, 'oil' might have a shorter pathway to 'bread'.

The retrieval of information is probably the key to understanding human memory (Weiten, 2007), as the information stored in the (as far as we know) unlimited LTM must be retrieved in order to be remembered. It must be considered however, that the retrieval from LTM is not a "mental videotape" but a sketchy reconstruction of the past.

The *tip-of-the-tongue* phenomenon, where you have feeling of that the information is just out of reach, is experienced by most people about once a week, a number that increases with age (Burke & Shafto, 2004, cited in Weiten, 2007). It is debated what exactly lies behind the phenomenon, but it has been shown that *retrieval cues*, such as remembering or being given the first letter of a word, for example, highly increased the chances of recollection (Weiten, 2007).

Another type of cues for recollection are related to *context*, which is illustrated by the fact that long-forgotten memories are reinstated when visiting or imagining the same place or situation in which a certain event occurred. It has shown successful in the enhancement of eyewitness recall in legal investigations (Chandler & Fisher, 1996, cited in Weiten, 2007) but can also have negative effects. When reinstating the context of an event under the influence of hypnosis, people have a tendency to report incorrect information, while being overconfident about the accuracy (Weiten, 2007).

3.8 DECISION-MAKING AND PROBLEM-SOLVING

We make decisions constantly, whether we are consciously aware or not, from when to get out of bed to which education to choose. The psychological aspect of decision-making has been studied for decades and research shows that people have a limited ability to process and evaluate information, resulting in a tendency to use simple strategies that focus on only parts of the available information, sometimes resulting in less than optimal choices. The focus on biases and mistakes in people's decision-making has highlighted the need to understand the underlying factors and has stimulated research on the subject (Weiten, 2007).

Two different decision-making strategies are the *additive* and *elimination by aspects* strategies. The additive strategy is based on a list of attributes associated with different choices, where the attributes are rated, and the results are added to a total, which would determine the most preferable choice. This can be exemplified by considering a choice between different apartments based on the judged ratings of rent, noise level, distance to work, etc. The second strategy builds on eliminating less attractive alternatives, on the basis of different prerequisites, e.g. choosing a car that is in a certain price range, of a certain color, etc.

Rasmussen's SRK (Skills, Rules, and Knowledge) model (1986) is an often-cited representation of the different levels on which human performance takes place.

Skill-based behavior, on the lowest conceptual level, emerges when actions do not require conscious attention or control (Rasmussen, 1986), and can be considered automated tasks, such as when a skilled driver changes gears or keeps the car on the road without conscious attention.

The next level, Rule-based behavior, is represented by actions that are controlled through a stored rule, even if the goal is not always formulated consciously. (Rasmussen, 1986). An example of this is when a driver reaches a red light and more or less automatically stops the car.

Knowledge-based behavior is utilized in unfamiliar situations, where a high degree of functional reasoning must be used, in order to reach an explicitly formulated goal (Rasmussen, 1986). For a driver, trying to find the right way in a new environment requires behavior to take place on this high abstract level.

The boundaries between the different levels are not explicit. The level of performance depends on experience and training; something that is carried out on a Knowledge-based level for one person, might be carried out on a Skill-based level for another. Performance is often found to be carried out in several of the levels simultaneously, such as riding a bicycle and steering away from a slippery patch in the road, where the skilled actions are 'modulated' by the higher level control behaviors (Rasmussen, 1986). Rule-based behavior normally involves Skilled-based as well, and Knowledge-based behavior normally includes all three levels of performance. The more a person carries out a Rule-based action, the more Skilled-based it becomes, freeing up mental resources. It is typically easier to describe how a Rule-based actions was carried out, as it involves more explicit knowledge and rules, than a Skilled-based action, which is more automated (Osvalder & Ulfvengren, 2008).

Different types of use errors can be divided into five categories: lapses, slips, rule-based mistakes, knowledge-based mistakes and deliberate violation. The latter will not be discussed further. The use errors can be related to the different levels of human performance. On the Skill-based level, users tend to make lapses and slips. Lapses are related to memory and to forget one's intentions; such as driving the car and forgetting where to drive, or why. Slips occur when users failure in the performance of routine tasks that normally requires little effort; such as locking the keys in the car because one gets distracted by something. Rule-based mistakes relate to failure to carry out a procedure or protocol correctly, or choosing the wrong rule; such as trying to change gears when driving an automatic transmission (because the driver is used to manual gear shifting). Knowledge-based mistakes are due to bad problem solving or insufficient knowledge; such as making a mistake when driving because the traffic light is out of function and one does not know what to do (Bligård, 2009).

3.9 THE USE OF COLOR IN INTERFACES

Color affects our perception of the world in many ways. It can stimulate different feelings, or create associations, depending on context and experience. For example, someone dressed entirely in black might create an association to funerals in one context, but to a certain type of music in another.

As light hits the retina in a spectrum of different wavelength, we process the information and perceive it as different colors. When we speak about color in daily life however, we normally don't talk about wavelength or components of primary colors, but of *hues* such as red, purple or green, which relates to the position on the wavelength spectrum. One common standpoint is to classify colors after hue, *lightness* and *chroma*. Lightness is explained by Kuehni (2005, p.39) as "the perceived brightness of a nonwhite object compared to that of a perfect white object." Chroma is a specific case of saturation, and can be defined as an "attribute of color used to indicate the degree of departure of the color from the gray of the same lightness" (Kuehni, p. 42).

Used in an appropriate manner in design, color can aid in attracting attention, assigning priorities, coding information, adding redundancy, assisting recognition etc. However, used in excess, colors might contribute to mental loading and overload human memory capacity (Gardiner & Christie, 1987). Many colors, and inappropriate hues, can also be send the wrong messages, e.g. 'too playful' (Osvalder & Ulfvengren, 2008).

The general advice is usually to keep the different colors on the screen at a low number; Osvalder and Ulfvengren suggest no more than four colors be used. Using more than seven colors on a screen decreases search performance according to Cooper and Reimann (2003), who also state the number four to be appropriate. Different shades of the same color can be used for emphasis, e.g. using different shades of grey is an acceptable color variation according to Cox & Walker (2002).

It is important that color is used redundantly, and never as the single code (Osvalder & Ulfvengren, 2008), for example as in stop lights, where the placement of lamps together with the color assign meaning to the light. For this reason, one guideline is to design in monochrome first, and apply color later (Cox & Walker, 2002).

It is important to consider that the perception of a color depends largely on the surrounding environment. The same color can look very different depending on the background color and the angle of view as well as the lighting conditions.

One other color aspect is the use of complementary colors, which are constituted by pairs of colors which when mixed create a neutral color; grey, white, or black. However, not all pairs of pigments that appear to be complementary are capable of producing a truly neutral color as the light-absorbing qualities of pigments are complex. Examples of complementary color pairs are red-cyan, blue-yellow and green-magenta. The complementary colors are illustrated in the phenomenon of *afterimage*, where one after staring at a point of a certain color (e.g. blue) for about a minute and then looks at a white surface, sees the complementary color (e.g. yellow). Complementary colors used together have the effect of appearing to saturate each other, creating a dramatic composition, while designs lacking complements are perceived as softer.

Another aspect of using color is the contrast, which must be sufficiently high between background and foreground for visual clarity. However, it should be considered that too much contrast and using complementary color in combination can lead to visual clutter; color vibration. Consider the map example in Figure 13. The map to the far left produces a visual vibration; dark spots between the corners of the shapes, while the map with low contrast to the right is comfortable to look at and could accommodate additional geographic detail.

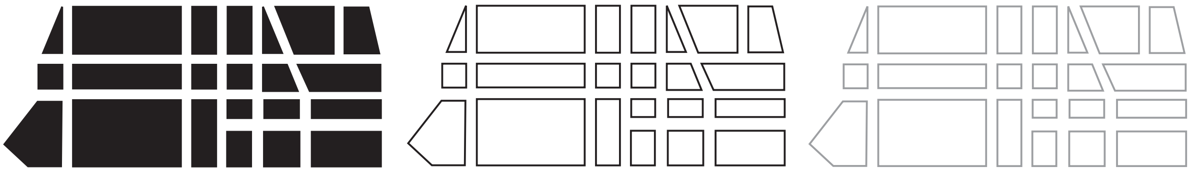

Figure 13. Example of color vibration. Modified from Jon Werheimer's student project on maps in 1985-1986 (cited in Tufte, 1990, p. 62).

In general, black, blue or white backgrounds work best and light blue should be confined to background areas if used, according to Cox and Walker (2002). The fore/background combination of red and navy can create a vibrating effect and should be avoided in digital interfaces (Cooper & Reimann, 2003). Also, when foreground colors differ from background colors only in hue they can be difficult to perceive; there should always be a difference in saturation or brightness (Cooper & Reimann, 2003).

Different meanings are also associated with different colors. In western culture the following stereotypes should be considered in designing interfaces (Bligård & Ulfvengren, 2008):

- Red: stop, danger, heat and fire
- Yellow: warning, slow and testing
- Green: OK, go, continue and ON
- Blue: cold, water and calm

3.10 THE GESTALT LAWS AND CULTURAL STEREOTYPES

The four classic gestalt laws should be considered when designing an interface: Proximity, Similarity, Continuity and Closure, see Figure 14.

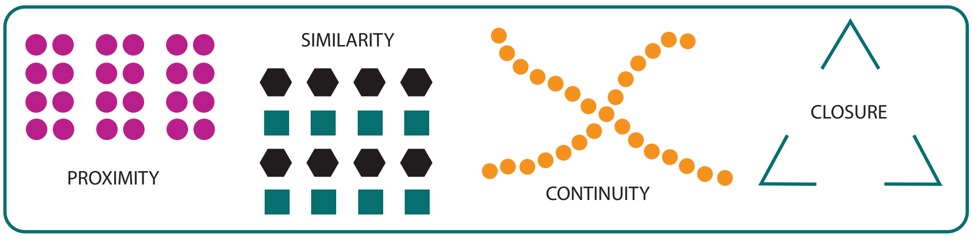

Figure 14. The classic Gestalt laws for design. Modified from Osvalder and Ulfvengren (2008).

The Proximity gestalt law states that humans automatically group pieces of information according to a judgment of 'closeness', so for example, information or control devices that belong together on a display or panel should be placed near each other. Objects for similar types of functions should also have the same appearance, according to the Similarity gestalt law, which states that humans group similarly shaped and colored objects. The Continuity gestalt law refers to the tendency to link items that follow each other to create a line. In Figure 14, you are probably more likely to see the Continuity image as two lines crossing, than as separate points, or two 'beaks' touching, even if these are alternative interpretations. Finally, the Closure gestalt law describes how humans automatically 'fill in' information to create meaning, which also enables us to make correct decisions on poor quality information (Osvalder & Ulfvengren, 2008).

The cultural stereotypes should be considered when designing. Typically, people (in the western world) interpret a design with movement upwards or to the right as an *increase*, and movements in the opposite directions as a *decrease*. The clockwise turn of a control usually signifies an increase, however, this stereotype can be ambiguous in applications on e.g. knobs for turning on gas bottles, as they work in the opposite direction.

Other examples of stereotypes commonly used in software interfaces are the use of so called radio buttons (round) for selections which exclude all other options, whereas square tick boxes normally mean several choices can be made. Shapes and surfaces of physical buttons and levers can invite to different use, for example, a rugged surface around a knob indicates that it can be rotated, and a thumb-shaped groove can invite to touch.

3.11 GENERIC DESIGN GUIDELINES BASED ON COGNITIVE PSYCHOLOGY

Generic guidelines can certainly be useful as one tool when designing or evaluating an interface but cannot be implemented pedantically without consideration to context (Gardiner & Christie, 1987). Before developing guidelines for the redesign of the USCOM, an investigation was made to find guidelines that can be supported by research on cognitive psychology, in order to base design choices as much as possible on research as opposed to 'a feel' for how humans will interact with the system.

Gardiner and Christie (1987) discuss the use of guidelines in the book "Applying Cognitive Psychology to Interface Design', and also present a set of guidelines that have been derived from research within cognitive psychology. The categories of guidelines in the book have served as a basis for the division of categories below.

3.11.1 Design of procedures and tasks

Procedures and tasks should be designed in a logical and consistent way, but most importantly, in a way that meets user expectations and promote user acceptance. Gardiner and Christie (1987, p. 249) also state that "tasks can be combined in the following ways: simple + simple, or complex + simple. A user should not be asked to perform two complex tasks together. This is especially true for novice users." This is related to the mental load that is imposed on the user; controlled sequences require use of working memory to hold at least alternative possible actions and outcomes whereas automatic processing does not load working memory (Gardiner & Christie, 1987). Hence, it is especially important to automate tasks which have to be carried out in combination with a high mental load. A study that supports this claim was done by Hamilton, Hockey and Rejman (1977, in Gardiner & Christie, 1987), where subjects were asked to perform alphabet transformations (e.g. 'B + 3' gives 'E'). When subjects were asked to perform a series of transformations, and keeping results in their heads to report only when finished all; an inverse relation between the size of the storage load and speed of transformations was found.

The fact that a high mental load to a high degree influences the human's capability to decision-making is also discussed by Rasmussen (1986). He found that, during observations, when the operator has to maintain mental models at different functional levels, procedures become slow and hesitating, with the operator seemingly insensitive to hints that would under other circumstances be evident to the him or her. (See Section 3.4 for more information on mental models.)

It should be noted, however, that Gardiner and Christie (1987) also state that critical or potentially dangerous tasks should not become automatic. Where there is need for the users to think about what they are doing, disruptive elements should be used, i.e. asking the user for confirmation.

Where key components of tasks need to be clarified to keep the task structure explicit, the use of extra, redundant information can be used (e.g. use of colors or involving several modalities i.e. auditory and haptic). However, it is important not to present irrelevant information and to avoid distractions. The need to make information clear and explicit is related to how people reason and the biases involved. Gardiner and Christie (1987) discuss two of the most well-known heuristic biases representativeness and availability.

The representativeness heuristic is used by humans to determine the probability that an item is belongs to a category, in which case relevant information, i.e. base-rate probabilities, often is ignored in favor of a biased judgment of how representative the item is for the category. Subjects were given the possibility that a person was either a bank teller, or a bank teller who is also a feminist. Given the information that a specific girl is involved in student politics and reads the *Guardian*, many of the test subjects judge it more likely that she is a bank teller who is also a feminist, rather than being only a bank teller. This is of course impossible, as the probability will always be higher for a person only being a bank teller than having both qualities (Tversky & Kahnemann, 1983, cited in Gardiner & Christie, 1987).

The availability heuristic is used to make judgment about the likelihood of events: "people do this not by a judgment of statistical proportions, but by the ease with which concrete examples can be 'brought to mind'" (Gardiner & Christie, 1987, p. 93). This heuristic can be exemplified with the following example from Tversky and Kahnemann (1974): Research subjects were asked to estimate the proportion of words in the English language that starts with the letter 'R' or 'K' versus those words that have those letters in the third position. It is easy to come up with words that start with the letters 'R' (ripe, rain, rose) or 'K' (kangaroo, kitchen, kiss). Coming up with words where 'R' or 'K' is the third letter (street, care, borrow) takes a more concentrated effort. That is why many test subjects answer that words starting with an 'R' or 'K' are more common, when the reality is the opposite. Words that have 'K' in the third position are in fact three times as common as words starting with 'K'.

Gardiner and Christie (1987) add to their discussion on the design of procedures and tasks that avoiding distractions is especially important when users are meant to remember visual abstract patterns. This relates to findings on the fact that visualization is disrupted by the presence of an interfering task during the retention interval.

3.11.2 Analogy and metaphor

Gardiner and Christie (1987) see large potential in using metaphors i.e. the 'desktop' and related analogy because they make use of the user's existing knowledge, which promotes the use of helpful mental models (discussed in Section 3.4). However, they also raise a warning for mixing different metaphors and using metaphors that are not representative for the task. If there is a mismatch between how a task would be carried out in real life and the metaphor, the metaphor can be counterproductive and confusing; and the user's attitude can be more negative than if a more conventional interface had been used (Gardiner & Christie, 1987). Metaphors are powerful means to introduce the user to a system, but it is important that the tone of the metaphor matches the attitude should have towards the system, for example, using 'jokey' metaphors or labels could imply that the system is not serious. If the functions of the system differ from the real-life situation that the metaphor refers to, it is important that it is clearly communicated to the user.

3.11.3 Task-user match

The match between task and user is discussed by Gardiner and Christie (1987) mainly from an age perspective. The guidelines in this category relates to the fact that not only cognitive, perceptual and physical performance degrades with age but also the working memory performance, hence it is important to consider that older users (>55 years of age) should be asked to keep less information in the working memory than younger users.

3.11.4 Feedback

For effective user performance, feedback is crucial and is usually mentioned when discussing interface design (e.g. Cooper & Reimann, 2003, Cox & Walker, 1993, Gardiner & Christie, 1987). Gardiner & Christie (1987) divides the types of feedback related to interface design into required feedback, which always should be given during task performance to let the user know that things are progressing satisfactorily or otherwise, and confirmatory feedback; which is only needed when a task or action is completed. The type of feedback that is needed depend firstly on the user's experience and secondly on the nature of the task. Novice users will have a larger need of feedback (e.g. to be sure that an e-mail has been sent) than experienced users. Controlled tasks, which require the user to think, need both required and confirmatory feedback, if possible with redundant information, whereas automated tasks need only feedback during the task sequence, and in one form.

3.11.5 Selecting terms, wording and objects

It is important that the language of interaction is selected to be comprehensible, easy to learn and compatible with known user characteristics (Gardiner & Christie, 1987). Where possible when presenting a dialogue to the user, affirmative sentences should be used; e.g. 'When you have collected 20 s of satisfactory profiles, press Freeze' as opposed to 'Do not press Freeze until you have collected 20 s of profiles'. Gardiner and Christie (1987) relate this to how human communication skills are learned and developed according to a large set of rules.

3.11.6 Consistency

Consistency is fundamental to interface usability and contributes in facilitating learning, minimizing errors and to help the user develop an effective and accurate system model. However, it is not always evident how consistency will be acquired as it is impossible to be consistent with e.g. previous versions, other systems and in a system as well. Gardiner and Christie (1987) suggest that consistency within a system should have the highest priority, but tradeoffs will always have to be made.

One reason for aiming for consistency is to avoid user slips (actions not as planned). As discussed in Rasmussen's Skills, Rules, Knowledge model in Section 3.8, slips occur when the user is performing a task which is routine, or which the user connects strongly with other routine tasks. An example of a slip could be using Control-C for the intention of copying text on a Mac (where the correct action is Command-C), because the user is also used to writing on a PC. However, if the user has never used a Mac before, and assumes that it works in the same way, this would be a Rule-based mistake.) One solution to avoid slips suggested by Gardiner and Christie (1987) is to make similar actions tasks consistent but point out where actions differ, and make different tasks unique.

3.11.7 Screen design and organization

Screen design deals with the manner in which information is presented to the user: e.g. organization and format, spatial layout and properties. Gardiner and Christie (1987) claims that optimal performance can be reached if attention is paid to known cognitive and perceptual characteristics of human behavior. The suggestions in 'Applying cognitive psychology to user-interface design' for this category relate mainly to maintaining logical and functional relationships between items, and considering separating independent items from others.

3.11.8 Navigation

Gardiner and Christie (1987) conclude that when carrying out a sequence of tasks, the user must have a clear idea of his or her position in the system, in order to develop an accurate model of the system. It is suggested that where applicable, orienting information that is related to preceding and following screens should be placed at the top and bottom of the current screen respectively. It is also important to inform the user of the current position. The reason is to promote the development of sufficiently correct mental models (explained in Section 3.4). By assisting the user to create correct and useful mental models of a system, errors can be avoided, and the user's sense of being in controlled can be raised (Gardiner and Christie, 1987).

3.11.9 Error management

Gardiner and Christie (1987) state that two approaches need to be taken to deal with errors; firstly, prevent or reduce errors, and secondly, recover from errors that will inevitably occur. Error management is crucial to interface design, but sometimes priorities must be made between the impact of the occasional minor error compared to speed and ease of use of a system.

3.11.10 Locus of control

The locus of control in a system can range from total system control to total user control, where as a guidance, the inexperienced or occasional user might need system initiatives to be taken to a larger extent, and a large amount of assistance should be available. As a user becomes more experienced, there should be a shift in the locus of control towards the user (Gardiner & Christie, 1987).

3.11.11 Use of symbols

When should symbols be used? Research has shown that human ability to remember and quickly recall concrete items is improved when the items are presented as images rather than words (Gardiner & Christie, 1987). However, Gardiner and Christie (1987) stress that it is important that the visual representation is easily interpreted, consistent with the user's previous experiences and that it represents something that is nameable to the user.

According to Osvalder and Ulfvengren (2008), when used correctly, symbols have several advantages over text; there is no need for translation, a symbol can take up less screen space and be seen from further away, and the perception will be quicker and with a smaller margin of error.

3.11.12 Generic design guidelines conclusion

To conclude, interface design can be improved if the ease with which people categorize and use regularities is considered. This can be reflected in for example the selection of labels and designations, formatting of screens to facilitate chunking together of related information, defining how the system of screens should be organized, etc. If the categorization feature of the human memory is capitalized upon, this can allow the user to build a 'picture' of what the system can do and in which way it does it, which facilitates optimal system performance (Gardiner & Christie, 1987).

3.12 INTERFACE DESIGN

An important part of the human-machine system, and the focus of this thesis project, is the interface between the human and the machine.

In the simplified view on the machine, the functions determines the utility and the design of the interface determines the usability. However, the design of the functions themselves have influence on the usability as well, e.g. in regard to the time required and the number of steps needed to complete a task. Bligård (2010) uses the card payment terminals in shops as an example; they all include the same functionality, but the sequence and organization of different terminals result in varying levels of efficiency and usability.

The usability also depends on how well the design of the machine responds to the user's mental model of the task, which must be supported by the interface design (Bligård, 2010).

3.12.1 Interface principles and abstraction level

The organization of a user interface can be described by two dimensions; decomposition levels and abstraction levels. The decomposition levels describe the structure and logic for the interface, while the abstraction levels refer to the design principles of the interaction. Bligård (2010) describes five design principles:

- Structure-based design
- Process-based design
- Function-based design
- Task-based design
- Situation-based design

Which principle to adapt in different situations depends mainly on four factors of the characteristics of use; frequency, variation, desired precision, and complexity of the task.

To exemplify the different design principles, Bligård uses a water faucet (the mixing valve), see Table 2 and Figure 15.

Table 2. Water mixing parameters.

Input parameters	**- Hot water** **- Cold water**
Output parameter	**- Warm water**
Machine process	**- Blending of hot and cold water**
Machine control	**- Valve for hot water** **- Valve for cold water**
Goal factors	**- Water flow out** **- Water temperature out**

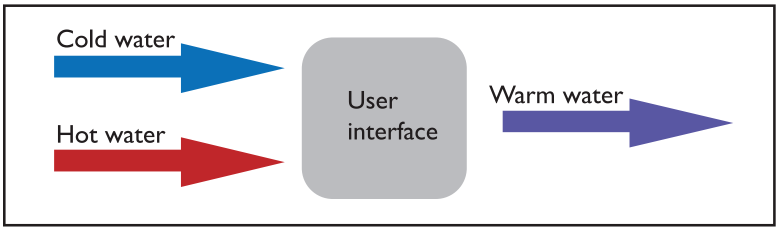

Figure 15. Water mixing task.

3.12.2 Structure-based design

The structure-based design is based on how the machine is built up, and requires the user to explicitly control the elements of the machine. For the water faucet, it means that the user controls *how open the valves* for hot and water are, respectively, see Figure 16.

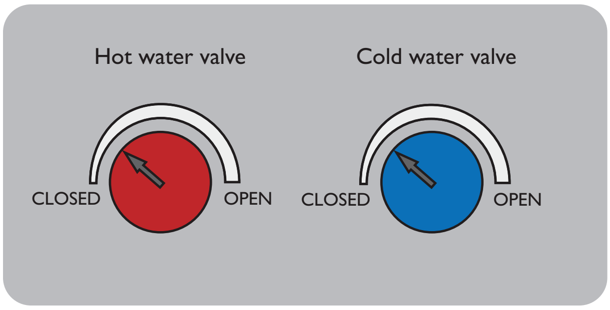

Figure 16. Example of structure-based design for water faucet. Modified from Bligård (2010).

The advantage with structure-based design is that it has a clear connection to the machine but it is not adapted to either the user's working procedure or the process of the machine.

The interface for analogue music mixer tables are normally structure-based to a high degree, see Figure 17.

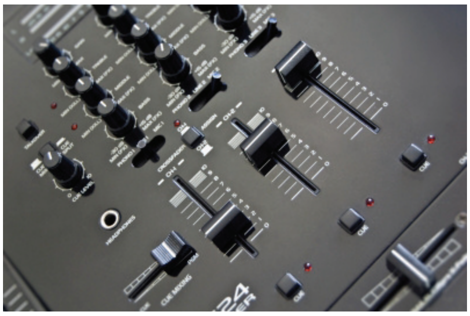

Figure 17. Analogue music mixer table.

3.12.3 Process-based design

The process-based design relates to the machine's process and the user controls the process parameters. For the water faucet, it means that the user controls the *flow* of hot and cold water respectively, see Figure 18.

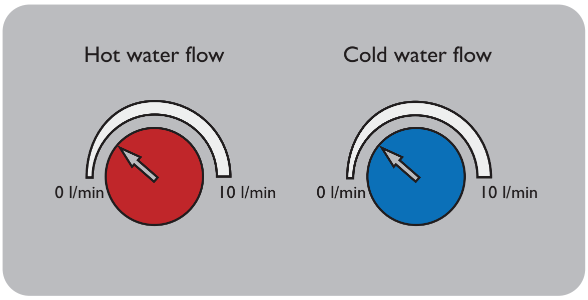

Figure 18. Example of process-based design for water faucet. Modified from Bligård (2010).

The advantage with process-based design has a clear connection with reality, but it is not adapted to the user's working procedure.

It is common to find process-based design in control room interfaces, such as for manufacturing or power plants, even though they normally include large elements of structure-based design.

3.12.4 Function-based design

The function-based design relates to the functionality of the machine, and the user controls each function. For the water faucet, it means that the user controls the water flow and the water temperature, see Figure 19.

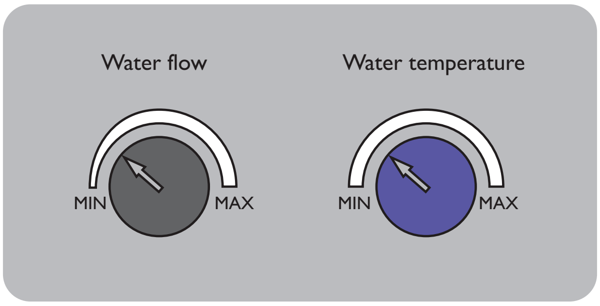

Figure 19. Example of function-based design for water faucet. Modified from Bligård (2010).

The advantages of the function-based design include that it clearly shows the possibilities and it has a clear connection to the technical function. However, it might not always be adapted to the user's working procedure.

Example of devices that are designed with the focus on functions can be found among electrical household appliances, such as espresso machines or radiators.

3.12.5 Task-based design

The task-based design focuses on the task that the system should perform, and the user controls the machine based on the current task. For the water faucet, it means that the user decides which task to perform, and then selects a choice, see Figure 20.

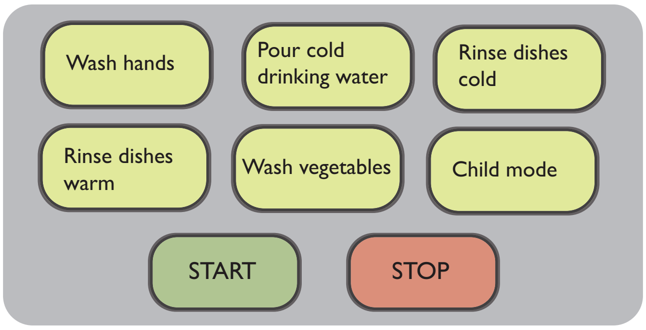

Figure 20. Example of task-based design for water faucet. Modified from Bligård (2010).

The advantage with task-based design is that it is highly adapted to the human's working procedure, but it is not clear how the machine works, and if many tasks are to be performed with the machine, the interface can become massive and inefficient.

Task-based design is common for e.g. dishwashers and washing machines.

3.12.6 Situation-based design

The situation-based design focuses on the context that the use takes place in, and the user controls against the goals to be achieved. It also means that the interface design can change to adapt to different situations, see Figure 21.

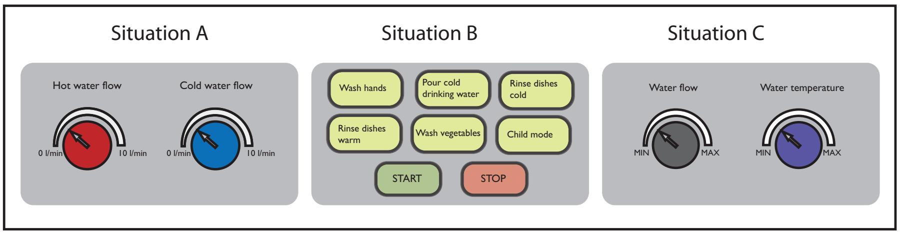

Figure 21. Example of situation-based design for water faucet. Modified from Bligård (2010).

The advantage of situation-based design is that it shows the information and the control devices that the user needs for the current situation, but on the other hand, it is not evident how the machine functions as the interface behavior changes. Also, this interface can become unnecessarily large if utilized in the wrong context. An example of where situation-based design is used is in softwares such as Microsoft Word or Adobe Illustrator. For example, imagine how the formatting palette in Word sometimes changes automatically to suit the current needs.

3.13 PHYSICAL ERGONOMICS

Ergonomics (Greek *ergon* [work], *nomos* [law]) concerns work performance with focus on worker safety and productivity. The International Ergonomics Association, IEA, defines Ergonomics (or Human Factors) as "the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance" (IEA, 2010). This section will give a brief overview of the physical aspect of ergonomics and some of the issues that should be considered in design.

The physical ergonomics area concerns human anatomical, anthropometric (body measurements), physiological and biomechanical characteristics of a workplace. Issues that are important to assess in order to prevent musculoskeletal disorders, improve workplace layout and enhance safety and health include human working postures, materials handling, and repetitive movements.

Ergonomists normally assess the ergonomics of a workplace using different checklists, which can include issues such as the physical demand and frequency of:

- Nature of action (dynamic muscular work)
- Part of body used
- Dimensions of action (turning, flexing, etc.)
- Accuracy of action
- Speed of action
- Resistance occurring (reactions of work object)
- Disturbing environmental factors

3.13.1 Anthropometric data

Anthropometric data are measures of the human body, which can be used to match design with intended users (another application is in medicine, to assess growth and body size). However, it must be considered that the data is constantly changing, and varies largely between different populations (Guastello, 2006). Population here refers to people belonging e.g. to the same sex, age group, ethnic background, etc. The first step in matching the design measurements with intended users is to determine the population to design for, and to accommodate as wide a range as possible (Bridger, 2003).

Anthropometric data is normally presented as average values with standard deviations, or in percentiles. Percentiles can be described with the following example: A selected range of values between the 5^{th} and 95^{th} percentile means that only 5 percent of the population has values lower than the range, and 5 percent has values that lie above the range, so any value in the range is are expected to suit 90 percent of the population.

It must be considered that on the one hand, sizes of body parts are often correlated, so if one body part is large, the rest of the body is often proportional. On the other hand, correlations are imperfect and sometimes low (Guastello, 2006). So e.g. when designing workplaces, care must be taken to the whole set of parameters, since designing with too much emphasis on each measurement can result in complete designs that are too small or too large for a large part of the population that the device is designed for. Guastello (2006) proposes that a way to get around the problem is to collect one's own data from a representative sample of the user population.

Different types of anthropometric data include structural, functional and Newtonian anthropometric data. Structural data are measurements of the body for static positions, while functional data represent movements of body parts in relation to a fixed point of reference. Newtonian data is used for biomechanical analyses of loads on the body (Bridger, 2003).

The lack of standardization in collecting anthropometric data together with the fact that the 'average person' is nearly impossible to find imposes a need for implementing the data with care (Bridger, 2003).

3.13.2 Acute and cumulative trauma

Musculoskeletal disorders retracted in workplace settings can be related to either *acute* or *cumulative* trauma. Acute trauma refers to an application of force of a size that exceeds the tolerance of the body structure, i.e. lifting a very heavy object. Cumulative trauma is associated with frequent application of a relatively low force, under a long period of time, wearing down the body structure. This type of trauma is becoming increasingly important to consider in workplace design as it has grown rapidly as a reason for musculoskeletal disorders as repetitive jobs are becoming more and more common in workplaces. Once inflammation and swelling in the tendons have begun, the cycle can be difficult to stop. This is why it is of essence to try to prevent cumulative trauma (Marras, 2006).

3.13.3 Body postures and movement

The upright posture, either standing or sitting, has traditionally served as a design model, however, it should be noted that no posture is perfect for humans during an extended period of time; the human body is made for movement. Human mobility (or flexibility) depend largely on age, health, fitness, training and skill (Kroemer, 2006).

Naturally, different body postures are more or less preferable, e.g. hands and feet should work areas should always be in front of the body and extreme deviations from a straight and relaxed body posture should be avoided, especially when high forces are applied (Kroemer, 2006).

The Working Postures Analysing System, OWAS, is commonly used for mapping and classifying working postures and defines an extensive range of postures which are all combinations of back (e.g. straight, bent, twisted, bent & twisted), arms, legs, head and load.

The list will not be discussed in detail, but it is related to Kroemer's (2006) list of basic work space design faults to avoid:

- twisted body positions; especially for the trunk and neck
- forward bending of trunk, neck, and head
- postures that must be maintained for a long time, especially in extreme limits of the range of motion (e.g. a rotation of about 70 degrees in each direction for the neck); especially important for the wrists, neck and back
- holding the arms raised; the upper limit for regular manipulation tasks is about chest height.

Marras (2006) claims that the shoulder part might play a much larger role in musculoskeletal disorders than previously acknowledged, second only to lower back injuries and neck pain. The shoulder has a complex structure, and can be hard to repair should problems develop. It is suggested that the angle of shoulder abduction (movement in the horizontal plane) should optimally not exceed 30 degrees from both a strength and fatigue standpoint. Also, even slight shoulder flexion (movement 'forward/backward') has been shown to dramatically increase fatigue (Marras, 2006).

Another common problem area is the wrist, which has been of increased interest for ergonomists over the last three decades. The optimal wrist position is in a neutral position, as any deviation results in a lower grip strength, and repetitive wrist motion with high frequency is identified as a risk factor for cumulative trauma. This is especially important when high loads are applied on the wrists, as this always increase the risk of discomfort and injuries (Marras, 2006).

A standing up position is generally preferable to sitting down, as the latter induces a higher load on the intervertebral discs, increasing the risk of back injuries. Objects that are to be manipulated should then be placed between hips and shoulder height of the human, to avoid a need to bend forwards or having to work with arms elevated (Bridger, 2003). Marras (2006) suggests a height between 95 to 110 cm above floor level. The most preferred height of the object, however, is always a trade-off between different parts of the body, e.g. between shoulders and neck. For work which requires high visual accommodation the work area should be placed higher than for work which is less precise. If prolonged work is required at a high level, problems can be minimized through shoulder and wrist support (Marras, 2006).

3.14 THE DEVELOPMENT PROCESS FROM A HUMAN-MACHINE PERSPECTIVE

The product development process that has been used in this work is based on the first phases of the process developed by Lars-Ola Bligård's Utvecklingsprocessen ur ett människa-maskinperspektiv (The Development Process from a Human-machine Perspective) (Bligård, 2010). The different phases of the process are seen in Figure 22, where the two last phases, which are not represented in this thesis project, are shaded in grey.

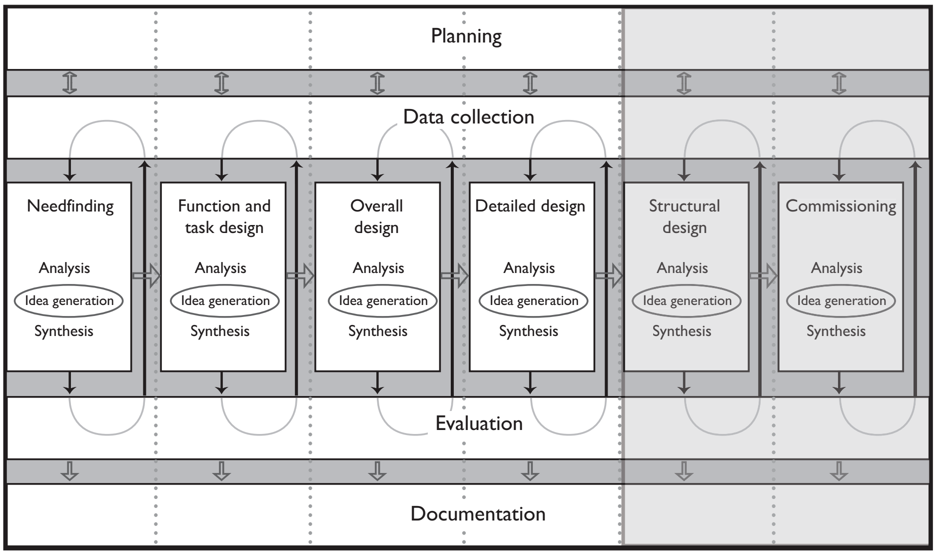

Figure 22. Modified model of the Development Process from a Human-Machine Perspective, by Bligård (2010).

Brief descriptions of all the phases in Bligård's process are presented below.

3.14.1 Planning

The planning activity is the first phase of the process, but must continue to be corrected and developed throughout the process, depending on the found data. It is illustrated as a parallel and continuous activity in Figure 22.

The first action is to clarify the purpose and goal of the product development process and make sure that all concerned parties have agreed on the premises.

In an organization, every product development project should have a human-machine system group that are responsible for planning and managing the work dealing with the human-machine activities in the project. This group should include people with good knowledge on ergonomics and human-machine activities as well as people on a system level, such as project leader, product manager and system engineers. Users can also be included in the group, or be represented in a separate user group.

3.14.2 Data collection

Because it is very difficult to know which pieces of information that will be relevant to collect throughout the project, and due to the fact that new information needs will arise during the course of the work, the data collection is described as another parallel and continuous activity in the development process.

Information should be collected regarding the user, the task, the environment (physical, psychological and social) as well as technical solutions.

According to Bligård's report (2010), to be able to consider human factors in relation to the machine, the following aspects are central when collecting data:

- Which tasks will the machine perform (system goals)?
- Which functions will the machine have?
- Which other machines will it be used with?
- Where will the machine be used?
- Which needs and demands do users have on the machine and the usage?
- What standard demands and guidelines (internal and external) and literature of reference are there?
- What are the positive experiences and problems with the old machine?
- What technical solutions are used today to perform the task?
- What future technical solutions are expected?
- The results from continuous assessments throughout the duration of the project.

Methods suggested by Bligård (2010) for data collection include literature studies, earlier project documentation, observations, interviews, surveys, focus groups, log studies, incident or deviation reports.

3.14.3 Evaluation

Evaluation is illustrated as a parallel activity in the development process by Bligård (2010), as it is important to continuously assure the quality of the machine. The evaluation should involve the aspects of usability, utility, use, performance and risk that the machine concerns. The earlier potential faults and weaknesses in the construction are found, the simpler and less costly they are to address.

3.14.4 Documentation

The last parallel activity, illustrated the furthest down in Figure 22, is the documentation, which aims to clarify and communicate the ongoing development process. In larger project, it is common to use special computer programs for keeping track of the different versions of the project documents. The documentation can include e.g. project plan and instructions, meeting and decision protocols, and requirement and design specifications.

3.14.5 Needfinding

The first of the sequential phases of the development process is the needfinding phase, to examine the prerequisites for the product development. The human-machine activities during the needfinding are done to understand the user and the usage; the situation and the problem (Bligård, 2010).

The first stage of the needfinding phase is to examine and describe the problem and the task for the development. The intended usage and users should also be examined and described, and the user needs should be elicited. Furthermore, the usability focus and efficiency goals for the human-machine system should be set up. It is also relevant to understand the company and the market, so a study of these factors should also be carried out during the needfinding phase.

The next stage is to define the Design specification, that is based on the use and user demands that were collected during the needfinding phase, and also from the design of function, task and use that have been decided on in this phase. The Design specification defines the prerequisites for enabling the intended usage of the machine and consists of the Task specification, Intended user and use specification and the usability orientation.

The final stage in this phase consists of the definition of the usability needs specification, which includes the usability needs, the effect goal and the utility level for the machine.

3.14.6 Function and task design

The Function and task design phase is carried out to clarify the function and intended use of the machine and to start designing the functions and tasks that the machine should perform. This phase forms the base for the development work, and if the activities are not carried out satisfyingly, this will have effects on the subsequent phases of the development. The data collection in this phase concerns more detailed information on the users, use, existing machines and technical solutions than that collected during the needfinding phase, and should be aimed to the intended users and use than the previous phase resulted in.

The first activity in this phase is to define the overall usage of the machine, e.g. by creating personas and scenarios. When this is done, the system functions should be analyzed and allocated between the human and the machine, as some tasks are better performed by one than the other.

The tasks that are to be performed by the human should then be analyzed, e.g. by performing Use cases and a Hierarchical Task Analysis, HTA. Ideally, all potential usage scenarios should be looked at, to avoid sub-optimizing the system. The same is done for the machine tasks and the result is compiled in a function description.

The output of this phase is the definition of specified Usability requirements and guidelines and Usability goals which should later be used to validate the development. The usability needs that were elicited in the needfinding phase should be validated against the usability requirements, to ensure that all needs are covered.

3.14.7 Overall design

The second design phase in the development process is the overall design, where the purpose is to find possible design solutions for the overall design, while avoiding locking in solutions too early. Complementary analyses of the usage and users might have to be carried out in this phase.

The first stage in this phase concerns the use; how should the user tasks be carried out in order to enable an ergonomic use, from both a physical and cognitive perspective? The second stage is to consider the environment i.e. light, noise etc. that will influence the usage; how can the machine be designed to use this information for an optimal interplay? The third stage deals with the interaction between the human and the machine; which steps and decisions should the user take?

The goal of this phase is to come up with one design concept that fulfils the usability goal and demands.

3.14.8 Detailed Design

When the overall design has been decided upon, the detailed design can start. In an organization, this phase includes designing the final function, physical form and interaction, as well as the design of manuals and training.

This thesis project include partly detailed design of the interface, represented later by redesign suggestions. However, they do not cover all aspects of the interface, and no design of manuals or training was carried out.

3.14.9 Structural design

The purpose of the structural design phase of the development process is to determine the final structure of the machine and the goal is to produce manufacturing material. The human-machine activities during this phase include testing the structure, performing a final risk analysis, and verifying and validating the structure.

The structural design phase was not included in this thesis project.

3.14.10 Commissioning

The final sequential part of the development process is the Commissioning phase, where the machine is taken to use in the fully functioning human-machine system that performs the intended tasks in the intended environment. This phase includes e.g. verification and validation of the machine performance, training of users, and follow-up on usage.

The commissioning phase was not included in this thesis project.

3.14.11 The development process with focus on interface design

The design of the interface should be considered throughout the development process of the machine, and below is a description of the issues to consider for interfaces in particular (Bligård, 2010).

Interface overall design

- Abstraction levels of interface design

  Decide on which levels of abstraction that the interface should act for information displays and control devices (see Section 3.12)
- Technical principles

  Decide which technical principles to use in the interface
- Overall design

  Decide on the overall design and functioning of the interface, including a suitable decomposition of the interface
- Design guidelines

  Draw up guidelines for the more detailed design of the interface

Interface detail design

- Organization of functions

  Describe how functions should be organized in the interface, e.g. in menu systems
- Detailed design

  Design the appearance and functioning of the interface in detail

4 HUMAN FACTORS ENGINEERING METHODS

This chapter presents and exemplifies the Human Factors Engineering methods that were used in this thesis project; for interface evaluations as well as different product development support methods. The methods are listed in order of appearance.

4.1 PERFORMING USE TESTS

Use tests are evaluations of the user interface, performed with test users that are as representative as possible of the intended end users. Nielsen (1993) classify the tests as either *formative* or *summative evaluations*.

Formative evaluations are done to improve the interface as part of an iterative design process, and the goal is to find positive and negative aspects of the design. A typical example is a thinking-aloud test, where the user is asked to interact with the interface to reach specific goals, while constantly describing his or her actions. The purpose is to find out where the problems in the interaction lie; situations in where the user cannot easily describe the next step and hesitates or becomes quiet. The experimenter will normally have to prompt the user to keep thinking aloud while not interfering with the interaction, such as asking questions about issues that the user might not have noticed yet.

Summative evaluations assess the overall quality of the interface and are used for competitor benchmarking or for selecting between different design solutions. A typical example is a measurement test, where usability attributes such as *learnability* and *efficiency of use* (see Section 3.3) are assessed through goals that are specifically set up for the interface in question, e.g. as the time it takes users to perform a certain number of specified tasks (Nielsen, 1993).

4.2 PERSONA-BASED SCENARIOS

When designing of a broad audience of users, it is tempting to design as broadly as possible, including all available functionality to please the most people. However, as Cooper and Reimann (2003) states, this approach will lead to a product with every possible feature but that pleases nobody. Cooper and Reimann (2003) further claim that software today is too often designed in this manner, resulting in a low user satisfaction.

One method for dealing with this problem is to focus on specific types of individuals with specific needs , and create *personas* to illustrate them. Cooper and Reimann (2003) explain personas as a means to help designers:

- **Determine** what the product should do and its behavior
- **Communicate** with stakeholders, developers, and other designers
- **Build consensus** and commitment to the design
- **Measure** the design's effectiveness, albeit not replacing the need for user tests
- **Contribute** to other product-related work, such as marketing and sales plans

The personas should be based on real-world observations, and are meant to engage the empathy from the development team. The fact that names and attributes, such as cars and family members, are sometimes given to personas is to support the feeling of connection between designer and persona. However, specific fictional attributes are not ends in themselves and should be used sparingly, just enough to make the personas 'come alive' (Cooper and Reimann, 2003).

The developed personas can be employed as the main characters in a set of *scenarios*, narrative stories to communicate, generate, and validate design ideas. Cooper and Reimann (2003, p.76) define persona-based scenarios as "concise narrative descriptions of one or more personas using a product to achieve specific goals". They also state that scenarios should be anchored in the concrete, but allow for fluidity; other members in a design team should be able to modify the scenarios.

4.3 USE CASES

Use cases are employed to give a generalized description of the *usage* of a system and to get an overview of the system *functionality* as well as finding *use needs* (Bligård, 2006). The use case concept was first presented by Ivar Jakobson in 1986 and has developed over the years to become an important means of specifying software. It is a structured way of describing what a system does (or should do), and can be depicted in diagrams, but are principally described in text as a narrative (Bittner & Spence, 2003).

Use cases are primarily a way to express a system's behavioral requirements, either functional (define the required behavior of a system) or non-functional (other qualities or constraints to which the system must conform). The basic idea behind use-case modeling is to focus on *who* (or what) will *use* a system, or be used by it, in order to get to the heart of what the system must *do*. After this, one must find out what the system must do for those users to become *useful* (Bittner & Spence, 2003).

A use case is a description of a system seen from the outside, and describe a goal oriented narrative of interaction between external actors and the system. The actors can be primary; initiating the interaction to reach the goal (e.g. a nurse who controls a ventilator), or secondary; actors who react to the system's actions (e.g. a patient receiving treatment) (Bligård, 2006).

The use case typically first list the basics for usage, e.g. who/what the actors are, where the use takes place, the external prerequisites for use, the system's limits and the conditions that must be met for the use to start, etc. Then follows a sequence where the primary actor tries to fulfill his or her goal. The use case can include possible extensions of the sequence, e.g. alternative routes that can be taken to fulfill the goal, or actions that lead to an unfulfilled goal. Use cases are normally written after a template, however, the exact layout can differ. Some guidelines for use case writing are to use terminology in the users' knowledge domain, and keep it general, as opposed to going into too much detail in describing the interaction (Bligård, 2006).

Bligård (2006) claims that use cases are a good way to initiate a human-machine interaction analysis, in order to get a good overview and define the components of the system: human, machine, environment and task. The use cases then form the basis for the continued analysis of those components. In this thesis, the use cases are based on a template suggested by Lars-Ola Bligård (2006).

Persona-based scenarios and use cases are both narrative ways of describing a system but serve different functions. Whereas scenarios define the behavior of a system from the standpoint of the personas, and allow for priorities between different functions, use cases are descriptions of functional requirements that focus on a low-level user action and system response (Cooper & Reimann, 2003).

4.4 DESCRIPTION OF HIERARCHICAL TASK ANALYSIS

Hierarchical Task Analysis (HTA), is one of the most common and popular task analysis methods employed in Human Factors (HF) (Stanton, Salmon, Walker, Baber & Jenkins, 2005). The task is broken down into a hierarchical system of goals, sub-goals, operations and plans, usually illustrated in a HTA tree diagram, exemplified in Figure 23. The main goal is first specified, in the top of the hierarchy, followed by a breakdown of the goal into meaningful sub-goals which form the *nodes* of the HTA. The breakdown continues until a sufficient level of detail has been reached, and the lowest level in the HTA can be considered single *operations*. A node together with its underlying nodes and operations is called a *function* (Bligård, 2007).

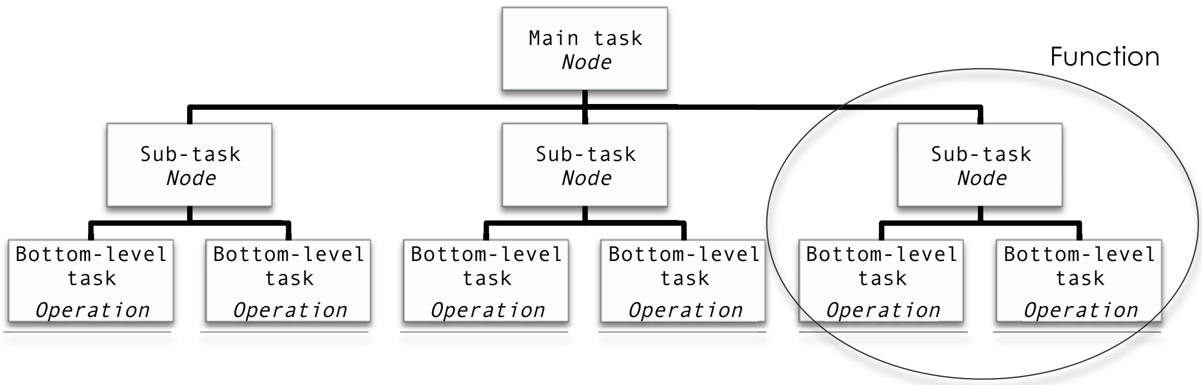

Figure 23. HTA tree with nodes, operations, and functions. Modified from Bligård (2007).

HTAs serve as input to many other HF methods, e.g. cognitive walkthroughs and error analyses. It was originally developed as a need arose to analyse the cognitive aspect of tasks in the chemical processing and power generation industries but it is now widely used in a large range of domains, as it is a generic method that can be applied to all types of tasks (Stanton et al., 2005).

4.5 HEURISTIC EVALUATIONS

The adjective *heuristic* (from Greek: heuriskein=find) is defined as "enabling a person to discover or learn something for themselves" (Oxford Dictionary, 2010) and describes finding a solution by trial and error or by rules of thumb.

In heuristic evaluations, a usability tester inspects an interface, preferable in relation to a set of *heuristics*, usability principles. The goal is to find all the potential usability problems in the interaction (Nielsen, 1993).

Heuristic evaluations can be performed by a single evaluator, but ideally, a larger number of people, at least three, should make their own evaluations of the interface in order to find a sufficient amount of the usability issues. Nielsen (1993), who has been the main developer of the methods, states that only around 35% of usability issues are found by a single evaluator, and that about five people is probably needed for a satisfying result.

Zhang et al. (2003) developed the heuristic evaluation method further, especially for medical devices. They state 14 heuristics that they recommend be evaluated, and the found usability problems should be graded on a scale from zero to four in severity. Zhang et al. (2003) have named them the 'Nielsen-Shneiderman Heuristics' as they are largely based on the two usability researchers' work. Below is a shortened list of the 14 heuristics (2003, p. 25-26) :

> "1. *Consistency and standards.* Users should not have to wonder whether different words, situations, or actions mean the same thing. Standards and conventions in product design should be followed.
>
> 2. *Visibility of system state.* Users should be informed about what is going on with the system through appropriate feedback and display of information".
>
> 3. *Match between system and world.* The image of the system perceived by users should match the model the users have about the system.
>
> 4. *Minimalist.* Any extraneous information is a distraction and a slow-down.
>
> 5. *Minimize memory load.* Users should not be required to memorize a lot of information to carry out tasks as it reduces users' capacity to carry out the main tasks.
>
> 6. *Informative feedback.* Users should be given prompt and informative feedback about their actions.
>
> 7. *Flexibility and efficiency.* Users always learn and users are always different. Give users the flexibility of creating customization and shortcuts to accelerate their performance.
>
> 8. *Good error messages.* The messages should be informative enough such that users can understand the nature of errors, learn from errors, and recover from errors.
>
> 9. *Prevent errors.* It is always better to design interfaces that prevent errors from happening in the first place.
>
> 10. *Clear closure.* Every task has a beginning and an end. Users should be clearly notified about the completion of a task.
>
> 11. *Reversible actions.* Users should be allowed to recover from errors. Reversible actions also encourage exploratory learning.
>
> 12. *Use users' language.* The language should always be presented in a form understandable by the intended users.
>
> 13. *Users in control.* Do not give users the impression that they are controlled by the system.
>
> 14. *Help and documentation.* Always provide help when needed."

The list above corresponds quite well to the Generic guidelines based on cognitive psychology that were presented in Section 3.11 but where Gardiner and Christie (1987) speak more generally about design guidelines, the Heuristics above are well organized and exemplified by Zhang et al. (2003) in the paper 'Using usability heuristics to evaluate patient safety of medical devices', to allow for grading usability issues.

4.6 ENHANCED COGNITIVE WALKTHROUGH

Enhanced Cognitive Walkthrough (ECW) is an inspection method that was developed by S Wass and L-O Bligård (Bligård, 2007) to overcome some of the detected deficiencies with the already established method Cognitive Walkthrough. ECW aims to simulate the user's problem-solving process in each step of the human-machine interaction in order to detect usability problems and to give an overview of the problem types and seriousness. It can be conducted by one person or a group. The most important factor is that the evaluators have knowledge about the actual usage and the users, or that users are present in the evaluating group.

ECW consists of three phases: preparation, analysis, and compilation in matrices. Before the method is employed, the identification of intended users and use must be made (Bligård, 2007).

The **preparation** phase includes the following parts: (1) selection and grading of tasks (*task importance*) for evaluation of interaction that is based on the intended use, (2) specification of the tasks (done by HTA, explained in Section 4.4), (3) specification of the user interface of the artefact in question, and (4) specification of users and the use situation. This is a crucial phase as if the information collected is deficient, incomplete or wrong, the results from the analysis will not be valid (Bligård, 2007).

The **analysis** phase is based on a set of questions that are posed for all the tasks. The questions are divided into two levels; the first applies to tasks/functions, whereas the second level applies to operations. The following questions are asked for the two levels of interaction (Bligård, 2007, p. 40):

Level 1: *Analysis of tasks/functions*

1. Will the user know that the evaluated function is available?
2. Will the user interface give clues that show that the function is available?
3. Will the user associate the right clue with the desired function?
4. Will the user get sufficient feedback to understand that the desired function has been chosen?
5. Will the user get sufficient feedback to understand that the desired function has been performed?

Level 2: *Analysis of operations*

1. Will the user try to achieve the right effect?
2. Will the user be able to notice that the correct action is available?
3. Will the user associate the correct action with the desired effect?
4. If the correct action is performed, will the user see that progress being made towards the solution of the task?

Each answer is justified with a *failure* or *success story*, also called the *problem severity*, and graded from 1 (Very little chance of success) to 5 (Very great chance of success). To each usability problem that is found, a *problem type* is then linked:

- User – the problem is due to user's previous experience and knowledge

- Hidden – the use or existence of the functionality is not clear
- Text/icon – placement, appearance and content is easily misunderstood
- Sequence – the order in which functions and operations should be taken is not natural
- Feedback - the user does not receive sufficient signals of what is happening or has been done

The last phase is the **compilation in matrices**, where different combinations of the four types of data collected in the analysis are made, in order to emphasize different aspects of the analysis. The four types of data are: *task number*, *task importance*, *problem severity* and *problem type*. Five possible matrices are suggested by Bligård (2007), e.g. Problem severity versus task importance (shows general condition of the interface) and Problem type versus task number (shows what type of usability problem that is the most common in the tasks).

4.7 PREDICTIVE USE ERROR ANALYSIS

Predictive Use Error Analysis (PUEA) is a theoretical analysis method to detect potential errors in the interaction and was developed by L-O Bligård (Bligård, 2007). It was a further development of the methods Action Error Analysis (AEA), Systematic Human Error Reduction and Prediction Approach (SHERPA), and Predictive Human Error Analysis (PHEA). PUEA was developed to counteract detected deficiencies in the listed methods, and to employ cognitive theory in the analysis, take into considerations the difference between functions and operations, and create a better way of presenting the results.

As with ECW, it is important that PUEA is conducted by a person or a group with knowledge of the use and the users. The **preparation** phase is similar to the first phase of ECW and the methods are well suited to be carried out together. The **analysis** phase of PUEA, a question process, is employed to identify potential incorrect actions, based on an interaction with correct handling sequences. The questions are (Bligård, 2007, p. 43):

Level 1: Analysis of tasks/functions

- What happens if the user performs an incomplete operation or omits an operation?
- What happens if the user performs an error in the sequence of operations?
- What happens if the user performs functions/tasks correctly at the wrong time?

Level 2: Analysis of operations

- What can the user do wrongly in this operation?
- What happens if the user performs the operation at the wrong time?

Potential errors discovered are noted and described according to the eight items in Table 3.

Table 3. Items of investigation for PUEA. From Bligård (2007, p. 43).

#	Item	Explanation
	Type	What is the type of use error? (categorization)
2	Cause	Why does the use error occur? (description and categorization)
3	Primary consequence	What is the direct effect of the use error? (description)
4	Secondary consequences	What effects can the use error have that lead to a hazardous situation for the user or other people, or to risk of machine damage or economic loss? (description and judgment of severity by a grade)
5	Detection	Can the user detect a use error before it has any secondary consequences? (description and judgment of severity by a grade)
6	Recovery	Can the user recover from the error before any severe consequences arise? (description)
7	Protection from consequences	Which measures does the technical system employ to protect the user and the environment from the secondary consequences?
8	Prevention of error	Which measures does the technical system employ to prevent occurrence of use errors? (description)

The final phase is the **compilation in matrices**, where five types of information from each investigation of use errors are suitable to combine in various ways to present different aspects from the analysis: Secondary consequences, Error type, Error cause, Detection and Task number. Bligård (2007, p. 44) lists ten variants of useful matrices, e.g. Consequences versus task number (shows which tasks involve use errors with the worst consequences) and Error type versus task number (shows what types of use errors occur in the different tasks.

4.8 SYSTEM FUNCTION ANALYSIS AND ALLOCATION

A useful system must contain functions, which are investigated by doing a function analysis. This allows for a function allocation to be made, which clarifies which functions in the system are best performed by a human, and which functions are advantageous to automate and allocate to the machine. The human strength is the ability to perceive and interpret information and to correspond correctly in a *variable* environment, something still not fully mastered by automated. Accordingly, humans must be allocated highly cognitive tasks (Mital, Motorwala, Kulkarni, Sinclair & Siemieniuch, 1994).

Mital et al. (1994) divide all manufacturing systems into three basic categories: predominantly manual (all functions require some type of human intervention), hybrid (some functions require human intervention, some not), and fully automated systems. The functions in these hybrid systems can be grouped in one of the following categories (Mital et al., 1994): (1) functions that can only be performed by humans, e.g. high level decision-making, (2) functions which can only be performed by machines, e.g. water-jet cutting, and (3) functions that both humans and machines can perform. This third type of functions in hybrid systems rises the question of human-machine function allocation. A poor choice can result in inefficiency, productivity loss, ineffectiveness and unnecessary costs, accidents, and injuries, according to Mital et al. (1994) who claim that each function must be thoroughly and systematically analyzed before it is allocated to either human or machine.

Mital et al. (1994) further present decision models for function allocation that will not be discussed in detail; the main issues discussed however, are human safety, economical benefit of automation versus human performance, whether technology to automate is available or not, and workplace ergonomics.

4.9 APPLIED COGNITIVE TASK ANALYSIS

Applied Cognitive Task Analysis (ACTA) was presented by Klein Associates Inc. in 1998 (Militello & Hutton, 1998) as a further development of the method Cognitive Task Analysis. It is an interview method that focuses on the cognitive elements, mental demand and level of expertise that is used to accomplish a certain task. It is used to detect difficult aspects of the task, to understand expert strategies for efficient ways of working, and to identify the errors that a novice could potentially be at risk of doing.

ACTA consists of tre parts: task diagram, knowledge audit and simulation interview. Ideally, three to six task experts are interviewed, and the result is compiled in tables over the cognitive demands that are needed in order to carry out the task successfully (Militello & Hutton, 1998).

<u>Task diagram</u>

The purpose of the first part is to get a good overview of the task, which is divided into three to six sub tasks. It is then identified which of the sub tasks that require cognitive skills; i.e. thinking skills such as problem solving, judgments and assessments. The task diagram is supposed to work as a 'road map' for the rest of the interview (Militello & Hutton, 1998).

<u>Knowledge audit</u>

The second part provides details and examples of cognitive elements of expertise; it contrasts what experts know and novices do not. The purpose is to receive detailed information about a certain task and to understand which aspects of the task that are difficult to carry out.

The knowledge audit examines the different aspects of expertise by posing the following probe questions (Militello & Hutton, 1998, p. 1622):

1. **Past and future**. Experts can understand how a specific situation has developed, and are able to imagine the future development of the situation. This allows the experts to stop problems from emerging. '*Is there a time when you walked into the middle of a situation and knew exactly how things got there and where they were headed?*'

2. **Big Picture**. Novices might not understand the whole situation in the way that an expert can. '*Can you give me an example of what is important about the Big Picture for this task? What are the major elements you have to know and keep track of?*'

3. **Noticing**. Experts can detect cues and patterns that novice users might not notice. *'Have you had experiences where part of a situation just "popped" out at you; where you noticed things going on that others didn't catch?'*

4. Job Smarts. Experts combine procedures and tasks in a more efficient manner than novices. Without cutting corners, experts can avoid wasting time and resources. *' When you do this task, are there ways of working smart of accomplishing more with less – that you have found especially useful?'*

5. Opportunities/Improvising. Experts are generally more prone to improvising and seeing what will work in a particular situation. '*Can you think of an example when you have improvised in this task, or noticed an opportunity to do something better?'*

6. Self Monitoring. Experts are aware of their own performance, and are able to change it in order to get the job done. *'Can you think of a time when you realized that you would need to change the way you were performing in order to get the job done?'*

The following probe questions are optional parts of the knowledge audit:

7. Anomalies. Experts can identify atypical situations, spot unusual events, and detect deviations from the norm. '*Can you describe an instance when you spotted a deviation from the norm, or knew something was amiss?'*

8. Equipment Difficulties. Novices usually trust the equipment, whereas an expert can be more sceptical to misleading information. *'Have there been times when the equipment pointed in one direction, but you own judgment told you to do something else? Or when you had to rely on experience to avoid being led astray by the equipment?'*

For each of the questions above, the respondent is asked to come up with an example for which the following questions are asked: *'How would you know this? What cues and strategies are you relying on? In what way would this be difficult for a less-experienced person? What makes it hard to do?'*

The results from the knowledge audit are to be compiled in a table for a good overview.

<u>Simulation interview</u>

The third and last part of ACTA is the simulation of a scenario that the respondent is introduced to. It offers an image of the task in its context and is used to identify the cues that are used for assessments, the strategies that are used to solve tasks and to identify novice use errors. The respondent is asked to identify the important *events* in the simulation, which could be assessments that were made, or decisions that were taken. The respondent is then asked to specify which *actions* that (s)he would take in the specific event, which *assessments* of the situation that (s)he makes, which *critical cues* that led to those actions and assessments, and the potential *errors* that the respondent believes that a novice use would be likely to do in that situation. The results from the simulation interview are compiled in a 'cognitive demands table', with suitable headings that provide a good analysis format for the specific task (Militello & Hutton, 1998).

5 DESCRIPTION OF WORK PROCEDURE

This chapter presents an overview of the actual work procedure that was employed in this thesis project.

The basis for the thesis development work was The Development Process from a Human-machine Perspective, as presented by L-O Bligård (2010). The method was presented in Section 3.14, and the following chapter aims at describing the actual work procedure that was employed in this thesis project, and its couplings to the development process described earlier. The work procedure for this thesis was iterative, with constant modification of the plan, data collecting, evaluation and documentation. The work procedure is illustrated in Figure 24, where the different stages refer to the sections in this chapter.

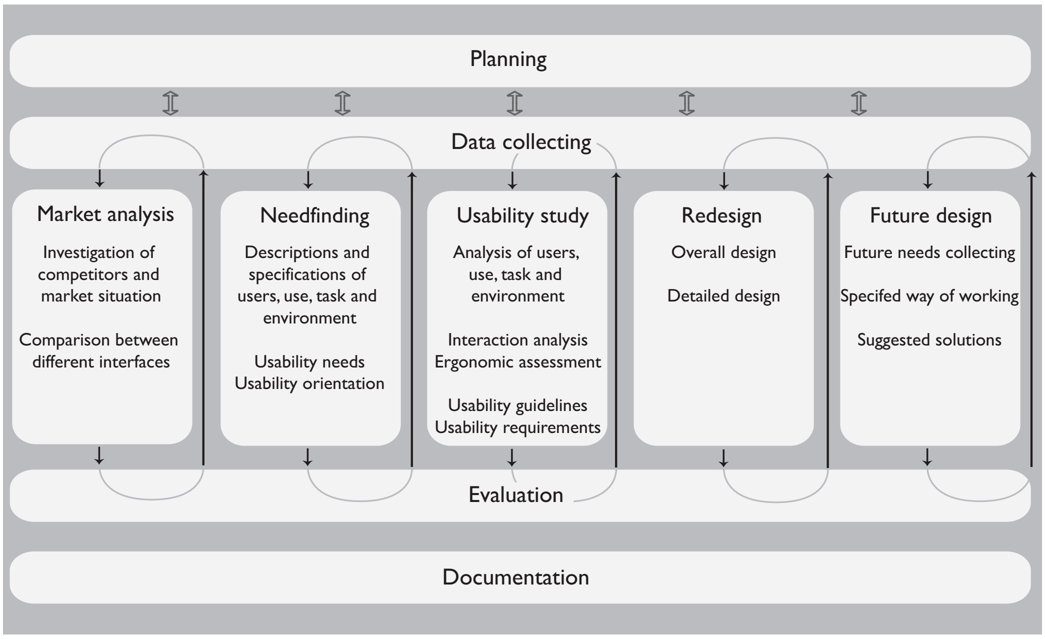

Figure 24. Work procedure description for this thesis.

5.1 PLANNING DESCRIPTION

The first phase of this thesis project was planning the work together while collecting basic information about the product USCOM and the company Uscom Ltd. This was to ensure that the work would be structured and to define the aim and goals. The planning was continuous, and subject to changes during the course of the work. A planning report was written as a part of the examination for this thesis.

5.2 DATA COLLECTING DESCRIPTION

The data collection is a very important part of any product development process and must continue throughout the work, as it is impossible to know exactly what pieces of information that will be needed in later phases. Also, needs for new information might arise as findings are made.

The main source of information when developing new products is studying the users and usage in reality (if possible) as it is impossible to reach a satisfying result without having an idea of what the real-life application of the product will look like. Information about the USCOM was collected regarding the user, the task, the environment as well as technical solutions, through literature studies, interviews with physicians and nurses, use observations, and use tests.

To find out finding out who the intended users of the USCOM are, and what specific qualities and needs they have in their use; study visits were made to two hospitals in Australia; The Royal Prince Alfred (RPA) Hospital in Sydney, and Bathurst Base Hospital (BBH), in Bathurst, a small town a few hours by train outside Sydney, Australia. The USCOM is not used at RPA, but all patients are hemodynamically monitored with the use of Pulmonary Artery Catheters. Consequently, it was of interest to study the users and the environment there, and examine other equipment in the Intensive Care Unit. At BBH, also the actual use of the USCOM could be studied as it is being used to a large extent there, especially in the ICU and the operating theatres. The USCOM has been developed in collaboration with physicians at BBH, so several of their users are considered expert users, but not all.

The data collection for this thesis also consisted of literature studies of the following subjects: other Master theses for inspiration and guidance, Human Factors Engineering methods, human cognitive processes, design, product knowledge and related subjects, such as Doppler technology and hemodynamics, in order to understand the needs. Also, information about competitors and other medical equipment, and standards and regulations for medical equipment development were studied to ensure that no interface changes that conflict with the rules would be suggested.

Surveys regarding the use were sent out to different parts of the world to support the qualitative methods that were used with a quantitative method to support design choices, but unfortunately no responses could be collected.

5.3 MARKET ANALYSIS DESCRIPTION

The first phase of the actual development process was the market analysis, where the most relevant competitors to Uscom Ltd. were investigated. The interfaces of other cardiac monitors and also of patient monitors were compared to USCOM and the results were compiled in a structured table.

5.4 NEEDFINDING DESCRIPTION

The next step in the process was the needfinding, where efforts were made to understand the intended user and the usage, and to examine the different situations that the USCOM is used in. The needfinding consisted to a large extent of data collecting and the result was the specification of the task, the intended user, the intended use, and a defined orientation for the usability of the USCOM. It also resulted in a list of usability needs, and the specification of an Effect goal for the USCOM and a specified level of Utility.

The examination of the company and the market is part of the needfinding process, but is presented in a separate chapter in the report. The intended use of the USCOM is therefore briefly presented in Chapter 1 and more thoroughly explained in Chapter 1.

5.5 USABILITY STUDY DESCRIPTION

After the identification of the intended users and use from the needfinding phase, the work of start designing the functions and tasks that the human-machine system should perform could start. The function and task design phase forms the basis of the development work and is important for the rest of the development activities. It was decided to present the function and task design phase together with an interaction analysis as well as ergonomic analysis of the existing product; the chapter that includes the function and task design was named Usability study.

The user, task, and interaction was further analysed in this stage, and data was continuously collected; in this phase it concerned more detailed information about the intended users, use, existing machines and technical solutions. Different Human Factors Engineering methods were applied, to examine the task as well as the interaction. During the course of the work, new, elicited usability needs were added to the list, and finally, they were translated into more specific requirements and more general guidelines, as well as a set of usability goals. These could be used in future evaluations of the interface usability. The usability requirements and guidelines were ultimately validated against the needs, to ensure that all the aspects of the interaction were addressed.

5.6 REDESIGN DESCRIPTION

The redesign suggestion of the USCOM is presented in Chapter 0, which comprises the phases Overall design and Detailed design in The Development Process from a Human-machine Perspective.

The new, intended overall use was first described, and design decisions were made to comply with the use. Different possible interface organizations and abstraction levels (as described in Section 3.12) were considered, and color coding and concept design for the USCOM was decided on.

Secondly, the detailed design of the USCOM was exemplified by the construction of fictional screenshots of the interface, modelled with the use of Adobe Illustrator. The redesign was fully based on the usability requirements and guidelines from the usability study, and serves to present the changes to the company and the reader, in a way that is easily comprehensible and firmly linked with reality.

5.7 FUTURE INTERFACE DESIGN SOLUTIONS DESCRIPTION

The research for the future development of the USCOM interface is based on how it is believed that the future use will be carried out. Interviews with physicians were carried out, in order to establish the diagnosis and treatment procedure of patient conditions. The results formed the prerequisites for the use, and different future design concepts were constructed.

5.8 EVALUATION AND DOCUMENTATION DESCRIPTION

The evaluation of this thesis project was done through regular telephone meetings with the supervisor and feedback from the product development department at Uscom Ltd.

The documentation of the project is in this case the report itself.

6 CARDIAC OUTPUT MARKET ANALYSIS AND INTERFACE COMPARISON

This chapter briefly analyses the cardiac output (CO) monitor market and the main competitors to Uscom Ltd; discussed with focus on the systems' user interfaces. Also, interfaces of hospital equipment that the USCOM might work together with will be briefly discussed and compared.

6.1 CARDIAC OUTPUT MONITOR MARKET

The market leader and current 'gold standard' in clinical use for measuring CO, and which new methods are compared against, is currently the Pulmonary Artery Catheterization (PAC) also commonly known as Swan-Gantz catheters. PAC is an invasive method, associated with risk of injuries and infections, and studies have shown that the risk with using PAC can actually be higher than the gain (Binanay et al., 2005; Connors et al., 1996).

The use of PAC has decreased over the last decades due to the high patient risk and high cost (Smartt, 2005) and cardiac output measurements are not believed to be carried out to their potential extent, as it could by using less invasive methods (Lidco, 2010; Uscom Ltd, 2010; Efferen, 2002). The opportunity of using an applicable model for non-invasive monitoring of critically ill patients could provide earlier prognostication and intervention (Efferen, 2002). A clear trend is now seen towards an extended use of non-invasive, or 'less invasive', methods (World Cardiac Output Monitoring Equipment Markets, 2001; Deltex, 2010; Nick Schicht (Uscom Ltd), personal communication, April 19, 2010) so only products that use 'less invasive', or semi-invasive, methods will be considered as competitors to the USCOM in this comparison.

The market for non-invasive cardiac monitoring is very favorable today, according to the Alfred E. Mann Institute (N.D.), which also states that the one great potential for less invasive products is found in the intensive critical care units, ICU, as well as after treatment, by offering clear and continuous monitoring of bodily fluids. The use of less invasive monitoring of children and infants is said to be especially value adding, since the PAC can be too large in size (Alfred E. Mann Institute, N.D.).

The worldwide medical market can be divided into three main regions represented by the U.S. with approximately 45 percent, Europe with 30 percent and the rest of the world with 25 percent (Praveenkumar, 2009). Frost & Sullivan estimates the global market for medical devices at US $315 billion, and mentions e.g. Minimally Invasive Surgical Devices and Cardiology as "Hot segments" in their report. The report US patient monitoring industry comprises approximately $7 billion and is believed to reach over $8 billion by 2015 (iData Research, 2008)

According to PULSION Medical Systems Annual Report 2009 (PULSION, 2010), the market leaders in advanced hemodynamic monitoring are Edwards Hemodynamics and Pulsion Medical Care, see Figure 25. It should be noted, however, that this comparison includes invasive methods i.e. PAC, and is not representative for the non-invasive market.

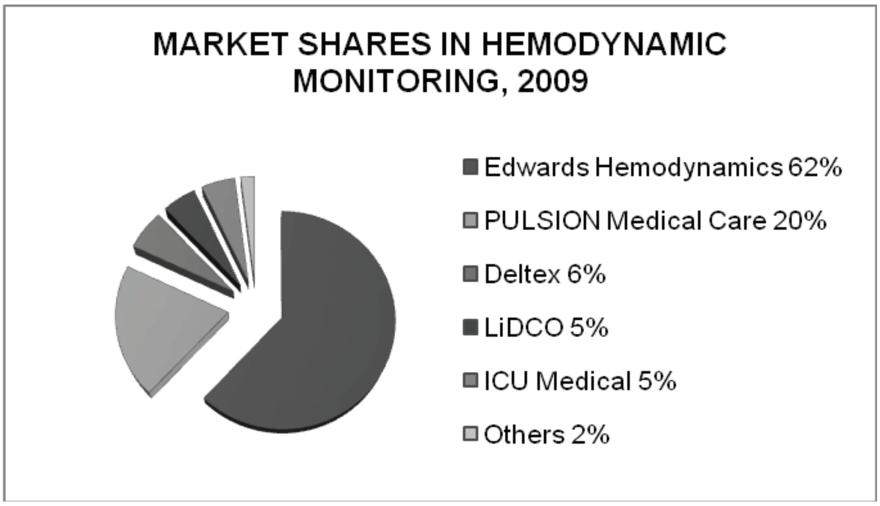

Figure 25. Market shares in Advanced Hemodynamic Monitoring 2009, modified from PULSION (2009).

6.2 COMPETITOR COMPARISON

Several manufacturers of CO measurement devices claim that their product is semi-invasive or "less invasive", due to less impact and risk involved than using PAC. However, there are only two methods among the competing products on the market that are truly non-invasive according to one definition of invasive devices: "A device which, in whole or in part, penetrates inside the body, either through a body orifice or through the surface of the body." (Council Directive 93/42/EEC, 1993, p. 52). The non-invasive monitors will be discussed in the first section, followed by a selection of semi-invasive monitors. The competitors that are compared all have in common that they distribute their products on the global market for non- or semi-invasive hemodynamic monitors that display CO.

6.2.1 Non-invasive monitors

The monitors listed in this section are all non-invasive (as is USCOM).

BioZ® Dx Diagnostic System

Company: SonoSite, US. SonoSite is registered on Nasdaq and had a yearly revenue of US$227 million in 2009, which accounts for a large range of products (SonoSite, 2010). The BioZ is only available in the U.S. SonoSite offers an iPhone® application that allows users of their products information resources, i.e. instruction videos and reimbursement information.

The BioZ® Dx uses impedance cardiography, ICG, which is based on detecting the small changes in thoracic impedance that occur as blood is pumped in and out of the heart. The BioZ® Dx is designed for use on adult patients and there exist patient conditions where ICG should not be used, or could demonstrate reduced accuracy (Philips, 2010). Disposable sensors that are attached to the patient's body are used for ICG and the measurement is completely non-invasive.

The BioZ Dx® has a very traditional color screen which resembles an old Windows interface of a PC and it is navigated through a physical keyboard. The interface has four different screens:

- Monitoring screen; displays up to six user-defined hemodynamic parameters
- Leads-off detection screen; shows if the sensors are disconnected or if there is a malfunctioning cable
- Data review screen; allows for reviewing 20 minutes of data
- Archive screen; allows for printing, deleting or transferring saved files

NICOM®$_2$

Company: Cheetah Medical, private company based in Israel and the U.S.

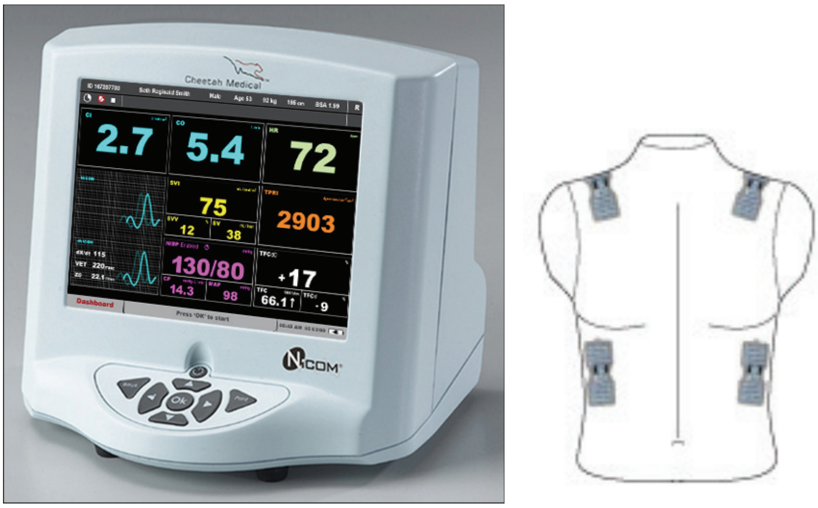

Figure 26. Left: NICOM®$_2$. Right: Placement of sensors for the NICOM®$_2$. With permission from Cheetah Medical (2010).

The NICOM®$_2$ (Figure 26) uses a technology called BIOREACTANCE®, which builds on Bio-impedance used by the BioZ® Dx above; the products have similar applications and properties. Sensors are placed out on the body to measure thoracic impedance (Figure 26). However, the NICOM®$_2$ analyses the data in a different way and the product is said to be more reliable than Bio-impedance based products when the patient is moving or agitated (Cheetah, 2010).

The interface, which consists of a combination of graphs and parameter values with color coding, is navigated by buttons below the screen.

6.2.2 Semi-invasive monitors

The semi-invasive monitors use methods that either involve inserting probes or connecting them to existing catheters, but are considered less invasive compared to using PAC (Pulmonary Artery Catheterization), hence 'semi-invasive'.

The first two products that are presented below, PiCCO®2 and LiDCO^{TM}*plus*, rely on similar 'calibrated' pulse pressure methods that involve inserting a ventral venous catheter, usually in the superior vena cava, and an arterial catheter (PiCCO, 2010; LiDCO, 2010).

PiCCO®2

Company: PULSION Medical Systems AG, Germany. €28.1 million in group revenue for 2009 (PULSION, 2010).

PiCCO stands for Pulse Contour Cardiac Output. The calibration of the PiCCO®2 is performed by thermodilution; injecting a fluid bolus and measuring the temperature change between two sites.

The PiCCO®2 has an interesting interface with a combination of physical buttons and a touch screen. The visual information is high in contrast and color-coded. Yellow represents Flow related parameters (CO, SV and SVR). Volume related parameters (preload volume and volume responsiveness) are shown in blue. Green represents Organ function (Pulmonary edema, Pulmonary vascular permeability, Cardiac Contractility and Cardiac power) and magenta signifies an Oxygenation related parameter (Central venous oxygenation, Oxygen supply, Oxygen consumption). See Figure 27 for the PiCCO®2 and a screenshot.

Figure 27. Left: The PiCCO®2 screen. Right: Customized view of the parameters on the right hand side of each screen. (With permission from PULSION, 2010).

The interface is navigated through three tabs, where the top one represents SpiderVision (Figure 28), where five parameter values are marked out on 'spider', or 'radar', graphs and compared to normal values. When all values are in the normal range the graph is green, when one parameter is out of the normal range the graph turns yellow, and when two parameters or more are out of range, the graph is red.

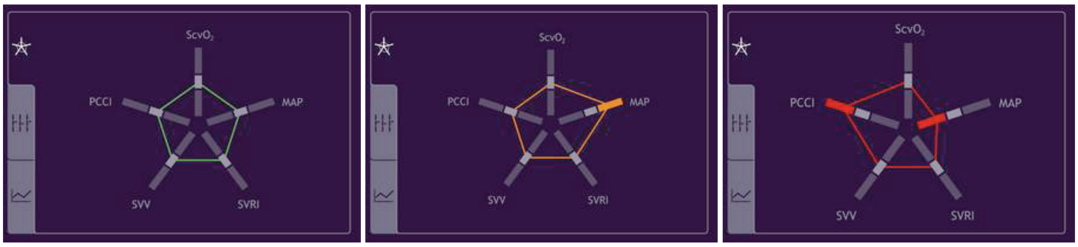

Figure 28. The PiCCO®2 'SpiderVision' with different warning levels (With permission from PULSION, 2010).

The second tab leads to the Profile screen (Figure 29), where column graphs are used to illustrate the parameters, with the values displayed. The user can choose to look at four basic values, or choose one of the categories: Flow, Volume, Organ Function or Oxygenation (each represented by a color as seen above).

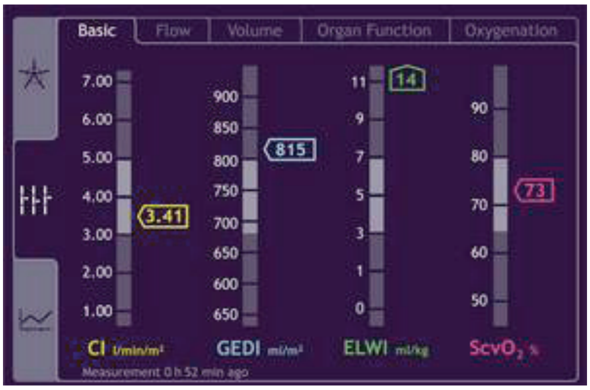

Figure 29. PiCCO®2 Profile screen (With permission from PULSION, 2010).

The third tab leads to a Trend screen (Figure 30), where the user can monitor up to eight parameters over time.

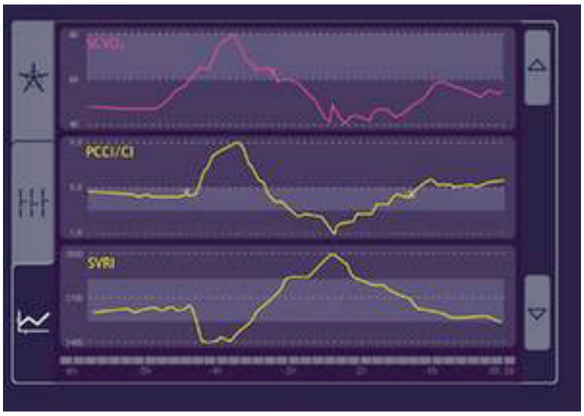

Figure 30. PiCCO®2 Trend screen (With permission from PULSION, 2010).

LiDCO™*plus*

Figure 31. LiDCO™*plus* on its roll stand. With permission from LiDCO (2010).

Company: LiDCO Ltd, England. LiDCO Ltd is part of LiDCO Group Plc, which had a revenue of £4.53 million for the financial year 2008/09 (LiDCO, 2010).

The LiDCO™*plus* method is similar to the PiCCO2 but is calibrated by injecting a small amount of Lithium chloride, and measuring the change in concentration in the blood between two sites. It is licensed for use in patients of over 40kg. The LiDCO™*plus* is seen on its roll stand in Figure 31.

The LiDCO™*plus* is navigated by a touch screen and the data interpretation is mainly done in four screens: the Trend screen (left in Figure 32), the Chart screen (right in Figure 32), the Graph screen (left in Figure 33) and the History screen (right in Figure 33). The top of each screen is dedicated to warnings related to different parameters, and to the right a large selection of navigation and data insertion buttons is available. The interface also offers an Event Response display (Figure 34). The CO and CI has a red color coding, and SVRI is green. MAP is black, SV blue, and HR magenta.

The Trend screen (left in Figure 32) displays continuous records of hemodynamic parameters with either actual or averaged data over a few minutes up to several hours. The screen uses many colors with varying degree of contrast between foreground and background, and can be interpreted as visually cluttered. The color coding is not obvious and many different colors are used in the interface.

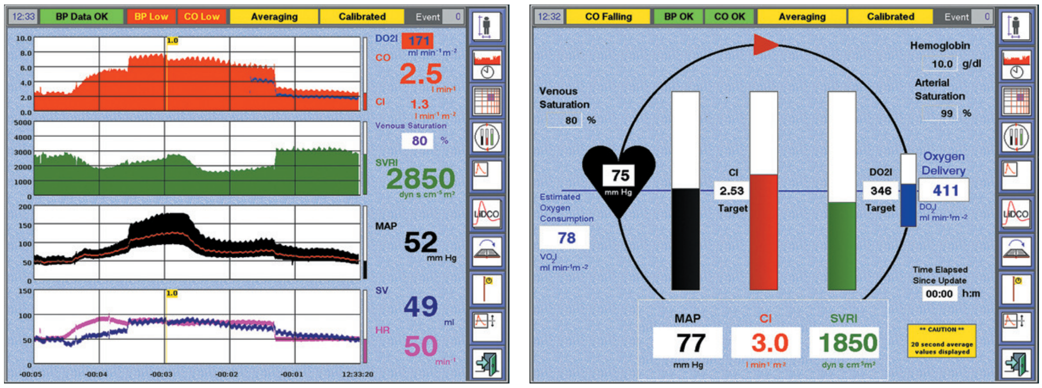

Figure 32. Left: LiDCO™*plus* Trend screen. Right: LiDCO™*plus* Chart screen. (With permission from LiDCO 2010).

The Chart screen (right in Figure 32) offers parameter relationships 'at a glance' and shows three bars with pressure, flow and resistance information with a marker for the patient's ideal status. The clinician has the possibility to enter target limits for CO/CI and Oxygen delivery (DO_2/DO_2I).

The Graph screen (left in Figure 33) shows a continuous display of the flow parameter values for the patient's last 12 heartbeats. MAP, CO or Oxygen delivery (DO_2I), and SVR is plotted against a target window, set by the clinician.

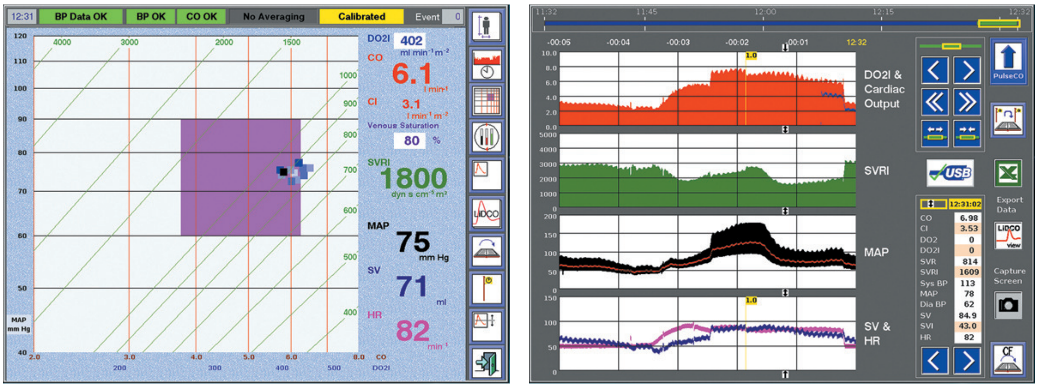

Figure 33. Left: LiDCO™*plus* Graph screen. Right: LiDCO™*plus* History screen (With permission from LiDCO 2010).

The History screen (right in Figure 33) is used to track up to 24 hours of patient data. It has a similar layout to the Trend screen but is specifically designed for audits, teaching, analysis and research as the data can be exported in different formats.

An Event response display (Figure 34) allows the user to view one or two variables in a higher resolution for fluid challenges or monitoring inotrope distribution. The start value ('Baseline'), current value, and percent change from start value are shown to the left, and the continuous graph is displayed to the right.

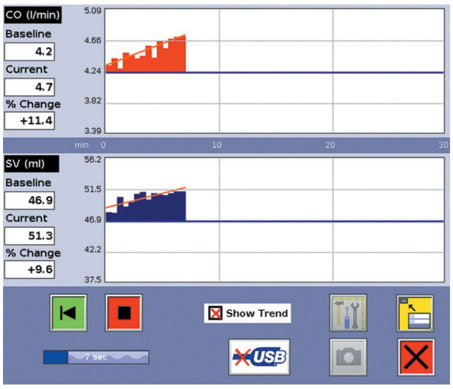

Figure 34. The LiDCO™*plus* Event response display (With permission from LiDCO 2010).

FloTrac System

Company: Edwards Lifesciences, U.S. $1.3 billion revenue in 2009. Note that the FloTrac System is not among the company's primary products, whereas PACs are (Edwards Lifesciences, 2010).

The FloTrac System, consisting of the FloTrac sensor and Vigileo Monitor from Edwards Lifesciences, uses a minimally invasive uncalibrated pulse pressure method. This device derives the CO through measuring BP and using an algorithm, and the performance and accuracy of the results have been questioned (Mayer et al, 2007; Compton, Zukunft, Hoffmann, Zidek & Schaefer, 2008). The traditional screen interface, which can show parameter values, trends, or a combination, is navigated by a rotation knob and physical buttons with symbols.

CardioQ-ODM

Company: Deltex Medical, UK. Deltex Medical is listed on the London Stock Exchange and had a yearly revenue of £5.6 million in 2009 of which approximately £1.4 constituted monitors sales. They have a strong market position on the 'less invasive' monitoring market in the UK (Deltex, 2010).

The CardioQ-ODM uses a Transoesophageal Doppler method that measures the flow in the ascending aorta by the insertion of a probe through the nasal or oral route (Deltex, 2010). Because the blood flow is not measured at the valve but in the ascending aorta, this method does not directly measure the complete CO, but assumptions on how much blood that goes to the upper body have to be made to approximate the actual CO.

The interface has a traditional screen which shows the Doppler profiles and a number of parameter values. It is navigated by physical turn knobs and push buttons.

6.2.3 Competitor comparison analysis

Because no competitors on the global market use the same method as the USCOM, some of the qualities of other competitors' devices and methods have been presented. As can be understood, the accuracy of the displayed CO is affected by what method is used and by what parameters are actually measured to calculate the CO. The different methods either have different indications for use, different levels of accuracy compared to the standard, or are more or less invasive, hence a single major competitor to the USCOM cannot be pinpointed.

Many of the products have a similar user interface, enabling the user to watch different parameters simultaneously and to view trend graphs of historical data. In the LiDCO, the clinician can set target values, to compare with the obtained values. LiDCO also offers a screen that is specifically designed for Fluid challenges, which could be of interest for the user. The PiCCO provides the user with typical values of the parameters as well, and offers the 'SpiderView' radar graphs for further guidance.

The monitors all have quite different color coding, and the PiCCO interface is the only one in this comparison that seems to have grouped the parameters into distinct groups. Most monitors have a black background, which is probably related to the fact that some colors appear with larger contrast against black than white. It might also be related to that less light is emitted from the screen, which is advantageous for screens which are on when the patient is asleep. Another reason for the apparent preference for dark background could be related to a trend toward it in the design of medical equipment. All the interfaces have at least one screen with one or several graphs, and parameters shown simultaneously.

The only detected 'Help' symbol in the compared interfaces is denoted with a question mark. No other common symbols have been found in the interfaces. More information on the comparison of the interfaces is found in the last section of this chapter.

6.3 INTERFACES OF COMMON HOSPITAL EQUIPMENT

Since the USCOM is operated by users who might be used to other medical devices in the ICU, ED or retrieval vehicles, it is of interest to have a brief look at the interfaces of some common equipment that might be used in hospitals. All the equipment in this section have touch screens. Some of them can be navigated with physical knobs or levers as well.

6.3.1 Patient monitoring systems

Patient monitoring systems are used for a continuously updated overview of the patient's status, and typically include views of parameters such as ECG (Electrocardiography, interpretation of the electrical activity of the heart) graphs ('leads'), HR, MAP, BP, SpO_2, body temperature, etc.

Philips monitors

A brief study has been done of the Intellivue and SureSigns monitors from Philips. Most of them use a combination of symbols and text on the buttons (either touch screen or physical), and have a black background display with color coding. As an example, HR is usually displayed in green or yellow, BP values are red or magenta and the SpO2 value is light blue.

Spacelabs Healthcare

Spacelabs is one of Uscom Ltd's distributors. It was therefore of interest to look at their other products. Their patient monitors Ultraview and élance both have a black background interface with color coding for graphs and parameters. On the Ultraview, a question mark together with the text 'Help' is used to designate the help function. HR is shown in green, BP is red or yellow, On the élance, HR is green, SpO2 is light blue, BP is red or orange. Both monitor types use a combination of symbols and text for buttons and show date and time. The élance is claimed to have a single-level menu, allowing the user to navigate the interface with single touches.

GE Healthcare

The CARESCAPE monitors from GE Healthcare have black backgrounds with HR displayed in green, and BP in red. The physical buttons on the interface have symbols or text, while the information on the screen is mainly text based.

Dräger

The Infinity Delta XL from Dräger has a similar interface to the monitors above, with black background, HR displayed in green, SpO2 in light blue and BP in red.

6.3.2 Mechanical ventilators

Mechanical, or medical, ventilators are used to mechanically move air in and out of the patient's lungs for patients who cannot breath sufficiently on their own, or during anesthesia.

Maquet

The SERVO-i ventilator from Maquet has a black background touch screen, with graphs to the left and parameters in yellow, green and light blue to the right. Selection buttons are located at the top and bottom of the screen. Ventilator settings can be made either via the touch screen, the main rotary dial, or a combination of both.

Dräger

The Evita 4 mechanical ventilator from Dräger has a white background and the colors grey, green, blue and black are used in the interface. The colors are not related to different parameters, which are all displayed in black text. Symbols are used to some extent on the screen, but the physical buttons are mainly text-based. The help function is indicated with the letter 'i' for information. On the Evita XL and Evita Infinity V500, the background is light blue and the parameters displayed in dark blue. The rest of the interface is mainly green, with black text. All the three models' interfaces can be navigated with a combination of touching the screen and turning a physical knob, and on some models, there is a selection of direct choice buttons.

6.3.3 Common hospital equipment comparison analysis

The most common help symbol in the interfaces of the studied hospital equipment is the question mark, just as for the CO monitors. The most common settings symbol is the 'tool box'. Most of the interfaces have a combination of text and symbols, and as for all interfaces reviewed, the parameters are usually located to the right of the graphs or leads. Touch screen navigation is common, sometimes combined with a knob and a selection of buttons. More information on the comparison of the interfaces is found in the next chapter.

6.4 INTERFACE COMPARISON CONCLUSION

For an organized overview of the similarities and differences between the different interfaces that were compared, see Table 4. For the table comparison, one specific product in each series of products was looked at, to be compared with the more general analysis in the previous sections.

The numbers in the columns correspond to the following interface features:

1. Mainly dark background (BG) color. The symbol √ means yes. No indication means mainly light background color.

2. The interface appears to have mainly:

text-based selection buttons, denoted in the table with T

symbol-based selection buttons, denoted in the table with ξ

symbols together with text on selection buttons, denoted in the table with ξ T

3. When graphs and parameter values are shown in combination;

↓ values are displayed under the graphs

→ values are displayed to the right of the graphs

↑ values are displayed above the graphs

4. The interface appears to have a single-level interface structure (that allows the user to access other screens or displays directly). The symbol • means yes, no indication means that the interface appears to have a deeper menu structure.

The following three column categories refer to the color coding. If the interface is not color coded, no indication is given. A question mark in any of the color categories means either that the information could not be retrieved, or that it is not applicable.

5. HR color

6. SpO_2 or $ScvO_2$ color

7. BP color

Note that the color coding might be modifiable by the user, which means that the color that is stated here might not be the single color available for that parameter value. The information in Table 4 is subjective judgments to some degree. Also, information might be incorrectly interpreted as only two of the interfaces have been examined in reality (USCOM 1A and CardioQ-ODM). The rest of the information comes from the companies' websites, as referred to in the previous sections. The comparison serves only as a means to find commonalities and differences between the interfaces. It should not be taken as a judgment of the quality of the interfaces. The selection of products is not representative for the whole market of monitors or ventilators but has been made mainly on the basis of products seen in hospitals that have been visited for this thesis.

Table 4. Overview of the interface comparison.

	1. Dark BG	2. Text / symbols	3. Para-meters	4. Single level	5. HR color	6. SpO_2 color	7. BP color
<u>CO monitors</u>							
Uscom Ltd: USCOM 1A		T	↓	•	red	red	red
Sonosite: BioZ Dx		ξ T	↑	•			
Cheetah: NICOM	√	T	↑		green	?	magenta
PULSION: PiCCO2	√	ξ	→	•	?	magenta	?
LiDCO: LiDCO*plus*		ξ	→	•	magenta	?	black
Edwards: FloTrac	√	ξ	↑		?	lilac	?
Deltex: CardioQ-ODM		T	↑				
<u>Patient monitors</u>							
Philips: Intellivue MP90	√	ξ T	→	•	green	light blue	red
Philips: SureSigns VM8	√	ξ	→		green	light blue	red
Spacelabs: Ultraview SL2900	√	ξ T	→	•	green	?	red
Spacelabs: élance	√	ξ T	→	•	green	light blue	red
GE: CARESCAPE B850	√	T	→	•	green	?	red
Dräger: Infinity Delta XL	√	ξ T	→	•	green	white	red
<u>Medical ventilators</u>							
Maquet: Servo-i Universal	√	T	→	•	?	?	?
Dräger: Evita Infinity V500		T	→	•			

It it obvious from Table 4 that it is very common to have a dark (in this case, black) background, especially for the patient monitors, where all the interfaces have black backgrounds.

The use of symbols, either on their own or together with text, varies between the interfaces. The only common symbols that have been found are the 'i' for information, '?' for help, and the 'tool box' for settings functions.

The placement of parameter values is quite strikingly consistent for all the monitoring and ventilator systems that were examined; the parameters are always placed to the right of the traces. For the CO monitors, there is a tendency to place the values above the trace, and the USCOM is the only monitor that displays the values below the trace.

Most of the systems appear to have an interface structure with few levels; other screens can typically be directly reached with the touch of a single button (or tab).

It can be concluded that there exists a common color reference system for some of the parameters on the patient monitor systems. HR is usually marked with green, SpO_2 with light blue, and BP is usually red. However, other color reference systems exist also. For the CO monitors; some color coding exists, but there is little consistency between the different systems. One of the two ventilators that was compared uses color coding, but as the parameters are not the same as for the monitors, the reference system is not the same.

7 NEEDFINDING

The first phase of the development process was the identification of usage needs that the USCOM must comply with. This chapter describes the needs that were found from studying the task, the user, and the environment that the device operates in.

7.1 TASK DESCRIPTION

The main task for the USCOM is to monitor the patient's hemodynamic status, to support the primary user with information for decision-making. These decisions mainly concern assessing a patient's response to fluid or drug therapy or diagnosing the patient. See Figure 35 for a simplified flow task diagram for the USCOM.

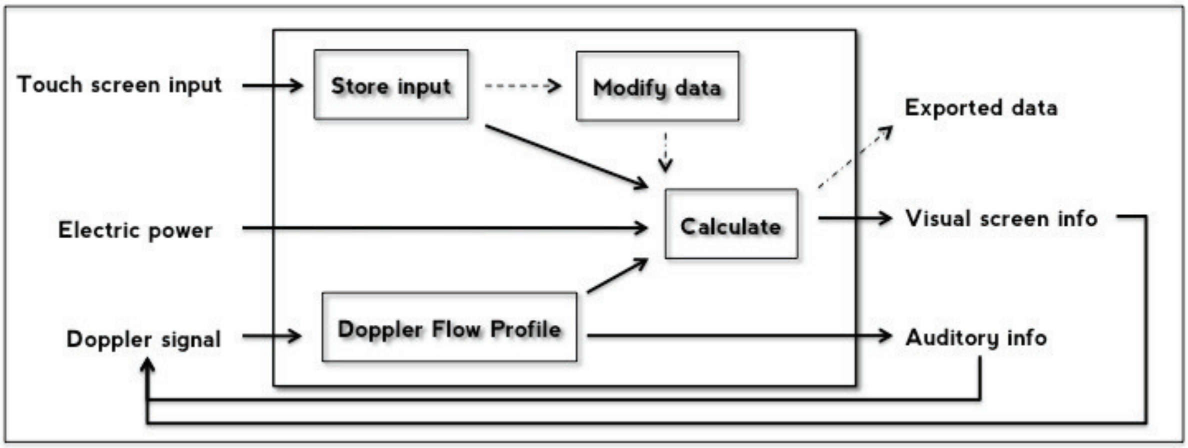

Figure 35. Flow task diagram for the USCOM.

The intended user task flow for performing a cardiac output measurement with the current design of the interface is the following:

1. Start up device; When the USCOM is turned on, a beep is heard and different start-up screens are shown for about 45 seconds, and finally the Welcome screen shows, see Figure 36.

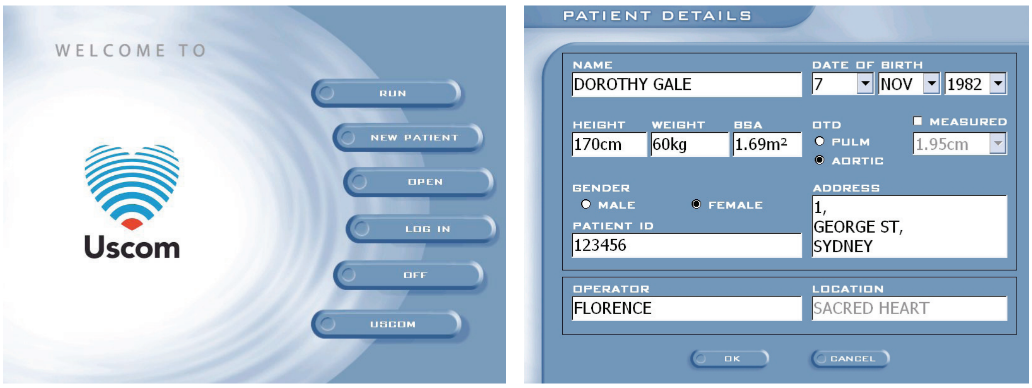

Figure 36. Left: USCOM Welcome screen. Right: USCOM Patient details screen.

2. Choose mode in the Welcome screen; 'Run' for critical situations, or 'New patient' or 'Open'. The two latter require the user to log in first, and require Patient details, see Figure 36.

3. The user is then referred to the Examination screen. Gel is applied to the transducer which is placed over the area of interest on the patient, and the patient's AV or PV Doppler Flow profile(s) are found and saved, see left in Figure 37. Each saved measurement constitutes one 'Card' (here the second 'Card' is displayed). One or several cards that have been created within 24 hours of time constitute one 'Examination'. If settings changes are desired, the Cogwheel symbol in the lower left corner of the screen is touched. For scale and zoom settings, the scale is touched.

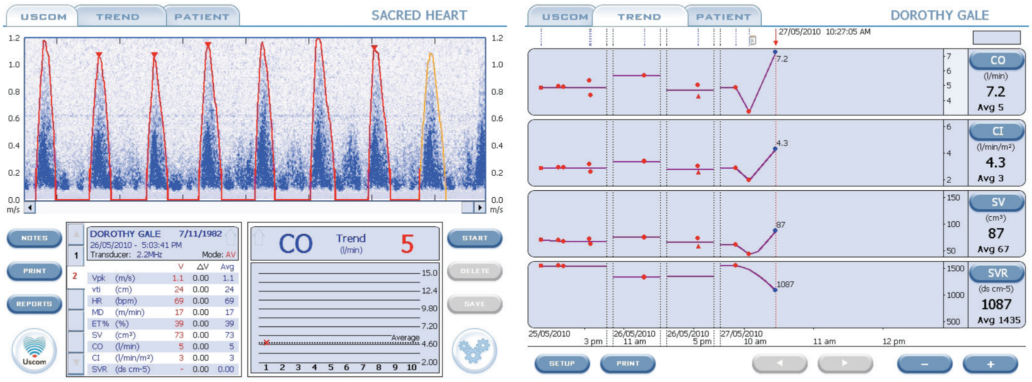

Figure 37. Left: USCOM Examination screen ('USCOM' tab). Right: USCOM Trend screen (tab).

4. After saving the 'Card', the user can either interpret the data in the Examination screen, or look at how the different parameters have changed over time in the Trend screen, chosen by touching the second tab, Trend, see right in Figure 37. Each 'Card' is here represented by a point; red for aortic measurements and blue for pulmonary. Each 'Examination' is represented by a short dotted blue line above the graphs. This means eleven 'Cards' are divided into eight 'Examinations' in the Trend screen in Figure 37. The dotted lines that cut through all the graphs means that the time line has been cut, to enable the user to see the whole period on the screen.

5. The third tab leads to the Patient screen, which contains patient information and 'Examination' information, see left in Figure 38. User and general settings, data export and print functions etc. are found in the Settings screen, reached from the Welcome screen, see right in Figure 38.

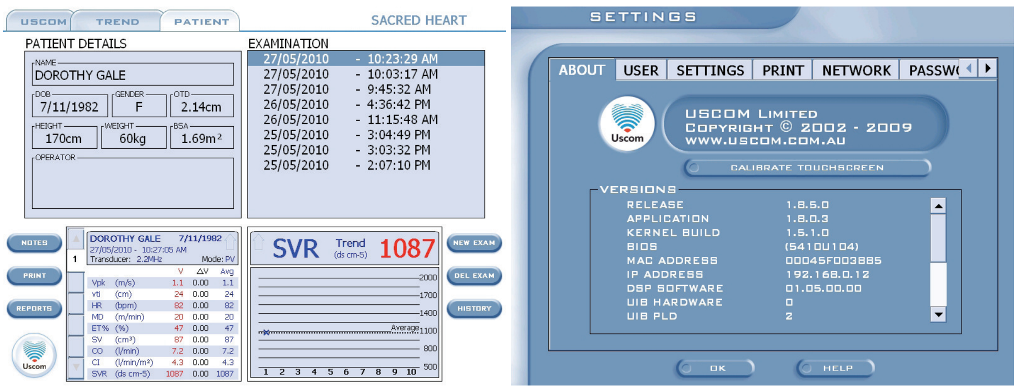

Figure 38. Left: USCOM Patient screen (or tab). Right: USCOM Settings screen.

7.2 SYSTEM DESCRIPTION

To reach a better understanding of the human-cardiac monitor machine system, a system analysis was carried out. The system includes not only the operator and the device, but also the patient, whether or not the patient is actively involved in the interaction. The system must also be seen in its proper context, the healthcare system.

The human-cardiac monitor system is described in Figure 39. The operator, patient and machine are the main components, and they are to be observed in the environment in which they work. The whole system is also part of the larger healthcare system, with the rules, regulations and customs that it entails.

An exchange of matter, energy, and information is constantly seen in the system. For example, the operator both receives and gives information and transfers energy (in form of electrical signals) to the machine, the interfaces being the handheld transducer and the touch screen. The patient can be more or less involved in the procedure, but is constantly exchanging information with the machine through the Doppler signals that are sent out from the transducer and are echoed back. There is also an exchange of information (and matter) between the patient and operator; all three are in constant exchange.

The environment that the system is in affects the cognitive processes both for the patient (unless unconscious) and the operator and has consequences for the machine performance. If the environment that a system operates in is not considered, it can lead to negative consequences. Some aspects are rather obvious, i.e. that noise and light levels must be considered, but there is also a need to understand 'hidden' aspects of the environment. As an example, patient information is confidential, thus there is a need to protect information that is stored in a medical device because of the risk of unauthorized usage.

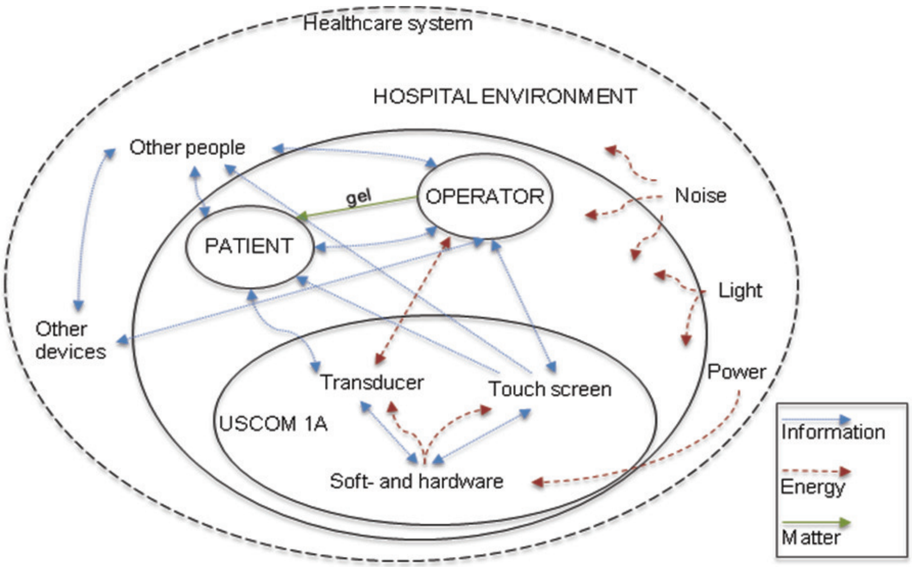

Figure 39. System description of the human-machine system for the USCOM.

The interrelations of the screens in the user interface of the latest released version (1.8.5) of the USCOM software can be seen in the diagram in Appendix B.

7.3 USER DESCRIPTION

A physician, nurse, paramedic or patient can operate the USCOM. The intended primary user is a nurse, who will forward the information to a physician when needed. However, for the time being, the physicians themselves mainly operate it.

The users work under a high level of mental load a large part of the time. The typical user is between 20-70 years of age, and can be assumed to have an understanding of hemodynamic parameters, ranging from basic knowledge (heart rate, blood pressure and possibly Systemic Vascular Resistance, SVR) to a deep understanding of most of the parameters. Some parameters are expected to be fairly unknown to most users.

Traditionally, ICU staff will be more accustomed to the parameters shown in the USCOM than for example ED staff (Beverley Jacobson (Uscom Ltd), personal communication, April 19, 2010). The concept of measuring CO for assessing the patient's hemodynamic status is new to many users, who are used to basing the assessment on blood pressure, heart rate and sometimes capillary refill time. The USCOM offers over 20 parameters, but most users only make use of three or four parameters, which is probably related to the fact they do not know how to use the rest of the information for clinical assessments. Three user groups of the USCOM can be identified (Beverley Jacobson (Uscom Ltd), personal communication, April 19, 2010):

1. User uses only cardiac output (CO).

2. User uses CO, stroke volume (SV), heart rate (HR) and systemic vascular resistance (SVR).

3. User uses a combination of many of the available parameters.

The user needs training in order to use the USCOM clinically; around 20 supervised exams and around 30 unsupervised exams have to be carried out before the user gets a certificate for the device. Almost all of the training is related to finding and identifying the accurate Doppler Flow profiles, and the number of exams that need to be done before a certificate is issued depends on the user and the application where it is to be used.

It can be noted that the concept of fluid optimization is a relatively new concept (about three to four years old) and that staff might be more accustomed to monitoring changes 2010ure than looking at stroke volume, which is essentially the case with the USCOM. Many potential users might find it difficult to find time to learn new products and as the USCOM is not actually replacing any other product, users might have difficulties understanding where to make use of it in their daily work (Beverly Jacobson (Usctom Ltd), personal communication, April 19, 2010).

Because there is not a high proportion of one-off users, the Guessability of the interface is not the highest priority in this case. For the USCOM, the Learnability, System potential and Re-usability are important issues since the device is often used in stressful situations, and even if all intended users are trained, there might be gaps of time in which the product is not used (Jordan, 1998).

7.4 ENVIRONMENT DESCRIPTION

The USCOM can be used for research or in clinical settings: in retrieval (ambulances, mobile ICU vehicles, rescue helicopters) or at a range of hospital departments. Today, the most common application is in the ICU, where it can be used for assessing hemodynamic response to fluid and medical therapy, diagnosing low or high cardiac output states in shock patients, management of patients with severe burns, perioperative care of cardiac surgery and high-risk surgical patients, and management of patients with heart failure, for example.

Other primary applications are Emergency Departments (e.g. Septic shock management and Resuscitation) and Pediatric care. The USCOM is well suited for Pediatrics since it is non-invasive, it can be used on patients of all ages, including neonates, and children are easy to perform measurements on (it is usually easier to acquire a good Doppler Flow profile on children than on adults) (Beverley Jacobson (Uscom Ltd), personal communication, April 19, 2010). Another likely environment for the USCOM is in Rural Health Care, where options are more limited and the device is a way of assessing hemodynamic status of patients at a low cost, across multiple disciplines (Uscom Ltd, 2010).

The hospital environment is generally clean, at normal room temperature or slightly below, and well lit up (at daytime). The ICU and ED can be expected to have rather high levels of noise and are associated with high levels of stress. The hospitals today are filled with medical machines, and cardiac monitors in an ICU might sit next to mechanical ventilators, external pacemakers, defibrillators and dialysis equipment. Two ICUs and one operating theatre in Australia have been studied for this thesis, and for these departments, the ICUs had a lower sound level than the operating theatre, where a larger number of people and devices worked close to the patient. Daylight was present at all locations, however, that is not the case for all possible environments that the USCOM could operate in.

7.5 DESIGN SPECIFICATION

The purpose and intended use of the USCOM was identified and is listed below, according to the suggestions proposed by Bligård (2010).

7.5.1 Task specification

The task for the human-machine system is to achieve sufficient information on the patient's hemodynamic status, to perform a diagnosis or guiding the next step of treatment. It is important that the task of achieving a correct signal accommodated in the best possible way by the interface, while keeping the locus of control in the hands of the operator.

7.5.2 Intended user specification

The intended users are primarily nurses, but also physicians and paramedics. Users are intended to receive training before using the USCOM clinically. The users device is marketed worldwide, but it is believed that the users are accustomed to western cultural stereotypes, so the same interface (translated) can be used for all markets.

7.5.3 Intended use specification

The intended use is hemodynamic monitoring, primarily in hospital settings, but also in retrieval vehicles. The operator is intended to stand up or sit down, holding the transducer in one hand and operate the device with the other hand during Doppler Flow profile acquisition. For reviewing data and making different settings, the operator can use both hands to navigate the interface.

7.5.4 Usability orientation

The orientation for the usability of the USCOM is to allow for easy and rapid acquisition and interpretation of the desired information, as well as intuitive navigation between different screens and settings for the interface.

7.6 USABILITY NEEDS SPECIFICATION

The observations and interviews with hospital staff identified a set of usability needs. The needs are listed below in positive phrasing, describing what the USCOM *is supposed to do*, expressed as attributes of the device, as suggested by Ulrich and Eppinger (2004). Note that the needs are not necessarily fulfilled with today's interface. The last part of the needfinding consists of stating the system's Effect goal and Usability level, based on the information gathered in the observations and interviews.

7.6.1 Usability needs

The usability needs that were found in the needfinding phase are divided into the following categories: Information input and symbol needs, Information output and display needs, Functionality and navigation needs, Physical qualities needs, and Market and production needs.

In the following tables, the Type column corresponds to which type of statement it is: I (Interview, expressed by user), O (Observation, observed need), or G (Generic guideline, see Section 3.11). The Validation column refers to either a usability requirement (R) or a usability guideline (G), to ensure that all needs have been considered in the development process. An explanation is given for the expressed needs that have not been responded to in the development process.

The needs that are related to inserting information and understanding text and symbols in the USCOM interface are found in Table 5; needs that are related to retaining information from the USCOM are found in Table 6; needs that are related to functionality and navigating in the interface of the USCOM are found in Table 7; physical qualities needs that the device must comply with are listed in Table 8; and the market and production needs are listed in Table 9.

Table 5. Information input and symbol needs.

Need nº	Need statement	Type	Validation
N1.1	Buttons are large enough for user to use index finger	O	R1.1
N1.2	Information input is intuitive and consistent with other common touch screen devices	G	G9
N1.3	A minimal number of operations is needed for information input	I, G	G10 & R1.8
N1.4	Symbols are easily interpreted	I, G	G3, G11
N1.5	Designations are relevant and unambiguous	I, O, G	G12
N1.6	It is easy to use only one hand to operate the device, especially during acquisition of the Doppler Flow profile	O	R1.2
N1.7	It is possible to enter patient specific information for identification	O	R1.3-6
N1.8	It is possible to enter patient specific information for calculation of flow parameters	O	R1.8
N1.9	The machine warns when unexpected information is entered	I, O, G	R1.10-R1.13
N1.10	It is not possible to enter invalid patient information	G	R1.11, R1.13
N1.11	It is clear which input boxes correspond to patient identification	O	R1.7 & R1.15
N1.12	It is clear which input boxes are important to fill out	O	R1.15
N1.13	It is possible to enter all available patient information before measurement begins	O	R1.16
N1.14	It is easy to enter valid patient information	O	R1.14, G9
N1.15	It is always possible to distinguish between patients	O	R1.15

Table 6. Information output and display needs.

Need n°	Need statement	Type	Validation
N2.1	The display output is focused on the important aspects of every screen	I, O	R2.1 & G14
N2.2	The display is kept free of irrelevant information	I, O, G	G20, R2.2-5 & R2.12
N2.3	The structure of the user interface is logical	I, O, G	G13
N2.4	The desired information is quick and easy to display and interpret	I, O, G	G14
N2.5	Abnormalities are 'beamed out'	I, O	R2.19
N2.6	It is easy to acquire and distinguish a good Doppler Flow profile	I, O	G15 & R2.1
N2.7	Necessary information to identify patient is displayed when performing measurements or reviewing data	O	R2.7
N2.8	Date and time is displayed when examining or reviewing data	O	R2.8
N2.9	Information on battery status is shown when the device is not connected to the electric grid	O	R2.9
N2.10	Information should be clear and easy to decode quickly	I, O, G	R2.14, R2.15, G11 & G14
N2.11	Output values can be compared to normal values for the patient	I	R2.10
N2.12	There is no need for average values for each patient's flow parameters	I	R2.11
N2.13	Visual information is possible to interpret from a distance	O, G	R2.14 & R2.15
N2.14	The visual information is clear to users of the age ranging from 20 to 70 of both genders	O	R2.14 & R2.15
N2.15	There is a need for more specific modes, e.g. Fluid challenges screen	I	R2.17
N2.16	There is no need for more specific modes **Comment: Inconsistent with N2.15. It was decided to create a screen design for 'Fluid challenges' for Uscom to decide whether to implement it or not**	I	Not responded to
N2.17	The auditory feedback from the device is possible to detect in a noisy environment	I, O, G	R2.18

Table 7. Functionality and navigation needs.

Need nº	Need statement	Type	Validation
N3.1	It is possible and evident how to exit all screens	I, O, G	R3.1
N3.2	The placement of selection buttons (e.g. Cancel, OK) is consistent throughout the interface	O	R3.2
N3.3	It is easy to transfer data to other types of media	I, O	R3.3-5
N3.4	The design of the user interface is consistent with other medical devices that might be operated in an ICU, ED, or retrieval vehicle.	G	G6
N3.5	It is possible to average flow parameters over a range of patients, for research purposes.	I	R3.6
N3.6	Important functions of the device are clearly marked.	O, G	G16
N3.7	It is possible to add notes	I	R3.7
N3.8	It is possible to edit notes	I	R3.8
N3.9	It is possible to make custom designed reports	I	R3.9
N3.10	It is possible to export data from more screens than previously	I	R3.4
N3.11	It is possible to search for patients through different methods	I, O	R3.10
N3.12	It is possible to use drag options where suitable	O	R1.2 & G9
N3.13	There is no need for the PATIENT screen	I, O	R3.11
N3.14	There is a need for a better Help function	I, O	R3.12
N3.15	There is no need for a Help function **Comment: Inconsistent with N3.14. It was decided to develop the Help function further.**	I	Not responded to
N3.16	It is possible to cancel choices in all selection screens.	G	R3.13
N3.17	There is a need for a pediatric focused 'package'	I	R3.14
N3.18	It is possible to go back in time to select Doppler profiles	I	R3.15

Table 8. Physical qualities needs.

Need nº	Need statement	Type	Validation
N4.1	It is as easy as possible to clean the device	O	R4.1
N4.2	The device in itself does not pose any danger to operator or patient	O, G	R4.2
N4.3	The device is portable, and can be disconnected from the power grid for shorter periods of usage	O	R4.3
N4.4	It is possible to place the device very close to the patient	I, O	R.4.4
N4.5	The device is not larger than previous model	I	R4.5
N4.6	The device is not heavier than previous model	I	R4.5
N4.7	The device has no loose parts	O	R4.1
N4.8	The device encourages ergonomic body postures	O	R4.6

Table 9. Market and production needs.

Need nº	Need statement	Type	Validation
N5.1	The design of the user interface is consistent with the previous versions to a high degree	I, O	G5
N5.2	The device design and functioning is in line with the company profile	O	G17
N5.3	The device is designed according to medical device requirements	O	G18
N5.4	The device is manufactured in the existing settings	O	G19

7.6.2 Effect goal

The effect goal describes what the human-machine system should achieve.

The system enables an easy and rapid assessment of a patient's hemodynamic status, for supporting physicians in important decisions regarding medical treatment. The system is efficient, and no time is spent on unnecessary actions. The user in the system is well-informed and can feel confident about his/her actions.

7.6.3 Utility level

The utility level states the usefulness and usability that is desired for the human-machine system.

The interface is intuitive and allows first time users to understand how to operate the device without any aid from other users or the manual. The new interface is easier to navigate than the previous versions.

8 USABILITY STUDY

This chapter contains a deeper analysis of the user, task and interaction with the USCOM as well as a the allocation of functions between human and machine. The physical ergonomics of the USCOM are also discussed. The needs that were found in the needfinding stage are in this chapter translated into usability requirements.

The usability study focuses on how well the user interaction interface works and how it can be redesigned to better suit user needs. It aims to address the types of use problems that may exist. The result of the usability study is a set of usability guidelines (with focus on software) that aim to increase the quality of the human-machine interaction: target achievement, efficiency, safety and user satisfaction. The guidelines are also later visualized through fictional screenshots for a redesign.

8.1 USER ANALYSIS

To reach a better understanding of the potential users of the USCOM, a user analysis was performed, which consisted of the identification of the user types according to Janhager (2005) (as described in Section 3.2), a set of user profiles, and the development of persona-based scenarios.

The primary users of the USCOM are nurses, physicians or paramedics, as well as the patient. However, the latter is normally not the operator. Other members of the medical staff are considered to be co-users (work with primary or secondary users without direct interaction with the machine) and people visiting the patient or working in the hospital environment (e.g. cleaners, janitors) are considered to be side users (can be affected by the machine without influence on the usage).

8.1.1 Interviews and observations

Most of the nurses and physicians at the hospitals that were visited; Bathurst Base Hospital, BBH, and Royal Prince Alfred, RPA; have a basic understanding of a few of the hemodynamic parameters, but only the expert users understand all parameters and the correlation between them. The interview template is found in Appendix C. A user survey was also sent out to current customers of the USCOM, as well as published on-line. Unfortunately, no responses were sent in. The survey is found in the same appendix as the interview template, Appendix C.

The PAC monitors at RPA show around 20 parameters, but they are not the same as the ones shown on the USCOM, as the range of different values measured can be combined into a vast range of parameters. This means that experienced users of hemodynamic monitors at one hospital might not be accustomed to the parameters shown by the USCOM.

The USCOM is used to some extend for research, but this user group is assessed by Uscom Ltd as small, and not a prioritized group in the development of the interface.

The users at BBH were observed and asked to use the USCOM for different use cases, and the result was the identification of a range of usability issues, but the overall impression was that the users could navigate through the interface without any large difficulties and the users were satisfied with most of the functions available. The identified user needs were added to the usability needs specification in Section 7.6.1.

8.1.2 User profiles

User profiles summarizes the mental, physical, and demographic qualities of the end-users, (Bligård, 2010) but are not biographical 'sketches' of individuals, unlike personas (Cooper & Reimann, 2003). For a general and objective view on the typical intended user, a set of user profiles for the most common user groups are described in this chapter.

See Table 10 for the characteristics of the different user profiles. For clarification, the following denotations have been given to the knowledge characteristics:

Domain knowledge: Describes the amount of knowledge the user has of the different hemodynamic parameters and their inter-relations.

Task knowledge: Describes the amount of knowledge the user has of using non-invasive hemodynamic monitors.

Table 10. User profile characteristics.

USER GROUP	ICU nurse	ICU physician	ED nurse
Age:	20-65	25-65	20-65
Language:	English /other	English /other	English /other
Primary user goal(s):	Monitoring for changes and data collection	Patient response to fluid and drugs.	Data collection
Domain knowledge:	Intermediate	High	Low
Task knowledge:	Intermediate	Intermediate	Low
Frequency of use:	Frequent	Frequent	Frequent/Intermittent
Medical machine experience:	High	High	High
Level of workplace stress:	High	High	High
USER GROUP	**ED physician**	**Paramedic**	**Researcher**
Age:	25-65	20-60	30-65
Language:	English /other	English /other	English /other
User goal:	Diagnose patient and assess response to drug and fluid therapy	Early hemodynamic assessment for drug or fluid administration during retrieval	Acquire hemodynamic data for research purposes
Domain knowledge:	Intermediate	Intermediate	Expert
Task knowledge:	Low	Low	Expert
Frequency of use:	Frequent/Intermittent	Frequent/Intermittent	Intermittent
Medical machine experience:	High	High	High
Level of workplace stress:	High	Very high	Varying

The level of knowledge of each of the different user profile groups is illustrated in Figure 40.

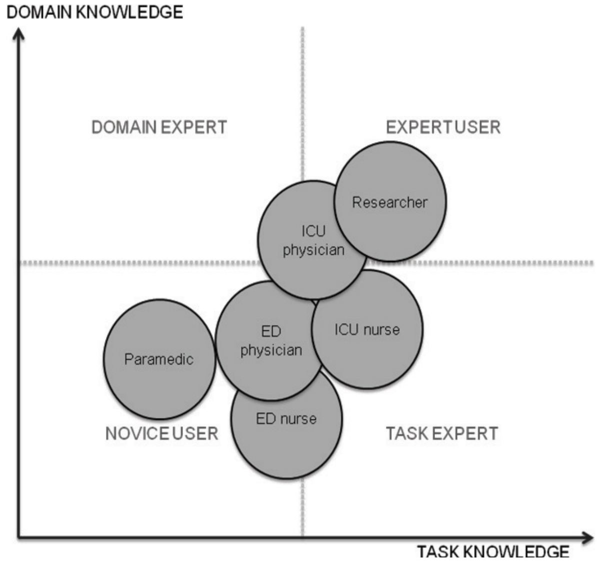

Figure 40. USCOM user profile knowledge. Model from Bligård (2010).

8.1.3 Constructed Personas and Scenarios

In order to reach a better understanding of potential users of the USCOM, three personas, fictional potential users, are described in Appendix D.

The three personas represent one physician (Stella), one anesthesiologist (Alexandre), and one nurse (Evelina), all of different ages. These groups do not represent all the user groups but should be enough to cover the main different aspects of use.

The personas were used in a set of narrative scenarios (also found in Appendix D), each describing a situation in one of the personas' lives. The term 'scenario' is familiar to people that work with usability, and it is a widely used method to solve design problems by constructing specific stories, starring personas that represent target potential users. The scenarios are fictional, but are anchored in real events at Bathurst Base Hospital, Australia. They should therefore also offer the reader with a better understanding of the context that the USCOM can be operated in.

8.1.4 Results from user analysis

The user analysis showed that the user has a very wide age range, with users from the age of around 20 to the age of around 65, which promotes the need to consider older users and their needs in the development. When the USCOM is used on children, it can be of interest to show the Doppler profile on the screen and to let them see what is happening, but children are naturally not considered intended operators of the device.

The users normally work in a stressful environment, and it is of essence to make the main tasks as easily understood and quick as possible to perform. The USCOM is used internationally, with users in different countries having different needs, as an example, some users want to be able to print paper reports with as many parameters as possible, while others are only interested in some of the parameters displayed on the reports.

The users will always receive training, as the task is considered quite difficult to master. There is not really an option now, or in the near future, to automate the task to a degree that allows novice users to use the device without training. However, many users might be intermittent users, and need support both in performing the main task of acquiring the correct signal, and also in making decisions based on the hemodynamic information. The users have very different needs, ranging from expert users that do not want time and space-consuming support, to users who feel very unconfident and require extensive support.

It has become clear that some users of the USCOM want as little information and screen cluttering as possible, and are confident regarding the implementation of the information that is given. Others, on the other hand, want a large amount of guidance, both regarding the acquisition of the Doppler profile, diagnosing the patient and understanding what actions are appropriate for the next stage of the treatment. From a patient safety and company responsibility point of view it is clear that the human must make the final diagnosis of the patient and consider all the aspects of the problem.

8.2 TASK ANALYSIS

To understand the task that the human-machine system consisting of the USCOM and its users, a task analysis was carried out. It consisted of interviews and observations of users and the construction of use cases and Hierarchical Task Analysis (HTA) trees.

8.2.1 Interviews and observations

As mentioned earlier, the operating theatre and the Intensive Care Unit (ICU) at Bathurst Base Hospital (BBH) were visited for an understanding of the environment, the user and the task. The full results are found in Appendix E and main findings are presented below.

The task of monitoring the hemodynamic performance of the patient is normally done several times throughout the patient's visit to the hospital. At the BBH, the USCOM is used by the bedside of the patient, and continuously throughout the care, either to assist in diagnosing the patient or to make sure that the hemodynamic parameters are stable, or heading in the desired direction. The USCOM was used on its stand, and for the operations, it was rolled with the patient from the operation preparation room into the operating theatre.

The task is performed rather quickly, in less than 5 minutes. The users that were interviewed for this thesis were not interested in looking at historic data to any large extent, but interested in the current measurement (and possibly the previous one).

In the Royal Prince Alfred's Hospital, the data from the Pulmonary Artery Catheterization (PAC) monitor was automatically transferred, and stored in a data system. The USCOM data at the BBH was not transferred further, but only stored in the device.

The analysis of the data is normally performed directly after the measurement as one of the main purposes for using the USCOM is Early Goal Directed Therapy, i.e. adjusting the cardiac preload, afterload and contractility to ensure appropriate oxygen delivery to the tissues. This approach has shown significant benefits in regards to outcome for e.g. sepsis and sepsis shock (Rivers et al., 2001).

The USCOMs at BBH did not have any notes attached to the devices, a sign that the interface does not require additional information for users to understand the navigation.

However, the baskets of the stands were equipped with typical hemodynamic values, explanations of the hemodynamic parameters, and diagnose decision trees and one of the

USCOM stands had a calculator in the basket, for calculating values that are not shown (see Figure 41). It should be noted that the device in question was used by very experienced users, who are experts in the parameter correlations.

The nurses at BBH carried out the measurements, and the results were communicated to a physician for evaluation. Only the Doppler (Examination) screen was used, and the nurses were not accustomed to the interface to any large extent as their task was completed after the acquisition of the parameters. The settings had been made by the head physician, and there was no interest from the other users in changing which parameters to show.

Figure 41. Basket of one USCOM stand at BBH. A decision tree for diagnosing patients is hanging down. The basket holds e.g. a calculator, wipes and examination gel.

8.2.2 Use cases

Three different use cases were made to describe and understand the functionality of the system with focus on the most common user situations. The result from analyzing the use cases was the identification of a range of usability needs, which have been added to the list in Section 7.6.1. The use cases are found in Appendix F.

8.2.3 Hierarchical Task Analysis (HTA)

A set of ten different user tasks were visualized by using Hierarchical Task Analysis (HTA), where tasks are broken into subtasks for further evaluation. It was done to show which user actions are taken in each step; for an overview of the different functions and to highlight problem areas for further investigation. The HTA also formed a basis for the Enhanced Cognitive Walkthrough (ECW) and Predictive Use Error Analysis, (PUEA) presented later in this chapter, as they require tasks to evaluate. The HTA trees are found in Appendix G.

8.2.4 Results from task analysis

All professional users of the USCOM are supposed to receive training with focus on acquiring a correct signal, before using the device unsupervised. The training hence covers the other main aspects of using the device, and it is not of interest to focus on introducing novice users to the system or creating a 'practice mode' as the introduction will usually be done by a professional.

The main usability issues that were identified in the task analysis are discussed below. The full list is found in Appendix E.

- The most important usability issue that was found is that some users misinterpret the average parameter values shown today, to think that they are typical values for that parameter.
- One of the most important usability issue was identified as a deficient level of consistency throughout the interface, with buttons placed in different orders, labels not corresponding to the following screen and symbols with different connotations in different screens.
- Overall, the use of metaphors in the interface is satisfactory; however, the keyboard metaphor for text input is not optimally designed and changes between screens.
- Users can be expected to range from around 20 to 70 years of age, so it is important that visual information is kept as clear as possible, with sufficiently large text and a high level of contrast between text and background colors, which is not the case everywhere in the interface.
- The touch screen interface should be possible to navigate without the use of a pen, so touch points should be sufficiently large for index finger touch.
- The scrolling functions in the interface are not optimally designed, and there are hidden choices that might be overlooked by inexperienced users.
- Some screens of the interface contain irrelevant information that clutters the visual image and can lead to interpretation errors.
- The organization of screens and information given in different screens was found to be another area with potential of improving; for example, after acquiring a sufficient Doppler profile, the screen can be used more efficiently to show data. The profile in itself is not interesting if correctly acquired.
- The user should always be able to easily exit screens, which is not the case in the current version of the interface. As an example, to get back to the Welcome screen from the Trend screen, four operations, that are hard to guess for an inexperienced user, are needed.

8.3 INTERACTION ANALYSIS

The interaction analysis consisted of performing a heuristic evaluation of the interface to begin with. This was followed by one method to identify usability problems with the interface, Enhanced Cognitive Walkthrough, and one method to predict use errors, Predictive Use Error Analysis; both methods are described in detail in Chapter 1.

The two interaction analysis methods were carried out based on the eight HTAs developed previously (which can be found in Appendix G).

The results from the interaction analysis were taken into consideration when constructing the usability requirements for the further development of the USCOM.

8.3.1 Heuristic evaluation

The results from the heuristic evaluation was the identification of how well the interface usability relates to the 'Nielsen-Shneiderman Heuristics', presented in Section 4.5. No specific grading of any deviations from the heuristics was carried out. Instead, the evaluation results were integrated with the results from the use cases and Hierarchical Task Analysis from the task analysis, and the full list of issues can be found in Appendix E. Identified usability needs were added to the list in Section 7.6.1.

8.3.2 Enhanced Cognitive Walkthrough results

The Enhanced Cognitive Walkthrough (ECW) resulted in the identification of 57 usability problems with the interface. The seriousness of the problems versus the importance of the task is displayed in Table 11, where the eleven usability problems that are within the grey area are the most crucial for further investigation. The table illustrates the interface's general condition, which is at a reasonably satisfactory level. A low number for problem seriousness or task importance indicates that the problem is serious or important, respectively. See Appendix H for all tables and result matrices and Section 4.5 for the explanations. The two most important issues (with Task importance 1, Problem seriousness 2) are related to exiting the Trend screen, which requires four actions that are not intuitive and which can cause irritation or, in worst case, that the examination of the next patient cannot be performed. The existence of this problem was confirmed in the user interviews.

Table 11. ECW matrix A: Problem seriousness versus Task importance.

	Problem seriousness			
Task importance	**1**	**2**	**3**	**4**
1	0	2	4	16
2	0	2	2	8
3	3	3	4	0
4	0	0	1	2
5	2	2	3	3

8.3.3 Predictive Use Error Analysis results

The Predictive Use Error Analysis (PUEA) resulted in the identification of 27 possible use errors that can be performed while operating the machine. See Appendix I for the full result from the PUEA, with result matrices. The explanation of the method is found in Section 4.7.

The matrix in Table 12 illustrates the consequence of the error versus the probability of detecting the error. A low number indicates a serious consequence or low probability of detection, respectively. The two most important use errors (marked grey) are related to the assessment of accuracy, and selection, of Doppler profiles. The assessment of accuracy is related to user experience and training to a high degree, and is difficult to automate. The selection of Doppler profiles has potential of being made easier and less prone to errors.

Table 12. PUEA matrix J: Consequence versus Detection.

	Consequence				
Detection	**1**	**2**	**3**	**4**	**5**
1					
2		1			
3		1			
4			2		2
5			7	4	10

8.4 SYSTEM FUNCTION ANALYSIS AND ALLOCATION

In order to reach the specified effect goal and utility level, the machine must contain a certain amount of functionality, which is examined by doing a function analysis. This was done for the functions in the USCOM, and the functions were then allocated between the human and the machine. This is done because certain functions are better suited for one than the other, and the optimal choice must be carefully considered. The functions are expressed by the use of a verb and a noun, to avoid being locked into solutions. The function allocation is illustrated in Table 13 and Table 14. The functions marked with grey are functions that should be shared.

Table 13. System function allocation – Human's functions.

Human functions				
Nº	**Verb**	**Noun(s)**	**Class**	**Comment**
F4	Interpret	flow parameters	Main function	The human must have sufficient knowledge to use the information
F5	Diagnose	patient	Main function	The human must make the final diagnosis of the patient
F7	Interpret	profile accuracy	Need	It is dangerous to leave the accuracy judgment to the machine due to large variances in profile sizes and shapes
F10	Detect	errors	Need	The human is still responsible for the diagnosis and must be aware that errors can occur
F20	Perform	settings changes (scale etc)	Need	The human should be in control of settings, to ensure that (s)he is interpreting data correctly
F23	Customize	settings	Desire	This function should be performed by the machine (store personalized settings) but should be possible to overwrite by the user

Table 14. System function allocation – Machine's functions.

Machine functions				
N°	**Verb**	**Noun(s)**	**Class**	**Comment**
F1	Transmit	Doppler signals	Main function	
F2	Receive	Doppler signals	Main function	
F3	Display	flow parameters	Main function	
F4	Interpret	flow parameters	Main function	The machine could guide the user in interpreting the parameters
F6	Display	Doppler flow profiles	Need	The human must be able to see the flow profiles, to determine accuracy even if it is only a means to reach the goal
F7	Interpret	profile accuracy	Need	The machine must help by tracing the profiles correctly and could determine accuracy better
F8	Allow	disconnection from electric grid	Need	
F9	Counteract	Errors	Desire	The machine interface should be designed to avoid errors
F10	Detect	errors	Need	The machine must aim to detect possible errors
F11	Indicate	errors	Need	Detected errors must be indicated (or solved)
F12	Allow	storing patient info (height etc)	Need	
F13	Allow	saving hemodynamic data	Need	
F14	Allow	Both AV and PV examination	Need	
F15	Allow	trending data	Need	
F16	Allow	exiting all screens	Need	
F17	Enable	portability	Need	
F18	Counteract	unauthorized usage	Need	Users must log in with password
F19	Allow	settings changes	Need	The interface must make changes of settings simple
F21	Give	feedback	Desire	The human must receive feedback on all actions
F22	Offer	Help function	Desire	The interface should offer guidance to all screens
F23	Customize	settings	Desire	This function should be performed by the machine (store personalized settings) but should be possible to overwrite by the user

8.5 ASSESSMENT OF PHYSICAL ERGONOMICS

The usability study includes a brief assessment of the physical ergonomics of the USCOM, in line with the discussions in Section 3.13.

8.5.1 Ergonomics assessment of the work environment

The day-time hospital environment normally allows for sufficient light to use the USCOM without problems, but the device could also be used outside the hospital or during night-time, when light conditions are poor. However, as the well lit-up screen is the main interaction interface between the human and the device, light conditions are not considered as an issue for the physical aspect of the ergonomics.

The sound level in the hospital environment should normally not exceed dangerous sound levels (80dB, according to the American Speech-Language-Hearing Association, 2010) but can sometimes camouflage the sound from the USCOM; consequently, it should be possible to increase the volume to a larger extent than on the current device.

8.5.2 Ergonomic assessment of body postures

The USCOM is normally used on its stand, enabling an upright standing position when examining data. The upper edge of the USCOM is at a height of 1300 cm, which creates a comfortable viewing distance for a person with a standing eye height of between 1405 and 1745 cm. That covers the 5th percintile woman to the 95th percentile man (see Appendix J). Furthermore, the arm positions are assessed to be comfortable for people of the mentioned heights, when the USCOM is located in front of the operator. See Figure 42 for an example of use of the USCOM in the operating theatre at BBH. When a measurement of a patient is performed, the body posture depends on the operator's position but used as intended, the USCOM is placed near the patient bed in front of the user so that extreme flexing or turning of body joints is avoided. Depending on the height of the bed, the user can stand up or sit down. In a standing position, leaning down over the patient could create fatigue in the lower back of the operator depending on the time spent on finding the correct signal, which should not exceed a few minutes for a trained operator.

Figure 42. Example of use of the USCOM in the operating theatre. The user might have to turn the neck in order to look at the USCOM while the signal is acquired, depending on the situation.

The angle of the screen imposes a flexion upwards on the wrists for writing if two hands are used on the keyboard, which is not ergonomically preferable. However, the USCOM is only used intermittently, and no long periods of time will be spent writing on the screen, therefore it should not cause any risk for cumulative trauma even for regular users. Also, the most common way of interacting with the touch screen is to use the index finger

8.5.3 Ergonomic assessment transducer handle and roll stand design

The handle of the transducer has been developed with focus on ergonomics, with a relatively large base and a concave area for the index finger, see Figure 43.

One user complained on the position of the basket on the stand for the USCOM, which makes it difficult to pull the device as close to the bedside as desired, see Figure 43. It has been identified as the most important physical ergonomics issue with the USCOM. It is suggested that the basket is moved underneath the USCOM and the handle is removed, as the roll stand is normally moved by holding the USCOM.

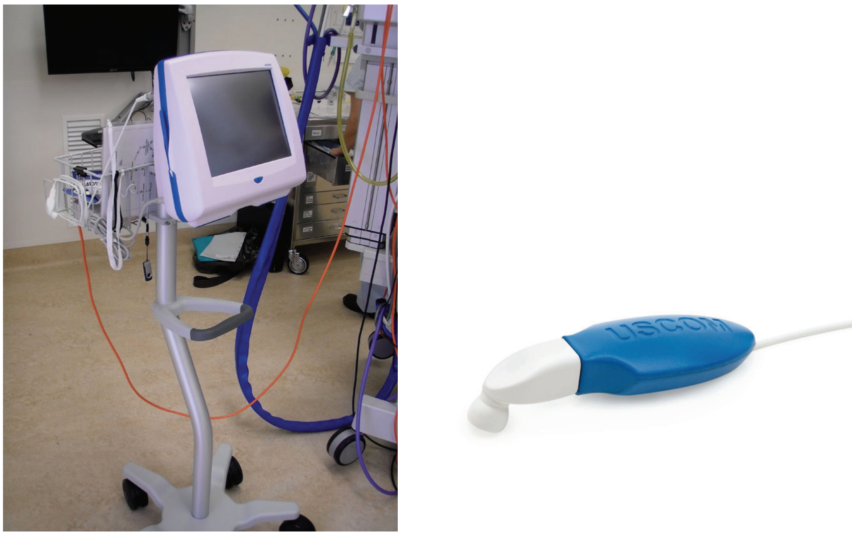

Figure 43. Left: USCOM on roll stand. Right: USCOM transducer.

8.5.4 Anthropometric data

For the redesign of the USCOM, the sizes of buttons and other touch areas were considered and anthropometric data was researched. It is found in Appendix J. The data suggests that the index finger breadth for a 95^{th} percentile man (see Appendix J) is 23 mm, so in order to be sure that most people can use the touch screen with the finger, that size would be the minimum in each direction. However, it is not reasonable to base the touch area sizes on the size of the index finger breadth as one does not have to use the full finger breadth. No anthropometric data that indicates how large touch areas must be for touches. Also, logically, this depends on the resistance of the touch screen. For this reason, it was decided that the measurable quality that would be used to determine the size of the touch areas would be to compare it to the current size of the buttons, which seems to support touches. In observations, it was found that only when smaller areas (than the buttons) of the screen were touched, a pen was used.

8.6 USABILITY REQUIREMENTS AND GUIDELINES

Based on the user, task, interaction and function analysis as well as the elicited needs and goals that must be achieved, usability requirements and guidelines were designed.

8.6.1 Usability requirements

The usability requirements in this section all correspond to one or several of the usability needs that were expressed in Section 7.6. Note that the needs are not necessarily represented by the requirements. For this reason, a needs validation was performed after the requirements and guidelines were set. This means that the needs that are not covered by the requirements are covered by a guideline, or not taken into consideration (if so, an explanation is given next to the need in question).

The requirements are formulated more specifically than the needs, and should be possible to verify. Furthermore, the requirements must be unambiguous and solution-independent. See Table 15 - Table 18 for the usability requirements for the USCOM, where the Reference column describes which usability need from Section 7.6 that each requirement corresponds to.

Table 15. Information input requirements.

Nº	Requirement	Value	Verification	Reference
R1.1	Touch areas are at least as large as the buttons in the current interface	>= 14mm in all directions	Measure	N1.1 & N.4.7
R1.2	No input action requires two hands	Single point touches or drag actions	Test	N1.6
R1.3	Possible to enter patient's first name separately	Separate box	Check	N1.7 & N3.11
R1.4	Possible to enter patient's surname separately	Separate box	Check	N1.7 & N3.11
R1.5	Possible to enter patient's date of birth	Choice of dates	Check	N1.7
R1.6	Possible to enter patient ID	ID box	Check	N1.7
R1.7	Patient identification boxes are grouped together	Apply Gestalt laws	Check	N1.11
R1.8	Patient details input screen contains all the patient information of interest	Possible to enter height, weight, measured Outflow Tract Diameter, blood pressure and oxygen	Check	N1.3 & N1.14
R1.9	If a height less than 50cm is entered, it is indicated that weight should be filled out too	Warning and direction to weight box	Check	N1.9
R1.10	A warning with confirmation is issued when unexpectedly tall height is entered	Height is expected to be under 220cm	Check	N1.9
R1.11	It is not possible to enter an invalid height	Height must be < 300cm	Check	N1.10
R1.12	A warning with confirmation is issued when height and weight correspond badly	Weight <1kg must correspond to Height <1m and Weight > 100kg must correspond to Height >1m	Check	N1.9
R1.13	It is impossible to enter invalid dates	All dates must correspond to a date that exists	Check	N1.10
R1.14	It is possible to enter date of birth in the chosen order (e.g. dd/mm/yyyy)	System allows for natural order	Check	N1.14
R1.15	Patient identification information is unambiguous	It is not possible to enter two patients with the same name and/or patient ID without different dates of birth	Check	N1.15
R1.16	It is possible to enter all the necessary information to display a parameter in one sequence of actions	When a parameter without value is touched, all necessary values to fill in are displayed	Check	N1.3
R1.17	Input boxes are organized in order of relevance	Humans normally scan from top left to bottom right	Check	N1.12, N1.14

Table 16. Information output and display requirements.

Nº	Requirement	Value	Verification	Reference
R2.1	When finding the Doppler profiles, that action is in focus	Only necessary buttons and parameters show	Subjective judgment	N2.1 & N2.6
R2.2	The location of the device is not inserted or displayed	No location box	Check	N2.2
R2.3	The patient address is not inserted or displayed	No address field	Check	N2.2
R2.4	It is clear which flow parameter values that are the current ones	Clear marking of current values	Subjective judgment	N2.4
R2.5	Necessary information to identify patient is displayed when performing measurements	Patient name or ID and if inserted, date of birth, always shows	Check	N2.7
R2.6	Information on battery status is shown when the device is not connected to the electric grid	Battery symbol with status full, half-full or almost empty is shown	Check	N2.9
R2.7	Normal values for the flow parameters are possible to display	Display normal values	Check	N2.11
R2.8	No average values are automatically displayed for patient flow parameters	Do not display average values	Check	N2.2, N2.4 & N2.12
R2.9	The interface is not visually cluttered	No more than 6 colors are used in the same screen	Check	N2.10
R2.10	The contrast between colors is sufficient	Light background color is paired with dark foreground color and vice versa	Check	N2.10
R2.11	Characters are visible from a distance of 2 m	Character height: >10mm, character width: 2/3 of character height, stem thickness: 1/6 of character height	Measure	N2.13 & N2.14
R2.12	Characters are easily distinguished from each other	Distance between characters: 1/5 of character height, distance between words and numbers: 2/3 of character height	Measure	N2.13 & N2.14
R2.13	A specific screen for ‘Fluid challenges’ is available	Fluid challenges screen	Check	N2.15
R2.14	The machine’s sound level should be higher than today’s	Two more steps on the volume scale is desired	Check	N2.18
R2.15	Abnormal values are ‘beamed out’	Abnormal values are highlighted in red	Check	N2.5

Table 17. Functionality and navigation requirements.

Nº	Requirement	Value	Verification	Reference
R3.1	There is always an exit option	Every screen has an exit option	Check	N3.1
R3.2	The placement of selection buttons (e.g. Cancel, OK) is consistent throughout the interface	The OK button is always to the left or at the bottom of the selection window	Check	N3.2
R3.3	It is possible to print screens of interest	Screens of interest can be printed	Subjective judgment	N3.3
R3.4	It is possible to export data from relevant screens	Relevant screens have an export option	Subjective judgment	N3.3
R3.5	It is possible to print group reports for patients	Group reports is an option	Check	N3.5
R3.6	Flow parameter values should be possible to average over group reports	Average option for Group reports	Check	N3.5
R3.7	It is possible to add notes	Add note's function	Check	N3.7
R3.8	It is possible to edit notes	Edit note's function	Check	N3.8
R3.9	It is possible to print custom designed reports	Custom design reports	Check	N3.9
R3.10	It is possible to search for patient's with different methods	Search options	Check	N3.11
R3.11	The PATIENT screen is removed	Remove PATIENT screen	Check	N3.13
R3.12	It is possible to receive guidance during use	Every screen has a help function	Check	N3.14
R3.13	It is always possible to cancel choices	Every selection screen has a cancel option	Check	N3.16
R3.14	There exists a pediatric-focused mode	Doppler profile scale and patient input values can be adjusted to suit pediatric needs	Check	N3.17
R3.15	It is possible to go back in the Doppler profile window to select Doppler profiles	It is possible to go back one minute	Check	N3.18

Table 18. Physical qualities requirements.

Nº	Requirement	Value	Verification	Reference
R4.1	Pen holders are removed	Absence of 'pen' holders improves cleaning and eases use	Check	N4.1 & N4.7
R4.2	No functions that impose danger for the user or patient are introduced	No introduction of potentially dangerous functions	Check	N4.2
R4.3	The device is portable and can be disconnected from the electrical grid	No changes to portability or battery is made	Check	N4.3
R4.4	It is possible to place the stand as close to the patient as possible	Place stand basket under device and in front	Check	N4.4
R4.5	The device is not larger in size than previously (except screen)	No change	No change	N4.5 &N4.6
R4.6	Ergonomic body postures are encouraged	Sufficiently large text allows for standing up and reading	Check	N4.8

8.6.2 Usability goals

Usability goals are wanted, measurable qualities of the man-machine interaction that could serve as the basis for a usability evaluation of the finished product. The goals are set after the intended use has been identified, and are based on the functionality, usability needs and requirements. The usability goals below have been recommended for the USCOM, however, no validation will be done in this thesis project.

Target achievement:

- 90% of certified users should be able to acquire the desired and correct hemodynamic information, including adding the needed patient specific information.
- 90% of first time users should understand how to change the scale and zoom when searching for the accurate Doppler profiles.
- 70% of all users should be able to change measurement mode (AV/PV), without pressing the wrong buttons.

Efficiency:

- 80% of first time users should be able to start up the device, insert patient details, perform a measurement (although not necessarily accurate) and save, using a trial and error strategy without guidance, within 15 minutes.
- 80% of certified users should be able to acquire the desired and correct hemodynamic information, including adding the needed patient specific information, within 10 minutes.

User satisfaction:

- Less than 5% of users should feel irritation when performing any action that is not related to searching for the accurate Doppler profiles.
- 90% of all users should grade the interface as 5 or better, on a scale from 1 = very hard to understand to 7 = very easy to understand.

Guessability:

- 95% of first time users should understand how to turn the device on and off.
- 90% of first time users should be able to start up the device, insert patient details, perform a measurement (although not necessarily accurate) and save, using a trial and error strategy without guidance.

Learnability:

- Users should rate their interface navigation skills as 5 or better, on a scale from 1 = very poor to 7 = very good, after using the device for 30 minutes.
- 80% of users should not express the need of an external manual when asked.

Memorability:

- After not having used the device for 5 weeks, 80% of users should, after performing one examination, rate their skills the same, or at the most two levels lower, compared to before the absence.

8.6.3 Usability guidelines

The usability guidelines presented in this section serve as the basis for the redesign of the USCOM interface, and are based on the expressed usability needs, observations and generic guidelines that have been presented earlier. The guidelines serve as a complement to the requirements, and aim to cover all aspects of the design that cannot be verified through objective measurements. See Table 19 for the usability guidelines, where the Reference column indicates if the source is a generic guideline (G) or an expressed need (N).

Table 19. Usability guidelines.

Nº	Guideline	Reference
G1	The interface should work in a monochrome design but be enhanced with redundant information, i.e. color coding	G
G2	Gestalt laws should be applied to all aspects of the interface design	G
G3	Western cultural stereotypes should be followed	G
G4	The design should be consistent throughout the interface	N3.2, G
G5	The design should be consistent with previous versions	N5.1
G6	The design should be consistent with the interfaces of other medical devices that the device might be used together with	N3.4
G7	The interface should not require that the user holds more than 5-7 pieces of information in the working memory	G
G8	The combination of red/green and blue/yellow should be avoided, to minimize the influence of color deficiencies	G
G9	Information input is intuitive and consistent with other common touch screen devices	N1.2
G10	A minimal number of actions should be necessary to complete tasks	N1.3
G11	Symbols should aim to follow conventions and should be easily interpreted by the intended users	N1.4
G12	Designations should be relevant and unambiguous	N1.5
G13	The interface should have a logical structure	N2.3
G14	The desired information should be possible to interpret quickly and easily by the user	N2.4
G15	The critical action of acquiring accurate Doppler profiles should be made as easy as possible, without too much distractions	N2.6
G16	Important functions of the interface should be clearly marked	N3.6
G17	The device design and functioning should be in line with the company profile	N5.2
G18	The device should be designed according to medical device requirements	N5.3
G19	The device should be possible to manufacture in the existing settings	N5.4
G20	The interface is kept free from irrelevant information	N2.2

8.6.4 Validation of usability needs

To ensure that all the desired usability needs were covered by either usability requirements or guidelines, a validation of the needs was carried out, and a Validation column was added to the usability needs list in Section 7.6.1. A few of the expressed needs were not responded to, according to different reasons; explained in the usability needs table.

9 REDESIGN OF THE USCOM

Before the redesign of the machine could start, it was essential that all the needs and requirements for the success of the human-machine system were taken into consideration. The first section in this chapter aims to summarize what the design aims at and which decisions that were made, and later in the chapter, the redesign suggestion of the USCOM is presented. Finally, the redesign suggestions are validated against the requirements.

First, the specific information needs that the users have are presented, followed by the decisions taken for a structured redesign of the USCOM interface. The design phases correspond to the specific Development process for interface design as presented by Bligård (2010); described in Section 3.14.

9.1 SPECIFIC INFORMATION NEEDS

The users of the USCOM have some important information needs during the primary usage, to find the hemodynamic information and make use of it. These needs have formed the basis for the redesign decisions. The information needs are listed in order of priority for each stage, respectively:

- During the acquisition of Doppler profiles stage
    - Visual feedback on size and shape of profiles
    - One or several hemodynamic parameters that will aid in finding the correct Doppler profiles
    - Auditory feedback on blood speed (higher pitched sound = higher velocity)
- During an information output stage
    - As many parameter values as the user desires
    - Typical parameter values for comparison
    - Trending of parameter values over time
    - Patient identity
    - Time and date of measurement
    - Transducer frequency

9.2 OVERALL REDESIGN

The following sections deal with the redesign of the USCOM on a conceptual level.

9.2.1 Abstraction levels for interface design

The five abstraction levels of interface design principles are: structure-based, process-based, function-based, task-based and situation-based (all described in detail in Section 3.12).

The current USCOM interface has influences from all the above design principles, with the highest focus on the task-based design principle. Different examples of applications of the five abstraction levels to the USCOM interface are found in Appendix K.

The redesign will keep focus on the task-based design principle, as it suits the needs for the USCOM, and extend the choices to include offering the user the possibility to make quick selections based on the current situation, e.g. making a Passive Leg Raising Test, and a shortcut to review patient data. It was decided not to introduce a 'quick link' for pediatric use, as it is believed that a specific setup for pediatric use will cover this need. Instead, a selection in the Patient details window can now be made; to choose between adult, child or neonate.

9.2.2 Technical principles

The Start/Freeze function in the Doppler profile screen could be done with voice control, to allow the user to stand further away from the USCOM while performing the measurement, and avoiding the potential transducer position change when the operator puts attention to the interface to press Freeze. However, the cost for implementing voice control is probably larger than the gain. The redesign instead suggests that the operator is allowed to go back in time (up to a minute) to select Doppler profiles that have been found, but are no longer displayed on the screen.

It should be possible to choose a higher level of sound for the Doppler shift, as this is an important factor in determining the quality of the signal. At least two more levels on the volume scale is desired.

No other changes to the technical principles of the USCOM are suggested in the redesign.

9.2.3 Overall design decisions and presentation of the interface organization

The following decisions were taken for the redesign:

- The users will still have to log in to the system, to ensure patient confidentiality, which should be upheld to the largest possible extent.
- The USCOM mainly aims at applications in accident and emergency settings, for use during anesthesia, or in general assessment of hemodynamics. The latter is typically suitable in rural health care, where all the expensive equipment available at large hospitals is not available. The USCOM is also especially well suited for pediatric applications. It can be used for research, however, developing the product for researchers' needs is not considered a priority for this redesign. The choice of exporting data for later examination in another application is available in the current interface, which covers this need sufficiently. The need for a pediatric-focused 'package' has been expressed by users. In the redesign, it is suggested that there should be a possible to set special default values for patient detail input, as well as scaling of the Doppler profile window to suit pediatric needs.
- The typical user is understood to not want to move through a large number of different screens in a large hierarchy, but be able to use the interface more as a web site. In such an interface layout, there is a common menu that allows for single touch entries into other screens and displays. This is also something that most of the examined patient monitors on the market have implemented, see Section 6.4.
- It was decided that no change in the interaction style with the device be introduced, such as changing the haptic interaction, introducing virtual reality or direct manipulation

interaction. The mode for the current interaction, menu-based interaction with elements of form fill-in interaction, is suitable for the interaction with the USCOM.

- The main organization of the redesign of the USCOM is similar to the organization in the current interface, which works well. The shortcuts in the Welcome screen to avoid the need to log in (only required for saving data) and to review or make measurements of patients who are already registered in the system are functional and promote the possibilities of using different paths through the interface. It is possible to reach the same final result by touching any of the three buttons 'Run', 'Open' or 'New patient'. Only the names of these buttons and the responding screens have been modified in the redesign.
- The user can choose between six different choices in today's Welcome screen, of which one is "Run". This selection does not require a log in, and could be separated from the others, allowing the user to select *either* to log in, or to work as an anonymous user. Some of the setup choices in today's interface relate to this 'anonymous user' which will be kept in the redesign suggestion.
- The 'tab' system to navigate between screens is found in many other interfaces that have been examined and was found suitable. It informs the operator of the current position in the interface, and allows for easy navigation. Hence, only small adjustments have been made to the tab navigation system. It was decided that the Patient screen (or tab) in the previous interface was not useful, and it has been removed in the redesign, and another screen to display the parameters more clearly has been introduced in its place.
- The clinical triad of preload, contractility (or inotropy) and afterload is the base for the evaluation of the results from a measurement, which should be emphasized in the interface, to help the user to differ between different aspects of the data. For this reason, a grouping of the parameters has been introduced. This is done to guide the user in rapid identification of the parameters, as well as to guide in the interpretation. The groups are the following five:
    - Preload related parameters: ET%, FT, FTc, SV, SVI, SVV, vti
    - Contractility related parameters: CI, CO, CPO, HR, INO, MAP, MD, Pmn, SW, Vpk
    - Afterload related parameters: PKR, SVR, SVRI
    - Oxygen delivery related parameters: SpO_2, DO_2, DO_2I, SVS
    - Heart rate

The comparison between the old and new organizations of the screens is seen in Figure 44 and Figure 45, where the Doppler profile related screens (or 'tabs') that have been deleted or added are marked in italics. The screen that the user will be directed to is marked out.

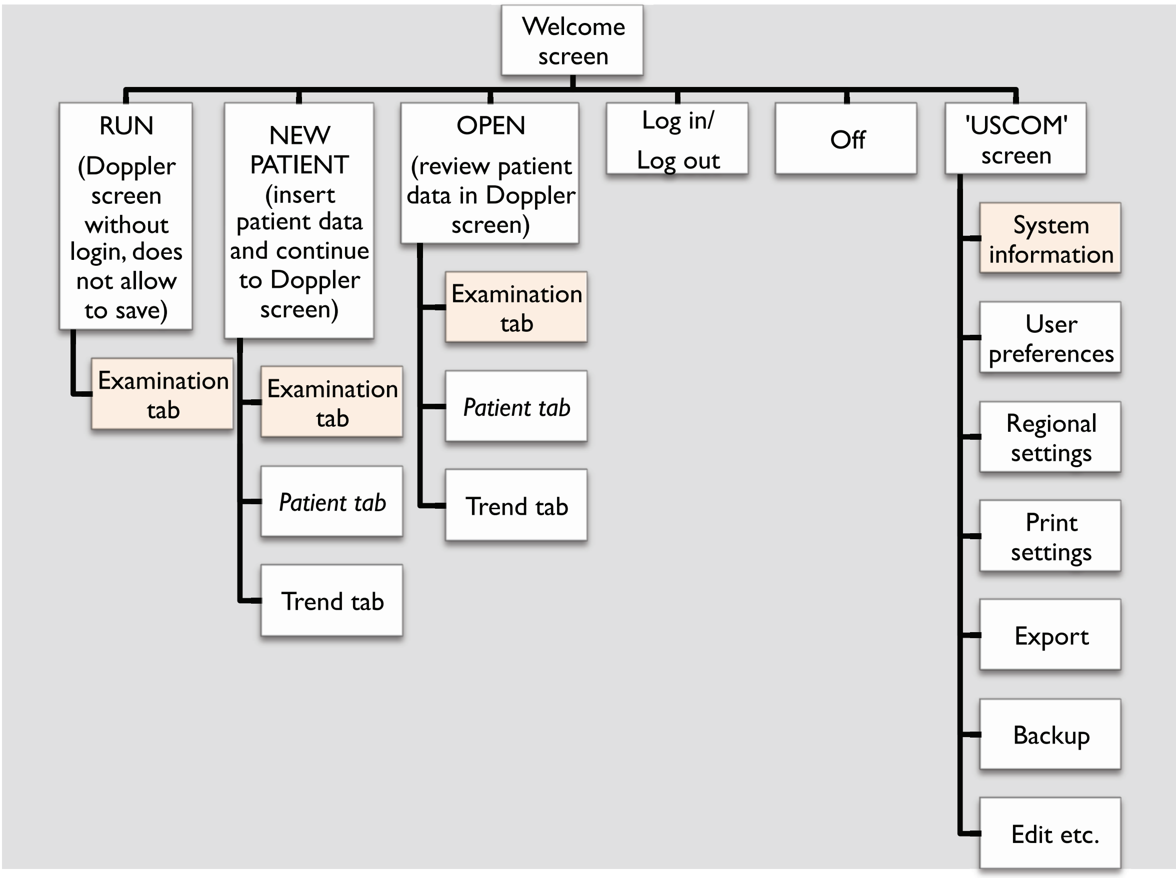

Figure 44. Simplified organization schema of the current USCOM interface.

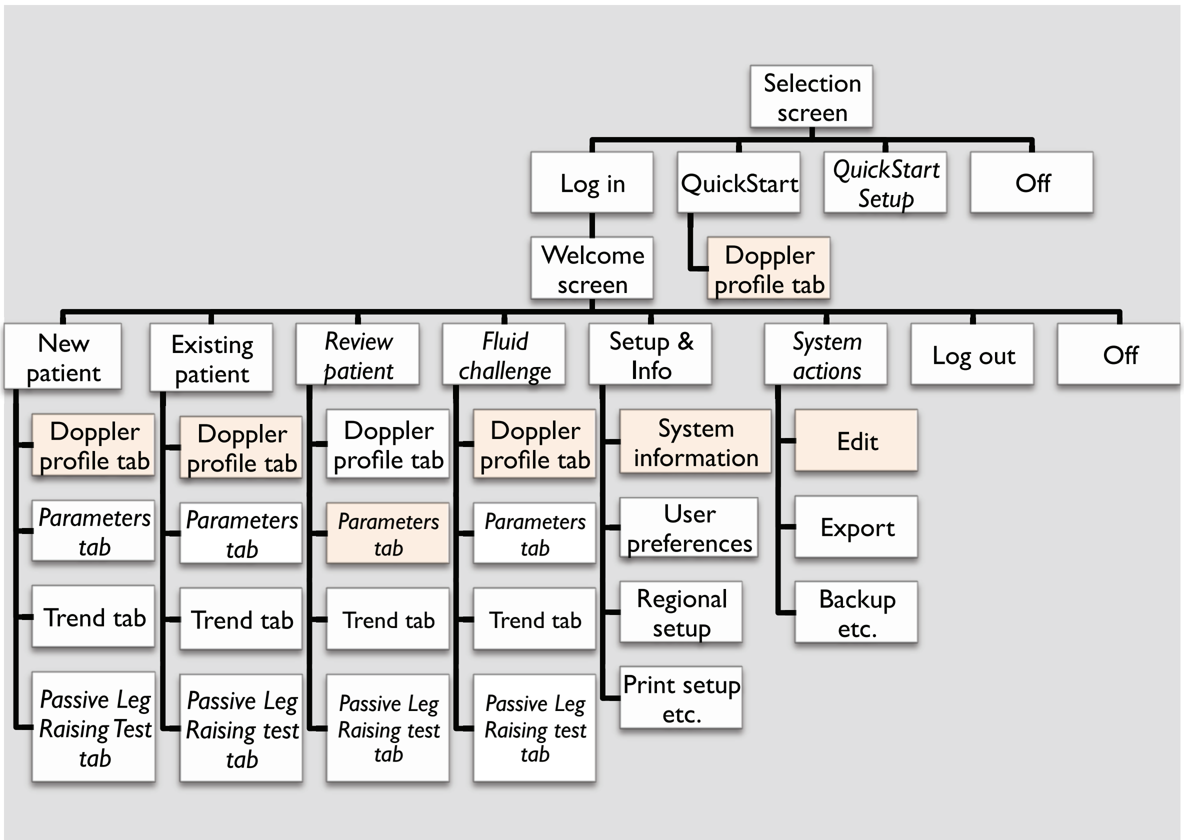

Figure 45. Simplified organization schema of the redesign of the USCOM interface.

The following screens are included in the redesign suggestion:

- Selection and Welcome screen
- Doppler profile screen
- Parameters screen (new)
- Trend screen
- Passive Leg Raising test screen and Help screen (new)
- Patient details screen
- Setup and Info screen
- System Actions screen (new)
- Settings display
- The Examination screen will now be called Doppler profile screen, and be focused to a larger extent on finding the accurate Doppler flow profiles than in the current interface, where the parameters are evaluated directly in this screen. The Patient screen (tab) in the previous interface is removed, and instead a screen that shows the parameters in a clearer way is introduced. The Passive Leg Raising test screen (or tab) is also added.

9.2.4 Design guidelines

The design guidelines for the redesign were presented in Section 8.6.3

9.3 DETAILED DESIGN DECISIONS

The decisions that were taken on a detailed design level are presented below.

9.3.1 Organization of functions

The user needs are to quickly change between patients, add patient specific information, print reports, etc. For this reason, a menu system has been introduced in the redesign, which is represented as a common menu in all the Doppler related screens (e.g. Doppler profile tab, Parameters tab). To enable the user to see the screen while making selections and not , the bar is placed at the bottom of the screens.

The function of achieving the correct Doppler profiles is currently the most important and difficult task, hence the interface should aim at making this task as easy and quick as possible. After acquiring the profiles, it is important that the user can see a large amount of information regarding the hemodynamic status, where it is of interest to see typical values for comparison, and the results of a few of the earlier measurements. There is sometimes a need to see trending of historical data, but it is not of highest priority for most users. The user could first acquire the correct signal and touch save, and the parameter tab could show automatically, however, to keep the locus of control in the user's hands, the redesign suggests that the user touches the parameter (or trend tab) for the analysis.

The functions of making default settings and performing less frequent actions should be kept separate from the crucial main task of achieving the hemodynamic parameters.

9.3.2 Presentation of the detailed design

For the detailed design of the interface; the gestalt laws and cultural stereotypes (presented in Section 3.10) were considered, in order to comply with the requirements and guidelines that were set up.

The following decisions were made for the design on a detailed level:

- It was decided that touch areas should be of the same color to introduce that this color signals that an action can be taken. In the redesign, most touch areas are white or light grey.
- A common menu system has been introduced in all Doppler profile related screens, to allow for the user to navigate more easily in the interface. The menu includes an **Exit** button denoted with a house symbol (replaces the USCOM symbol which is hard to interpret), and a **Settings** button denoted with a cogwheel symbol, as in the current interface, to keep consistency.
- It was decided to keep the mainly light background. To keep consistency with previous interfaces, the light background is advantageous and also, the opinions to whether 'dark on light' or 'light on dark' is easier to read differ between people but the classic 'dark on light' always works. Moreover, there is lack of evidence that black backgrounds save energy on LCD displays, but rather the contrary (Greenemeier, 2007). The company colors (blue, red and orange) are all dark hues that work well on a light background so it was decided to keep that, and introduce the company colors to the interface, for a design in line with the company profile. If 'light on dark' were to be implemented, it could be as an option for the user to switch to. However, no fictional screen shots for this option have been produced in this work.
- There exists an informal color coding system for at least some of the patient monitors on the market today. One can decide that the device should look different, and hence not follow the common color coding for these parameters, or decide to abide. What is not desired, is to follow the conventions to such a large degree that the users expect the same product behavior, but not follow through. This leads to users being confused and making slips that can lead to serious errors. An example of this could be to use black background, and have some of the parameters in the same color as they are on another device, but not all. Or to use a very similar interface design to another product, but using a different navigation system. With reference to the interface comparison in Chapter 1, and the color discussion in Section 3.9 it was decided that the following colors (or hues) will be used in the new interface for the USCOM:
    - Blue; already used to a large extent and highly connected to the Uscom Ltd company profile as it is a company profile primary color. Will be used to denote Oxygen delivery related parameters, in line with that these are often shown in light blue on patient monitors.
    - Red; company profile primary color. It is already used for the outline of the Doppler profiles which was decided to be a good color combination. For this reason, using red does not add an extra color. Red will be used to denote Contractility related parameters. As warm colors seem to approach the viewer, it

is advantageous for important parameters such as CO and it is commonly used on other patient monitors.

- Orange; company profile secondary color. Will be used to denote Preload related parameters. Orange is another warm color that suits the important Preload parameters.
- Purple; will be used to denote Afterload related parameters.
- Jade green; will be used to denote HR to follow normal convention.
- Grey; company profile secondary color. Will be used for background coloring.

Also, black, white, and variations of brightness and saturation of the above hues will be used to enable the user to distinguish groupings, buttons and other touch areas. Some deviations from color combination guides (using both red and green for example) have been made, to suit the company profile colors and medical device custom. However, the parameter colors are only used as redundant information, and will not be the only means for distinguishing the parameters from each other, hence this should not be a problem. Also, none of the unsuitable color combinations (e.g. blue and red) will be used on top of each other, but separately. It should be noted that blue and red is already used together in the Doppler profile window. Other combinations were tested, but red and blue were found to work well in this application as it is important that the edges of the profiles 'stand out' well. This color combination is kept in the redesign as it has been decided that it works well; no color vibration occurs. It would probably work less favorably for text.

9.4 ILLUSTRATION OF THE REDESIGN

The redesign decisions are illustrated by fictional screenshots (made in Adobe Illustrator), and explained more in depth in the following sections. The degree to which the icons that are used in the illustrations are recognizable have not been empirically tested, and no structured comparison between different alternatives has been carried out. Generally, when icons have been identified as 'classic' and clear enough, they are used on their own, and in all other cases, they are used together with text. They then serve as help to quicker identify alternatives once the function has been understood.

9.4.1 Selection and Welcome screens

Main improvements in the redesign:

- Improved overall organization, with focus on minimizing the number of steps required, and with a higher
- Grouping of related buttons
- Context-focused Help function
- Color scheme
- Clarification of connotations
- Use of icons for rapid identification of functions

Instead of being the first screen, the Welcome screen will now be the second screen that is shown after the system has started up completely. First, a selection must be made to either log in (leads to Welcome screen), or to go directly to the Doppler profile screen through **Quick**

Start. The choices given to the user have been grouped, and the functions and designations are different in the redesign. See a screenshot of the previous interface in Figure 46 and fictional screenshots in Figure 47.

Figure 46. Current screenshot of Welcome screen.

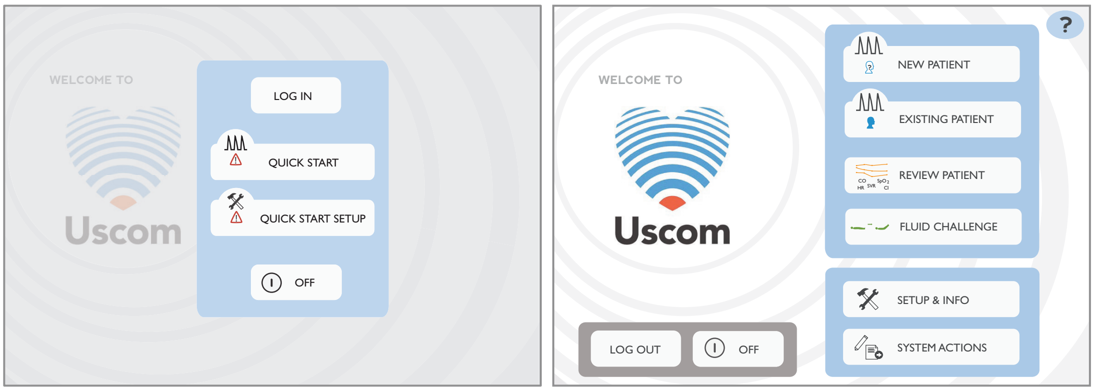

Figure 47. Fictional screenshot of introduced Selection screen, and redesigned Welcome screen.

The Selection screen is introduced in the redesign, to clarify to the user that the option is either to log in and work as a logged in user, or to use **Quick Start** (previously called **Run**). The setup that can be made in this screen correlates to the setup that the user could do as an anonymous user in the current interface. In the current interface, it is not clear to the user that those settings only applies when the user is not logged in. The buttons are placed in order of intended use, from top to bottom, and icons are introduced.

The redesigned Welcome screen introduces the following changes:

- The buttons have been grouped to clarify which are related to each other, and icons have been designed.
- The Doppler profile screen related buttons have been placed at the top, in the same order as before (with the **Run** or **Quick Start** button removed as it is selected in the previous screen). **Open** is now divided into **Existing patient** and **Review patient** for clarification, and to minimize the number of steps for the user.
- The **USCOM** button is now divided into **Setup & Info** and **System actions**, to clarify that one has to do with user preferences and other setup choices, and the other are actual actions, e.g. Export and Edit. The other reason for dividing this button in two is that the setup choices and actions available to the user are constantly increasing in number, and to be able to keep a reasonable number of tabs in each screen, it is

advantageous to have one button for setup and one for actions. It was decided to keep the tab system in both two options, to let the user know which other options are available, and to let them know where (s)he is in the interface.

- The **Log out** (previously **Log in/Log out**) and **Off** buttons have are now placed at the bottom, as these actions are taken last in the interaction, if used as intended.

The icons were designed to speed up and clarify the choices to the user. However, they are used together with text, for maximized explanation for each choice. Only the **Help** button uses an icon without text, as this symbol was interpreted to be universal and easily understood.

The idea is that the **Help** button should first lead to explanations related to the current screen, and also have a Search function and Menu, to easily find information related to other aspects of the USCOM use. A suggestion for a possible **Help** screen is found later in this chapter.

New intended main user task flow:

1. Select **Log in** (or choose **Quick Start** instead)
2. Select New patient.
3. Carry out the measurement and exit the Doppler profile screen.
4. Select **Off** or **Log out**. If **Log out** is chosen, the Selection screen will show, to allow the user to setup the **Quick Start Setup**, or allow another user to log in.

9.4.2 Doppler profile screen

Main improvements in the redesign:

- Focus on acquisition of Doppler profiles
- Common menu system at bottom of screen
- All touch areas large enough to use finger
- Drag function for moving time scale
- Elimination of 'cards'
- Improved accessibility for zoom, scale, changing patient, etc.

The Doppler profile screen was previously called Examination screen, see Figure 48. To clarify that it is related to the actual acquisition of the Doppler profile, and because the connotations 'Examination' and 'Card' have been questioned, it was decided to rename this screen to Doppler profile screen. It is now denoted with a symbol of a set of Doppler profiles, so this new connotation relates well to the symbol.

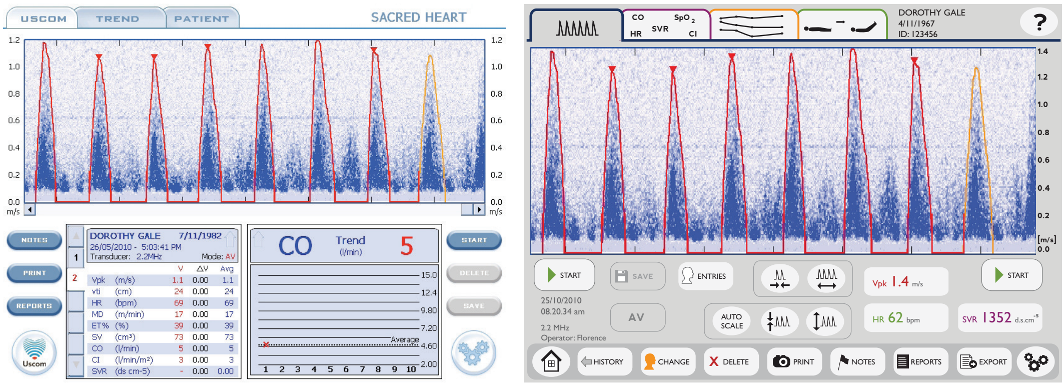

Figure 48. Left: Current screenshot of Examination screen. Right: Fictional screenshot of the Doppler profile screen (previously Examination screen).

The idea is to focus this screen more on the acquisition of the correct Doppler profiles as this is the critical moment in the use of the USCOM. If the Doppler profiles are incorrect, the calculations will be faulty. The user should only use three values (Vpk, HR and SVR in this screenshot) on the screen, as an aid in finding the correct profiles, and then change to either the Parameter screen (new) or Trend screen for reviewing the data. This gives more room on the screen for the Doppler profiles (in the fictional screenshot, Vpk=1.4 compared to Vpk=1.2 in the current screenshot) buttons related to finding the correct profile, i.e. zoom and scale, etc.

The bottom of the screen is turned into a 'menu bar' with buttons that are common for all four tabs and enable the user to exit at all times (touch the House symbol, which now always leads to the Welcome screen as opposed to the different connotations that the Uscom Ltd symbol in its place was associated with), change patient, see previous measurements, etc.

If **History** is touched, the user can choose to look at a previous measurement and in this screen, the Doppler profile for that measurement should show, and if **History** is touched in the Parameter screen, the related parameters should show, etc.

The Delete option should give the choice of deleting the current measurement, older measurements, or the patient data. The **Print**, **Notes**, **Reports** and **Export** buttons should lead to the same screens as in the current interface, but should include the choices of cancelling choices and moving back in the interface, without having to start over, which is currently the case for e.g. **Reports**. When one Report has been previewed in the current interface, the user must have the choice to go back and Preview other reports without having to exit the screen. Notes should also be editable, which is not the case in the current interface.

When the user acquires the Doppler profiles, it is important to have shortcuts to the most important buttons, rather than being able to see the parameter values. The introduction of shortcuts to **Entries** (add blood pressure etc), **Zoom**, **Scale** and **Auto scale** improves the accessibility for the user. Whenever too much time is spent changing settings and making choices on the screen, it is easy to make the mistake of changing the position of the transducer, which leads to that the user must start over to find the correct signal. Accordingly, the **Start/Freeze** button has been made larger than the others, and is positioned on both sides of the screen to enable the user to have the screen on either side of the patient and still be able to reach the button easily. Users have asked for automatic scale change for when the Doppler profiles reach the top of the screen, but as this would make it difficult to notice a change and might be confusing, the redesign suggests an automatic scale button instead, to keep the locus of control in the hands of the user.

The user can also change between the modes **AV** and **PV** by pressing that button (disabled in this screenshot). This is another function that users have requested, and is of high importance for the use. The fictional screenshot illustrates a situation following that the user has pressed **Save**, hence this button is disabled. The connotation 'Card' is removed and each measurement is now considered as one isolated measurement, instead of being one 'Card' of an 'Examination'. These connotations are considered awkward to users, and it has been easy to misunderstand the system and save incorrect measurements by mistake, which creates an incorrect trending of values. The exception is for Fluid challenges (see Section 2.6 and Section 9.4.5) where it is of interest to group the measurements.

The rather old-fashioned font on the buttons have been replaced with text in the font Gill Sans, which is easy to read and has a more modern appearance. Color coding is now used for the different parameters and to clarify connotations, e.g. red for **AV** measurements and blue for **PV**, red for **Delete**, etc.

The color combination red/blue for the Doppler profile window has been kept in the redesign as explained in Section 9.3 but other color combinations (with blue) were tried too. Blue was kept as it works well on a light background and stands for "medical" and "clean" in this context. In a future interface, where the device could possibly separate a more accurate signal from a poorer one, it could be advantageous to color code the Doppler profiles. Green, which symbolizes 'OK' might be used, as to the left in Figure 49. Another example of a color which works well with blue is purple (right in Figure 49), which is analogous to blue (next to it on a color wheel). It might not be as high in contrast as red/blue, but it creates a better harmony in the image.

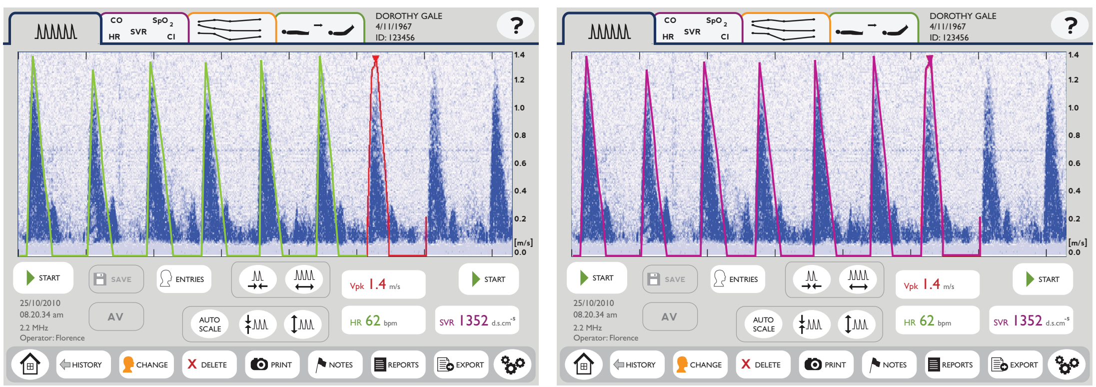

Figure 49. Examples of different color schemes for the Doppler profile window.

New intended user task flow for measuring CO:

1. Enter the Doppler profile screen.

2. If needed, touch the AV/PV button to toggle mode.

3. If desired, touch one or several of the touch areas that show parameter values, to change shown parameter.

4. Place the transducer (with gel on it) over the area of interest on the patient for AV or PV measurement respectively.

5. Touch Start.

6. If needed, touch the Zoom, Scale or Auto scale buttons in order to get a good view of the Doppler profiles. If additional adjustments, e.g. Gain are needed, the Settings display is entered.

7. When adequate Doppler profiles are found, touch Freeze and touch the profiles to select or unselect inappropriate ones. If it is desired to go back in time, slide the finger on the screen to go up to one minute back.

8. When a selection has been made, touch Save to store the data and select either the Parameter screen or Trend screen to analyze the data.

9.4.3 Parameter screen

Main improvements in replacing the Patient screen with Parameter screen:

- Eliminates unnecessary pieces of information
- Directs focus and improves readability
- Encourages the user to make use of more of the resulting parameter values

Because it is difficult to differ between the parameter values in the current screen, and that it takes space from choices that are more important for the acquisition of the Doppler profiles, it was decided to create another screen for displaying the values, see Figure 50.

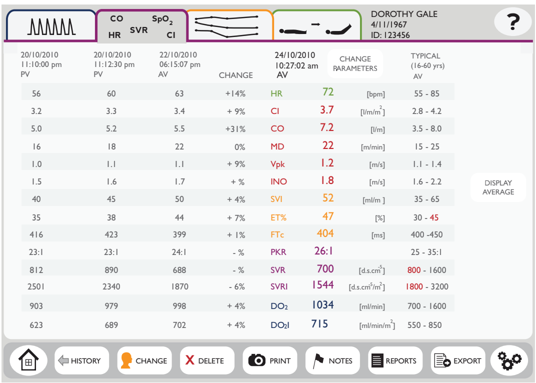

Figure 50. Fictional screenshot of Parameter screen.

The average values have been replaced with typical values (inserted or confirmed by a physician at the workplace), however there is an option to display average values too. Users have said it is common to incorrectly interpret the average values on the current interface as typical values, which is of more interest than average values. The introduction of typical values for users to base their decision-making on (to whether a specific value should be considered high or low) would be very advantageous.

A choice between displaying more or less values than the 14 in Figure 50 should be available, and also the current option of changing values to display. This should be made more intuitively by using the common technique of 'drag and drop' instead of the current technique of touching the value and then touching where you want it to appear (see Figure 51 for the current parameter choice display). Users have complained over the difficulty of understanding how to change the parameters, and it is thought that users might not realize that the option even exists, so a designated button is introduced in the redesign.

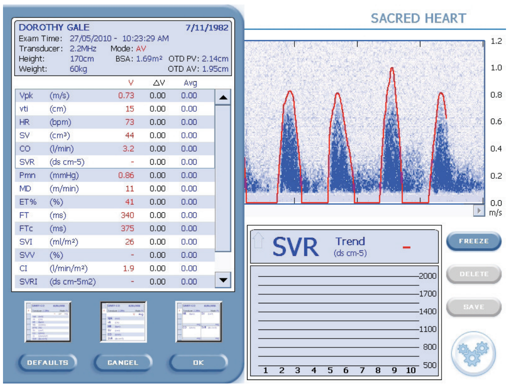

Figure 51. Screenshot of the current parameter choice display. The user must touch a value and then touch the desired location and it is suggested that a drag-and-drop action, which is more intuitive, is introduced instead.

9.4.4 Trend screen

Main improvements in the redesign:

- Improved functions for time scale and positioning
- Possibility to change patient, Exit, etc.
- Increased functionality with shortcuts

The Trend screen works quite well at the moment (see left in Figure 52), with four areas that can show the parameter of choice, or modified to show the trend of down to one parameter, taking up more of the screen.

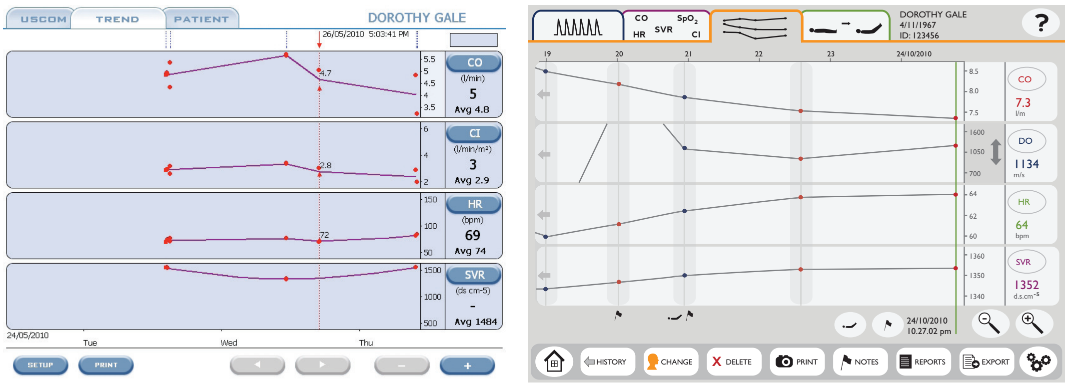

Figure 52. Left: Current screenshot of Trend screen. Right: Fictional screenshot of Trend screen.

However, the user cannot exit or change patient without first going back to the USCOM tab (Examination screen) and press the USCOM symbol and then press Cancel twice, to exit . With the redesign (right in Figure 52), the user has the same options as in the Doppler profile (and other screens) and the machine to use a drag technique for going back in time is available and should be implemented. The existence of grey arrows indicate that previous history exists, together with the lines that go back out of the screen.

The zooming should never go further out than to allow the user to touch each line separately, to change the current selection, marked with red dots in the current interface, and with a green line in the redesign. As before, when the graphs do not fit into the typical value window, an arrow is shown to indicate that it can be pressed to adjust the scale. Instead of grouping values that are close in time, only Leg Raising Tests should be automatically grouped, and the existence of a Leg Raising test is indicated with a symbol. As before, the Notes symbol is shown for measurements that have been noted.

The reason for only grouping fluid challenge measurements in the redesign is that the intended use is to make separate measurements in the Doppler profile window, and if users want to make several measurements in a short period of time, they should use the Fluid challenge window. Consider this example: a patient's CO is measured in the evening and in the morning. These two measurements would have been grouped to one in the current design, but as users claim that they are interested in seeing trends for the last few measurements, it is better to see these measurements as separate. The other reason for not grouping normal measurements is that previous measurements 'disappear' into the 'Card' in the current design. If a poor measurement is saved by mistake, that measurement affects the average value (which is currently shown as a 'group' in the trend screen), which leads to an incorrect interpretation.

9.4.5 Fluid challenge screen and Help screen

Main improvements by introducing the Fluid challenge screen:

- Relates to user's way of working
- Improves readability and directs focus to the next step of action
- Further user guidance

The introduction of a fourth tab in the interface is related to the further guidance of the user. The intended use of this screen is for *Fluid challenges* or *Passive Leg Raising (PLR) tests*, where several measurements of SV, stroke volume, is made under a short period of time. The user is first directed to the 'normal' Doppler profile screen, to find the current Doppler profile. As soon as **Save** is touched, however, the user is directed to the Fluid challenge screen (left in Figure 53), where SV is plotted over time. The user can go back to the previous measurement, or carry out another measurement. For each new measurement, the change of SV in percentage is displayed, and the user is supported with patient status messages. Every screen should have a dedicated Help screen (right in Figure 53), which leads to a common Help menu and that can be used to search for different terms.

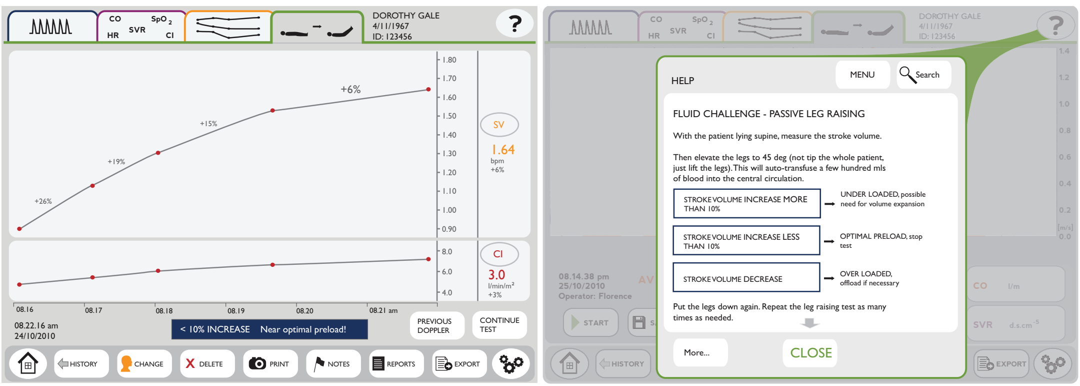

Figure 53. Left: Fictional screenshot of the Fluid challenge screen. Right: Fictional screenshot of the Help screen (here for Fluid challenges).

9.4.6 Patient details screen

Main improvements in the redesign:

- Grouping of related input

- Elimination of unnecessary input
- Elimination of unnecessary steps
- Clarification of OTD, BSA
- Always an Exit option

The Patient details screen has been improved by grouping the related boxes and adding more information input areas: Oxygen and Blood pressure (BP). It is common, especially for BP, to add this information, and including those entries already in this step minimizes the steps for the user. See Figure 54 for a current screenshot of this screen to the left and the redesign suggestion to the right.

It has now been made clearer that BSA stands for Body Surface Area, and that it is not put in manually, but calculated by the USCOM, which was not clear before. The Outflow Tract Diameter has also been explained, and it has been made clearer which values are calculated and which are manually inserted as this can be easily misunderstood in the current interface.

The input areas **Address** and **Location** were identified as unnecessary information that cluttered the interface, and have been removed. It was decided to keep the choice **Operator**, as most users have been found to only have one User account, and using the Operator field to identify which user who made each measurement. As the Patient details screen pops up both for new patients, and when a new measurement is made for a patient (unless a measurement has been made in the same session), the user should have the choice of both choosing Cancel and exiting completely.

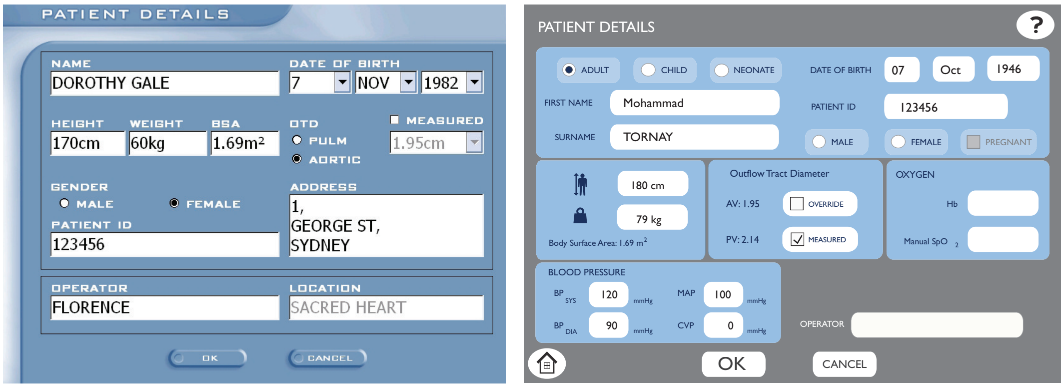

Figure 54. Left: Current screenshot of Patient details screen. Right: Fictional screenshot of Patient details screen.

9.4.7 Setup & Info and System actions screens

Main improvements in the redesign:

- All options are visible
- Unambiguous connotations
- If more tabs are needed, create two rows instead of hiding options

The previous **USCOM** button has been replaced by the **Setup & Info** and **System actions** buttons, to clarify what information can be found, and to separate setup choices i.e. user default setup, print setup etc., from actions, i.e. export data and edit patients. The reason for this is that **Settings** previously included for example **Print** (for print setup) and **Export** (for actually exporting data) which was confusing. Also, the current use of naming the button

USCOM and the screen that pops up **Settings**, was not found to be logical. The term *Settings* will now instead be used only for designating choices that the user makes in displays related to the screens, i.e. changing gain, volume, changing blood pressure etc.

Instead of scrolling through the tabs, they should be placed in rows, so that all options are always available to the user. The use of connotations i.e. **Save** when the actions is actually **Export** and the use of **OK** when the actions does not actually confirm a choice, but cancels the operation, should be overlooked. See Figure 55 for the current screenshot to the left and the redesign suggestion to the right.

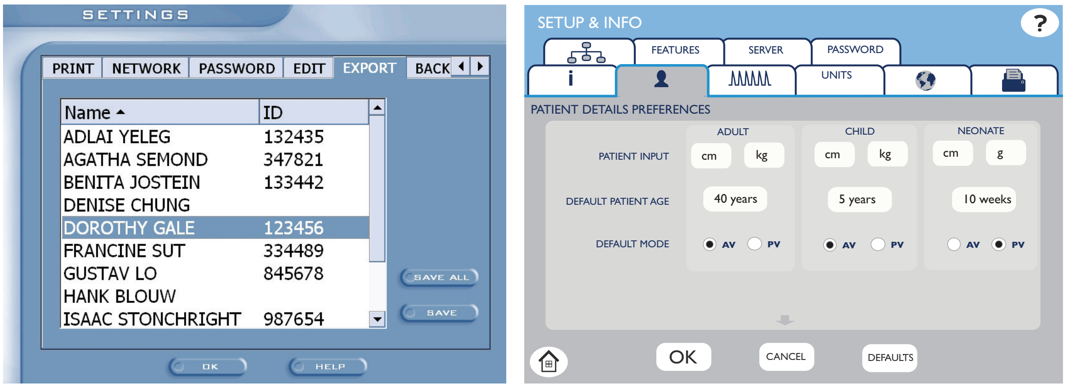

Figure 55. Current screenshot of USCOM (Settings) screen.

For the System actions fictional screenshot to the left in Figure 56, the search option for selecting patients to edit is shown. With the current interface, the whole list of patients is loaded each time, which is power consuming and not safe when it comes to patient security. There is also a lack of an option to search for the patients using the latest exam date, which has been asked for by users. This option is available in the redesign, which only displays the patients with a match of the search word, entered through the redesigned keyboard. The selected patients are marked with a darker hue of green, to be edited after touching the Select button. The idea is that the user is directed to a special Editing screen after this, to delete patient profiles, editing birth days, ID, etc. See right image in Figure 56 for a screenshot of the current Select patient display.

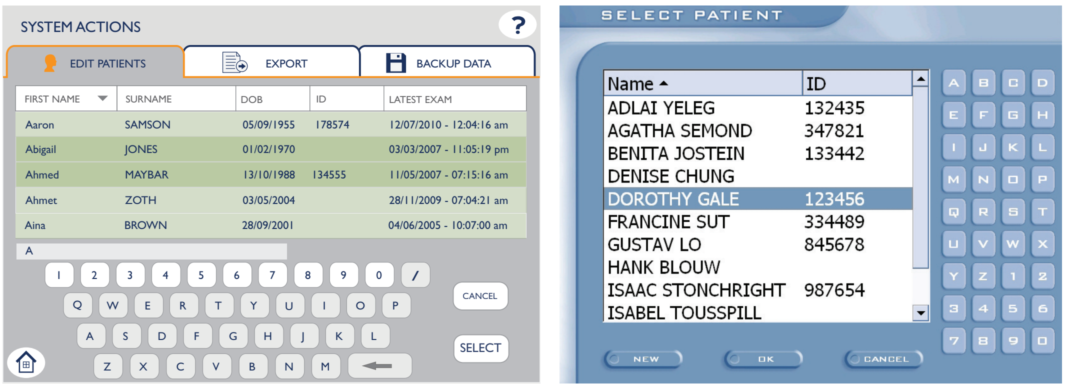

Figure 56. Left: Fictional screenshot of the System actions screen. Right: Current screenshot of the Select patient display.

The icons (e.g. for Export and Print) that have been developed for the Setup & Info and System actions screens can be used on their own, or together with text, as in Figure 56, for supplementary information. All developed icons are considered as probably easily understood by users of modern technology but should be tested in a usability test before implementation.

9.4.8 Settings display

Main improvements in the redesign of the Settings display:

- Clarification of selected choices
- Elimination of unclear connotations and abbreviations that are not obvious to users
- Consistency with other screens for OK and Cancel button placements

The Settings display is reached by touching the Cogwheel symbol to the right of the introduced Menu bar. See Figure 57 for the current screenshot to the left and the redesign suggestion to the right.

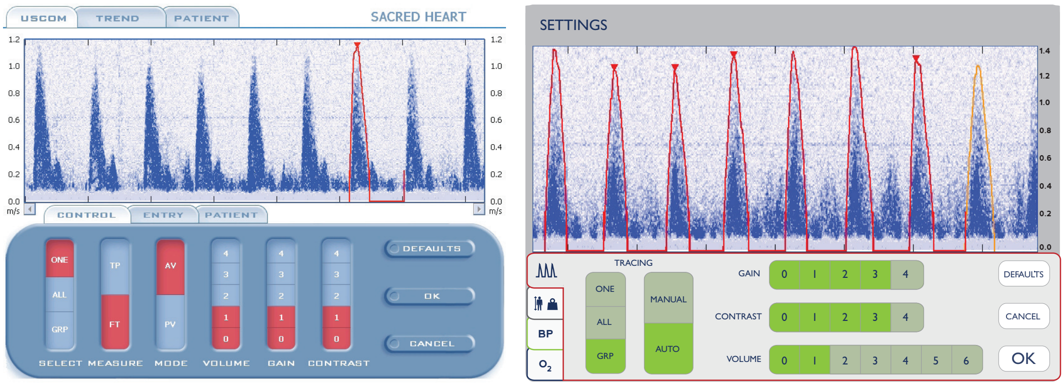

Figure 57. Left: Current screenshot of the Settings display. Right: Fictional screenshot of the Settings display.

The Settings display is arranged with the tabs to the left, to avoid covering the display while changing between the tabs. The unclear denotations Control, Entry and Patient have been changed to symbols which explain more, and one tab for inserting oxygen related measures is added. In the current interface, it is not clear which selections have been made, which is made clearer by using the same colors in different hues in the redesign. The position of the OK button is now at the bottom, in line with other screens of the interface, to avoid user slips. Note also that the option Mode: AV/PV has been deleted as this is now done directly on the screen, without entering the Settings display, and that the unclear denotations TP (Touch Point) and FT (Flowtracer) has been exchanged for Manual and Auto, as it was found that users do not understand the current denotations. The choices that are related to Tracing have also been grouped under that title, to separate them from options that are related to levels of gain, contrast and volume.

9.5 USING THE REDESIGNED INTERFACE

The user will first encounter a selection screen, where (s)he decides whether to log in or not. If not, the Doppler profile screen shows, and if the user chooses to save the measurement, (s)he will be asked to log in, as with the current procedure.

If the user chooses to log in immediately, the Welcome screen shows. This is based on a task-based design principle. This means that the user can select from a relatively large range of choices that correspond to the task that is of interest at the moment.

When the user acquires the Doppler profiles, the focus will only be on this task, as opposed to with the current interface, where a lot of result information is shown on the same screen. The user will now have to go to the more informative Parameters or Trend screens in order to see the results, which are adapted to a higher degree to the information needs of the user. A more automated and context-suited screen for Passive Leg Raising tests is also introduced, which can be used for monitoring fluid and drug distribution.

It should also be noted that it might be possible to allow for *continuous* monitoring of children already now, as the Doppler profiles are much easier to find on children than on adults. For this reason, it should be possible to switch between the Doppler profile and Parameters screens without having to save first. The values in the Parameter screen should then be updated with an interval of e.g. 10 seconds, or heartbeats, a value that should be possible to set by the user. When the user tries to exit, the user should be asked whether to save the measurement or not.

Wherever the user needs a higher degree of support, (s)he can touch the question mark, which leads directly to a section of the Help function that is designed for the screen in question.

The common menu for all Doppler profile screens will allow the user to switch faster and easier between the different functions, and the user will be able to exit to the Welcome screen in less than two steps from all screens (sometimes Cancel will have to be selected first).

If the user chooses to log out in the Welcome screen s(he) will be directed to the first selection screen, where there is a possibility to setup the interface for users who are not logged in, and also to turn off the USCOM.

9.6 IMPLEMENTING REDESIGN SUGGESTIONS

The main change in the design of the USCOM interface is the new organization of the different screens, allowing the user to navigate through the interface in a manner which is adapted to the user's way of working and clarifies which functions that the user must log in to use. The introduction of screens for Passive Leg Raising tests and the pediatric focused automatic setup increases the task-based design of the interface, which has been questioned for by the users. The common menu bar at the bottom of the screen facilitates quicker and easier navigation, while the tab system has been kept to allow for understanding of the where in the interface that the user is working. However, these changes are quite large and would need additional work before an implementation.

Some of these redesign suggestions could be implemented without changing the organization, such as the naming of screens and choices, and the positioning of different buttons, according to the redesign suggestion. The possibility for the user to change between patients has been identified as one of the main obstacles with the current design, which could easily be facilitated by introducing a 'home' button in more screens, e.g. the trend tab. Also, the use of colors to distinguish different selections should be looked over. The current use of red and blue is not intuitive, and variations of the same hue (in the redesign, green), would clarify the selection better.

Finally, the change that would have the most impact on guiding users is to implement typical values in the interface.

9.7 REDESIGN VALIDATION AGAINST REQUIREMENTS AND GUIDELINES

In this section, the redesign is validated against the usability requirements and guidelines that were presented in Section 8.6.

Information input requirements

R1.1 Touch areas are at least as large as the buttons in the current interface

The dimensions of buttons have been set to start from 16 mm in Adobe Illustrator.

R1.2 No input action requires two hands

No such input buttons or levers have been introduced.

R1.3 Possible to enter patient's first name separately
R1.4 Possible to enter patient's surname separately
R1.5 Possible to enter patient's date of birth
R1.6 Possible to enter patient ID
R1.7 Patient identification boxes are grouped together
R1.8 Patient details input screen contains all the patient information of interest

All the requirements above are fulfilled in the Patient details screen.

R1.9 If a height less than 50cm is entered, it is indicated that weight should be filled out too
R1.10 A warning with confirmation is issued when unexpectedly tall height is entered
R1.11 It is not possible to enter an invalid height
R1.12 A warning with confirmation is issued when height and weight correspond badly
R1.13 It is impossible to enter invalid dates
R1.14 It is possible to enter date of birth in the chosen order (e.g. dd/mm/yyyy)
R1.15 Patient identification information is unambiguous
R1.16 It is possible to enter all the necessary information to display a parameter in one sequence of actions

The requirements above are issues that are not illustrated by the screenshots but should be considered in the programming of the interface.

R1.17 Input boxes are organized in order of relevance

Input boxes in the Patient details screen are organized in order of subjectively judged relevance from top left to bottom right.

Information output and display requirements

R2.1 When finding the Doppler profiles, that action is in focus

The fictional screenshot of the Doppler profile window focuses on finding the Doppler profiles to a higher degree than the previous solution.

R2.2 The location of the device is not inserted or displayed

R2.3 The patient address is not inserted or displayed

The requirements above are fulfilled in the Patient details screen.

R2.4 It is clear which flow parameter values that are the current ones

The current values in the Parameters screen are marked out with colors (other values are grey), are larger in size than other values, and it is marked out in text.

R2.5 Necessary information to identify patient is displayed when performing measurements

The redesign shows the patient's name, date of birth and/or patient ID in all Doppler related screens.

R2.6 Information on battery status is shown when the device is not connected to the electric grid

This is not illustrated by the redesign as the normal use is having the USCOM connected to the electric grid.

R2.7 Normal values for the flow parameters are possible to display

R2.8 No average values are automatically displayed for patient flow parameters

It is suggested in the redesign suggestion that average values are replaced by typical values, but that the user should have the option of displaying the average values if desired. This is because no deep investigation has been done to whether some users want this information, but the decision is made on expert opinions from physicians claiming that average values are of no use.

R2.9 The interface is not visually cluttered

None of the redesign screenshots contain more than 6 colors, black and white not included. The large degree of colors used is partly due to the grouping of parameters, which means that at least four different colors must be used if the groups are to be color coded. This grouping can be discussed, maybe it is better to keep the colors at a lower variety. However, the color coding of parameters is widely used on patient monitors today and was decided to be advantageous.

R2.10 The contrast between colors is sufficient

The match between fore- and background colors in the redesign suggestion was considered in all the fictional screenshots.

R2.11 Characters are visible from a distance of 2 m

R2.12 Characters are easily distinguished from each other

Because no actual prototype has been produced, the requirement verification values could not be measured. However, a more modern and easily read font is suggested in the redesign.

R2.13 A specific screen for 'Fluid challenges' is available

A Fluid challenges screen is illustrated in the redesign.

R2.14 The machine's sound level should be higher than today's

This requirement is not illustrated in the screenshots. It was verified by Uscom Ltd that the next version of the USCOM will have a higher sound level.

R2.15 Abnormal values are 'beamed out'

Parameter values that are outside the typical range are highlighted in red in the redesign.

Functionality and navigation requirements

R3.1 There is always an exit option

Every screen in the redesign has a direct exit option through the 'home' symbol.

R3.2 The placement of selection buttons (e.g. Cancel, OK) is consistent throughout the interface

The OK button is always to the left or at the bottom of the selection window in the redesign illustrations, and the Cancel button is next to it.

R3.3 It is possible to print screens of interest
R3.4 It is possible to export data from relevant screens

No change to which screens that can be printed or exported from has been introduced in the redesign. The common menu now covers these options.

R3.5 It is possible to print group reports for patients
R3.6 Flow parameter values should be possible to average over group reports

These alternatives are not illustrated in the redesign due to the limited time and presentation space.

R3.7 It is possible to add notes

This is possible (in the same screens as before) through the common menu that is introduced

R3.8 It is possible to edit notes
R3.9 It is possible to print custom designed report

This is not illustrated in the redesign.

R3.10 It is possible to search for patient's with different methods

The search options are extended in the redesign, see Figure 56.

R3.11 The PATIENT screen is removed

This screen is removed in the redesign suggestion.

R3.12 Every screen has a help function

The screens in the redesign all have specific Help screens that can redirect to a main Help.

R3.13 It is always possible to cancel choices

This is true in the redesign screens.

R3.14 There exists a pediatric-focused mode

No special 'mode' for pediatrics was introduced in the redesign, but an interface that adapts to different age settings is suggested instead. The Doppler profile scale and patient input values can automatically adjust to different needs.

R3.15 It is possible to go back in the Doppler profile window to select Doppler profiles

This is not illustrated by the fictional screenshot but should be considered when programming.

Physical qualities requirements

These requirements are not illustrated by the fictional screenshots as they concern other issues than the interface.

Usability guidelines

G1 The interface should work in a monochrome design but be enhanced with redundant information, i.e. color coding

The color-coding that is applied in the interface can be removed without loss of information.

G2. Gestalt laws should be applied to all aspects of the interface design

In all screenshots, relevant grouping of related values and buttons have been made and the design aims at visual balance.

G3. Western cultural stereotypes should be followed

This is true in the redesign. For example, buttons to increase values are placed on top or to the right of decrease values buttons. The color red is used to signify a value that is out of range, which follows the stereotype. However, it is also used for one of the parameter groups. This is due to a number of reasons, as explained in Section 9.3.2.

G4. The design should be consistent throughout the interface
G5. The design should be consistent with previous versions

Obviously, it is not possible to fulfill both the above guidelines to the same degree, but a balance must be found. The emphasis in the redesign is on consistency throughout the interface, while keeping similarities to the previous one where suitable.

G6. The design should be consistent with the interfaces of other medical devices that the device might be used together with

This is mostly followed in the sense of placements of parameters and graphs. No deep investigation to the functioning of other medical devices was made, and in some cases, it was found unsuitable to follow the design of similar products, e.g. patient monitors. The design should differ enough for the user not to mix different products up, and thereby be confused in the interaction. However, the user should be able to expect that similar symbols should lead to similar actions etc., which is thought to be fulfilled in the redesign.

G7. The interface should not require that the user holds more than 5-7 pieces of information in the working memory

The user is not expected to memorize any information while navigating the interface.

G8. The combination of red/green and blue/yellow should be avoided, to minimize the influence of color deficiencies

These colors are not used next to each other in the redesign.

G9. Information input is intuitive and consistent with other common touch screen devices

It is believed that this is true to a higher extent than earlier, e.g. by removing the scroll bar and introducing 'finger slide' to move around on the screen.

G10. A minimal number of actions should be necessary to complete tasks

'Minimal' can be discussed, as there is always a trade-off between minimizing the number of actions needed (or screens to go through) to complete a task and cluttering the screen. However, it is believed that a good balance has been reached in the redesign, where the number of actions has been lowered, while keeping the screen clutter low. This is exemplified by the Patient details screen that allows for direct input of more patient information than earlier. Another example is the common menu on the bottom of the screen, that enables a more direct navigation between screens.

G11. Symbols should aim to follow conventions and should be easily interpreted by the intended users

The idea was to use symbols on their own when it is believed that they are easily interpreted, and in other cases, they are combined with text. In these cases, the symbols are there to speed up the recognition of the button or selection. Some of the symbols were appreciated as easy to understand by the Uscom Ltd. staff when they were presented with the redesign, while it was discovered that others were ambiguous to some. For an implementation of the redesign straight from the fictional screenshots, it is therefore necessary to investigate which symbols that work on their own, and which need to be replaced by or combined with text.

G12. Designations should be relevant and unambiguous

It is believed that the designations in the redesign are more relevant and easily understood than in the current interface.

G13. The interface should have a logical structure

The structure of the interface has been carefully considered in the redesign.

It can be noted that Uscom Ltd. explains some of today's confusing designations and navigation issues with the fact that functions have been added on over time, without having taken 'a step back' to get a good overview.

G14. The desired information should be possible to interpret quickly and easily by the user

The redesign aims at fulfilling this guideline as well as possible.

G15. The critical action of acquiring accurate Doppler profiles should be made as easy as possible, without too much distractions

It is debatable whether it is of interest to show the Doppler profiles once they have been selected. The redesign is based on the conception that it is more important to focus on the acquisition first, and then focus on the acquired values in the next step.

G16. Important functions of the interface should be clearly marked

This guideline has been considered. For example, the Start/Freeze button has been made larger and has an unambiguous symbol, the 'Play' sign indicated by an arrow.

G17. The device design and functioning should be in line with the company profile

It is believed that the new design and functioning is in line with the company profile by the use of colors, and with regards to safety and simplicity.

G18. The device should be designed according to medical device requirements

They requirements that must be fulfilled are to the author's knowledge satisfied. The investigated regulations include the Australian Therapeutic Goods Administration (TGA, 2010), the US Food and Drug Administration (FDA, 2010) and the European Commission Consumer Affairs CE marking directives (Council Directive 93/42/EEC, 1993).

G19. The device should be possible to manufacture in the existing settings

The physical aspects of the device are only altered by the removal of the pen holder, which should be possible to manufacture in the existing settings. The USCOM display resolution (600x800 pixels) does not allow for direct implementation of the redesigned interface, which would either have to be altered to suit a lower resolution, or a higher resolution would have to be used for the USCOM.

G20. The interface is kept free from irrelevant information

The only information that was decided to be irrelevant that has been kept is the frequency of the transducer. There is only one transducer that can be used today, which it was seen as irrelevant information during the project. However, USCOM claims that it is traditionally shown on ultrasound equipment and that it could confuse users not to see the frequency. Also, one other transducer frequency might be added in the future. For these two reasons, it was decided to show the frequency.

10 FUTURE INTERFACE DESIGN SOLUTIONS

In this chapter, research on the visual display of quantitative information and on the diagnosing procedure is presented. This is followed by future design recommendations for the USCOM.

The USCOM can now present over 20 parameters which are interrelated and sometimes hard to interpret for users. In order to optimize the use of the USCOM, on one hand to simplify diagnoses and on the other hand to guide treatment, it is of interest to guide the user further than in the current interface.

Different options to guide the user further in either diagnosing or treating the patient, or both were compared and are presented in this chapter. The result of the comparison was a decision on the most suitable option for the USCOM, the 'decision trees'.

Furthermore, one problem with the USCOM is that it is not 'continuous' today, i.e. the user must choose profiles and afterwards look at the results. In an ideal monitor, the user could see constantly updated accurate values, which today's technology does not support. In the near future, however, it is possible that the USCOM will have a continuous display of values, where another interface would be of interest.

Another aspect of the possible future needs is the adaptation of the interface to a smaller device with fewer functions, which would be more portable than today's product.

A brief analysis of how the interface could be adapted to suit these expected future needs is held in the latter part of this chapter.

10.1 RESEARCH ON VISUAL DISPLAY

> 'What is to be sought in designs for the display for information is the clear portrayal of complexity.' (Tufte, 2001, p. 191).

The research on visual display of quantitative information that was done includes firstly general design guidelines and examples, and secondly the ways in which the USCOM could be presenting large quantities of data in a different manner from today, e.g. in different types of graphs or interactive design solutions.

The design guru Edward Tufte has written three beautiful books on design, and specifically to display large quantities of data: *Envisioning Information* (1990), *Visual Explanations: Images and Quantities, Evidence and Narrative* (1997), and *The Visual Display of Quantitative Information* (2001). The design guidelines in these books were considered when making the redesign suggestions for the USCOM. This section contains a brief description of some interesting design points that Tufte makes.

Attractive displays of statistical information, according to Tufte (2001):

- have an appropriate format and design; consider how to combine sentence, table and graphic
- combine words, numbers and drawings; words and pictures belong together, and explanations that allow for better understanding for the data make graphics more attractive to the viewer
- are well balanced, proportional and relevantly scaled; consider for example the nature of data to suggest the shape of the graphic, and if possible, aim for horizontal graphics about 50 percent wider than tall
- are accessible to the viewer; e.g. words run from left to right and are spelled out where possible, as opposed to abbreviated

Tufte (1990) stresses that 'chartjunk', i.e. information that is not value-adding when presenting visual information, should be avoided. Examples of chartjunk include thick bars of grid boxes, unnecessary grid lines that camouflage the data, and other graphical decoration that does not carry information. Sometimes the data can be made clearer to the observer by even erasing part of the data (creating a white grid) as to the right in Figure 58.

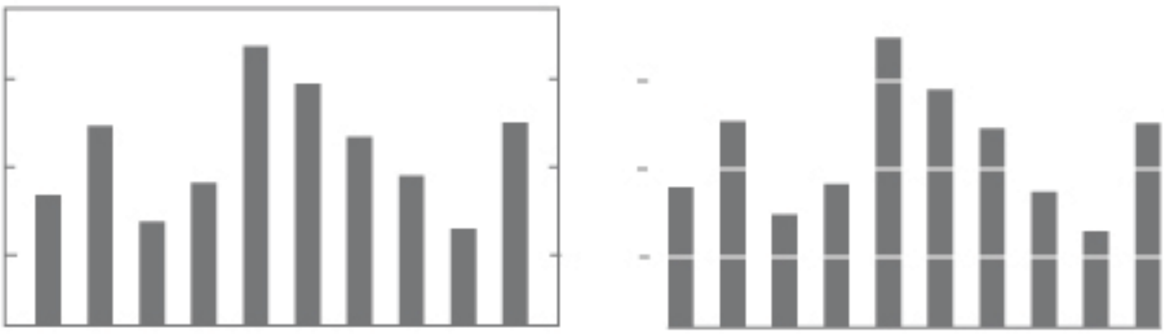

Figure 58. Example of erasing data while keeping, or even adding, information. Modified from Tufte (2001, p. 127).

The typology design guideline that tables should not be set as 'nets with every number enclosed' (Tufte, 1990, p.55) has been used for the design of the Parameter screen in the redesign suggestions. Tufte (1990) also claims that vertical rules in grids should be avoided if possible. The grid should never steal too much attention from the actual data that should be displayed.

10.2 RESEARCH ON THE PROCEDURE OF DIAGNOSING AND TREATING PATIENT CONDITIONS

In order to understand the process of diagnosing patients in an emergency department (ED), an interview specifically focused on the cognitive aspects of making a diagnosis was carried out with an anesthetist working at St. Vincent's hospital in Sydney. A particular interview protocol was used to do the interview; Applied Cognitive Task Analysis (ACTA), described in detail in Section 4.9.

Task diagram

The task to investigate was specified as 'Diagnose a patient, in particular one who is hypotensive (abnormally low blood pressure)'. The respondent listed the following examples of potential causes: hypovolemia (decrease blood volume for some reason), cardiogenic (the heart is the primary problem), neurogenic (e.g trauma to the spinal cord), or septic (whole-body inflammatory state), vasodilatory (due to widened blood vessels for some reason, could be due to sepsis), or obstructive vascular causes (such as stenosis of the pulmonary artery). The respondent was asked to break down the task into a few steps. The result is seen in Figure 59.

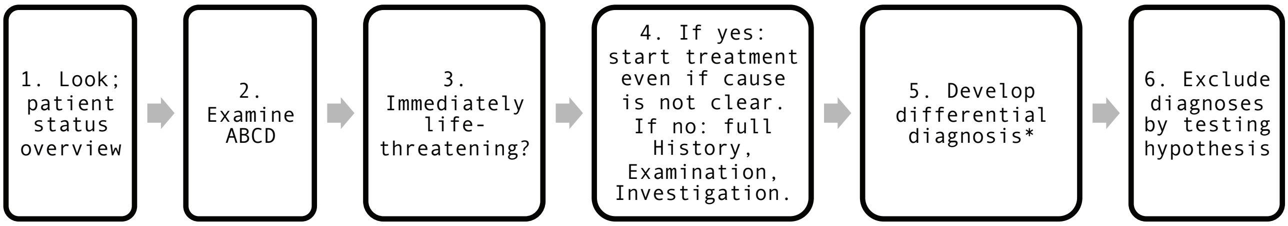

Figure 59. ACTA Task diagram for diagnosing.

The steps in the task diagram are described in more detail below:

1. Look, get patient status overview. This includes assessments such as 'Is the patient conscious?', 'Can the patient communicate?', and 'What is the color of the patient's skin?', etc. This is a very general assessment of patient status that does not pose great cognitive demands on the physician. Think about the context; for example, if someone is in ICU, they might be kept unconscious for a reason, whereas another person who is unconscious is so because of a serious patient condition.

2. Examine ABCD. The mnemonic rule ABCD stands for Airway, Breathing, Circulation and Degree of disability (neurological problems). While the examination is carried out, one also tries to help the problem. This step is very routine-based and includes checking vital signs such as pulse and oxygenation of the blood (if the patient is connected to a monitor).

3. Immediately life-threatening? The subsequent steps depend on whether the condition appears to be acute or not.

4. If yes: start treatment even if cause is not clear. If no: full History, Examination, Investigation. The History concerns patient history such as 'a history of previous heart attacks'. The Examination is a more thorough examination of the patient, and the Investigation relates to tests that can be carried out, such as blood tests, X-ray, CT scan, ultrasonography (medical imaging, not to be confused with the ultrasound used in USCOM, which does not produce an image), etc.

5. Develop differential diagnosis. This means that, ideally, all possible diagnoses are listed (or thought of).

6. Exclude diagnoses by testing hypotheses. If no diagnosis can be made after all the hypotheses are tested; the diagnostician has either not thought of that diagnosis, made an error in the investigation, or the true diagnosis is unknown to medicine.

Obviously, none of the steps in the suggested task diagram can be done without using any cognitive skills, however, the only step that was identified as really cognitively demanding by the physician was step *5. Develop differential diagnosis*. This step requires a lot of knowledge and experience, in order to think of all the possible diagnoses that could apply in each situation. If one has been able to list all possible diagnoses, it is rather straightforward to start to exclude the incorrect ones.

Knowledge audit and Simulation interview

The second step of the ACTA is the knowledge audit, which provides details and examples of the cognitive elements of the respondent's expertise. For each example, the clues and strategies that the expert used, and why it is a difficult situation, is noted.

The third and last step of the ACTA is to make the respondent think of a particular situation and list the events that happened, and the actions, assessments, critical cues and potential errors that a novice would have done. The situation in this case was to diagnose a case of Pulmonary Embolism (PE, a blockage of the main lung artery, or one of its branches, by a substance that has travelled through the bloodstream from another part of the body). This is typical to contract from long flights, for example. Some diagnoses are easy to make, for example when a patient comes in with an asthma attack, whereas PE can be very difficult to diagnose. The respondent claims that literature suggests that it is a widely under-diagnosed condition.

The results from the two steps above are found in Appendix L.

10.3 PROPOSED WAY OF WORKING

After having investigated the way that physicians make their diagnoses (even though this surely differs between different cultures, hospitals and even physicians), a proposal to how cardiac output monitors should be used in the process of diagnosing could be presented.

The proposed way of including the USCOM in the future for assisting in diagnosing is the following:

1. Get an overall view of the patient. This is done to take in all the basic facts such as if the patient can communicate or not. All the relevant patient information available can make a difference to what the diagnosis will result in.

2. Examine the Airway, Breathing, Circulation and Degree of disability (neurological problems). Use the cardiac output monitor to collect information about the patient's hemodynamic status. CO (or CI), especially together with additional parameters, is useful for understanding the patient condition. This step is important, and monitoring the hemodynamic parameters is the only way to know for sure what the status of the patient's Circulation is. Knowing the parameter values and understanding the relations excludes today's guesswork from the physician's task.

3. Decide whether the condition is life-threatening or not and take the appropriate action. A cardiac output monitor can assist in both guiding treatment, such as monitoring stroke volume for successful fluid challenges, and to find the cause of the symptoms.

4. Use a cardiac output monitor to aid in both coming up with a differential diagnosis, as well as excluding the impossible diagnoses and guiding the actual treatment.

10.4 USING THE CLINICAL TRIAD

One way to guide the user, and which has been partly implemented in the redesign suggestion, is to clarify which parameters that are related to which part of the clinical triad of *Preload, Contractility* and *Afterload,* as discussed in Section 2.6. The only competitor found to have divided the parameters into categories is the PiCCO (*Flow, Volume*, *Organ Function* or *Oxygenation*). The four categories are color coded in the PiCCO. As the PiCCO shows different parameters to the USCOM, the categories are not directly transferable; the *Flow* is related to both CO, SV and SVR while the *Volume* category relates to the *Preload* and the *Organ Function* is related to *Contractility.* See Figure 29 in Section 6.2.2 for the PiCCO screen that is divided into categories.

Because the user's decisions should be based on an understanding the balance between *Preload, Contractility* and *Afterload,* it is advantageous to inform the user on which parameters that belong to which category. In the redesign suggestion, the parameters have been listed together with the other parameters in the same group, and color coded after the three groups and Oxygen delivery. One idea for a future interface is to group the parameters more explicitly and only display one or two in each group for the user to grasp the situation quickly. This type of design, which focuses on only a few parameters, is probably more advantageous on a device that measures the values continuously, and it is therefore recommended that it is only implemented if the USCOM manages continuous measuring in the future.

10.5 POSSIBLE FUTURE LAYOUTS FOR GUIDING TREATMENT

Different possible layouts that can aid in making diagnoses, guiding the treatment, or both, are presented in this section. The design suggestions all have in common that they are not ready to be directly implemented to the interface without further work being done.

10.5.1 Radar graphs

The parameter values can be shown in so called Radar graphs, where a selected number of parameters are plotted in a star shape. One of the competitors, PULSION, show a similar solution, with five parameters plotted in what is called 'SpiderView'. It is claimed to show the parameter status 'at a glance', however, it is questionable what this graph adds to the data. This is because deviations from the normal ranges can easily be shown without using the 'SpiderView'. However, there is potential in plotting different patterns that could match different patient conditions. The problem is that many conditions are related to patient history in ways that the physician at hand must consider (Gomez & Chandrasekaran, 1981). Even with a large number of parameters displayed, the decision to whether a condition is related to e.g. heart failure or cardiogenic shock, is hard to take entirely from looking at a graph. If it could be proven that a certain number of parameters are sufficient to determine one condition from another, and the selection and order of these parameters were to be constant, a match could be made, but it would probably take a lot of research and clinical validation to be able to guide the user this far.

The graphs could be used as a means of showing the user in which direction the therapy has taken, by using different shades of the same color to point out what the patient status is at the moment, and where it was for a history of measurements. See Figure 60 for an example of how the Radar graphs could be used to match a certain condition. The value scales start at the middle of each graph, increasing outwards, with the typical values plotted within the green area, and abnormal values outside the green area.

If this idea were implemented in the interface, variations of the radar graphs with other parameters would be necessary to examine in order to find unambiguous patterns, also, further medical research must be done on connecting parameters with certain conditions.

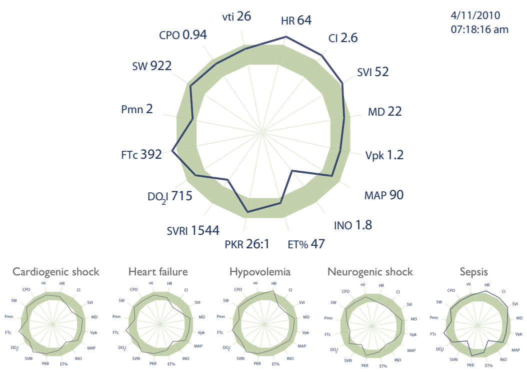

Figure 60. Examples of using Radar graphs for identifying different patient conditions. Note that the different patterns are only loosely based on actual conditions and are not validated by any physician. The values shown in this figure cannot be used to guide the diagnosing of patients without further validation.

Another application of the radar graphs is to plot the patient condition over time, by illustrating earlier values in a less saturated color, as in Figure 61. However, it is questionable how much value that is actually added to the information, as the same information can be easily taken in by looking at the parameter values in a matrix. If implemented, it should be as an alternative for the user to decide whether this option is more convenient or not.

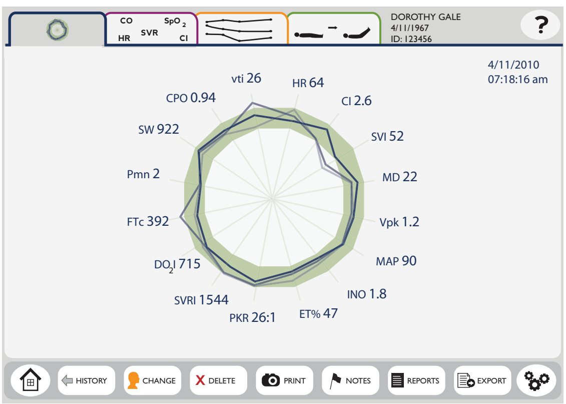

Figure 61. Example of how a Radar graph to plot changes over time could be implemented in the USCOM interface. The differences in saturation of the graph aims at illustrating the direction that the different values are taking. For example, it could mean that 20s ago, the least saturated blue graph was measured. 10s ago, the medium saturated graph was measured. The current values are shown in the highest saturated blue color.

10.5.2 2D graphs

One other competitor, LiDCO, uses a '2D graph' to show the current values for, and relationships between, MAP and CO. A window of typical values for both, and constant lines of SVR are plotted. This is also an option for guiding the user to the next step of therapy.

A variation of these graphs could be to plot different conditions, e.g. sepsis, on the graph for the user to decide whether it matches the patient condition or not. The same problem as above occur however, concerning difficulties in diagnosing patients judging from a set of parameters, without relation to patient history, visual observations and judgments.

One difference between the LiDCO and USCOM is that the LiDCO shows continuous values, which creates a possibility of constantly showing the guiding 2D screen. For the USCOM, the user would have to make a measurement, and then display the result on the 2D screen. In the future however, it is likely that the measurement will be continuous also for the USCOM, which would allow for a continuous display of values.

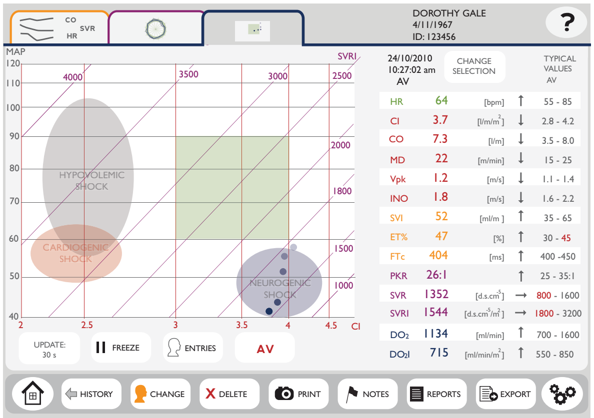

Figure 62. Example of how a 2D graph with different patient conditions marked out could be implemented in the USCOM interface. Note that the placements of the different shock areas are only loosely based on real conditions, and have not been verified by any physician. The values shown in this figure cannot be used to guide the diagnosing of patients without further validation.

10.5.3 Decision trees

One option that has been considered is to implement 'decision trees' into the interface. The training material for the USCOM include decision trees developed by Smith (2009) and the study visit to Bathurst Base Hospital showed they had a set of decision trees hanging on the basket of the USCOM stand.

The advantage of using the decision trees is that the crucial decision making is left in the hands of the user, as opposed to the USCOM taking too much control of the decisions, that might be influenced by other factors than the ones that are put into the USCOM. Also, if other devices are used to measure for example HR or DO_2, which are not connected to the USCOM, the user could still use the Decision trees.

At least one competitor (PULSION) displays a decision tree on their homepage for guiding therapy (PULSION Training, 2010), but no competing CO monitor has been found to integrate decision trees into the interface.

See Figure 63 for an example of how an interactive decision tree could be implemented in the USCOM interface. The user should not need any manual or other physical material to make guided decisions and the action of moving to different pages and sections in a physical representation of a decision tree could be made quick and interactive by implementing the guide, preferably with guidance to the user to how the measured values correspond to typical values, but letting the user make the decision to whether the value should be considered typical or not in each step, allowing for other aspects of patient information and history to be evaluated.

The user could be guided with typical values and at the same time viewing what the actual value is for the parameter of interest. This allows the user to add other pieces of information into the assessment of whether a value should be considered low, normal, or high. The interface could guide the user to quickly identify which 'route' to take through the decision tree, whilst leaving the final decision in the hands of the operator.

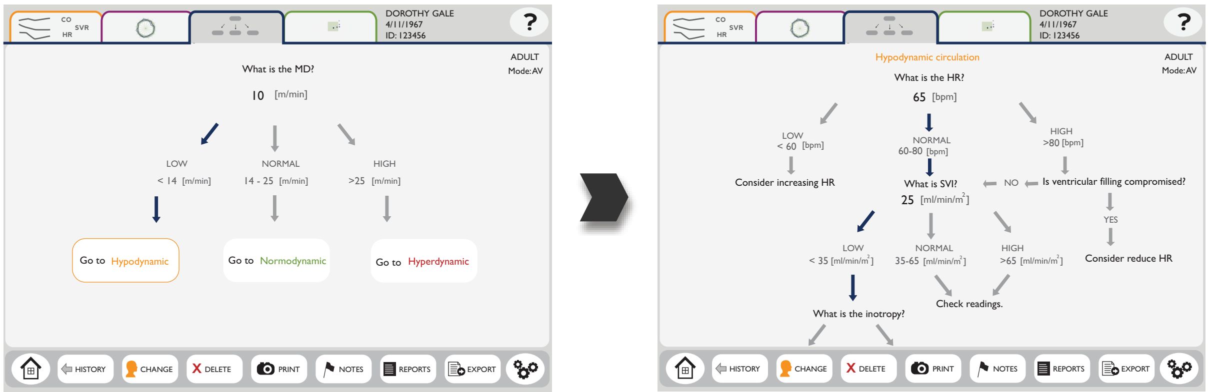

Figure 63. Example of decision tree implementation. The user is guided by the green arrows to the suggested route through the tree, while still being able to make other decisions. For example, the physician might consider a minute distance (MD) of 14 to be 'Normodynamic' even though the interface would suggest the 'Hypodynamic' route in this case. Note that the information in this image should not be used for making diagnosis, but merely serve to exemplify the concept.

10.6 COMPARISON OF POSSIBLE DISPLAY LAYOUTS

Gomez and Chandrasekaran (1981) suggested in their paper "Knowledge Organization and Distribution for Medical Diagnosis" that a diagnostician's knowledge of diseases, causes of them, or other information relevant to a diagnosis, is distributed in a hierarchy similar to that of a botanical or zoological classification. Hence, distributing the knowledge in a medical device according to a hierarchical structure is likely to promote the building of an appropriate mental model (explained in Section 3.4) for the user. It is believed that the biggest potential in aiding the user in diagnosing is in implementing decision trees in the interface. The decision trees puts the user in control in the decision-making and allows for the user to also consider external patient information. All the information that can be relevant in diagnosing a patient is not possible to formulate into input to a medical device (at least not with modern technology), and some human knowledge might only be brought to mind in the right context. Gomez and Chandrasekaran (1981) use the example of a doctor examining a patient with hepatitis, and trying to figure out the cause. Let one piece of patient information be: "the patient is a farmer". This might lead the doctor to bring to mind the world knowledge: "farmers often drink water from wells", which might cause the doctor to suspect that the patient has contracted a viral infection from drinking well water. However, in another medical context, the information "the patient is a farmer" might have gone unnoticed.

When it comes to guiding the user further in fluid and drug administration, the introduction of the Fluid challenge screen is one step in that direction. Another could be the 2D graph which allows for the user to see in which direction that the previous actions have led to, or the radar graphs that show varying patient states over time. Furthermore, decision trees have been identified as a useful tool in making fact-based decisions both for making diagnoses and guiding the treatment.

The proposed solution for future use of the USCOM is to implement decision trees into the interface. This solution leaves the decision making in the hands of the physician, and allows for the physician to consider external information, that does not have to be entered in the device.

10.7 TAKING THE INTERFACE FURTHER

In the future, other applications of the USCOM might be interesting to look at.

10.7.1 Continuous monitoring

In a near future, it is possible that sufficient signal quality can be determined by the machine, and also that the technology of the USCOM allows for continuous monitoring. For this situation, it is suggested that the Doppler profile screen be removed from the interface, allowing the user to choose between a modified Parameters screen and the Trend screen. One option is to combine these screens to a common one, see an example of a possible layout in Figure 64. If the monitoring is continuous, no need to **Save** exists, and the user would only have to concentrate on making use of the parameters. It is suggested that an update interval for the values is modifiable by the user, e.g. every ten seconds, or for every ten heartbeats. The shortest interval is naturally to update for each heartbeat, but updating the screen that often would make it impossible for the user to follow more than a couple of the parameters simultaneously.

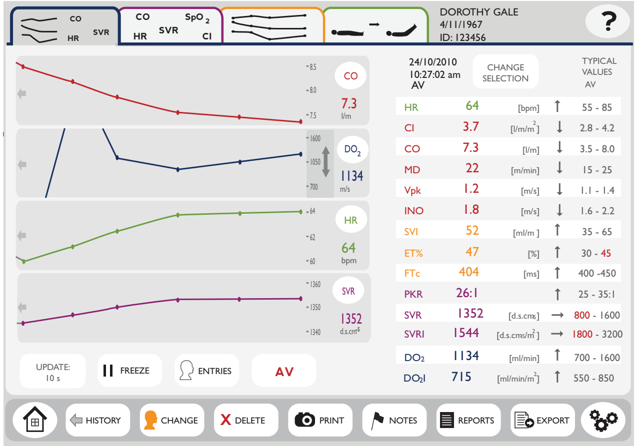

Figure 64. Combination screen that could be used for continuous monitoring.

10.7.2 Adaptation of the interface to handheld device

For a possible future development of the USCOM as a handheld device, the interface would have to look different, due to the smaller screen.

The redesigned interface is easily adopted to a handheld application, as the Doppler profile screen focuses on the acquisition of profiles, to a larger extent than the current interface does. Depending on the desired size of the screen, the interface could either allow for index finger touch, or the use of a stylus to make selections. This would have to be tested, as it is hard to estimate the accuracy of e.g. selecting different Doppler profiles of various sizes. See Figure 65 for an example of how the handheld device interface could be designed.

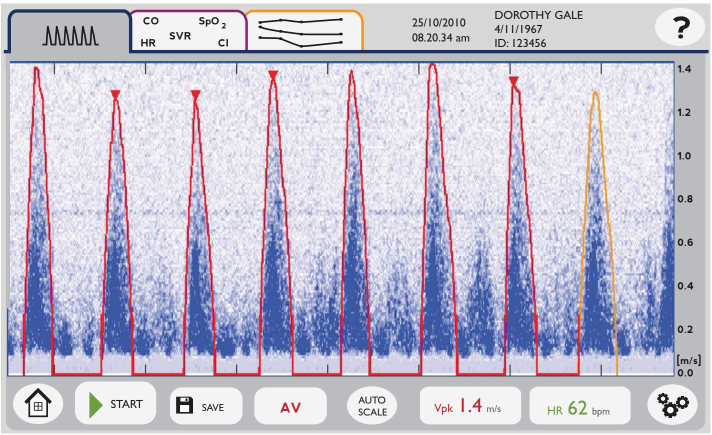

Figure 65. Example of how a handheld USCOM interface could be designed.

11 DISCUSSION

The discussion is based around how well the scope of this thesis is addressed, and aim to answer the questions posed in the introductory chapter. The experience of the methods used and the chosen way of working will also be discussed.

The scope of this thesis included two parts; firstly, the usability of the USCOM was to be examined and redesign suggestions proposed, and secondly, recommendations for further development of the interface to guide the users to a higher degree were to be given.

The usability study of the USCOM was based on a development process which has the user very much in focus. The scope has been fulfilled to the degree that a more intuitive interface has been presented, however, it would have been advantageous to involve actual users as well as potential users to an ever higher degree. It was surprisingly difficult to come in contact with users, as the USCOM is not used to a large extent in Sydney. It was very useful and interesting to go up to Bathurst to meet actual users, and to see the product in actual use. The study visits were very positive for the outcome, and had there been more time, more visits would have been even better.

11.1 ADDRESSING THE THESIS QUESTIONS

It is impossible to say for certain that the usability (target achievement, efficiency, safety, and user satisfaction) of the USCOM has been increased without any previous data, and as no usability test have been carried out. However, what is certain is that the detected areas that are potential causes of errors have been addressed. It is therefore reasonable to believe that the usability is higher now than before. Hence, the question '*Which are the most important usability issues to deal with for the interface of the USCOM?*', posed in the introductory chapter, has been answered in this thesis. The question '*What are the usability needs of users of cardiac monitors?*' is addressed throughout this thesis, and is organized and answered in the usability needs (in the needfinding chapter) as well as in the usability requirements (in the usability study chapter).

Another questions that was posed was '*How should an interface of a cardiac monitor be built up in order to enhance the cognitive processes and promote the correct mental models of users?*'. The studied theory on cognitive processes, as well as the guidelines that were based on cognitive psychology should form a good basis for a development in the right direction. Also, the different layouts for interface organization (interface principles and abstraction levels) that were examined and applied to the USCOM interface have covered the need to imagine other build-ups of the interface. My belief is that the user does not want to move through a large number of different screens in a large hierarchy, but be able to use the interface more as a web site, where there is a common menu that allows for quick and easy movement between screens and displays. The mental model of the user is promoted by pushing the organization of the interface closer to both web sites as well as other patient monitors.

The last questioned posed for this thesis, '*How can large amounts of information be presented in a simple manner?*' is addressed in the whole latter part of this thesis. Of course, it is quite a broad area, and there is no limit to the size of the answer. In the scope of supporting the interface design choices for the USCOM, however, the subject has been thoroughly examined.

11.2 EFFECTS OF THE LIMITS OF SCOPE

For a real development project at Uscom Ltd, it would be natural to be more acquainted with the software programming limitations; either to adapt the design, or to search for other software programs that could fulfill the design suggestions. As the redesign suggestions in this thesis can be implemented in a number of ways (the fictional screenshots are there to illustrate one possible implementation), I do not believe that this limit of scope has affected the outcome largely.

It is natural not to consider the mechanical or electrical functioning of the USCOM for a usability study. The possibility of mechanical or electrical errors would of course affect the interaction, but as these errors are hard to predict, and are already under constant 'repair' by Uscom Ltd, is was not of interest to include this part of the design in this thesis project.

The automation of the correct Doppler profile finding and selection is definitely an interesting area that is under process of being developed further. However, introducing that part of the design into this thesis project would have made it enormous, and it was not an option. For some of the future design solutions in the latter part of this thesis, it is assumed that this part of the interaction will be automated. However, as it is a future possibility, it was not considered automated for the proposed redesign.

11.3 WORK PROCEDURE DISCUSSION

The work procedure for the project builds to a large degree on the product development process from a human-machine perspective presented by Bligård (2010). The process suited this thesis project very well, only a small number modifications to the process were made. The iterative nature of the process suits human-centered design, where it is impossible to know from the beginning of the process what the coming data collection and planning needs will look like. Furthermore, since the presentation of the development process that Bligård suggests is still under development (the actual process is finished), it has been very interesting to use the process while being able to give feedback to the presentation of it as well.

11.4 METHODS DISCUSSION

Interviews and observations formed the most important basis for the development of the USCOM, and to verify that issues that were found in the analyses that did not include users were real problems. However, not everything that was mentioned in the interviews were implemented in the design, as opinions differ, and users have not always pondered the possibilities. Users are normally focused on the design in its current form, and can find it hard to imagine revolutionary solutions. Henry Ford (1863-1947) supposedly commented as follows on the subject: "If I had asked people what they wanted, they would have asked for faster horses"; a quote often cited by Steve Jobs (1955-, co-founder and currently chief executive officer of Apple Inc.).

The observations of users using the USCOM led to the discovery of issues that would not have been noticed without doing it. Furthermore, the observations served very well to get an understanding of the user's general needs and working situation. Consequently, the observations are an important part of the data collecting process.

Aside from interviews and observations, much of the data collecting was made through literature studies and studying competitor's home pages and information sheets. It would have been useful to study other products' interfaces in reality, e.g. at a medical equipment fair, but the most important conclusions could be drawn from the research that has been carried out.

The use of personas and scenarios are probably a good way of understanding and imagining the user needs in many product development projects, however, in this particular one, they did not serve to change the direction of the development to any significant degree. This could be due to the fact that they are loosely related to the use cases, that were carried out much earlier in the process. The use cases were excellent as a starting point of the development process to receive a good overview of the product. They stimulated the imagination of possible other paths through the interface, or other outcomes. The use cases were also very effective in the use tests with actual users of the USCOM.

The heuristic evaluation of the USCOM was carried out continuously throughout the project. Even though generic guidelines should not be directly applied without consideration, heuristic evaluations made against guidelines with a basis is cognitive psychology or research are definitely effective for discovering and avoiding potential sources of errors or irritation from users.

The allocation of functions between human and machine is a very relevant issue for the future development of the USCOM, however, the most important issue, the automation of finding and selecting the correct Doppler profiles, was outside the limit of the scope. Accordingly, it did not affect the outcome of the redesign to any large extent, but it is always important to consider each function's allocation.

The use of Enhanced Cognitive Walkthrough (ECW) and Predictive Use Error Analysis (PUEA) that were based on the Hierarchical Task Analysis, (HTA) led to the discovery of a large part of the usability issues. They are suitable methods for analyzing the human-machine interaction of a device such as the USCOM and are certainly effective. It was interesting and rewarding to be able to discover potential causes of errors, and then watch users perform errors related to these issues in the actual usage. The methods are quite time-consuming however, and might not always be the first choice for improving the human-machine interaction for a product at a small company such as Uscom Ltd.

11.5 IMPLEMENTATION OF THE REDESIGN

The redesign is not intended to be implemented directly, screen by screen as in the fictional screenshots. Instead, the idea is to take the requirements and guidelines and implement these into the current interface to the extent that Uscom Ltd desires. The company has been positive towards the redesign suggestions and the solutions for the future interface, and are likely to implement some of the ideas. No supplementary training is likely to be needed for the changes that are suggested, but users are expected to interact with the interface in an even more intuitive manner than before. For the USCOM to continue to be competitive on the CO monitor market, I believe that the implementation of some of the changes to the interface, together with a more modern design e.g. in terms of fonts and symbols, are necessary actions.

By implementing at least parts of the redesign suggestions, less use errors and a higher degree of usability can probably be achieved, which is increasingly important with today's high degree of use of advanced medical technology.

11.6 PRACTICAL ISSUES

This thesis was carried out over approximately 20 weeks, but the work of finding a company to collaborate with, and to prepare the project started a few months before. The planning was quite extensive, and the need to prepare a planning report is good, as it requires that everything is written down. The high pace that the project was started with enabled for the work to be carried out within the time frame; even though some issues were left until the very end. It is difficult to see the needs beforehand, and were I to do the project over again; even more time would be spent on really understanding and planning the details of each part.

The choice of carrying out the thesis telecommuting between Australia and Sweden is something I will never regret, but it did have some practical implications. The supervisor feed-back was done over Skype, something that turned out to work really well, even though the time difference between the two countries poses a slight problem. It would not have worked out without the terrific backing from my supervisor at Chalmers, Lars-Ola Bligård, who identifies potential and opportunities before problems. That is also something that is absolutely necessary for a successful outcome if one takes on the challenge of doing the thesis on one's own, and one the other side of the planet. It would have been easier in many ways to do the thesis with a company in Sweden, who have previously had thesis workers, than to go somewhere where even the idea of writing a thesis such as this with a company is a relatively untouched subject. On the other hand, it has been an amazing experience to work together with an Australian company and it has probably meant more for my personal development than doing the thesis on 'tested ground' would have done. I hope that my work can contribute to Uscom Ltd in ways that working with a company at home, who are used to collaborating with thesis workers, could not. The cultural exchange is hopefully a good experience for both sides, and it was certainly a very rewarding time. I am lucky to have found a company that was supportive and interested in what the thesis could bring.

The project has given me some insight in the hospital world in general and knowledge about hemodynamics in particular, which are very interesting areas. I have learnt how to apply some Human Factors Engineering methods for analyzing levels of usability and to transform user needs into specific recommendations. I know now that I have a structured approach to usability tests and evaluating interfaces. Also, I learnt a lot about design and the human cognitive processes and senses. But most importantly, I realized again that what may seem like too much of a challenge in the beginning is possible to achieve with a positive approach.

To finish off; the person who reads this thesis and quotes the following, I shall reward with chocolate:

"Whether you think you can, or you think you can't; you are right."

- Henry Ford

12 RECOMMENDATIONS

The recommendations in this chapter concern the further development of the USCOM from a usability perspective, but also the most important factors for successful product development in general for Uscom Ltd. The recommendations are also addressed to thesis workers in similar projects.

For an ideal product development of the USCOM from a usability perspective; the usability goals that were stated in this thesis should be validated in empirical usability tests. It would be interesting to test the current design of the USCOM against the goals; introduce the suggested changes; and then test it again.

The most important recommendation is to do the changes to the interface that are quick and easy to implement, but not focus too much on reorganizing the interface as it works relatively well in its current form. It is of higher interest for Uscom Ltd to find ways of automating the process of finding and selecting correct Doppler profiles, as this has been identified as an area where users sometimes are insecure, and which can lead to the product not being used. None of the detected usability issues that were in the scope (which the Doppler profile identification is not) are believed to affect the users' experience of the usage to the same extent as the process of finding profiles does. However, it is advisable to implement some of the recommended changes as discussed in Section 9.6.

For future evaluations of the usability of the USCOM without involving the users, the ECW and PUEA methods could be used. However, they present extensive results and are time-consuming, albeit effective methods for finding every potential area for human-machine interaction improvement. The methods need only be carried out once in a product development process. Therefore, it might be more time-efficient and have a higher pay-off for Uscom Ltd. to carry out heuristic evaluations based on generic guidelines for interface design (as presented in this thesis) and to perform user observations to understand potential problems in the interaction for future developments. Icons and designations should be empirically evaluated before implementation.

To other thesis workers who contemplate going abroad for the thesis project, I recommend to go ahead, but be prepared for the challenge. Is might be harder to collect information when not being at your home university with access to the library, support desks and professors' book shelves, for example. Try and collect and bring with you the literature that you expect to be hard to find. Obviously, the Internet is a fantastic source of information, and if you can access another university's library, that makes it much easier too. Be sure that you have a supervisor that will support you from a distance; it is easy to lose motivation and feel left out of 'where it happens' if you have to make all the contact yourself, especially if you do the project on your own. Finally, plan the work thoroughly before you begin, while allowing for changes along the way; nothing ever goes exactly as planned.

13 CONCLUSIONS

This chapter summarizes the most important conclusions that were drawn in this thesis project.

The following conclusions were made:

- It is essential that medical equipment is developed already from the beginning with a user-centered perspective in order to achieve successful outcomes. Usability is sometimes seen as common sense, but is still overlooked in a high number of products on the market; a structured approach is needed to attain high usability. If medical equipment companies can make use of knowledge about cognitive processes and human factors that affect the outcome of the human-machine interaction, it will result in fewer errors and higher operator and patient satisfaction as well as higher efficiency in use and cost-effective development.
- Product development should not solely be made on the basis of customer feedback and ideas. It is important to understand the users' needs and how they use a product, and interviews and observations are valuable as validation of theories and as inspiration. However, completely new ideas and revolutionary thinking should not be expected from users, but a structured approach to go beyond expectations must be taken by the product developers. Or as Ford (1863-1947) supposedly expressed it:

  "If I had asked people what they wanted, they would have asked for faster horses."
- It is critical to begin the development process from a human-machine perspective with studying the task, user, environment, technical solutions and market. This is done in order to get a good overview and to understanding of the actual usage. The product must be designed to fit into the actual environment, being used by the actual users.
- There exists an informal color coding and placement system for certain parameters on patient monitors, which is not being followed in many of the cardiac output monitor designs. One can decide that the device should look different, and hence not follow the common system, or decide to abide. What is not desired, is to follow the conventions to such a large degree that the users expect the same product behavior, but not follow through. This violates the mental models of users that use both products, which can lead to confusion and users making slips that can lead to serious errors.
- The most important usability issue that is found in the USCOM interface is that users misinterpret average values of parameters, and think that they are typical values. The introduction of typical values for users to base their decision-making on (to whether a specific value should be considered high or low) would be very advantageous. This is because many of the users, and potential users, of the USCOM are not that well acquainted with the parameter values and their typical values to make good decisions, so aiding in that area could have a very positive outcome.

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APPENDIX A: USCOM PARAMETERS

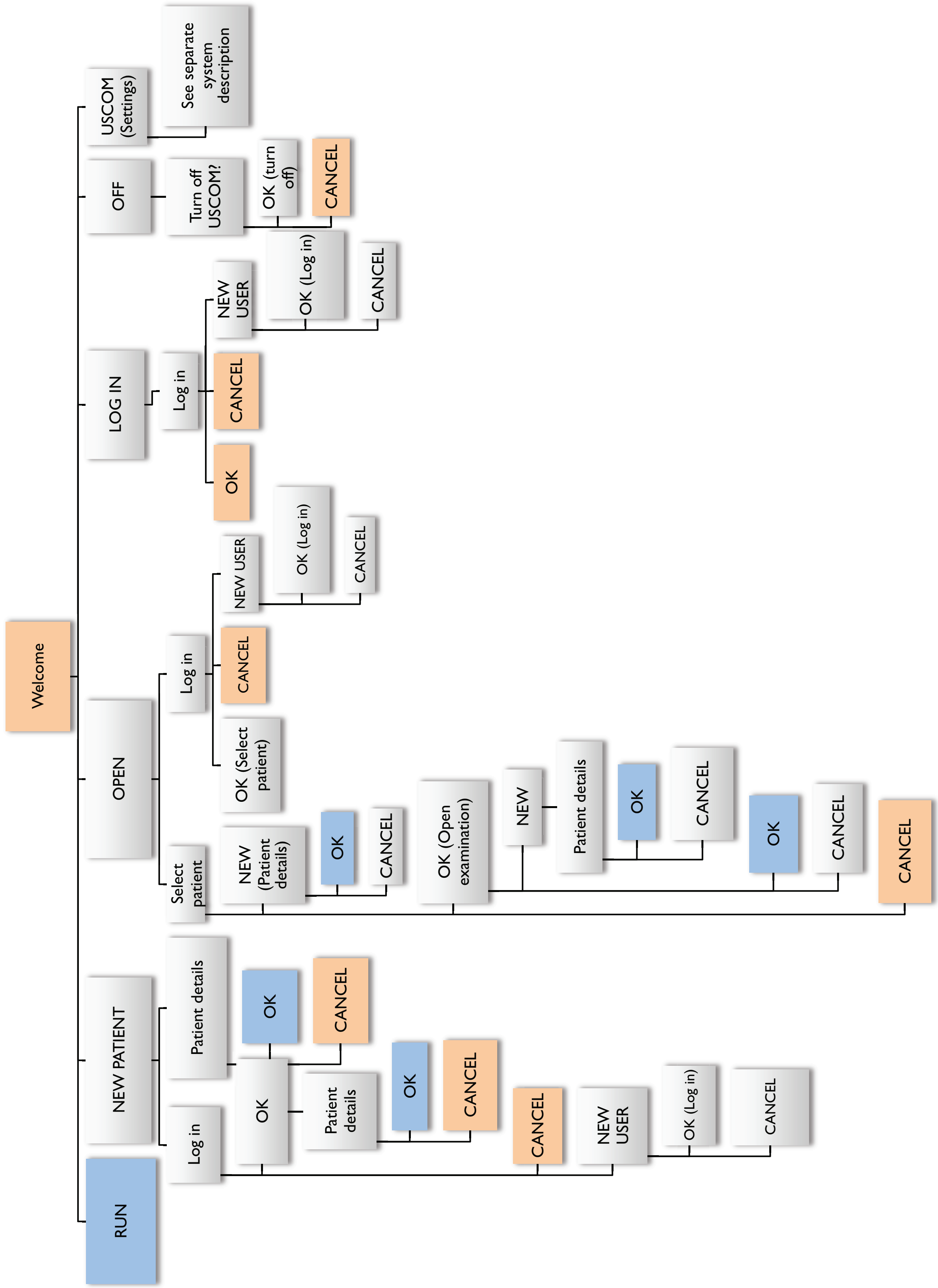
The following 17 parameters are always available in the latest version (1.8.5) of the USCOM interface.

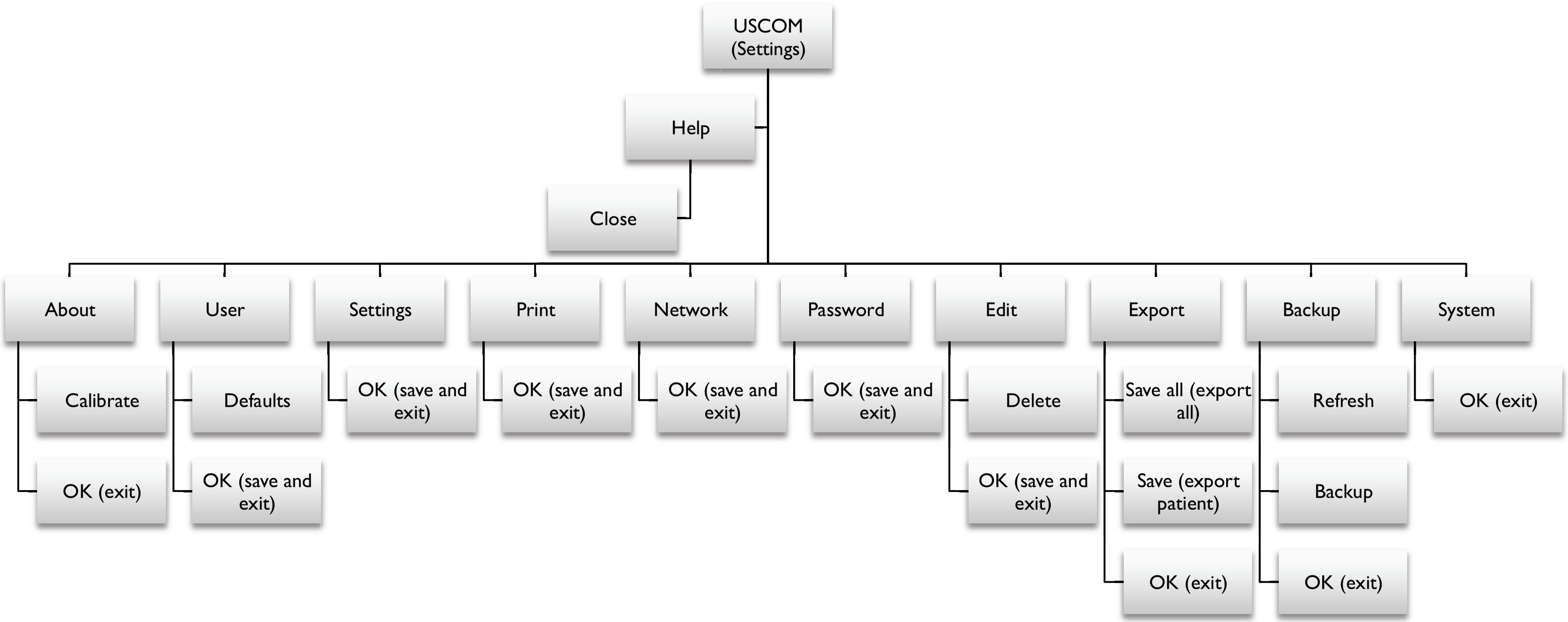
Vpk: Peak Velocity of flow
vti: Velocity Time Integral
HR: Heart Rate
MD: Minute Distance
ET%: Ejection Time Percent
SV: Stroke Volume
SVI: Stroke Volume Index
SVV: Stroke Volume Variability
CO: Cardiac Output
CI: Cardiac Index
SVR: Systemic Vascular Resistance
SVRI: Systemic Vascular Resistance Index
Pmn: Mean Pressure Gradient
FT: Flow Time
FTc: Flow Time Corrected
SW: Stroke Work
CPO: Cardiac Power

With the addition of the OXYCOM product the following additional parameters are available:

SpO2: Oxygen Saturation
DO2: Oxygen Delivery
SVS: Stroke Volume Saturation

APPENDIX B: DETAILED SYSTEM DESCRIPTION




USCOM (Settings)
Help
Close
About
Calibrate
OK (exit)
User
Defaults
OK (save and exit)
Settings
OK (save and exit)
Print
OK (save and exit)
Network
OK (save and exit)
Password
OK (save and exit)
Edit
Delete
OK (save and exit)
Export
Save all (export all)
Save (export patient)
OK (exit)
Backup
Refresh
Backup
OK (exit)
System
OK (exit)

APPENDIX C: INTERVIEW QUESTIONS AND USER SURVEY

Interview

General

1. Name and position?
2. For how long have you used product X, and to what extent?
3. Which parameters do you use to assess hemodynamic status?
4. If CO, how do you measure it?
5. What do you find are the most useful applications of product X?
6. Which devices do you normally use product X together with?
7. How do you normally use product X?
8. Do you put in all the user and patient details that are asked for in product X?
9. Have you come across any features that you did not like? Which, why?
10. Do you feel like the information you get is useful?
11. Do you think that product X has a logical interface?
12. Considering the interface, does it differ in terminology or use from other products that you use in your work?
13. Can you recall pressing the wrong button at some stage?

USCOM specific

14. Do you find that the Default settings are the ones that you use most?
15. Do you make Notes? How do you find the feature Notes?
16. Do you print reports? How does that feature work for you?
17. Are the designations clear to you?
18. Did you know that the feature that allows you to change the Style of the cards (4, 6, 9) parameters?
19. Do you use the feature Run?
20. Did you know you could change the order of the measurements? Is there a need?
21. Do you use Oxycom?
22. Is the Card/Exam clear to you? What would you call a measurement?

Perform use test based on use cases

USCOM 1A USER INTERFACE SURVEY 1(2)

The purpose of this survey is to receive your important user input for future interface developments.
Please select one answer per question and specify where needed.

1. Where do you work?
◯ Intensive care ◯ Emergency ◯ Pediatrics ◯ Retrieval ◯ Other: ________________

2. What is your position?
◯ Physician ◯ Nurse ◯ Paramedic ◯ Other: ________________

3. How long have you been using the USCOM 1A?
◯ 0-6 months ◯ 6-12 months ◯ More than one year

4. How frequently do you use the USCOM 1A?
◯ Daily ◯ Less than once a day ◯ Less than once a week ◯ Less than once a month

5. Which of the following best describes your most common purpose for using the USCOM 1A?
◯ Assess response to fluid or drugs ◯ Monitor for changes ◯ Fluid challenges ◯ Diagnosing patients
◯ Sepsis treatment ◯ Research ◯ Other: ________________

6. Do users of the USCOM 1A at your workplace have a personal user Login?
◯ Yes ◯ No, we share a common ◯ I am the only user

7. How do you choose to enter the Examination screen (Doppler profile screen) for a new patient?
Please select one answer per row for this question.

	For 100-50% of patients	For less than 50% of patients	Never
Through RUN (Quick start):	◯	◯	◯
Through OPEN >> NEW PATIENT:	◯	◯	◯
Through NEW PATIENT:	◯	◯	◯

8. Do you think it would be useful to separate the Patient Name box into First name and Surname?
◯ Yes ◯ No ◯ No opinion

9. Would it be useful for you to be able to export patient data from any screen?
◯ Yes ◯ No ◯ No opinion

Please turn page over.

USCOM 1A USER INTERFACE SURVEY 2(2)

10. How often do you fill in the following details for a new patient?
Please select one answer per row for this question.

	For 100-50% of patients	For less than 50% of patients	Never
Name:	○	○	○
Date of birth:	○	○	○
Height:	○	○	○
Weight:	○	○	○
Measured OTD:	○	○	○
Gender:	○	○	○
Patient ID:	○	○	○
Address:	○	○	○
Operator:	○	○	○

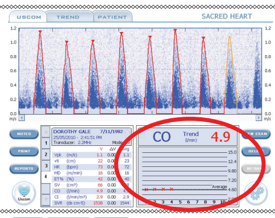
How well do you agree with the following statements?

11. 'It is obvious to me what this icon symbolizes.'

○ Strongly disagree ○ Disagree

○ Agree ○ Strongly agree ○ No opinion

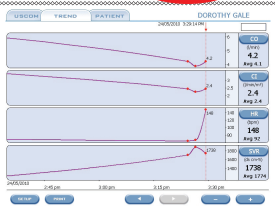
12. 'The Trend Graph Display is useful.'



○ Strongly disagree ○ Disagree

○ Agree ○ Strongly agree ○ No opinion

13. 'It is easy to navigate in the Trend screen (Trend tab).'



○ Strongly disagree ○ Disagree

○ Agree ○ Strongly agree ○ No opinion

14. Do you have other comments or suggestions?

Thank you! Please send your survey to Uscom:
Suite 1, Level 7, 10 Loftus Street, Sydney NSW 2000 Australia
Fax: +612 9247 8157
E-mail: uscom@uscom.com.au

APPENDIX D: PERSONAS AND SCENARIOS

In order to reach a better understanding of potential users of the USCOM 1A, three personas, fictional potential users, are described below.

STELLA

Stella works as a physician at the ICU at a small-scale hospital a few hours outside Sydney, Australia. She is 52 years old and used the USCOM 1A a lot five years ago, when she was working at another hospital. Since then, there has been no USCOM 1A at her workplace until now. Stella has a long experience of cardiovascular diseases and hemodynamics, and before using the USCOM 1A she would base her assessment of patient's hemodynamic status through measuring blood pressure and heart rate. Stella has expert knowledge both in the domain and the task, which makes her an Expert user. However, it has been a while since she used the device on a regular basis.

A typical working day for Stella is stressful and it annoys her that people around her does not take full responsibility for their work, which means she has to do it herself. After using hemodynamic monitors herself, it is disturbing for her when other doctors do guesswork when assessing a patient's status and she is keen on getting the other physicians and nurses in the ICU more interested in hemodynamics.

Stella is divorced with two grown up children. Making up for the fact that they left home a few years ago, Stella's two cats are now the center of attention and they keep her company when she is solving crosswords or playing online computer games, which has become a little bit of an obsession lately.

ALEXANDRE

Alexandre is an anesthesiologist, which means he is a physician who distributes anesthesia to patients and provides medical treatment to patients before, during and after surgical procedures. He works in the operations theatres at a large hospital in Paris, France. Alexandre is 35 years old and has been working as an anesthesiologist since he finished his diploma 8 years ago. Alexandre had his USCOM 1A certificate taken two months ago and will be considered a Domain expert since he has a long experience of hemodynamics and extensive knowledge on human physiology in general, but he is rather new to using the USCOM 1A.

Alexandre's working day normally consists of 4-6 operations, in which he is responsible for things like minimizing pain for patients, inserting ventilator tubes and monitoring for changes in patient status during the operations. The work involves dealing with very nervous patients who are going into surgery, and Alexandre is lucky being a naturally calm and relaxed person with whom the patients are usually comfortable discussing their problems with.

If Alexandre was not a physician, he would probably have gone into psychology. In his spare time, he spends hours reading the latest findings on human mental behavior, or plays soccer with his old friends from the Paris suburb where he grew up.

EVELINA

Evelina is 22 years old and has just finished her nursing diploma in Lund, Sweden. She has started to work in the ED at the largest hospitals in the city and has taken the training for the USCOM 1A, but has not yet received her certificate, because she needs to do both supervised and unsupervised exams first. Evelina will be considered a Novice user, but has used the USCOM 1A enough to know how to acquire a correct Doppler Flow Profile.

Evelina is very ambitious and keen on learning everything she can, as fast as possible, and she goes out of her way to please her mentor at work, the 'all-knowing' 58 year-old ED and USCOM 1A guru, Gunnar. With everything so new and exciting around her, Evelina has problems falling asleep at night as she lays thinking about today's events and tomorrow's new challenges. This makes her tired, but she does not let it on to anyone.

In her spare time, Evelina plays the bass guitar with her band or takes her dog on long walks around Lund, to ease the stress she takes home from work. If she was not a nurse, Evelina would have dedicated her life to music and she still dreams of becoming a rock star and leaving quiet Lund for a life in the U.S.

Persona-based Scenarios

The personas described in the previous chapter have been used in a set of narrative scenarios, each describing a situation in one of the personas' lives. The term 'scenario' is familiar to people that work with usability, and it is a widely used method to solve design problems by constructing specific stories, starring personas that represent target potential users. The following scenarios are fictional, but are anchored in real events; why they should also offer the reader with a better understanding of the context that the USCOM 1A can be operated in.

STELLA'S MORNING

Stella arrives at the ICU at 7am, just in time to see one of the new nurses spilling coffee all over the front desk and over a whole bunch of patient journals. Great... She does not have time to help the nurse wipe it off as the beeper goes off and she rushes off to help out with a patient who complains over chest pains.

After examining the patient and changing his medications, she walks up to the bed next door, where a woman with suspected sepsis is being monitored by a night nurse who is still on duty. Stella pulls the USCOM 1A as close to the bed as possible and places some gel on the woman's neck while explaining that she will do an ultrasound examination which will not cause any pain. The woman jokes that they say that for every procedure, and they all hurt so she does not believe her, but lets Stella do her work.

As this is the first USCOM examination of the patient, Stella enters the woman's data after logging into the system and when the examination screen shows, she places the transducer on to the woman's neck and touches the Start button. She enters the blood pressure, which the nurse has just taken and appears normal, to display more of the flow parameters. It is easy to find good Doppler signals, and after two minutes, Stella freezes the image and removes the transducer. Immediately, the nurse wipes the gel off the woman's neck and the transducer.

Stella selects the accurate Doppler profiles and saves and then takes a look at the Heart Rate, Stroke Volume Index, Systemic Vascular Resistance (SVR), corrected Flow Time and Cardiac Index, and decides to administer a fluid bolus to increase the woman's preload (the amount of blood in the ventricle immediately prior to the next ejection out of the heart). After a few minutes, Stella does a new examination to verify that the flow parameters have gone in the desired direction, and she then administers noradrenalin to increase the SVR.

After this, the day nurse comes, who also has a certificate to use the USCOM, and Stella gives her instructions on which parameters she is interested for the nurse to monitor. Stella then takes the USCOM to the next patient, an eight-year old boy with anemia. She tries to get out of the examination screen she is in, but even though she used the USCOM yesterday, it takes her a little while to remember how to change to a new patient, which irritates her.

ALEXANDRE'S OPERATION

It has been a busy week for Alexandre, with complicated operations on several children, which always affects Alexandre more than adults. It is finally Saturday, and starting tomorrow, Alexandre has three days off. He makes plans for his days off as he scrubs up to meet the first patient of the day, a man with bowel cancer who is having a part of his large intestine removed. The operation requires epidural anesthesia, why Alexandre will insert a catheter while the patient is still conscious, and after that, the patient will receive general anesthesia. To monitor the hemodynamics, Alexandre starts by performing an USCOM 1A examination. He notices that the patient's heart rate is high, and the SV and SVR are noticeably low. However, Alexandre's experience tells him that the heart rate is normal for a patient who is anxious to have an operation, and as the patient has had fluid intake for several hours, the fact that he is a little dry is nothing that should raise an eyebrow.

The patient is very nervous, and as Alexandre inserts the epidural catheter; the patient faints. He is embarrassed as he wakes up again, and Alexandre and the nurses must go through the disinfecting procedures again, which leaves them behind the time schedule.

The surgeons are waiting for the patient to come into the operating theatre and Alexandre is under a bit of pressure as he performs the insertion and checks the hemodynamic status of the patient again, using the USCOM 1A. Finally, the patient is set to go and the operation can begin. To monitor that the patient is stable during the operation, and under a sufficient amount of anesthetics, Alexandre checks the ECG monitor and performs regular USCOM 1A examinations. However, as the surgeons are sometimes required to operate close to the patient's head, there is not always room for Alexandre to do the measurements when he desires. With the constant beeps from other monitors, and the sound coming from the mechanical ventilator, Alexandre finds it hard to hear the 'swooshing' sounds that he uses as aid in finding the correct Doppler profiles, even when choosing the highest volume level.

After the operation is over, Alexandre displays the trends of some of the USCOM 1A flow parameters, and is happy with how the patient's hemodynamic status has developed. Alexander decides he will show the trends to his interns at the morning the following day.

EVELINA'S TRAINING SESSION

After a quick lunch sandwich, it is time for Evelina to meet with her mentor Gunnar, and a few other nurses, for them to practice using the USCOM 1A on each other. She doesn't have any problems logging in, as the user name is ED and the password is already saved. No one really remembers it anymore, but as long as no one un-ticks the 'Remember password' box, it works. It is not the first training session, so the other nurse's 'patient information' is already in the system, why Evelina enters through 'Open', and then chooses the nurse from the list of patients.

While Evelina performs the examination, Gunnar asks her to check one flow parameter that is not currently displayed on the screen, and as she tries to choose other parameters, she fumbles and is embarrassed that she cannot do it quickly enough. Finally she gets the hang of it, and the display shows the flow parameter that Gunnar asked for.

The nurse that Evelina examines is a young male who runs laps every morning, which means that his heart is very dynamic, and as Evelina is starting to find the aortic valve by aiming the transducer in different directions, the Doppler Flow profiles go way above the top of the display. Gunnar is standing behind Evelina now, and even though she knows that touching the scale will open the 'scale and zoom' screen, she starts looking in the Setup menu to find the scale options. After only a few seconds though, she realizes her mistake and goes back to the examination screen and touches the scale instead. She has now concentrated on fiddling with the screen settings and forgotten about keeping the transducer in the same position, why she has to start over with the three-step procedure to find the aortic valve again. After five minutes, she has managed to find Doppler Flow profiles that both she and Gunnar are happy with, and she and the other nurse change roles, to continue with the training.

APPENDIX E: RESULTS FROM TASK ANALYSIS

Design of procedures and tasks

The design of procedures and tasks is important for optimizing the system's functionality, while keeping the load posed on the user as small as possible (Gardinger & Christie, 1987). A range of minor usability issues have been found in the category for design of procedures and tasks:

- The scrolling function in most screens is not optimal, as well as the use of drop-down menus.
- Adding Location when logging into the USCOM adds an extra step and the relevance of this information can be discussed.
- While acquiring the Doppler Profile, the typical user is working with a high level of mental load, why it is important that the Examination screen is as automated as possible. For example, changing the scale is unnecessarily complicated. The amount of information that is not directly necessary for acquiring a profile should be kept at a minimum for this task.

Analogy and metaphor

The analogy with 'tabs' for switching between screens works well, and does not violate the user's expectations on how it should work. The metaphors for keyboards differ between screens and include irrelevant choices for users. The number pad metaphor differs from both number pads on computer keyboards and calculators but to keep consistency with the previous interface, the number pad metaphor will not be discussed in the redesign guidelines.

Training and practice

All professional users of the USCOM 1A are supposed to receive training with focus on acquiring a correct signal, before using the device unsupervised. The training hence covers the other main aspects of using the device, and focus for this project has not been on introducing novice users to the system or creating a 'practise mode' as the introduction will usally be done by a professional.

However, it has been noticed that the Help function is not used to its full extent, as it is only reached from the Uscom ('Settings') screen, and not related to any specific task but only shows the manual.

Task-user match

The task-user match works quite well with the USCOM 1A. There exist optional ways for users to carry out several tasks, and the interface does not differ significantly from what one would expect from a medical device. A few minor issues have been identified:

- In order to find a patient later, first and second names might be appropriate to enter, and to be able to sort on these two names later (as well as on Patient ID or Date of birth).
- There is a need to investigate if users actually log in as different 'Users'. If not, this feature could be deleted and if they do, it should be possible to transfer patient data to other users.

- Users can be expected to range from around 20 to 70 years of age, why it is important that visual information is kept as clear as possible, with sufficiently large text and a high level of contrast between text and background colors which is not the case everywhere in the interface.
- Some users might want to use the device for specific tasks, like a 'Fluid challenge', where related information ('Frank-Sterling curve') could be an alternative.
- The typical users are not familiar with all the parameters and need further guidance related to typical flow parameter values and interpreting the values. The latter is related to Visual Display which is dealt with in the later part of the thesis, and will not be discussed in the redesign guidelines.

Feedback

The feedback from the device has been found satisfactory. Whenever the screen is touched, a sound is heard; if the action is correct, a 'click' is heard and if not, a 'ringing' sound is heard. It can be discussed if all the auditory feedback when entering larger amount of data through the 'keyboard' is necessary or poses irritation, however, Cox and Walker (1993) state that people feel uncomfortable when keyboards are silent, why it is decided that this issue will not be further discussed.

In general, actions taken when handling the USCOM 1A is connected to some kind of visual and/or auditory feedback.

Selecting terms, wording and objects

The selections of terms in the interface is seen as one of the largest issues:

- Many tabs and object connotations are difficult to understand.
- The use of 'Cards' and 'Exams' is not consistent with the hospital terminology.
- 'USCOM' is used to denote both 'Settings', 'Home' and the Examination screen tab, which is confusing.
- 'SAVE' is used when user means to export data to flashstick. The 'OK' button in the same screen is misleading, as this cancels the operation whereas Cancel is used in other screens for this purpose.
- Several buttons lead to screens with other names.

Consistency (throughout interface and with other devices)

There are a few consistency issues in the interface:

- Placement of 'Default', 'OK' and 'Cancel' buttons is not consistent throughout the interface, which could lead to irritating user slips.
- The Uscom symbol has different actions connected to it in different screens.
- The allowed characters on the 'keyboard' changes depending on screen in an illogical manner.
- Touching values on the Measure Card to show on Trend Graph display does not work for 4 value cards, but for 6 and 9 value cards.
- A value that needs input values (eg SVR) can be touched on the Measure Card, for input values to be filled in. Doing the same on the Trend Graph display will have a different outcome.

- ‘Changing settings’ is denoted with different symbols or words throughout the interface.

Screen design

- The Welcome screen can be organized in a manner that makes it easier for users to both understand the features and select faster by the use of grouping associated features, using images and changing designations.
- When the user watches graphs, they should be easily zoomed out or in to show the full graph.
- With a touch screen, a lot of information must be shown on the screen why it is important that unnecessary features be removed. Certain pieces of patient information might be removed, as well as user options like Location and Operator. (However, if only one ‘User’ is used, the choice of Operator could be relevant.)
- The use of colors should be looked over. Firstly, it can be used to differ between features and selections; and secondly, the contrast could be enhanced in some screens.
- The amount of information to the user in the Examination screen (designated USCOM) is overwhelming and all the information is not relevant.
- Where letters and numbers are used together for the user to choose from, separating the two could increase the perceptibility.
- It is recommended that 20s of Doppler Flow Profiles are acquired before saving, but there is no time line in the Examination screen.

Organization

The organization of screens and information given in different screens has been found to as an area with potential of improving:

- When wanting to change the main settings, users might not be interested in the USCOM 1A information that comes up first, but be able to pick another choice instantly.
- When reviewing a patient’s history, one of the exams must first be selected. This is time consuming, and the user probably wants to see trends as opposed to seeing the Doppler Profile from a specific session.
- After acquiring a sufficient Doppler Profile, the screen can be used more efficiently to show data. The Profile in itself is not interesting if correctly acquired.
- The Patient screen shows almost the same information as the Examination screen why the organization of screens should be looked over.

Multimodal and multimedia interaction

The information given from the USCOM is mainly visual, with auditory feedback given in the Examination screen (signal frequency) and whenever the screen is touched. It is not desired to change the level of auditory or haptic feedback with the current design of the interface.

Navigation

Navigating between screens has not been found to be a large problem with the interface, but a few issues were identified:

- The user should always be able to 'opt out'. As an example, to get back to the Welcome screen from the Trend screen, four operations that are hard to guess for an inexperienced user is needed.
- The user cannot exit the examination screen after the 'Start' button has been pressed (or if the user enters through 'Run'), but must press 'Freeze' first.
- Navigating between the tabs in the Uscom screen ('Settings') is difficult, as some of the tabs are hidden, and it is tricky to scroll between the tabs.

Error management

The interface of the USCOM 1A is relatively good at handling the typical use errors such as touching the Log out or Off buttons by mistake, by asking the user to confirm.

Before the user exits the examination screen, the user is asked whether the 'card' should be saved or not, however, if the user entered through the Run mode, this is not asked, which could be questioned.

Locus of control

It is important that the user is in control, which is mainly the case as the USCOM 1A interface responds to actions taken by the user, however, a few issues were found that mainly concern patient and user profile control:

- The users cannot actually edit, but only delete patient files in the Edit tab of the Settings screen.
- It is not possible to directly exchange patient data between different users.
- Users cannot see which other user profiles that exist in the system.
- Patient Notes cannot be edited or deleted by users.

Use of symbols

Symbols are not used to any large extent in the interface; the only symbols are the Uscom symbol (which has different connotations but is supposed to define 'Home') and the Cogwheel symbol that represents settings in the Examination screen. It is not evident that users recognize the Cogwheel symbol as a 'settings' symbol.

APPENDIX F: USE CASES

Use case name:	Login to USCOM 1A
Use case number:	1
Target system:	USCOM 1A
Primary Actors:	Physician or nurse
Secondary Actors:	Patient, other physicians and nurses
Context:	Clinical settings

Abstract:
The user starts up the system and inserts user details in order to log into the system.

Goal:
The user is logged in as a user.

Pre conditions:
The user is registered in the system from before. The device is switched off.

Normal course:

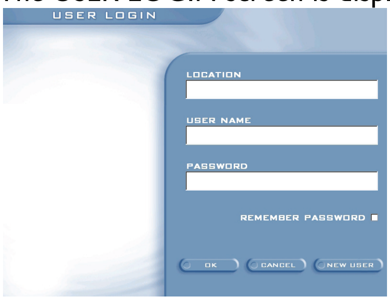
Initialisation (triggers)

The user touches the power button.

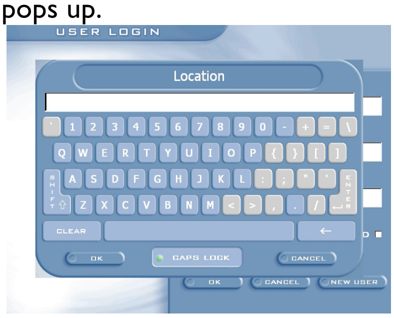
Process

1. The Welcome screen is displayed.
2. The user touches the LOG IN button.

3. The USER LOGIN screen is displayed.

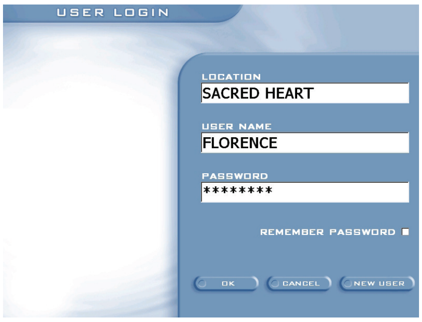


4. The user touches the LOCATION box and enters location on the keyboard that pops up.



5. The same procedure is done for USER NAME and PASSWORD, with the exception that only letters can be used for passwords and all other symbols and numbers are disabled.

6. The user can choose to tick in the REMEMBER PASSWORD option if desired.



Termination

The user touches OK.

Alternative course:

User first touches RUN, makes a measurement and when Save is pressed, The USER LOGIN screen is shown.

User first touches NEW PATIENT or OPEN. The USER LOGIN screen will automatically show first if user is not logged in.

If the user has previously ticked in REMEMBER PASSWORD, it will automatically be filled in when USER NAME has been entered.

Post conditions:

Following the normal course, the Welcome screen will be displayed, with LOG OUT instead of LOG IN. If alternative courses are taken, the post conditions will differ but the goal will be achieved.

Exceptions:

- If the user touches RUN by mistake, and wants to get back to the WELCOME screen, the user must first press FREEZE, then the Uscom symbol. Not knowing this can lock the user in the RUN screen.
- The user does not enter user name in the same manner as before and can therefore not log in. A new user will have to be created.
- User cannot remember password. User will have to create new user or contact distributor for aid.
- If the user touches Cancel at any stage, the system shows the previous screen.
- If the user adds the info, but presses NEW USER again, instead of OK in the USER LOGIN screen, the information will be lost and the user must start over by adding user name etc.
- On the keyboard that pops up, some of the symbols on the keyboard (ie parentheses) are disabled, and are shown in grey instead of blue. If the user tries to press them, or any other 'dead' screen area, a noise is heard and nothing is inserted.

Use case name:	Make a measurement on a new patient
Use case number:	2
Target system:	USCOM 1A
Primary Actors:	Physician or nurse
Secondary Actors:	Patient, other physicians and nurses
Context:	Clinical settings

Abstract:
The user needs to carry out a measurement of Cardiac Output on a patient who is not registered in the system from before.

Goal:
The patient is successfully registered and the data is saved.

Pre conditions:
The patient is not registered in the system from before. The user has logged into the system and sees the welcome screen.

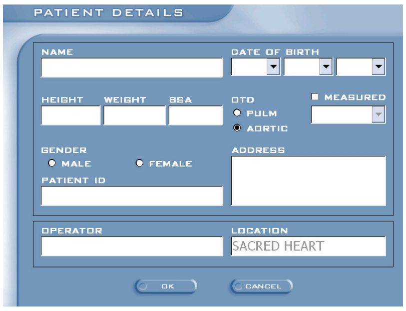
Normal course:

Initialisation (triggers)

The user touches the NEW PATIENT button.

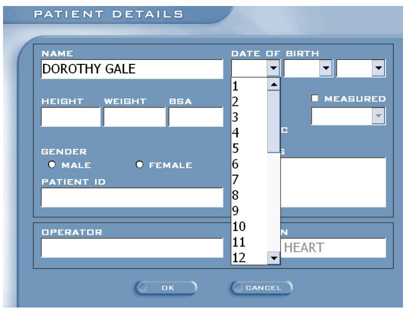
Process

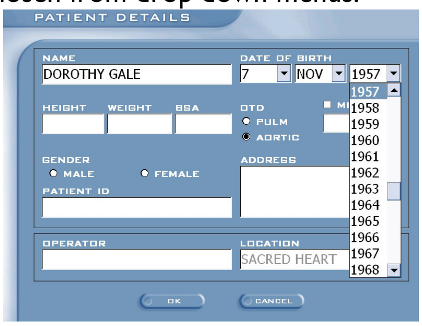
1. The PATIENT DETAILS screen shows.



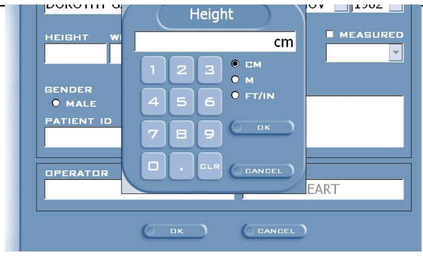
2. The user touches the NAME box and the keyboard is shown.

3. After inserting the patient's name, the user touches OK.
4. The DATE OF BIRTH details are chosen from drop down menus.

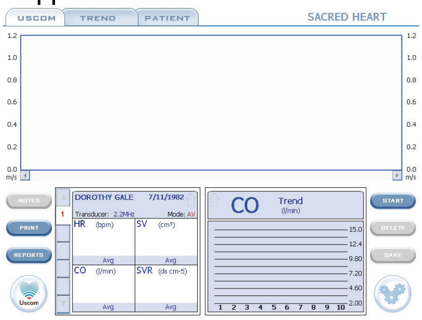


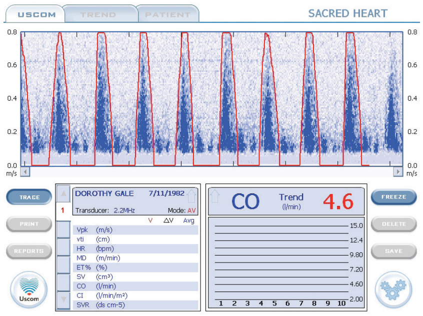


5. The user touches HEIGHT box, and a 'calculator' keyboard is shown. After adding height in cm, m or feet/inches, the user touches OK.

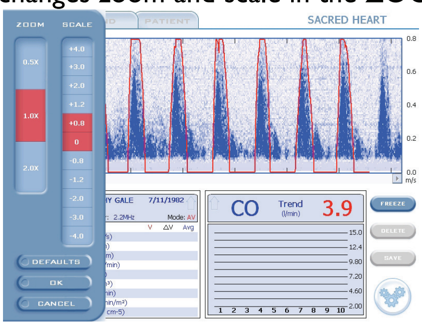


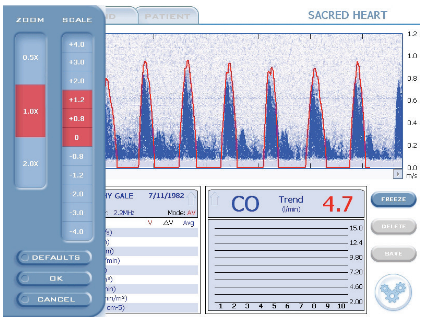
6. The same is done for Weight, in kg, g, or lb/oz.
7. The BSA (Body Surface Area) is calculated automatically and cannot be edited by the user.
8. OTD (Outflow Tract Diameter, necessary for CO calculation) is calculated automatically but can also be edited by user by first ticking the MEASURED box, and overwrite the calculated value for either the Pulmonary or Aortic valve (or both).
9. GENDER is chosen.
10. PATIENT ID box is touched. The keyboard shows, with some of the symbols disabled.
11. ADDRESS box is touched. The keyboard shows, with all buttons enabled.
12. OPERATOR box is touched. The keyboard shows, with some of the symbols disabled.
13. The Examination screen shows.
14. The user touches Start (which changes name to Freeze) and starts acquiring Doppler Flow Profiles.



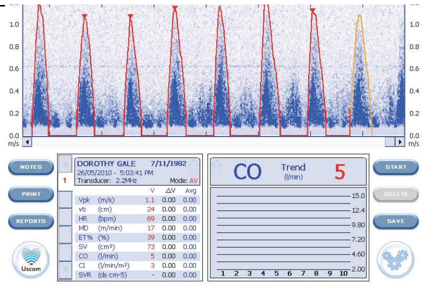


15. The user cannot see the full Doppler Profile and therefore touches the scale and changes zoom and scale in the ZOOM/SCALE window. User touches OK.

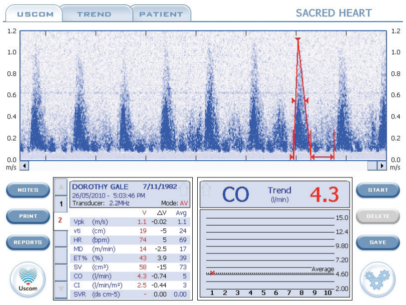




16. User touches FREEZE. Other flow parameters are displayed.

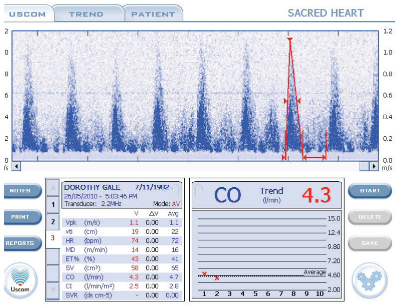


17. User can edit which Doppler Flow Profiles to be chosen, automatically with FlowTracer, or (only one) manually with TouchPoint. The parameters are re-calculated in this case.



Termination

User touches SAVE.



Alternative courses:

1

a. User first touches RUN.
b. The Examination screen shows and a measurement immediately starts but no values show since patient information is not put in (height must be entered for CO calculation).
c. User touches FREEZE. Heart rate value is shown.
d. User touches SAVE.
e. The SELECT PATIENT screen is shown, where user can create a new patient profile (user could also select an existing patient).
f. Patient is created as above.
g. Card is saved and parameters are calculated.

2

a. User first touches OPEN.
b. The SELECT PATIENT screen shows, where user can select NEW and add patient details.
c. When OK is touched, user sees the Examination Screen.
d. User makes measurement and touches save.

Only the patient's name or a patient ID is needed to create a patient, why data could be saved only on those premises. However, that means no parameter values are shown. Normally, at least height is inserted, in order to show CO values.

The user can add needed patient information while doing the measurement by pressing the desired parameter that is not shown on the Card (eg if CO is needed, user touches CO and enters height and, if wanted, weight and overriding Outflow Tract Diameters). Patient specific values can also be inserted through the "Controls" icon, and selecting Entry or Patient, depending on which values to insert.

User can change viewing settings and insert patient data while acquiring the Doppler Flow Profile, see Use case 3.

Post conditions:
The user still sees the Examination screen, which is ready for another measurement or for data analysing. The Card number has switched to the next number (in this case 3, because the TouchPoint created Card 2), while the parameters and Doppler Flow Profiles are still showing.

Exceptions:

- If the user does not acquire a signal that is recognised by Flow Tracer (or added manually by Touch Point), the card cannot be saved.
- If the user makes a slip and pushes another button than NEW PATIENT, RUN or OPEN, the user must go back to the main screen.
- The user could also make a knowledge-based mistake and think that USCOM means that the examination screen will appear, but instead the settings and information comes up.
- The user might not know that it is possible to enter from all three different options, and choose to go back to the main screen and start over.
- In the ZOOM/SCALE window, user slips and touches Cancel or Defaults instead of OK.
- User does not understand which one is TouchPoint vs Flowtracer and has problems.

Use case name:	Change settings during acquisition of Doppler Profile
Use case number:	3
Target system:	USCOM 1A
Primary Actors:	Physician or nurse
Secondary Actors:	Patient, other physicians and nurses
Context:	Clinical settings

Abstract:
The user wants to change the settings and add blood pressure to patient data while acquiring the Doppler Flow Profile.

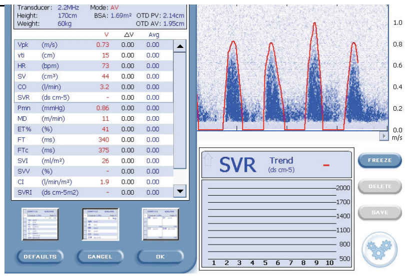
Goal:
The desired parameters are calculated and shown on the screen.

Pre conditions:
The user has started the Doppler Flow Profile acquisition and sees the SVR on the Trend Graph display and six parameters on the Measure Card.

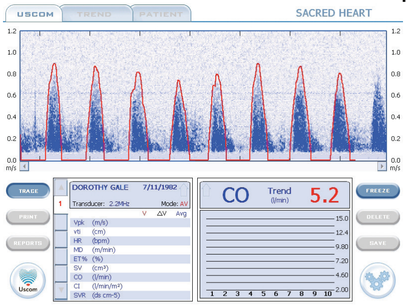
Normal course:
Initialisation (triggers)
User touches the header on the Measure Card display to change which parameters to be shown on the Card.

Process

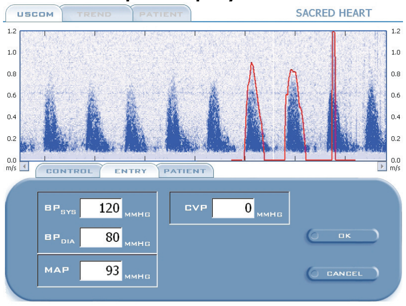
1. User touches the desired values and style and touches OK.



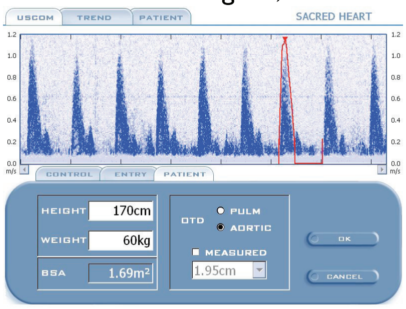
2. User wants to change parameter from SVR to CO shown on Trend Graph display and touches CO on Measure Card display to display it.



3. User wants to add blood pressure values to display SVR, so touches SVR on the Measure Card display to insert the needed values. This will also result in SVR showing again on the Trend Graph display.



4. User wants to change settings to measure pulmonary valve and touches the Cogwheel icon. After touching PV, user touches OK.



Termination

User returns to Examination screen.

Alternative courses:

To add blood pressure, user can touch the Cogwheel icon and choose ENTRY tab to enter values. To change parameter shown on Trend graph display, user can touch the heading of the display and choose the parameter from a list.

Post conditions:

User sees the Examination screen and Card is not yet saved. Pulmonary valve is chosen.

Exceptions:

- If the '4 parameter' style is used on the Measure Card, touching a value on the card will not automatically show on the Trend Graph display but the user will be prompted to choose which values to show instead.
- If previous values of blood pressure has been inserted, touching SVR on the Measure card again will not lead to 'insert blood pressure' screen but either show a list of the parameters to show, or change the value on the Trend Graph display as seen above.
- The user might think that touching SVR on the Trend Graph display will lead to 'insert blood pressure' screen, but instead a choice of parameters to switch to are shown.
- When touching the Cogwheel, the user is confused of which value of AV/PV that is chosen and therefore does not change it correctly.
- The user looks at the PATIENT tab in the Cogwheel screen and sees the choice between Pulmonary and Aortic (meant for checking or overwriting the OTD), changes to (look at) the Pulmonary and incorrectly thinks that a Pulmonary measurement is carried out.

Use case name:	Review hemodynamic patient history
Use case number:	4
Target system:	USCOM 1A
Primary Actors:	Physician or nurse
Secondary Actors:	Patient, other physicians and nurses
Context:	Clinical settings

Abstract:
The user wants to see trend graphs of previous measurements of the hemodynamic parameters CO, HR, SVR and FTc.

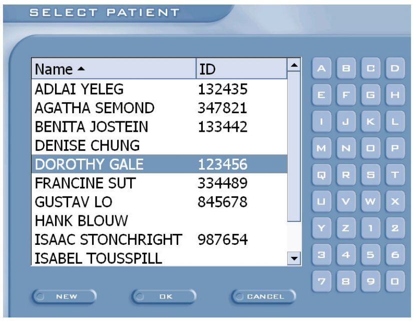
Goal:
The trend graph is found quickly and the parameters can be chosen and viewed without any problem, after which the user wants to exit the system.

Pre conditions:
The user is logged in and sees the Welcome screen.

Normal course:
Initialisation (triggers)

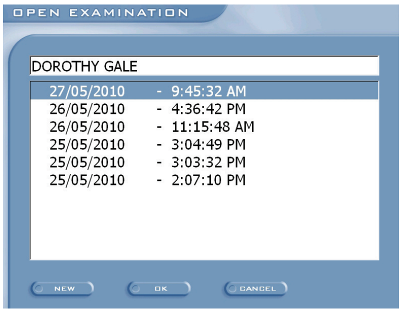
User touches OPEN.

Process
SELECT PATIENT screen shows.



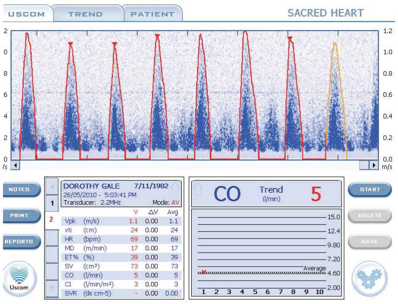
1. User selects patient by scrolling down to the correct name and touches OK.

OPEN EXAMINATION screen shows.



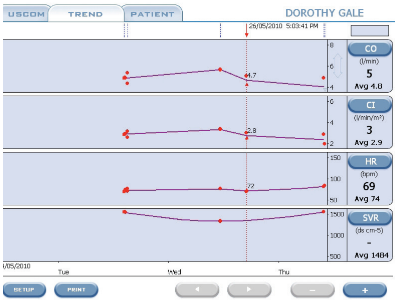
2. User chooses an examination and touches OK.

USCOM Examination screen is shown.

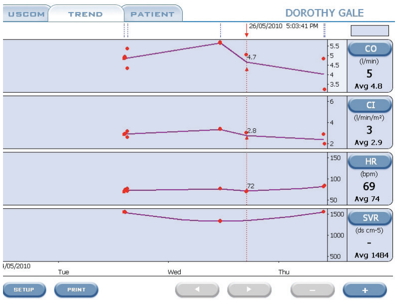


3. User touches TREND tab.

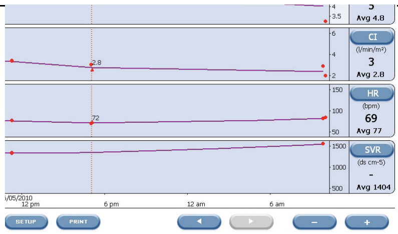
The user cannot see the whole CO graph and therefore touches the scale to automatically zoom out.



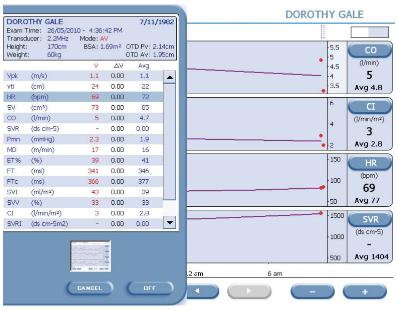
The user wants to zoom in on the values and therefore touches the + button.

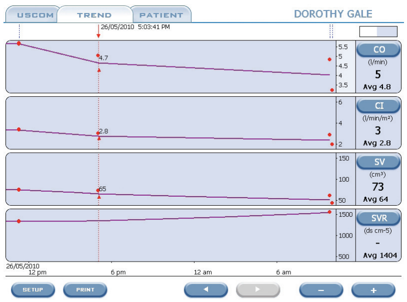


The user is interested in watching only the last measurements, and touches the right arrow at the bottom of the screen.



The values shown are not the desired ones. User touches the value button for HR to display SV instead.





4. The user wants to exit the screen and touches the USCOM tab.
5. User touches USCOM symbol.
6. User touches CANCEL in the OPEN EXAMINATION screen.

Termination

User touches CANCEL in the SELECT PATIENT screen.

Alternative courses:

User can choose to double touch when choosing patients and exams instead of touching OK.

Post conditions:

User sees Welcome screen.

Exceptions:

- User chooses the wrong button in the Welcome screen and has to start over.
- User has not made the previous examinations and can therefore not view them.
- User touches the wrong parameter to display, as they are close to each other.

Use case name:	Export patient data
Use case number:	5
Target system:	USCOM 1A
Primary Actors:	Physician or nurse
Secondary Actors:	Patient, other physicians and nurses
Context:	Clinical settings

Abstract:
The user wants to export patient data to a USB Flashstick.

Goal:
The desired patient's data is exported successfully.

Pre conditions:
The user is logged in and sees the Welcome screen. A Flashstick is inserted into a USB port.

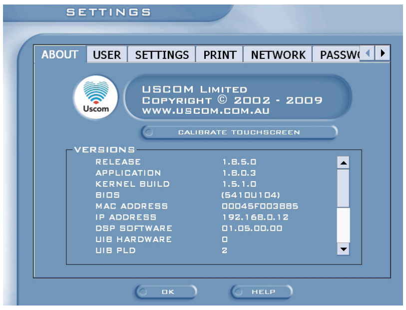
Normal course:

Initialisation (triggers)

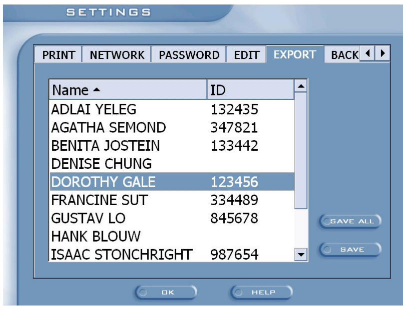
User touches USCOM.

Process

1. SETTINGS screen is shown.



2. User touches arrows to reach EXPORT tab.



3. User scrolls down to patient's name (if needed) and touches SAVE.

Termination

Patient's data is stored on Flashstick.

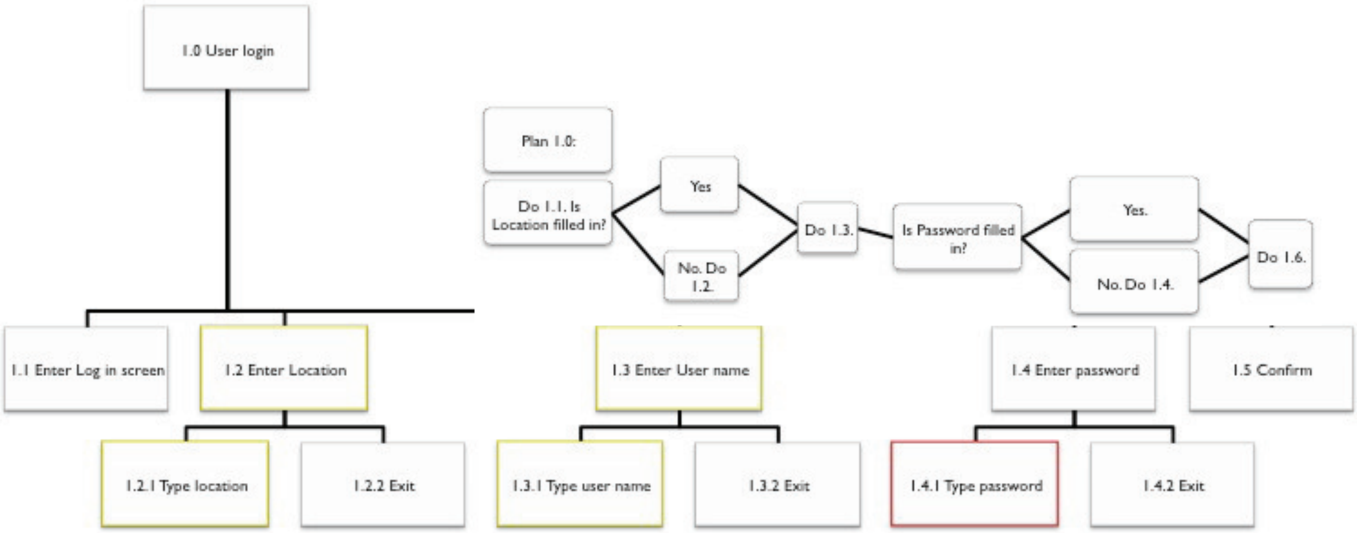
Alternative courses:
-

Post conditions:
User sees Welcome screen.

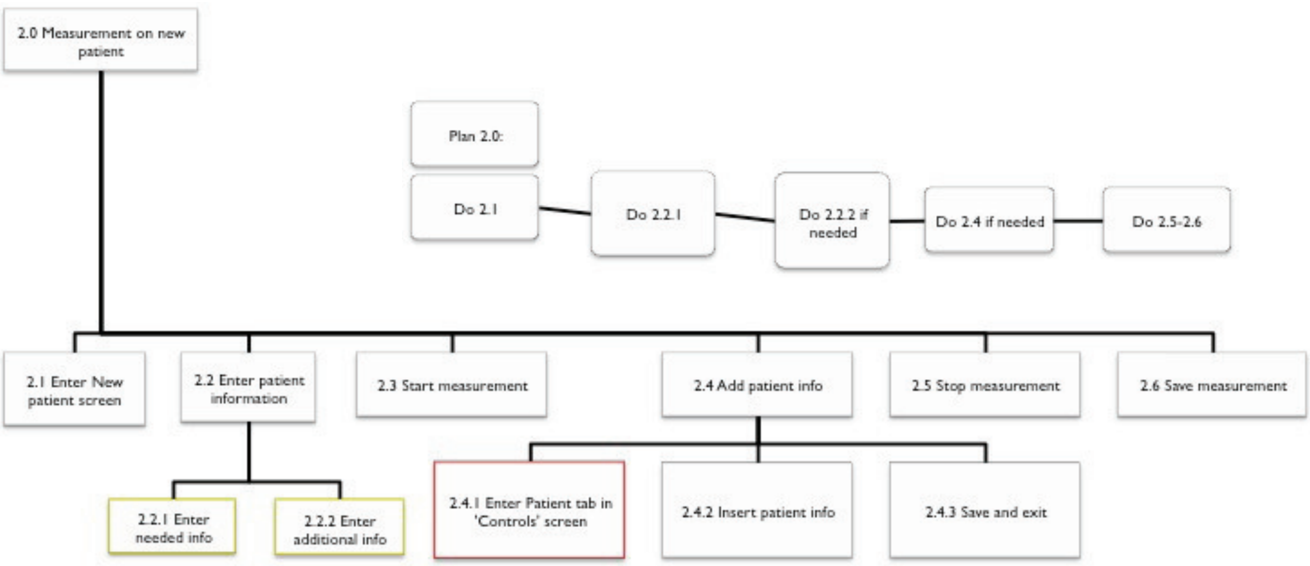
Exceptions:

- User chooses the wrong button in the Welcome screen and has to start over.
- Another user was logged in for the patient's examination, and current user can therefore not find it.
- User cannot find the Export tab in SETTINGS.
- User thinks that OK will save the data to the Flashstick and touches that instead of SAVE. The user will then be returned to the Welcome screen.

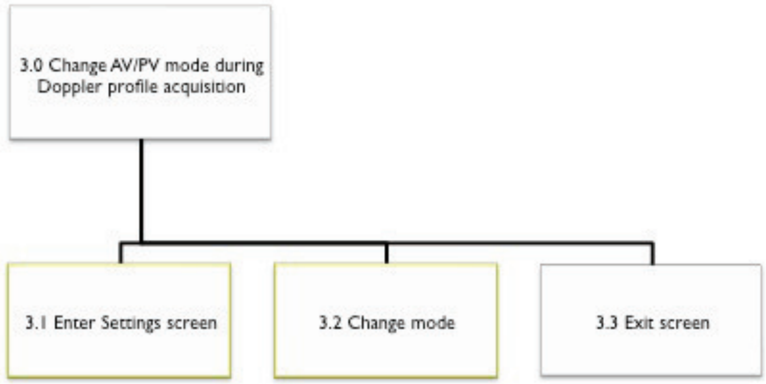
APPENDIX G: HIERARCHICAL TASK ANALYSIS TREES



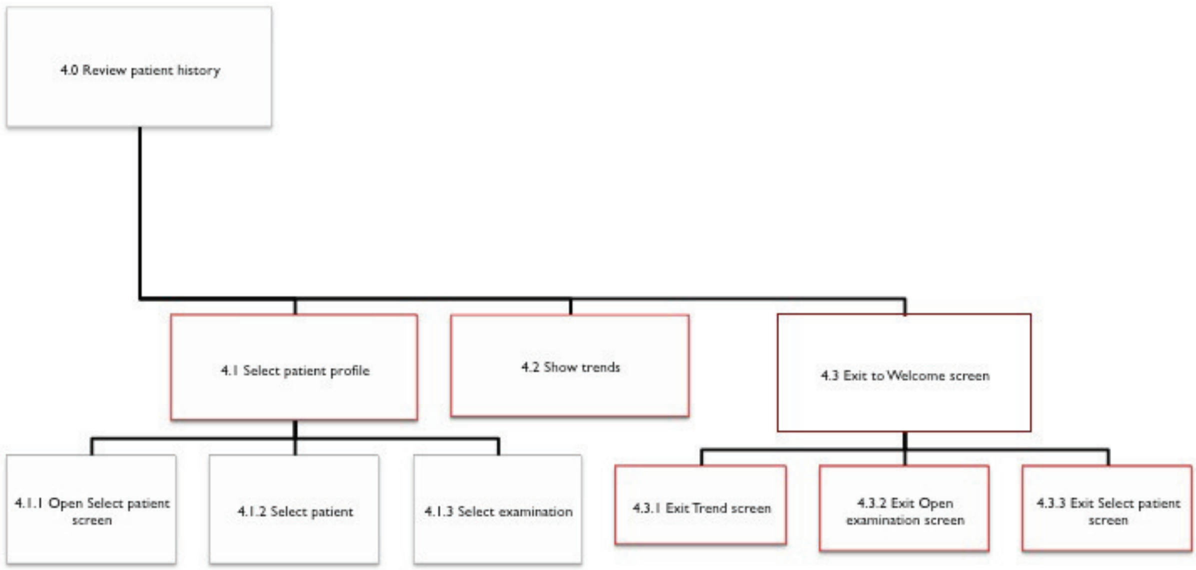
HTA1. User login



HTA2. Measurement on new patient

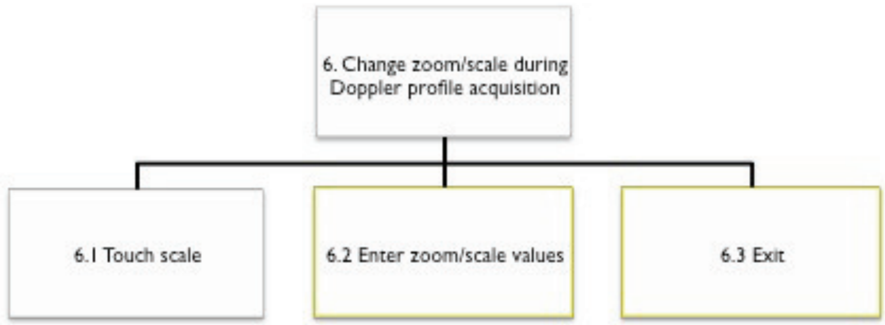


HTA3. Change AV/PV mode during Doppler profile acquisition

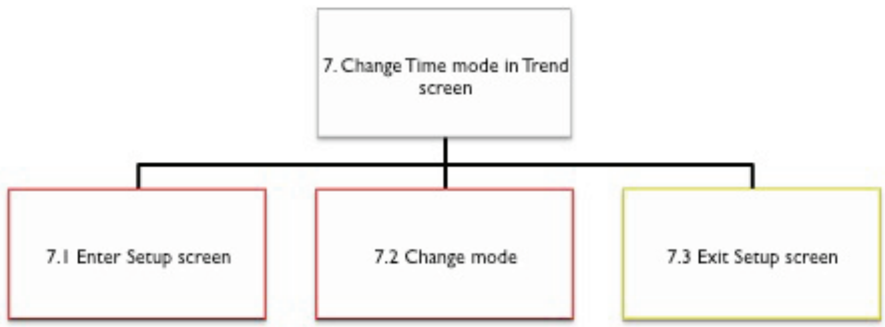


HTA4. Review patient history

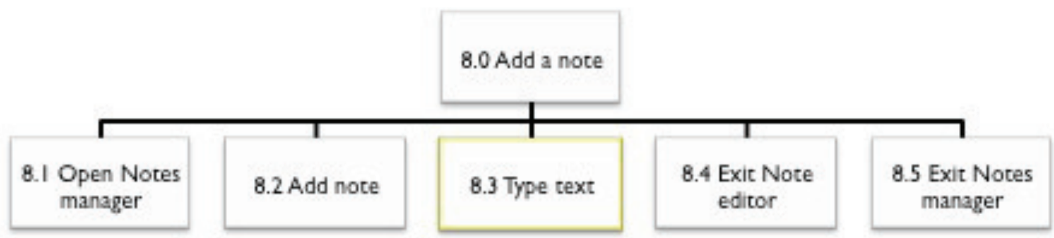
HTA5. Export patient data



HTA6. Change zoom/scale during Doppler profile acquisition



HTA7. Change Time mode in Trend screen



HTA8. Add a note

APPENDIX H: ENHANCED COGNITIVE WALKTHROUGH

This first four tables are the application of the Enhanced Cognitive Walkthrough (ECW) on the USCOM for the third HTA: Change AV/PV mode. Because the method is so extensive, this single example will serve to show how the method was used. The same questions were posed for all the functions and operations of all eight HTAs. The example is followed by the result matrices from all the ECWs.

Example of how the ECW was performed.

Function: 3.0 Change AV/PV mode	Task: Change AV/PV mode	Task importance: 2	
Questions	**Success/failure Story**	**Problem Seriousness**	**Problem Type**
1. Will the user know that the evaluated function is available?	Probably, domain knowledge.	4	U
2. Will the user interface give clues that show that the function is available?	Not explicitly.	3	H
3. Will the user associate the right clue with the desired function?	Probably	4	T
4. Will the user get sufficient feedback to understand that the desired function has been chosen?	Not really.	2	F
5. Will the user get sufficient feedback to understand that the desired function has been performed?	Yes, Doppler screen changes.	4	T

Operation: 3.1 Enter Settings screen	Action: Touch Cogwheel		
Questions	**Success/failure Story**	**Problem Seriousness**	**Problem Type**
1. Will the user be trying to achieve the right effect?	Maybe.	4	U
2. Will the user be able to notice that the correct action is available?	Yes.	5	
3. Will the user associate the correct action with the desired effect?	Not certainly.	2	T
4. If the correct action is performed, will the user see that progress is being made?	Yes, Control tab shows.	5	

Operation: 3.2 Change mode	Action: Touch AV/PV		
Questions	**Success/failure Story**	**Problem Seriousness**	**Problem Type**
1. Will the user be trying to achieve the right effect?	Maybe.	4	U
2. Will the user be able to notice that the correct action is available?	Probably.	4	T
3. Will the user associate the correct action with the desired effect?	Yes, but easy to slip.	4	T
4. If the correct action is performed, will the user see that progress is being made?	Yes, Doppler screen changes.	5	

Operation: 3.3 Exit Settings screen	Action: Touch OK		
Questions	**Success/failure Story**	**Problem Seriousness**	**Problem Type**
1. Will the user be trying to achieve the right effect?	Yes	5	
2. Will the user be able to notice that the correct action is available?	Yes	5	
3. Will the user associate the correct action with the desired effect?	Yes	5	
4. If the correct action is performed, will the user see that progress is being made?	Yes, tab closes.	5	

Result matrices from the ECW

Problem seriousness versus task importance
(Interface's general condition)

	Problem seriousness			
Task importance	**1**	**2**	**3**	**4**
1	0	2	4	16
2	0	2	2	8
3	3	3	4	0
4	0	0	1	2
5	2	2	3	3

Problem seriousness versus task type
(Overall problems with the interface)

	Problem seriousness			
Problem type	**1**	**2**	**3**	**4**
U (user)	0	1	7	11
H (hidden)	2	3	1	1
S (sequence)	0	0	1	2
T (text/icon)	3	4	4	13
F (feed-back)	0	1	1	2

Problem type versus task importance
(Which problems are most important to rectify?)

	Problem type				
Task importance	**U**	**H**	**S**	**T**	**F**
1	5	2	3	10	2
2	5	2	0	5	0
3	4	2	0	4	0
4	2	0	0	1	0
5	3	1	0	4	2

Problem seriousness versus task number
(Which tasks have more problems?)

Task number	Problem seriousness			
	1	2	3	4
1			1	2
2			1	10
3		1	1	5
4		2	2	4
5	3	3	4	
6		1	1	3
7	2	2	3	3
8			1	2

Problem type versus task number
(Which types of problems are more common in the tasks?)

Task number	Problem type				
	U	H	S	T	F
1	2			1	
2	2	1		6	2
3	3	1		3	
4	1	1	3	3	
5	4	2		4	
6	2	1		2	
7	3	1		4	2
8	2			1	

APPENDIX I: PREDICTIVE USE ERROR ANALYSIS

The Predictive Use Error Analysis (PUEA) was performed on all eight HTAs. All the PUEAs are presented in this appendix. The PUEAs include all the potential use errors that were detected for the USCOM. The actual analysis protocols are presented first, and are followed by the result matrices from the PUEA.

PUEA for HTA1. User login:

Questions Functions:	1. What happens if the user performs an incomplete operation or omits an operation? 2. What happens if the user performs an error in the sequence of operations? 3. What happens if the user performs this function at the wrong time?					Notes:			
Questions Operations:	4. What can the user do wrongly in this operation? 5. What happens if the user performs this operation at the wrong time?								
Function/	Error			Consequence		Mitigations			
Operation	Description	Type	Cause	Primary	Secondary	Detection	Recovery	Protection	Prevention
1.0 User login	1.0a The user tries to enter Examination screen without logging in.	P2. Incorrect plan executed	Lapse: User forgets it is needed to login	The user is not logged in	5. User cannot perform measurements immediately	5. Log in button is not changed to Log out/User will be asked again	Login when trying to perform measurement	User is asked to login when trying to perform measurement	Instructions in manual
1.0 User login	1.0b The user omits one or several operations.	A8. Action omitted	Slip: User gets distracted	The user is not logged in	5. User cannot perform measurements immediately	5. System warns if operation is needed	Perform omitted operation	System warns	Obvious sequence of operations
1.1 Enter Login screen	1.1a The user chooses the wrong button	S2. Wrong selection	Slip: Buttons are close & marked similarly	None if Open is selected. If Off is selected, confirmation screen appears.	5. User cannot perform measurements immediately	5. Other screens show.	Go back and try again	If Open is selected, user will automatically be asked to log in	None
Turn page									

Function/ Operation	Error			Consequence		Mitigations			
	Description	Type	Cause	Primary	Secondary	Detection	Recovery	Protection	Prevention
1.3 Enter User name	1.3a User enters incorrect User name and/or password	T2. Wrong message transmitted	Lapse: User forgot info	User cannot log in	3. The user cannot log in	5. System warns	Try again, contact support or create new user	Upper case/lower case is ignored	None
1.4 Enter Password	1.4a User enters password in lower/upper case wrongly	P3. Correct plan incorrectly executed	Slip: User does not check that Caps Lock is on/off	Wrong password is typed in	3. The user cannot log in	5. System warns	Change Caps Lock and try again	None	None

PUEA for HTA2. Measurement on new patient:

Questions Functions:	1. What happens if the user performs an incomplete operation or omits an operation? 2. What happens if the user performs an error in the sequence of operations? 3. What happens if the user performs this function at the wrong time?					Notes:			
Questions Operations:	4. What can the user do wrongly in this operation? 5. What happens if the user performs this operation at the wrong time?								
Function/	Error			Consequence		Mitigations			
Operation	Description	Type	Cause	Primary	Secondary	Detection	Recovery	Protection	Prevention
2.0 Measurement on new patient	2.0a User enters through Run (omits entering New patient window)	S2. Wrong selection made	Knowledge-based mistake: User did not know what to choose	Patient details are not entered	5. User will have to enter patient details in screen	5. Wrong screen opens	Enter patient details in screen	Offer user other possibilities	Offer user other possibilities
2.2 Enter patient info	2.2a User omits necessary information to 'Save' patient	A8. Action omitted	Knowledge-based mistake: User did not know what was necessary	Patient details are not stored	5. Patient details can not be trended or reviewed	5. System warns	Add necessary info	System warns	System warns
2.2.2 Enter additional info	2.2.2a User thinks that OTD choice means measurement of AV/PV	R2. Wrong info obtained	Knowledge-based mistake: Inappropriately designed buttons	User thinks that Pulmonary/Aortic measurement is chosen	3. Doppler signal is not correct	4. Screen will not be adjusted for PV/AV measurement	Change to PV/AV measurement	None	Selection shows on screen, however small
Turn page									

Function/ Operation	Error			Consequence		Mitigations			
	Description	Type	Cause	Primary	Secondary	Detection	Recovery	Protection	Preventio n
2.4.1 Enter Patient tab in 'Controls' screen	2.4.1a User tries to touch large Patient tab	S2. Wrong selection made	Rule-based mistake: Confusing marking	User cannot find right tab	4. Parameters are not calculated	5. Large Patient tab cannot be chosen	Try different solutions	Large patient tab is disabled	Informati on in user manual
2.4.1 Enter Patient tab in 'Controls' screen	2.4.1b User touches Entry tab.	A6. Right action on wrong object	Rule-based mistake: Confusing marking	User cannot find right tab	4. Parameters not calculated	5. The right boxes are not found under Entry tab	Try other tabs	None	Marking of tab
2.4.3 Exit and save	2.4.3a User touches Cancel instead of OK	A6. Right action on wrong object	Rule-based mistake: Confusing placement	Patient details are not stored	4. Parameters are not calculated	5. Parameters are not calculated	Perform function again	None	None
2.6 Choose Doppler profiles	2.6a User selects inaccurate Doppler profiles because of misinterpretati on	S2. Wrong selection made	Knowledge-based mistake: User did not know that the profiles were inaccurate	The calculated parameters can be highly incorrect.	2. Patient hemodyna mic status is incorrectly assessed	2. Hard to detect unless experience d physician and USCOM 1A user.	Perform new measureme nt.	None.	Training, informati on in manuals
2.6 Choose Doppler profiles	2.6b User selects inaccurate Doppler profiles because of a slip	C2. Checking incomple te	Slip: Failure to check accuracy of tracing	The calculated parameters can be moderately incorrect.	2. Patient hemodyna mic status is incorrectly assessed	3. Doppler profiles are not traced correctly.	Unselect incorrect Doppler profiles and resave.	None.	Training, informati on in manuals

2.7 Save measurement	2.5a User presses Start instead of Save	A6. Right action on wrong object	Slip: Failure of attention	Doppler profiles are not saved	3. Patient details can not be trended or reviewed	4. Lack of saving feedback	Perform new measurement	None	Placement of Save button

PUEA for HTA3. Change AV/PV mode:

Questions Functions:	1. What happens if the user performs an incomplete operation or omits an operation? 2. What happens if the user performs an error in the sequence of operations? 3. What happens if the user performs this function at the wrong time?	Notes:
Questions Operations:	4. What can the user do wrongly in this operation? 5. What happens if the user performs this operation at the wrong time?	

Function/ Operation	Error			Consequence		Mitigations			
	Description	Type	Cause	Primary	Secondary	Detection	Recovery	Protectio n	Preventio n
3.0 Change AV/PV mode	3.0a User cannot find 'Settings'	R1. Informati on not obtained	Rule-based mistake: Unclear marking of button (Cogwheel)	Mode is not changed	3. Doppler signal is not correct	5. Screen does not change	Try different selections	None	Easy to see that screen has not changed
3.0 Change AV/PV mode	3.0b User cannot see which selection has been made	R1. Informati on not obtained	Knowledge-based mistake: Unclear marking of choices (red/blue)	Mode is not changed	3. Doppler signal is not correct	5. Screen does not change	Try different selections	None	Easy to see that screen has not changed
3.0 Change AV/PV mode	3.0c User presses Cancel instead of OK	A6. Right action on wrong object	Slip: Placement of buttons	Mode is not changed	3. Doppler signal is not correct	5. Screen does not change	Perform function again	None	Easy to see that screen has not changed

PUEA for HTA4. Review patient:

Questions Functions:	1. What happens if the user performs an incomplete operation or omits an operation? 2. What happens if the user performs an error in the sequence of operations? 3. What happens if the user performs this function at the wrong time?								
Questions Operations:	4. What can the user do wrongly in this operation? 5. What happens if the user performs this operation at the wrong time?						Notes:		
Function/ Operation	Error			Consequence		Mitigations			
	Description	Type	Cause	Primary	Secondary	Detection	Recovery	Protection	Prevention
4.3 Review patient	4.3a User cannot find way out of Trend screen	R1. Information not obtained	Rulebased mistake: User expects Exit button	User cannot exit	3. User cannot perform measurements on other patients immediately	5. User cannot exit	Try different options	None	None

PUEA for HTA5. Export patient data:

Questions Functions:	1. What happens if the user performs an incomplete operation or omits an operation? 2. What happens if the user performs an error in the sequence of operations? 3. What happens if the user performs this function at the wrong time?					Notes:			
Questions Operations:	4. What can the user do wrongly in this operation? 5. What happens if the user performs this operation at the wrong time?								
Function/ Operation	Error			Consequence		Mitigations			
	Description	Type	Cause	Primary	Secondary	Detection	Recovery	Protectio n	Preventio n
5.1 Enter settings screen	5.1a User makes incorrect selection in Welcome screen	S2. Wrong selectio n made	Rule-based mistake: Unclear marking of buttons	Data is not exported	5. Patient data cannot be transferred	5. No Export button is found elsewhere	Try different solutions	None	Instructio ns in manual
5.2 Find and enter Export tab	5.2 User cannot find Export tab	S1. Selectio n omitted	Knowledge-based mistake: Hidden tab	Data is not exported	5. Patient data cannot be transferred	5. No Export tab is found	Try different solutions	None	Instructio ns in manual
5.4. Export patient	5.4 User presses OK	A6. Right action on wrong object	Rule-based mistake: OK usually means an action is taken	Data is not exported	5. Patient data cannot be transferred	4. No feedback is given	Perform function again	None	Instructio ns in manual

PUEA for HTA6. Change zoom/scale during Doppler profile acquisition:

Questions Functions:	1. What happens if the user performs an incomplete operation or omits an operation? 2. What happens if the user performs an error in the sequence of operations? 3. What happens if the user performs this function at the wrong time?						Notes:		
Questions Operations:	4. What can the user do wrongly in this operation? 5. What happens if the user performs this operation at the wrong time?								
Function/ Operation	Error			Consequence		Mitigations			
	Description	Type	Cause	Primary	Secondary	Detection	Recovery	Protection	Prevention
6.1 Touch scale	6.1a User cannot find zoom/scale function	R1. Information not obtained	Knowledge-based mistake: Hidden function	User cannot see full Doppler profiles	3. Incorrect Doppler profiles are collected	5. Screen does not change	Try different options	None	Instructions in user manual
6.3 Exit	6.3a User touches Defaults instead of OK	A6. Right action on wrong object	Slip: Buttons placement	Default values are chosen	5. Time is consumed choosing right values	5. Default values are chosen	Perform function again	None	Instructions in user manual
6.3 Exit	6.3a User touches Cancel instead of OK	A6. Right action on wrong object	Slip: Buttons placement	No change is made	5. Time is consumed choosing right values	5. No change is made	Perform function again	None	Instructions in user manual

PUEA for HTA7. Change Time mode in Trend screen:

Questions Functions:	1. What happens if the user performs an incomplete operation or omits an operation? 2. What happens if the user performs an error in the sequence of operations? 3. What happens if the user performs this function at the wrong time?	Notes:
Questions Operations:	4. What can the user do wrongly in this operation? 5. What happens if the user performs this operation at the wrong time?	

Function/	Error			Consequence		Mitigations			
Operation	Description	Type	Cause	Primary	Secondary	Detection	Recovery	Protec tion	Preventi on
7.2 Change mode	7.2a User incorrectly thinks Time mode is on/off	R1. Informatio n not obtained	Rule-based mistake: Red blue, not optimal marking	It is hard for the user to get a good view of trends	4. Interpretation of results is difficult	5. User still cannot see whole graph when reentering trend screen	Perform function again	None	None
7.3 Exit Setup screen	7.3a. User touches Cancel instead of OK	A6. Right action on wrong object	Slip: In many other screens, OK is at the bottom	User will have to perform function again	5. Time is consumed for doing action again	5. User still cannot see whole graph when reentering trend screen			

PUEA for HTA8.

Function/	Error			Consequence		Mitigations			
Operation	Description	Type	Cause	Primary	Secondary	Detection	Recovery	Protection	Prevention
Print notes	User touches Print instead of Notes>Print	P2. Incorrect plan executed	Rule-based : 'Print' could be mistaken for printing notes	If a Flashstick is inserted, a screenshot will be saved.	5. No note will be printed, screenshot takes up space on flashstick	4. Probably understands that notes have not been printed	Enter Notes and print from there	None	Instructions in manual

PUEA result matrices:

PUEA Matrix A

Consequence versus task number
Shows in which tasks the most serious consequences of errors exist.

	Task number							
Consequence	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1								
2		2						
3	2	2	3	1		1		
4		3					1	
5	3	2			3	2	1	1

Errors with the most serious consequences (see PUEAs for more info):

1.3a User enters incorrect User name and/or password

1.4a User enters password in lower/upper case wrongly

2.2.2a User thinks that OTD choice means measurement of AV/PV

2.5a User presses Start instead of Save

2.6a User selects inaccurate Doppler profiles because of misinterpretation

2.6b User selects inaccurate Doppler profiles because of a slip

3.0a User cannot find 'Settings'

3.0b User cannot see which selection that has been made

3.0c User presses Cancel instead of OK

4.3a User cannot find way out of Trend screen

6.1a User cannot find zoom/scale function

PUEA Matrix B

Error type versus task number
Shows which type of use error exists in the various tasks.

	Task number							
Error type	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Plan	2							1
Action	1	4	1		1	2	1	
Checking		1						
Retrieval		1	2	1		1	1	
Communication	1							
Selection	1	3			2			

PUEA Matrix C

Error cause versus task number
Shows the causes of the use errors in the different tasks.

	Task number							
Error cause	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Lapse	2							
Slip	3	2	1			2	1	
Rule-based mistake		3	1	1	2	1	1	1
Knowledge-based mistake		4	1		1			
Violation								

PUEA Matrix D

Error type versus consequence
Shows which error type gives rise to the highest risks.

	Consequence				
Error type	**1**	**2**	**3**	**4**	**5**
Plan			1	1	3
Action			2	2	6
Checking		1			
Retrieval			5	1	
Communication			1		
Selection		1			3

PUEA Matrix E

Error cause versus consequence.
Shows which error cause gives rise to the highest risks.

	Consequence				
Error cause	**1**	**2**	**3**	**4**	**5**
Lapse			1		1
Slip		1	3		5
Rule-based mistake			2	4	3
Knowledge-based mistake		1	3		3
Violation					

PUEA Matrix F

Error cause versus
error type
Shows what coupling exists between
error cause and error type

	Error type					
Error cause	**Plan**	**Action**	**Checking**	**Retrieval**	**Communication**	**Selection**
Lapse	1				1	
Slip	1	6	1			1
Rule-based mistake	2	3		3		1
Knowledge-based mistake	1	1		3		2
Violation						

PUEA Matrix G

Detection versus task number
Shows in which tasks there are errors
that are difficult to
detect.

	Task number							
Detection	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1								
2		1						
3		1						
4		2			1			1
5	5	5	3	1	2	3	2	

PUEA
Matrix H

Detection versus error type
Shows which type of error is difficult to detect

	Error type					
Detection	**Plan**	**Action**	**Checking**	**Retrieval**	**Communication**	**Selection**
1						
2						1
3			1			
4	1	2		1		
5	4	8		5	1	3

PUEA Matrix I

Detection versus error cause
Shows the causes of the errors that are difficult to detect.

	Error cause				
Detection	**Lapse**	**Slip**	**Rule-based mistakes**	**Knowledge-based mistakes**	**Violation**
1					
2				1	
3		1			
4		1	2	1	
5	2	7	7	5	

PUEA Matrix J

Detection versus consequence
Shows how serious the consequences are for errors that are difficult to detect.

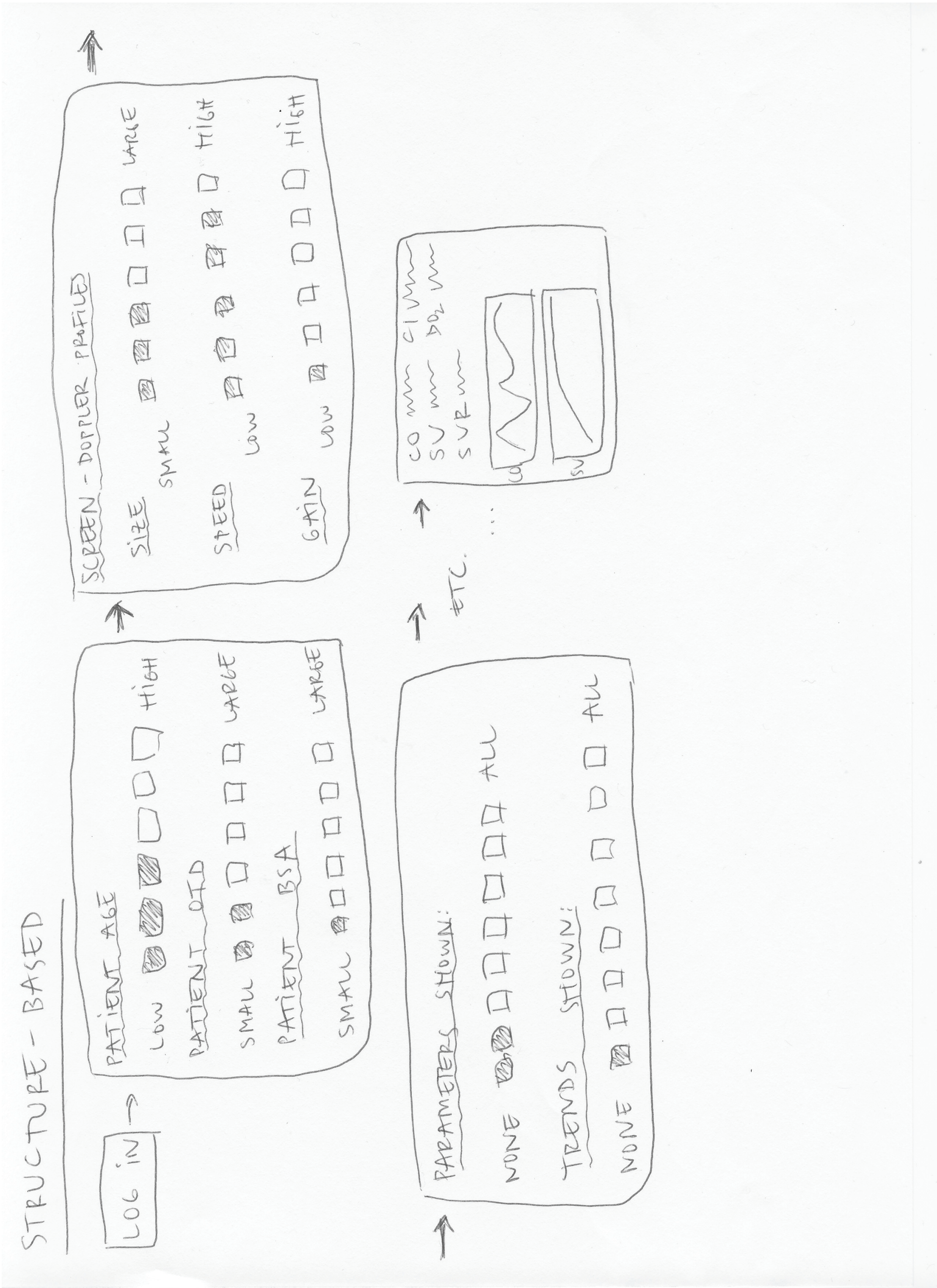
	Consequence				
Detection	**1**	**2**	**3**	**4**	**5**
1					
2		1			
3		1			
4			2		2
5			7	4	10

APPENDIX J: ANTHROPOMETRIC DATA

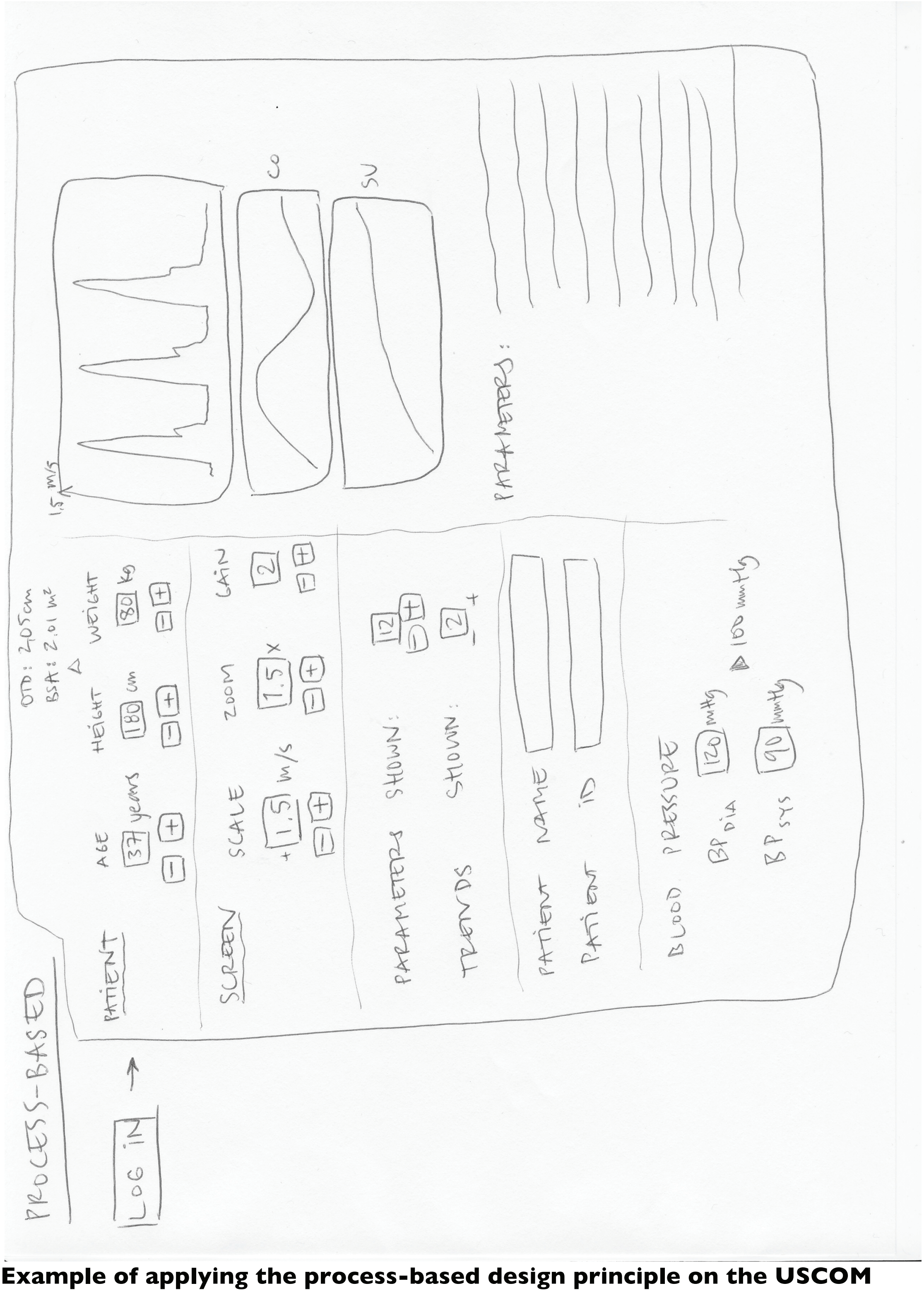
	Men		Women	
Dimension [mm]	5th %ile	95th %ile	5th %ile	95th %ile
Hand length	173	205	159	189
Palm length	98	116	89	105
Thumb length	44	58	40	53
Hand breadth (across thumb)	97	114	84	99
Hand breadth (metacarpal)	78	95	69	83
Hand thickness	27	38	24	33
Index finger breadth	19	23	16	20
Thumb breadth	20	26	17	21
Eye height (standing)	1515	1745	1405	1610
Eye height (sitting)	735	845	685	795

Data from Pheasant (1996, p.83).

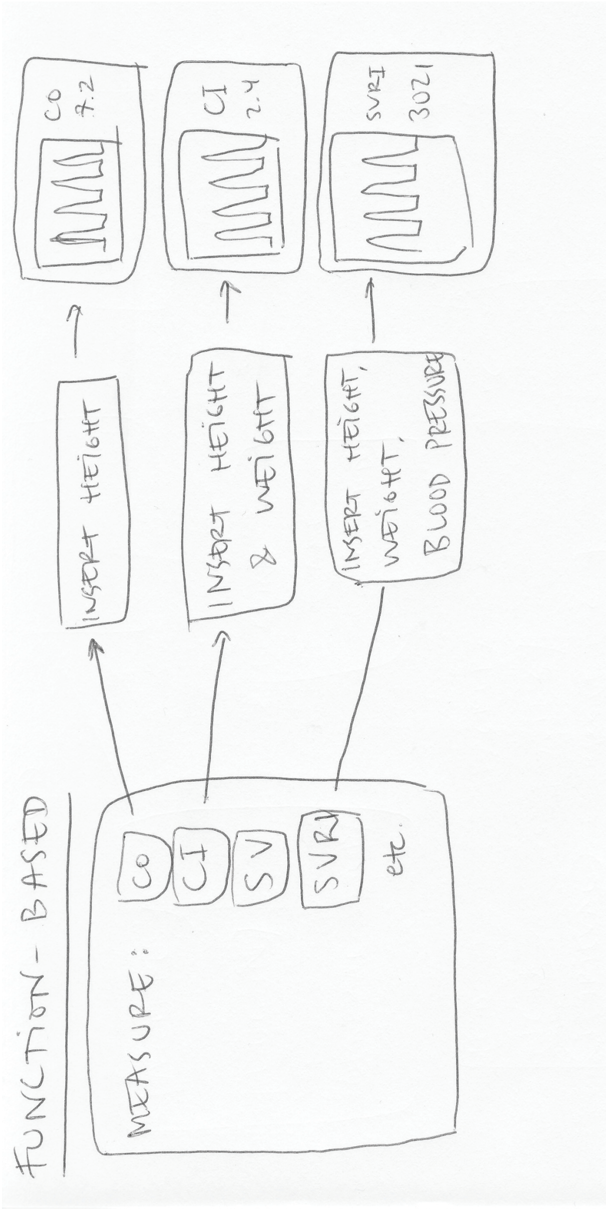
APPENDIX K: EXAMPLES OF ORGANIZATIONS OF THE USCOM INTERFACE



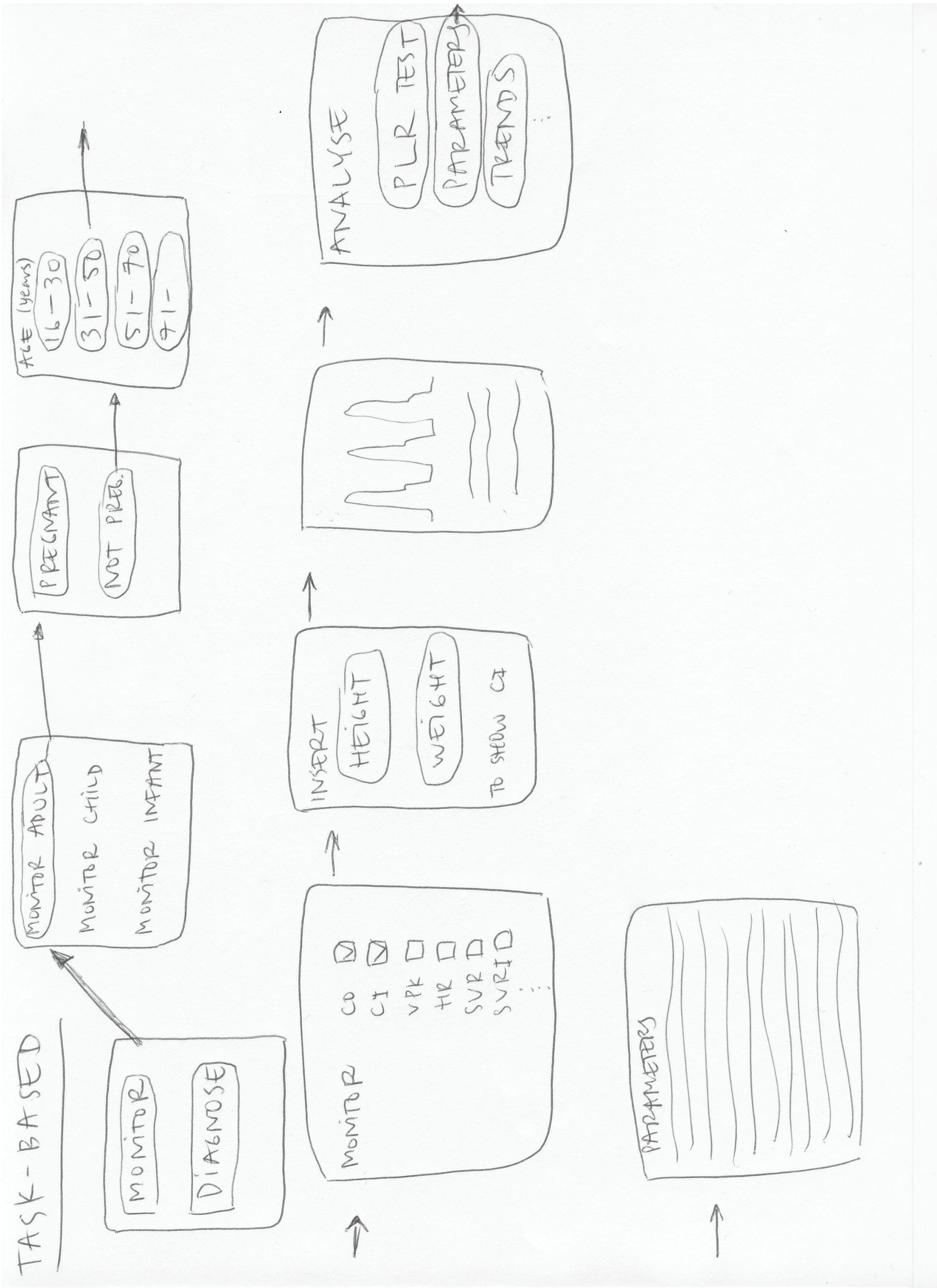
Example of applying the structure-based design principle on the USCOM interface.



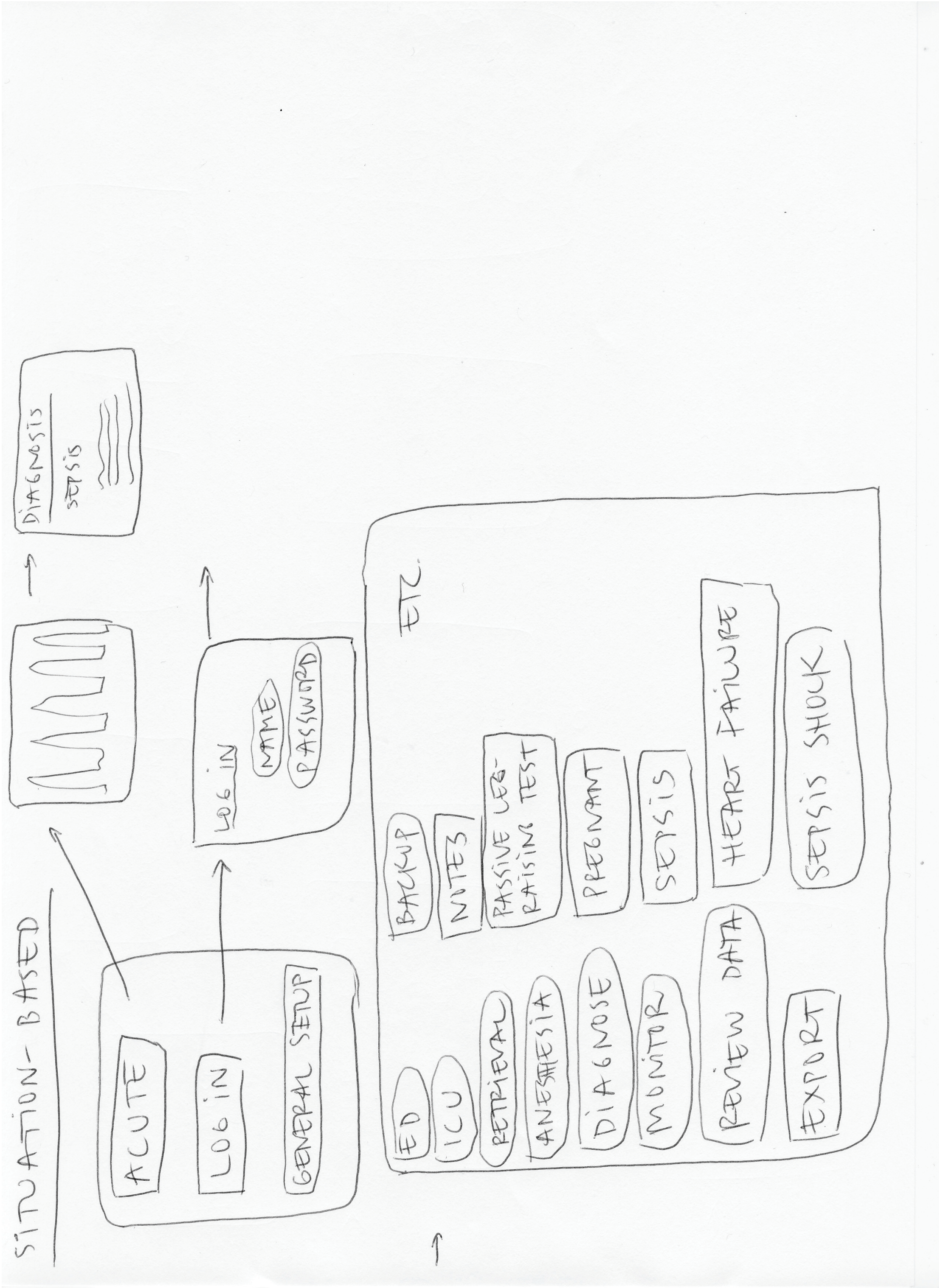
Example of applying the process-based design principle on the USCOM interface.



Example of applying the function-based design principle on the USCOM interface.



Example of applying the task-based design principle on the USCOM interface.



Example of applying the situation-based design principle on the USCOM interface.

APPENDIX L: ACTA RESULTS

ACTA Knowledge audit

TASK: Diagnose a patient with suspected shock		
Aspects of expertise, examples	**Clues and strategies**	**Why difficult?**
Past & Future Got a call from another operating theatre: 'The CO2 trace has dropped and the arterial line "isn't working". The respondent realized that the patient probably had a cardiac arrest	Clue: The combination of the two problems. The respondent realized that it was probably not a problem with the arterial line (which is common) but the equipment actually showed that the patient's heart had stopped. Strategy: 'Is there anything life-threatening?'	It's a matter of pattern recognition, and the experience helped the respondent to understand the situation
Big picture One can gather a lot of information just by looking at, and talking to a person, and thinking about the situation. For example, if a patient comes in with a suspected allergic reaction, some questions are more interesting than others.	Look at the patient! Information about patient status can never work in isolation, but the patient history and context must be considered. If the patient is allergic to peanuts, it is relevant that (s)he just visited a Thai restaurant	Unexperienced staff might not be able to put information in the right context
Noticing A situation where the respondent realized that the equipment wasn't showing the correct values	The respondent could tell that the patient's CO was fine from examining the patient, although the PAC equipment showed very poor values	Novices would trust the equipment to a larger degree and would not have the experience to see other signals. A novice might have given unnecessary medication
Job smarter There are protocols to follow in anaesthetics, such as 'COVER: Color & circulation, Oxygen, Ventilation & vaporiser, Endotracheal tube, & Reassess the ABC'		Experienced users know the protocols by heart and can work on a more skill-based level, going through different protocols
Opportunities/Improvising Wanted to transport from theatre to ICU while still delivering nitric oxide, was able to invent an improvised connection for the tubes	Having experience from the equipment and basic knowledge and experience gives possibility to improvise	Lack of experience of the equipment makes it harder to come up with ideas
Self monitoring Interpreting echocardiography images can be difficult, and sometimes one might have to ask for help	Not being sure about the interpretations	Novice users might not have the insight to determine where additional help is needed

ACTA Simulation interview

Event	Actions	Assessment	Critical cues	Potential errors
Patient complains of chest pain and shortness of breath	Listen to patient and get overview	Life-threatening condition or not?		Mistake in overall assessement of patient condition
Information gathering: History	Collect information about patient history and situation context	Anything of relevance for condition?	Important! Has the patient been on a plane, or is a typical PE risk patient?	Not knowing what to ask for to understand the history
Information gathering: Examination	Examine patient	Where do the signs point?	Low oxygen saturation, rapid breathing, rapid heart rate	Not examining the correct aspects, misinterpreting signs
Information gathering: Investigation	Perform tests	Perform the correct tests to test the hypothesis		Not making the right tests
Development of differential diagnosis	Come up with all possible diagnoses	Have I thought of everything possible?	Enough knowledge and experience to imagine the correct diagnosis	Missing to include PE to the list
Excluding diagnoses	Exclude the diagnoses one by one	Is the hypothesis correct?		Misdiagnosing PE for pneumonia or a cold