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Prototyping an Experimental Setup for Understanding Affective Response in a Ship Bridge Scenario

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Prototyping an Experimental Setup for Understanding Affective Response in a Ship Bridge Scenario

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THE NORWEGIAN UNIVERSITY
OF SCIENCE AND TECHNOLOGY
DEPARTMENT OF ENGINEERING DESIGN
AND MATERIALS

MASTER THESIS AUTUMN 2015
FOR
STUD.TECHN. KITTIL KITILSEN LEIKANGER

Experimental Approach towards Intuitive Alarm Systems in Applied Engineering Design

- *set-up of in-situ experiment on cognitive load and/or stress level and/or implementation of physiological measurement tools*
- *implementation of learning algorithms*
- *running subjects*
- *pre-processing data*
- *analysing data*
- *also, it is expected to contribute to one or more scientific publications during the master*
- *creating concepts towards intuitive alarm systems*

Formal requirements:

Three weeks after start of the thesis work, an A3 sheet illustrating the work is to be handed in. A template for this presentation is available on the IPM's web site under the menu "Masteroppgave" (http://www.ntnu.no/ipm/masteroppgave). This sheet should be updated one week before the master's thesis is submitted.

Risk assessment of experimental activities shall always be performed. Experimental work defined in the problem description shall be planed and risk assessed up-front and within 3 weeks after receiving the problem text. Any specific experimental activities which are not properly covered by the general risk assessment shall be particularly assessed before performing the experimental work. Risk assessments should be signed by the supervisor and copies shall be included in the appendix of the thesis.

The thesis should include the signed problem text, and be written as a research report with summary both in English and Norwegian, conclusion, literature references, table of contents, etc. During preparation of the text, the candidate should make efforts to create a well arranged and well written report. To ease the evaluation of the thesis, it is important to cross-reference text, tables and figures. For evaluation of the work a thorough discussion of results is appreciated.

The thesis shall be submitted electronically via DAIM, NTNU's system for Digital Archiving and Submission of Master's theses.

The contact person is Professor Martin Steinert.

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Summary

This document concerns the process and outcome of a master project undertaken at the Department of Engineering Design and Materials (IPM) at the Norwegian University of Science and Technology (NTNU) in the fall of 2015. The assignment for the project was to conceptualize, build and conduct an experiment targeting stress and affective response in a ship-handling scenario.

The first chapter gives the background for the thesis assignment. The challenges of the assignment are discussed to explain the approach taken and the evolved aim of the thesis – introducing the wayfaring approach for the development of a pilot experiment. Chapter two is presented as a conference paper dedicated to the unprecedented development strategy. This includes the theoretical background for human experiments in interaction design and for the wayfaring model in its current form as an early-phase product development methodology. Furthermore, it provides an overview of the pilot experiment before exemplifying how we deployed the wayfaring approach onto the development process by giving concrete examples highlighting the main aspects of the model. Conclusively, we propose an extended wayfaring model for developing experiments focused on: probing ideas, merging multidisciplinarity, agility and speed. Chapter three provides a comprehensive documentation of the solutions employed in the pilot experiment. This includes descriptions of the technical solutions for physiology measurements and data capturing, ship simulator setup and experimental tasks, as well as protocol solutions. The findings of the data analysis are included in chapter four. Chapter five provides a critical analysis of the pilot experiment and highlights aspects for improving the experimental setup. These issues and more are addressed in chapter six, where we suggest measures for further improvement.

This thesis should be relevant for the reader interested in the following topics:

- Affective engineering
- Interaction design
- Experiment development
- The wayfaring model
- Physiological measurement tools
- Stress

Sammendrag

Dette dokumentet beskriver prosessen og utfallet av en masterprosjekt utført ved Institutt for Produktutvikling og Materialer (IPM) ved NTNU høsten 2015. Oppgaven for prosjektet var å utvikle og utføre et eksperiment for å måle stress og affekt hos skipsførere.

Det første kapittelet forklarer bakgrunnen for oppgaven. Utfordringene blir diskutert for å forklare løsningsstrategien og det utviklede målet for oppgaven – å innføre wayfaring-modellen i utviklingen av et piloteksperiment. Kapittel to består av en konferanseartikkel som omhandler den nyskapende utviklingsmetodologien. Her blir den teoretiske bakgrunnen lagt for interaksjonsdesigneksperimenter, samt for wayfaring-modellen i sin nåværende form som en tidlig-fase produktutviklingsmetodologi. Videre blir det gitt en oversikt over piloteksperimentet før utviklingsprosessen blir gjennomgått ved å eksemplifisere hovedaspektene ved wayfaring-modellen. Avslutningsvis blir det presentert en utvidet wayfaring-modell for utvikling av eksperimenter fokusert på å: prøve ut ideer, slå sammen forskjellige disipliner, hurtighet og bevegelighet. Kapittel tre inneholder en omfattende dokumentasjon av løsningene som inngikk i piloteksperimentet. Dette inkluderer beskrivelser av tekniske løsninger for fysiologiske målinger og andre målinger, skipssimulator design og eksperimentelle oppgaver, så vel som protokoll-løsninger. Funn fra dataanalysen blir presentert i kapittel fire. Kapittel fem gir en kritisk analyse av piloteksperimentet hvor aspekter med forbedringspotensial blir fremhevet. Disse problemområdene blir behandlet i kapittel seks, hvor vi foreslår forbedringstiltak for videreutviklingsarbeidet.

Denne oppgaven er relevant for lesere interessert i følgende temaer:

- Affective engineering
- Interaksjonsdesign
- Utvikling av eksperimenter
- Wayfaring-modellen
- Fysiologiske måleinstrumenter
- Stress

Acknowledgement

I would like to thank the team: Elise Almås and Stephanie Balters, for the good collaboration resulting in this project and professor Martin Steinert for the support and for supervising the process. Furthermore, I would like to express my gratitude to everyone who partook as test subject during the development process and in the pilot experiment, making this thesis possible.

Finally, I want to thank all my professors and fellow students for everything they have taught me during my time at NTNU.

Table of contents

List of figures

List of tables

1 Project background

The thesis assignment stems from the front-end (FFE) (Kim and Wilemon, 2002; Koen et al., 2002) of a comprehensive research project currently undertaken by TrollLabs at NTNU addressing user interaction design (Moggridge and Atkinson, 2007) in a ship bridge scenario. One aim of the project is to generate adaptive interface solutions, such as alarm systems, suitable to the ship bridge operators under the various conditions of workload they are facing (Stanton, 1994). Importantly, the solutions should help manage operator stress to enhance their performance during critical events. This challenge fits within the realm of affective engineering (Dahlgaard and Nagamachi, 2008), where we seek to understand the relationship between our designs and the behavioral response of the user. To (1) be able to decode and quantify human behavior and subsequently (2) be able to design stress-adaptive interface solutions, there was established a need to build competence on capturing affective response in the specific context of the user interaction scenario. Therefore, a three-person team, including the author, was appointed to develop an experimental setup to explore the opportunities for capturing affective response in a ship-handling scenario.

1.1 Challenges

Facing the task of conceptualizing an experimental setup three areas of challenges emerged;

1. Understanding affective response
2. Understanding the context
3. Understanding human experiments

(1) Decoding human behavior, we encountered knowledge domains outside the immediate expertise of the team, such as psychology, physiology and neuroscience. To quantify this behavior, we needed to attain fundamental knowledge in physiological sensor technology and other measurement techniques capturing affective responses, involving domains such as electro-physics, signal processing and programming. (2) Furthermore, we needed to be able to reproduce the ship-handling setting in a controlled environment. Specifically, creating a cognitively challenging "stressful" scenario in comparison to a baseline scenario within the control room of a ship or, more realistically, within a ship simulator environment. (3) Importantly, we needed to gain experience in all the practical aspects of running human experiments. Including; creating a robust experimental protocol, finding test subjects and technical solutions such as software for data synchronization.

Developing an experimental setup from scratch without prior experience in human experiments, we were facing the challenge of acquiring a large amount of new knowledge in multiple disciplines. Furthermore, the process of managing the multidisciplinary aspects during decision making imposes a high degree of complexity and uncertainty, making the task of developing an experimental setup a highly time consuming and expensive process (Antony, 2014; Kirk, 1982).

1.2 The approach – introducing wayfaring in experiment development

Facing these challenges, we identified a general need to reduce the time and resources required to develop new experimental setups for affective engineering. While many proven experimental setups exist for traditional user-interaction scenarios, we are continuously redefining the way we interact with the world around us. As product developers seeking to understand the experiences and behavior of the user, it is therefore urgent to be able to efficiently generate compatible experimental setups to keep up with the pace of innovation. Given our project's **high degree of**

uncertainty due to the complexity of the task, the **high degree of freedom** to explore provided by the project owner, and the large amount of learning required in the **limited amount of time** available, we saw the potential benefits of applying the wayfaring model (Leifer and Steinert, 2014; Steinert and Leifer, 2012) onto the development process. Although not previously projected onto conceptualizing and building experiments, we recognized the methodology's ability to manage similar conditions in the early concept creation stage of product development projects with a high degree of intended innovation (Gerstenberg et al., 2015). Acknowledging that one cannot predict an optimum solution for something that has not been previously been done, the model proposes a bias towards action approach, rather than a planning approach based on a predefined outcome. Through proof-of-concept prototypes and rapid probing cycles, the aim is to uncover a problem and solution space at low-risk investment (i.e. fast and cheap). Rather than fixating our requirements based on assumptions and investing in high-end solutions, the model encouraged us to start with low-resolution experiment "prototypes", to accumulate practical experience and empirical evidence of our envisioned system quickly (Figure 1). Importantly, this approach enables the process of "safe failing" – making discoveries changing the requirements of the system at a minimum cost. Adopting this train of thought, we set out to discover the requirements of our experiment by probing ideas from day one, rather than through meticulous planning.

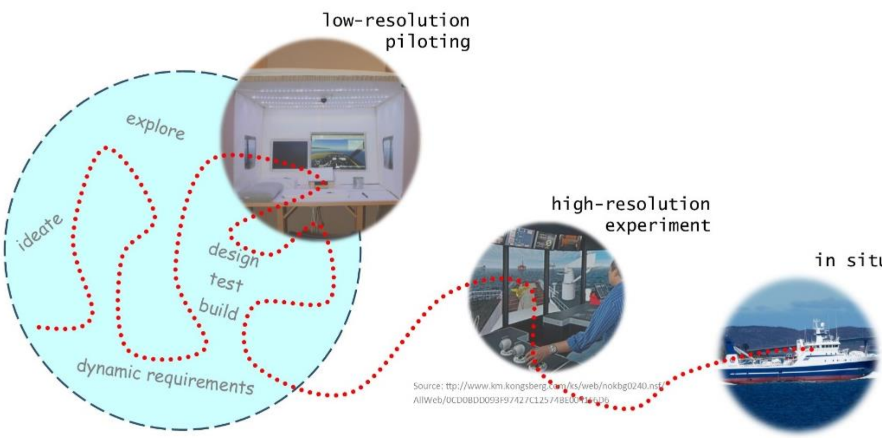

Figure 1. Envisioned experiment development journey

We were presented an opportunity to use students from the course TMM4280 Advanced Product Development as test subjects for our pilot experiment, as a part of their introduction to interaction design experiments (IDE). Although this meant the experimental setup needed to be ready after only four weeks of development in accordance with the course schedule, we grabbed this opportunity, as participants are not easily available. The four weeks after the experiment was spent sharing our experiences and helping the students set up and conduct their own small-scale IDE projects. Specifically, the project assignments were devised to explore additions and improvements to our pilot experiment.

In addition to the author, a second master student and a PhD student/supervisor partook in the development process. A separate thesis by the other master student will concern specific analysis methods outside the scope of this thesis, such as cortisol measurements and heart rate variability. To facilitate the further development of the experimental setup, the purpose of this document is to give a comprehensive description of the solutions employed in the pilot experiment and to provide a critical analysis of the current level of development. Importantly, the weaknesses of the pilot experiment should be emphasized to highlight the most critical areas for improvement. Furthermore, the unprecedented development strategy made an evolved aim of the thesis is to investigate the applicability of the wayfaring model for the development of human experiments in interaction design experiments.

2 Development process – introducing wayfaring

This chapter contains a paper currently under review for publication at the International Design Conference (IDC) 2016 in Dubrovnik, Croatia. It is included to provide an explanation of the development process leading up to the pilot experiment. The main topic of the paper is how we projected and applied the wayfaring approach onto the development of our experimental setup. The full paper, serving as chapter two in this document, is presented similar to its original IDC formatting. It covers background material on human experiments in interaction design and engineering design science, as well as the wayfaring model as described in the product development context. Furthermore, it provides an overview of the pilot experiment before exemplifying how we deployed the wayfaring approach onto the development process. Conclusively, it presents an extended model of wayfaring applied to the development of interaction experiments.

N.B. the paper does not discuss saliva samples taken for the experiment. It was decided to wait to publish this part of the experiment for a forthcoming paper dedicated to cortisol measurements and that avoiding this detail does not affect the process-oriented topic of the paper. The saliva probes will be included in the subsequent chapter (chapter 3) describing the experiment in detail.

INTERNATIONAL DESIGN CONFERENCE - DESIGN 2016
Dubrovnik - Croatia, May 16 - 19, 2016.

INTRODUCING THE WAYFARING APPROACH FOR THE DEVELOPMENT OF HUMAN EXPERIMENTS IN INTERACTION DESIGN AND ENGINEERING DESIGN SCIENCE

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Keywords: interaction design, conceptual experiment design, wayfaring model, stress, physiology sensors

1. Human experiments in interaction design and engineering design science

Interaction design [Moggridge 2007] science and related human-computer interaction (HCI), human factor engineering (HFE) and Ergonomics, and affective engineering aim to understand the underlying mechanisms of the interaction between human and object. This formulates the objective to be able to control and/or predict the (re-)action of the computer/machine and more crucially the (re-)action of the human, expressed as behavioral response. While the forecasting and manipulation of the behavior of computers and machines lays (mostly) within programmed rationality, remains the behavior of humans irrational and for now, thus, unpredictable. Shiller [2000] frames this concept of humans neither behaving fully rational nor in stable patterns as his Nobel prize winning framework of "irrational exuberance", supported by research in cognitive sciences [Kahneman and Tversky 1979, 1984; Kahneman 2011]. As a first major step in the challenging attempt to decode this black box of human behavior, important inroads have been done aiming to measure and quantify human behavior. Beside the approaches of analyzing facial expressions [Ekman et al. 1971; Ekman and Friesen 1978; Gottman and Krokoff 1989], amplitude and pitch of voice [Kappas et al. 1991; Cowie and Cornelius 2003; Bachorowski and Owren 1995; Russel et al. 2003] and the coding of body posture and gesture [Coulson 2004; Dael et al. 2012], the communities of and related to HCI and affective engineering especially focus on using physiology measurements, such as heart rate measurements [Hjortskov et al. 2004; Rowe et al. 1998], skin conductance measurements [Jung et al. 2015; Mandryk and Atkins 2007], eye tracking [Chen et al. 2011; Zhou et al. 2015], and brain measurement tools such as electroencephalography (EEG) [Nguyen and Zeng 2012, 2014; Steinert and Jablokow 2013; Steinert et al. 2012] and functional near-infrared spectroscopy (fNIRS) [Solovey et al. 2015; Maior et al. 2015]. For an extensive overview on physiological measurement tools and conducted studies, we propose to read [Balters and Steinert 2015]. In order to firstly develop an experiment aiming to capture human behavior, to secondly analyze and interpret generated data and to lastly build a grounded hypothesis argumentation, the experimenter needs to possess the fundamental knowledge in multiple knowledge domains, such as engineering design, electro-physics, psychology, physiology, and even neuroscience. The development process of an experiment gains, thus, complexity. The main challenge is then to combine the complementary and yet potentially contrary aspects of each domain that influence decisions within the development process – resulting in high degree of complexity and uncertainty. This is especially the case in scenarios with no obvious experiment precedes, when the experiment is to be built from scratch. The development of experiments with such multi-disciplinary aspects and moreover high degree of freedom is complex and thus time consuming and expensive [Kirk 1982; Antony 2014]. In that way, it resembles the journey of product development projects with high degree of intended innovation. Being trained to approach such complex challenges in the context of early product development with methods from design thinking, we recently presented our wayfaring approach for product development [Gesternberg et al. 2015]. The model grounds on abductive learning [Burks 1946; Eris 2004; Leifer and Steinert 2011] and Steinert & Leifert [2012]'s hunter gatherer model and encourages to include all knowledge domain disciplines of the project from the beginning and iteratively probe ideas in design, build, test cycles. In this paper, we propose a modified version of the wayfaring model, applied for experiments that include multi-disciplines and thus high degree of complexity. We support our model by the concrete example of the development of an experiment in affective engineering. We were facing the challenge of building and conducting an experiment aiming to monitor stress-levels of ship pilots, in order to subsequently (engineering) design stress-adaptive ship bridge interfaces based on these research results. By applying the wayfaring approach, we were able to develop and build an experiment from scratch to running participants within four weeks.

In the next section we give background and lay the theoretical foundation of the wayfaring model. We further describe the (engineering design) challenge of our example case (section 3). In section 4, we will highlight the main components of wayfaring and give concrete examples from our case experiment. Conclusively, we propose our wayfaring model for conceptually developing experiments in interaction design in section 5.

2. The wayfaring model

The wayfaring model, founded on Ingold [2007] and Steinert and Leifer [2012], is described as a exploration journey rather than a planning based approach to discover innovative ideas. It has since been further refined as a methodology for the early concept creation stage of product development projects with a high degree of intended innovation by Gerstenberg et al [2015]. The main premise of the model is that an optimum new solution to a problem cannot be preconceived and targeted, as we do not have empirical evidence for the outcome of something that has not previously been done. Consequently, the model establishes the need for a pragmatic exploration of the problem and solution space - a bias towards action approach to uncover the unknown. The methodology as depicted in figure 1 includes four main aspects:

1. Probing ideas - exploring opportunities, sometimes simultaneously, by means of low-resolution prototypes, to fail early and to enable abductive learning.
2. Merging multidisciplinarity - including all knowledge domains from the beginning, to uncover interdependencies and build interlaced knowledge.
3. Speed - planning based on short iteration timeframes, to maximize the number of iterations possible.
4. Agility - opportunistically choosing the next step, letting the development process shape the outcome, to make room for serendipity findings and innovative outcomes.

(1) By employing iterative probing cycles, the aim is to test critical functionalities of the envisioned system early on and get proof-of-concept feedback. A probing cycle is initiated by a divergent thinking phase, coming up with as many solutions as possible from the current understanding of the problem. These ideas are rapidly prototyped - design, test, build - focusing on the most critical functions. This creates an opportunity to reflect and converge towards the most promising option, enabling the use of abductive reasoning [Burks 1946]. Importantly, the methodology facilitates the process safe failing, failing as early in the development process as possible to minimize the resources spent developing into a disadvantageous direction. (2) When working on projects involving components from multiple disciplines, these components should be prototyped simultaneously and merged to test the system at large as soon as the components are available in their most rudiment form. The aim is to discover interdependencies early, and to build interlaced knowledge between the different disciplines. (3) Instead of planning the development process based on a predefined outcome, the process is scheduled in short iteration timeframes. This ensures a rapid progress, increasing the number of iterations possible, minimizing the time and resources spent developing into a disadvantageous direction and maximize the efficiency towards innovative solutions. (4) Rather than having a predefined outcome from which the development process can be pre-planned, the wayfaring model lets the development journey shape the outcome. The development journey consists of many iterative probing cycles, each of which is able to increase the understanding of the problem and solution space. In other words - learning by doing. This fast-learning process enables you to opportunistically choose the next step from the continuously updated practical knowledge base, entering a successive probing cycle. Accordingly, the perceived target shifts as you wayfare, making room for discovering highly innovative solutions that could not have been preconceived.

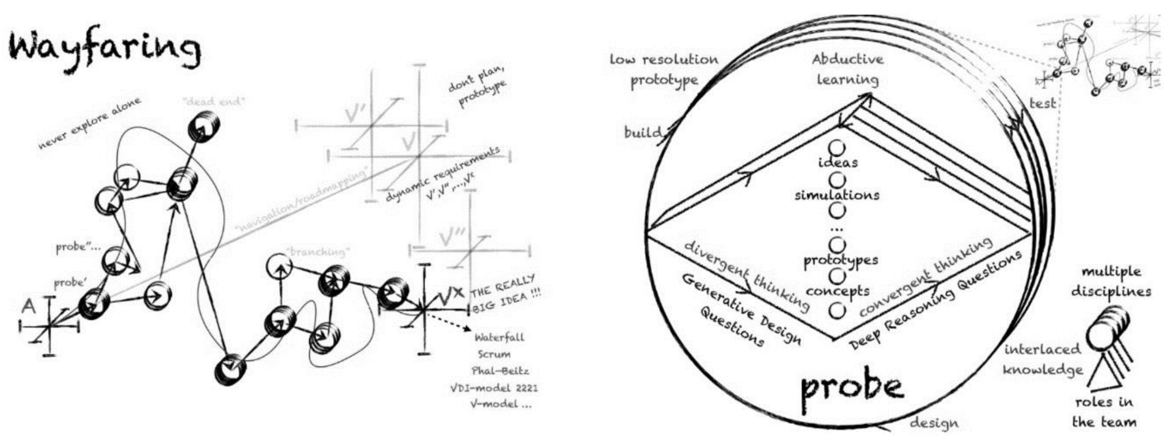

Figure 1. Wayfaring as proposed by Gerstenberg et al. [2015]

3. Case example, piloting a ship bride interaction experiment

The following example case is extracted from the fuzzy-front-end of an affective engineering project conducted by TrollLabs at NTNU, addressing interaction design in a ship bridge scenario. Importantly, the designs should help reduce operator stress, and be applicable to the user under various conditions of stress. Therefore, we decided on the need to create a corresponding experimental setup to test different solutions of user interaction design. However, with our limited experience with the multidisciplinary experimental components required, along with the ambiguity of the term "stress" including how to correctly induce and measure it, we could not immediately decide on an optimum experimental setup. Instead of starting looking for expert consultant, we decided to employ a fast-learning development process inspired by the wayfaring model, setting up a pilot experiment in four weeks. We drew our inspiration to apply this approach from its successful application in innovative early phase product development projects with a high degree of uncertainty [Gerstenberg et al. 2015]. The focus of this paper is how we projected and applied the wayfaring approach onto the development of an interaction design experiment. This section provides an explanation of the resulting experimental setup of our example case, to give an understanding of the outcome of the development journey discussed in the following section.

3.1. Experimental tasks

All simulated boat-conducting tasks were run on a 2x3.60 GHz CPU 16 GB RAM computer with using Ship Simulator 2008 software, a commercial ship simulation game developed by VSTEP [2007].

Three experimental tasks were custom-made using the "Mission Editor" application in the Ship Simulator 2008 software package:

- A trial run where the participant is given one minute to get a feel for the game in the environment "Marseilles". No traffic or obstacles are added to the environment, nor is there any objective to the game. Weather conditions are set to the software's default "Good weather" settings, time is set at noon and the "VSTP7" vessel is set as the player object. Overall, the task is designed to be a simple introduction to the dynamics of the game, with a minimum of taxing elements.
- A cruising task with the intent of being a "non-stressful", undemanding task to perform. Weather conditions are set to the software's default "Good weather" settings, time is set at noon and the "VSTP7" vessel is set as the player object in the "Phi Phi Islands" environment. No objective is given, as the participant is instructed to just enjoy cruising around for the duration of the task, which last for 5 minutes.
- A racing task with the purpose of creating a "high stress", increasingly demanding task for the test subject. The task is set in the "Atlantic Ocean" environment, where rows of stationary "Supertanker" vessels are used to confine the straight-lined course area. Increasing the difficulty was accomplished by manipulating the density of various obstacles such as ships, ramps and icebergs, and by manipulating weather condition variables; "Rain", "Thunder", "Fog" and "Waves & wind". These factors where manipulated at "waypoints" which occurred at fixed length intervals. Furthermore, the participant is set to play the course with the "Hydrojet", combining high speed and aggressive steering dynamics to be, what we consider, the game's most difficult vessel to maneuver. The course was designed to be impossible to finish within the fixed duration of 5 minutes, after which the performance of the participant is recorded manually by the experimenter as the number of "waypoints" attained. The participants were informed in the pre-game instructions that the best performer receives a gift card of 500 NOK for the university cafeteria to encourage a competitive mindset. In addition, it was informed that they would be able to check their performance on the class website, implying that the performance will be publicized and comparable. This is to encourage a competitive mindset also for the participants who perceive their gaming skills to be deficient in taking away the top prize.

Simultaneous to performing the racing task, the participants were instructed to do simple calculations as they appeared on the instruction screen. The calculations were implemented to analyze how the increasing difficulty of the racing task affected the performance of a secondary task. The first calculation appeared 24 seconds into the task. In total, nine calculations appeared on the screen for 6 seconds each, with 24 second blank screen intervals between them. The participants were informed in the pre-game instructions that this secondary task was equally important to their overall performance score.

3.2. Sensors and data capturing

Five biometric sensors, all provided by Libelium [2015], where used to collect physiological response data from the test subject, shown in figure 2. A GSR sensor was placed on participant's non-dominant hand to gather skin conductivity measurements, with the electrodes on the middle and ring finger. An accelerometer was placed on the top of the dominant hand, to measure hand movement during execution of experimental tasks. An airflow sensor collected the respiratory rate from the nostril openings. A temperature sensor placed on the left side of the neck measured body temperature. An ECG sensor was used to measure the electric activity of the heart. Due to electrical interference between the ECG and GSR sensor, no neutral electrode was used for the ECG. The negative electrode was placed on the left side of the chest, while the positive electrode was placed on the right side. Resulting signal noise was removed in pre-processing. The biometric sensors where initiated through an Arduino UNO with an e-Health sensor shield. An Ethernet shield was used to transmit the data to the synchronization software provided by iMotions [2015], run on a 2x1.80 GHz CPU 8GB RAM computer.

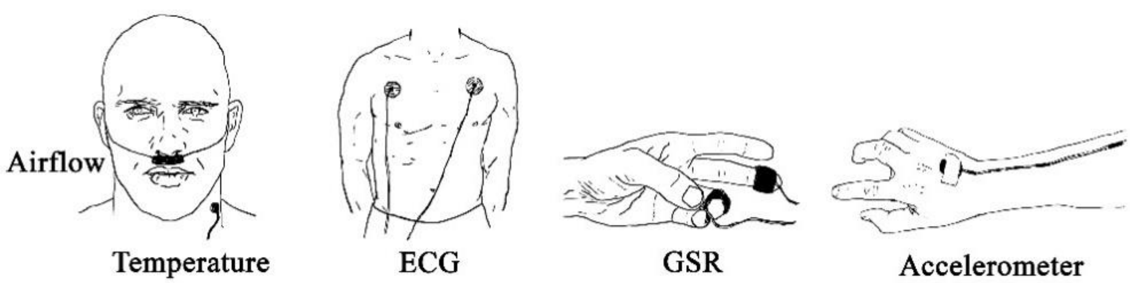

Figure 2. Sensor placement (for right-handed participant)

Emotional response data was generated automatically by iMotions from facial expressions captured by the respondent camera. Affect grids [Russell, Weiss, and Mendelsohn 1989] were used to gather emotional response data by means of self-report. A scene camera was used to record the participant, the gaming screen and the performance of the secondary task, all within the same frame.
A pre-experimental questionnaire was used for mapping demographics, specific health issues, diets and current emotional state. A post-experimental questionnaire was used to uncover prior experience level in boat conducting and computer gaming, current emotional state, as well as general feedback on the experiment.

3.3. Mockpit

The experiment was conducted within a simple ship cockpit environment, as illustrated in figure 3, from now on referred to as the Mockpit. A 24" LED gaming monitor was integrated into the rear wall of the mockpit, to mimic the feeling of looking out of a cabin window when performing the experimental tasks, along with a 17" LCD monitor to give instructions during the experiment. The four arrow-keys on a regular computer keyboard were used for maneuvering during execution of the experimental tasks, with all other keys disabled by a physical barrier cover. A notepad was fixed in the center of the Mockpit for performing the secondary task. An armrest to restrict non-dominant hand movement and the affect grids changed places according to hand-dominance. A box was placed in the rear to collect the affect grids.

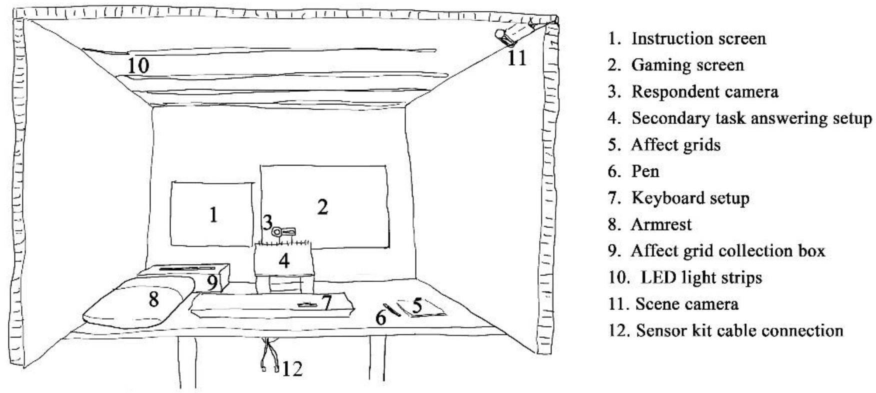

Figure 3. Mockpit layout (for right-handed participant)

3.4. Protocol

34 mechanical engineering students and 6 engineering department employees performed the experiment, distributed over the course of five days. Three experimenters were used to conduct the experiment.

In the invitation for the experiment, the participants were informed not to eat, drink any caffeinated drinks or use any nicotine substances within the hour before their assigned experimental time slot. Upon arrival, the participant was greeted by the 1st experimenter who guided them to a preparation room. The participant was assigned to fill out the pre-experimental questionnaire along with a compulsory consent form, before being outfitted with the sensors and hearing protectors to cancel any external noise.

The participant was then guided to the experiment room by the 2nd experimenter, where the participant was seated in the mockpit. After the 2nd experimenter had connected the sensor kit, she left the room in an obvious manner.

All instructions following this were presented on the instruction screen. The instructions, as well as the secondary task, were initiated automatically by the iMotions software. The experimental tasks were initiated by the 3rd experimenter manually, and presented on the gaming screen. The participant was given no clue of the presence of the 3rd experimenter. The secondary task was presented on the instruction screen during the racing task. Half of the participants were randomly assigned to do the experimental tasks in the order of; trial run - cruising task - race task, while the other half did the cruising task and racing task in the reverse order. A sequence of; affect grid - 1 minute baseline signal - affect grid, was implemented after each experimental task. The same sequence followed the final task, succeeded by an instruction informing of the completion of the experiment.

The participant was then guided back to the preparation room by the 2nd experimenter.

The 1st experimenter detached the sensors, before assigning the participant to fill out the post-experimental questionnaire.

4. Experiment developing through wayfaring

By the end of our four week development journey, we had gone from scratch to being able to run a comprehensive experimental pilot setup, implementing multidisciplinary experimental components previously far beyond our proficiency. The rapidness of which we accomplished this, we attribute to our bias towards action approach, facilitating fast-learning, inspired by the wayfaring model [Steinert and Leifer 2012; Gerstenberg et al. 2015]. This section highlights the main aspects of the wayfaring model, as described in section 2, by giving concrete examples from our development journey.

4.1. Week 1 - example of probing ideas

At the start of the development process, the three-person team was already familiarized with the extensive research project conducted by TrollLabs at NTNU addressing user-interaction design in a ship bridge scenario. Through the research in this project prior, we could quickly reach common ground that understanding the impact of stress was going to be an important factor for the experiment. Our "problem" of "making an experimental setup in order to understand the influence of stress in a ship bridge interaction scenario", immediately gave us a vague vision of some experimental components we would probably need - a physical space "ship simulator", a bunch of biometric sensors, and crucially, a ship-navigation-task that induces "stress" in comparison to a baseline task. By the end of the first day we had built a low-resolution ship simulator space out of cardboard, a monitor and a trial version ship simulation game (see figure 4).

Figure 4. First day low-resolution ship simulator

Within a week we had done multiple physiological measurements in the simulator, using a low-cost, open-source biometric sensor kit [Libelium 2015] consisting of ECG, GSR, airflow, accelerometer and airflow sensors. The approach was to explore our opportunities as fast and cheap as possible, to avoid wasting resources developing into a disadvantageous direction. Through this "bias towards action" approach, we started building practical experience from day one. This was especially crucial regarding the biometrical sensors, of which we had limited experience. The experiences gained in this process of probing ideas, importantly including experiences of failing, enabled the use of abductive reasoning, increasing our understanding of the problem and solution space. Simply put - learning by doing.

4.2. Week 2 - example of merging multidisciplinary components

Entering the second week, the team split into different problem areas. Two team members were resolving an uncovered electrical interference issue between the ECG and GSR signals, along with implementing all the aforementioned biometric sensor signals into a synchronization software [iMotions 2015]. The other team member was working on creating a "high stress" and a "low stress" simulator task and refining the mockpit. An alternate solution of using an open source algorithm for extracting pulse rate from a facial video recording [Wu et al. 2012] was tested to replace the GSR signal, but deemed unsuitable for our purpose due to its low tolerance on subject movement within the video frame and the light condition changes from the computer screen induced by playing the simulator game. While the GSR/ECG interference issue remained unsolved, we were able to confirm or reject potential solutions efficiently by directly integrating them with a meaningful experimental task. Consequently, the sensors gave us indications on factors within the game that were able to induce stress related responses in the sensor signals. The complexity of developing a plausible experimental setup was in large parts due to the interdependencies arising between the multidisciplinary experimental components. When probing on isolated components, e.g. biometric sensors, one is restricted to uncovering issues in that particular problem domain only, such as the electrical interference issue between the ECG and GSR signals. However, not until connecting two or more experimental components, one can discover arising confounding variables, such as the impact of task-induced limb movement and task-dependent sensor placement on signal data. These unknown interdependencies are revealed when merging different experimental components. For instance, our experimental setup needed to enable comfortable execution of the experimental tasks for both right handed and left handed participants. Beside a suitable experimental space layout, enabling a common ergonomically comfortable task execution, this meant for example to keep a flexible wire connection to the biometric sensors, to be able to reversely switch the item positions inside the simulator space, and to provide time buffer for the possible resulting reconfiguration in the protocol. These factors were discovered and thereafter solved, by probing the experimental components in context. As the wayfaring model proposes, including as many multidisciplinary components as possible, as soon as possible, is all-important to be able to fail early. By probing the "global" problem instead of its constituent subproblems separately, we were able to uncover the essential interdependencies of our envisioned system, which can render spending a lot of time optimizing a subproblem futile. To save time, we would temporarily divide the team, solving different problem domains, e.g. sensors, simulator and programming. By working side-by-side, each within their continuously expanding field of expertise, we could merge and test our multidisciplinary components for integration issues quickly.

4.3. Week 3 - example of speed

At the beginning of week three, we were presented an opportunity to invite an engineering class to be participants in our pilot experiment. While we still had a long way to go, we decided to grab this opportunity even though this meant we would have to finalize an experimental setup in two weeks. To ensure a rapid progression of our development, while keeping the entire experimental protocol under control, we imposed short iteration timeframes of one day, meaning we had to conduct at least one test run of a comprehensive experimental protocol at the end of each day leading up to the experiment, using the team members and colleagues as test subjects. Working more closely on creating a complete experimental protocol, the approach was to focus on the critical functionalities and leave the "nice to have" add-ons for later. We moved our setup from the lab into an isolated room we could use for the experiment without being disturbed. We built a cardboard wall to separate the experimental area with an observation area for the experimenter. We further implemented an instruction screen in addition to our gaming screen into the mockpit, in order to give task instructions during the experiment. Focusing on making the critical functions work, we decided on a solution for ECG/GSR interference issue we discovered by disabling the grounding electrode of the ECG sensor. This brute solution allowed us to finally get reasonable skin conductance readings, however, at the cost of increased noise in the ECG signals; yet still good enough to extract reliable data to calculate heart rate. Following the iteration timeframes, the development process was not planned according to a fixed outcome, but on a day-to-day basis. Each iterative experiment providing clear feedback in terms of the most critical issues we had to resolve to increase the robustness of the subsequent iteration of our setup.

4.4. Week 4 - example of agility

In the final week we were finalizing our protocol by testing it within the team and on colleagues. Some changes had to be made accordingly, notably switching from alternating between two sensor kits to using only one, after experiencing several malfunctions in the synchronization software [iMotions 2015] from interchanging. This put extra time strain on our protocol, luckily, we had implemented a time buffer between subjects in our schedule that made this possible. Gaining confidence on the robustness of our setup, we decided to test the possibility of implementing a secondary problem-solving task for the high stress condition, being one of the "nice to have" add-ons that had been in the back of our minds while focusing on the more critical functionalities. We focused on making this solution as simple as possible to avoid conflicting with the proven protocol, by adding a separate answering sheet setup and camera recording to analyze the time the participant used to answer simple calculations given on the instruction screen (see figure 5).

Figure 5. Experimental setup including secondary task

As a serendipity finding, this additional camera recording was able to eliminate the need of two separate video recordings; a scene camera recording and a simulation game recording, by including all the necessary information within the frame of the new camera angle. Conducting final trial runs of the entire protocol with this addition did not reveal any integration issues so we decided to implement it in our pilot experiments. Instead, this "irresponsible" last minute addition, encouraged by the agility principle of the wayfaring model, ended up increasing the overall robustness of our setup. Throughout the entire development process, our approach was to be agile, exploring opportunities that were not pre-planned and letting the wayfaring journey shape the outcome of our process.

5. Principles of the wayfaring model applied in an interaction design experiment

Based on our experiences briefly described in the example case, we want to arrive at some more general conclusions in this section. While the wayfaring approach has previously been promoted towards tangible product development [Gerstenberg et al. 2015; Reime et al. 2015], we want to further its application to developing interaction design experiments on the basis of our experiences described in the previous sections. The main argument for implementing the wayfaring approach is its ability to drastically reduce development time for projects involving a high degree of uncertainty, while enabling innovative solutions. This is descriptive of the kind of scenario we encounter when developing a new experimental setup for interaction design experiments. The complexity, thus uncertainty, of this development process is in large parts due to the multidisciplinary knowledge domains you have to handle and bring together, such as psychology, physiology, programming and engineering.

5.1. Probing ideas

We start our journey with a vague vision of the setup we want to achieve, as depicted in the wayfaring model as starting point A and initial vision V of our experimental setup, making initial, more or less naïve guesses on the design of the relevant components required to get there. The user-interaction scenario for our project is known, thus probing a low-resolution representation of the context becomes a natural first step, along with sensors to see how we can capture human behavior in this environment. If possible, we temporarily divide the team into the different problem domains, designing, building and testing various ideas in the different disciplines simultaneously, trying to get fast proof-of-concept feedback, to fail early and to converge on the most promising solutions. We focus on representing the component's critical function, utilizing readily available resources to remove uncertainties in essential operations quickly. This can be depicted as the first probing cycles in the wayfaring model (figure 6). Each probe is initiated by asking open-ended questions in a divergent thinking phase; designing, building and testing the ideas quickly, creating empirical evidence for reflecting and implementing the most promising option in a convergent thinking phase.

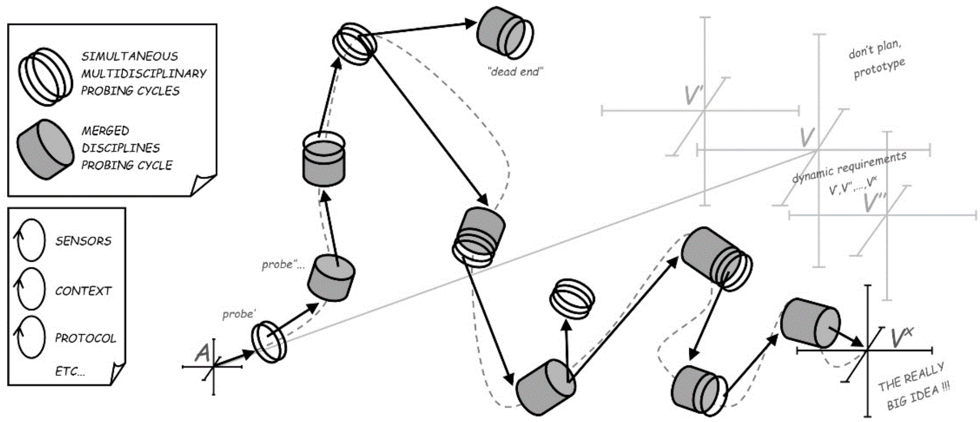

Figure 6. Wayfaring in the development of an experimental setup

5.2. Merging multidisciplinarity

Whenever a probing cycle proves an experimental component fulfilling its critical function, it ought to be merged with the other components in the subsequent iteration round to check for integration compatibility and discover unexpected interdependencies. In our updated wayfaring model, we propose depicting this as cylinder rather than a circle, to illustrate handling two or more experimental components as one coherent part of your design. The aim is always to test the global solution before fixating on the local solutions. An important point is that having an expert within each isolated knowledge domain does not mean you have expert knowledge on your experimental setup. You can only start accumulating expert knowledge on a new experimental setup when you start bringing the multidisciplinary experimental components together. This interlaced knowledge is crucial know-how you need to make a successful/robust experimental setup. This is not to say that having expert knowledge in each of the relevant domains would not be a good thing. However, in reality this is rarely the case. Neither is this a prerequisite for starting the wayfaring journey, as we gradually overcome this inexperience through the fast learning process it enables.

5.3. Speed

Instead of focusing on reaching a fixed target, that is a predefined experimental setup and the actions necessary get there, we set short time frames, e.g. 1 day or 1 week, for completing the current probing cycle while remaining open towards where it might lead us. Setting these deadlines is helpful to create a balance between the divergent and convergent thinking phases, to maximize the efficiency of the development process. While divergent thinking is largely accomplished by asking open-ended questions and overcoming the fear of failure [Lee et al. 2004], a fixed time frame creates a need to converge on the most promising solution. Setting short iteration timeframes, increases the number of iterations possible to ensure a rapid progression, minimizing the time spent developing into a disadvantageous direction, while allowing the exploration of a multiple of solutions. Through the iterative process, each probing cycle provides new knowledge deductively, inductively and/or abductively. This enables us to master each of the experimental components, and importantly mastering the components in context, as we wayfare - learning by "making it work". However, while it is possible get a good understanding of our experimental setup while probing within the development team, a setup cannot be proven until tested on unbiased test subjects. Including the human factor is crucial for uncovering unknown unknowns, undiscovered parts of your solution that affects your outcome in an unrevealed way. Essentially when trying to induce certain affective responses, verification can only be attained after running pilot experiments, including all the experimental components in a comprehensive probing cycle. Following the same mindset as previously described; doing this as soon as possible is all important, to fail early and increase your understanding before entering the next iteration.

5.4. Agility

The low-risk probing method enables us to discover dead-ends quickly, avoiding developing into a disadvantageous direction. In addition, by restraining from fixed variables early on, the wayfaring model encourages an agile approach, opportunistically choosing the next step from the continuously updated understanding of the envisioned experimental setup. This creates room for serendipity findings as it enables us to develop into directions that were not initially perceived as beneficial. Ultimately, the probing method is bound to uncover unknown unknowns and unexpected interdependencies, causing requirement changes to our designs [Gerstenberg et al. 2015]. These are essential parts of our envisioned experimental setup we were unaware of prior to probing. This is the point; we want to facilitate the process of failing rather than try to avoid it, because we realize it is an inevitable part of the development journey towards something that has not previously been proven. Failing early is essential to minimize the cost and time utilized to make these discoveries, as well as providing us with an empirically sound platform to build on our initial ideas through abductive logic. The initial "naïve" guesses gradually changes into more "educated" guesses, deflecting our journey towards the dynamically evolving experimental setup. Accordingly, the perceived outcome of the development process shifts as we wayfare, depicted as iterative targets V, V', V"…, in the model. Rather than having a predefined outcome from which the development process can be planned, the wayfaring approach lets the development journey shape the outcome.

6. Some concluding personal remarks

We successfully applied our iterative wayfaring product development process for early stage concept development to the conceptualization and design of an interaction experiment. Like in product development, the journey became one of intense learning, based on fast and early failures. And, like in product development, the speed and agility of the process has overpassed our own expectations, allowing for achieving extra milestones. Now, we are fully aware that once an experiment design enters its later stages or if an experiment is of confirmatory or incremental nature, a traditional plan do check act cycle or similar approaches are appropriate. However, based on our experience, we believe that as long as high degrees of freedom and unknown unknowns are still within the current scope of the experiment design setup, a wayfaring and probing approach is superior due to its sheer learning speed. For comparison, we would invite fellow researcher to share their experiment design approaches in the phase 0, and, if nothing else, we invite you to wayfare and probe rather than navigate – this way truly unknown shores might just be reached faster.

Acknowledgement

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3 Detailed description of the solutions employed for pilot experiment

3.1 Physiological measurement tools

Five non-invasive sensors, as depicted in Figure 2, were used to gather physiological response data: (1) a galvanic skin response (GSR) sensor, (2) an accelerometer, (3) an airflow sensor, (4) a thermometer, and (5) an electrocardiogram (ECG) sensor. Except from the accelerometer[1], all sensor solutions are provided by Libelium as part of the open-source *e-Health sensor platform kit V2.0*[2] compatible with Arduino and Raspberry Pi. The sensors are connected to an Arduino UNO board with an e-Health sensor module. An Arduino Ethernet shield is used for transmitting the sensor signals to the synchronization software. The resulting sensor kit configuration is depicted in Figure 3. The hardware is concealed in an insulated pouch worn around the neck by the test subject.

Figure 2. Sensors; GSR (left hand), ECG (chest), airflow (nostrils), thermometer (neck) and accelerometer (right hand)

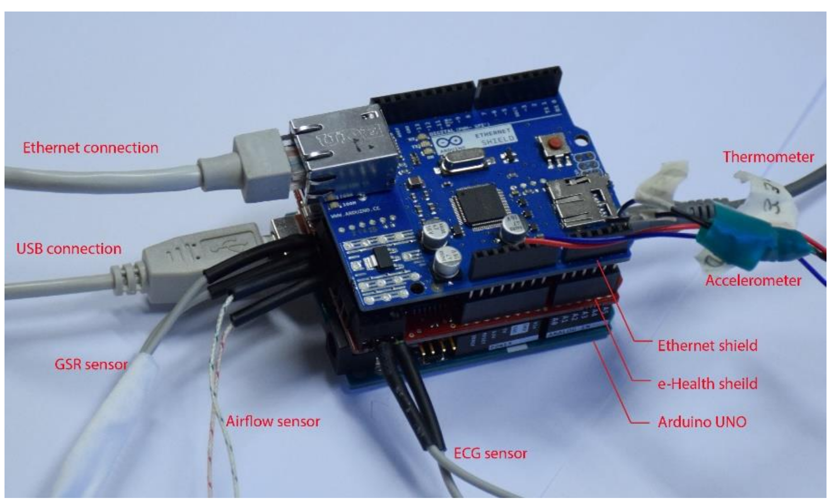

Figure 3. Sensor kit configuration

[1] https://www.sparkfun.com/products/12756
[2] https://www.cooking-hacks.com/ehealth-sensors-complete-kit-biometric-medical-arduino-raspberry-pi

Due to malfunctions experienced when using recent versions of the Arduino application, version 1.0.5-r2 was used to run the initiation code included in Appendix F. The code requires the installation of a library for the e-Health sensor kit[1] and a library for the accelerometer[2], as these include functions to initiate the sensors and read the data. Due to the high-resolution requirement to capture the heartbeats from the ECG signal, the sensor kit is run at a baud rate of 57600.

The following sections describes the application of the different sensors for the experiment. For an extensive overview of physiological measurement tools, Balters and Steinert's *Capturing emotion reactivity through physiology measurement as a foundation for affective engineering in design science and engineering practices* (2015) is a recommended read.

3.1.1 Galvanic skin response (GSR)

The GSR sensor consists of two electrodes, measuring skin conductance from the participant's non-dominant hand. The electrodes are placed on the middle phalanx of the middle finger and the ring finger using Velcro straps, as depicted in Figure 2. As the sensor signal is prone to be impacted by movement, the non-dominant hand was attached to an armrest during the execution of the experiment. A small voltage of 0.5 V is applied to the electrodes to measure the conductance (reciprocally from the resistance) of the skin tissue. The variation of skin conductance enables a measurement of arousal level (Jung et al., 2015; Mandryk and Atkins, 2007), as the conductance of the skin is related to the moisture (sweat) secreted. Dry skin results in low conductance, whereas moist skin results in increased conductance. Higher arousal levels produce more moisture resulting in higher skin conductance measurements. It is however important to note that while the GSR sensor is able to provide a measurement of arousal level, it cannot distinguish between positive and negative arousal states. Therefore, GSR measurements are often used in combination with other measurements, such as heart rate and temperature, to get more accurate information of the affective state (Healey and Picard, 2000; Wen et al., 2010).

3.1.2 Electrocardiogram (ECG)

The electrical activity of the heart is measured using a two-electrode ECG solution. A positive electrode is placed on the right side of the chest and a negative electrode on the left side of the chest, as depicted in Figure 2, metering the electrical potential difference caused by the cardiac cycle (Park and Bronzino, 2000). Usually, ECG measurements includes a third, neutral electrode to filter out electrical noise from the signal. However, due to an issue of electrical interference with the GSR sensor, the ECG solution without the neutral electrode was implemented as proposed by the manufacturer[3]. This solution makes it possible to achieve reliable GSR measurements and detect heart beat peaks in the ECG signal. As a trade-off, this solution is not accurate enough to measure the real voltage amplitude of the ECG signal. As the additional neutral electrode is normally used to filter out electrical noise from the signal, removing the neutral electrode results in increased ECG signal noise that has to be filtered out in pre-processing (Appendix H). One of the physiological stress responses is rapid increase in heart rate in response to sympathetic activation of the autonomous nervous system. It is therefore possible to use changes in heart rate

[1] https://www.cookinghacks.com/media/cooking/images/documentation/e_health_v2/eHealth_arduino_v2.4.zip
[2] https://cdn.sparkfun.com/assets/learn_tutorials/2/4/9/SFE_MMA8452Q-library.zip
[3] https://www.cooking-hacks.com/blog/how-to-acquire-physiological-signals-with-arduino-and-measure-stress-with-e-health-sensor-platform/

as an indicator of stress. In contrast, parasympathetic response results in a lowering of the heart rate.

3.1.3 Airflow sensor

The airflow sensor is placed right underneath the nostril openings secured by a string fitted around the head of the subject, as depicted in Figure 2. As the sensor measures the breathing pattern from the nostrils, the subject is instructed to breathe through the nose throughout the experiment. Furthermore, the subject is outfitted with a small (non-obstructive) strip of tape on the lips as a reminder not to breathe through the mouth. The sensor consists of a thermocouple, a metal wire of different Seebeck constants underneath each nostril. The exhalation of warmed air induce a thermovoltage in the thermocouple, due to the Seebeck effect, which is measured. As responses to stress, breathing rate, breathing regularity, depth of breathing and the pause time between inhalation and exhalation is influenced by the emotional and physical arousal level (Carter and Lewsen, 2005; Chaitow et al., 2014). Calmness and positive emotions result in decreased breathing rate, a more regular breathing pattern, and a longer exhalation time compared to the inhalation time.

3.1.4 Thermometer

The electronic thermometer is attached on the left side of the neck (Figure 2) with tape close to the carotid artery to get an estimation of the core body temperature (Jay et al., 2013), . As body temperature is strongly affected by the temperature of the surroundings, the temperature of the experimental room was monitored and kept constant at 20 degrees Celsius to maintain consistent conditions throughout the experiments. Several studies have shown a correlation between negative emotions and a decrease in skin temperature, whereas excitement and anger elicit an increase in skin temperature (Ekman, 1993; Philippot et al., 2004; Rimm-Kaufman and Kagan, 1996).

3.1.5 Accelerometer

The accelerometer is attached on top of the subject's dominant hand with tape (Figure 2), measuring acceleration in the x-, y- and z-direction. Using the default 2g settings in the coding and summing up the absolute values of each axis provides a measure movement/non-movement of the hand used for executing the experimental tasks. These measurements can be used to detect periods of increased movement to exclude signal error in the other sensor signals sensitive to movement, in a process called adaptive filtering (Lee and Chung, 2009).

3.2 Additional data capturing

3.2.1 Affect grids

Affect grids (Russell et al., 1989) are implemented at various points during the experiment (Figure 15) to collect emotional experience measurements by means of self-report. The affect grid, as shown in Figure 4, is reported by placing a mark inside one of the boxes. The 9-by-9 matrix consists of a vertical axis representing a scale of arousal, whereas the horizontal axis represents a scale of pleasure (valence). All affect grids are presented as separate, numbered, physical copies stacked next to the subject during the experiment. Upon instruction, the affect grid is filled out and delivered by the participant in a designated box.

3.2.2 Questionnaires

A pre-experimental questionnaire (Appendix B) is used for mapping demographics, specific health issues, diets and current emotional state. A post-experimental questionnaire (Appendix C) is used to uncover prior experience level in boat conducting and computer gaming, the amount of effort to perform the experimental tasks, current emotional state, as well as general feedback on the experiment. To grade the various questions regarding subjective experiences, the NASA-task load index (Hart, 2006) is used. Affect grids (section 3.2.1) are included in the questionnaires for mapping emotional state before and after the experiment. Both questionnaires are presented as physical copies, handed to the participant by the experimenter.

3.2.3 Saliva probes

Saliva probes, provided by St. Olavs Hospital, are used to extract saliva samples prior, during and after the experiment to measure the cortisol level prior, during and after the experiment. The subject is instructed to place the absorbent probe in the mouth (Figure 5) and remove it after 30 seconds, as suggested by the supplier. The probes are contained in an airtight test tube marked with participant number and time of sample, stored at below negative 20 degrees Celsius. Hormonlaboratoriet at Oslo University Hospital executed the analysis of the samples, where the cortisol levels of the samples are measured. Studies have shown that psychological stress as well as physiological stress can lead to increased cortisol levels (Dickerson and Kemeny, 2004). However, the correlation between cortisol levels and elevated stress levels has not yet been clearly established and recent studies propose different methods for doing these measurements (Nagy, 2015). An extensive explanation of these measurements and the results of the analysis is presented in a forthcoming paper dedicated to the subject.

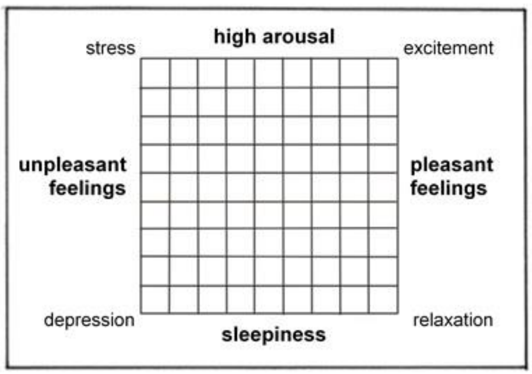

Figure 4. Affect grid

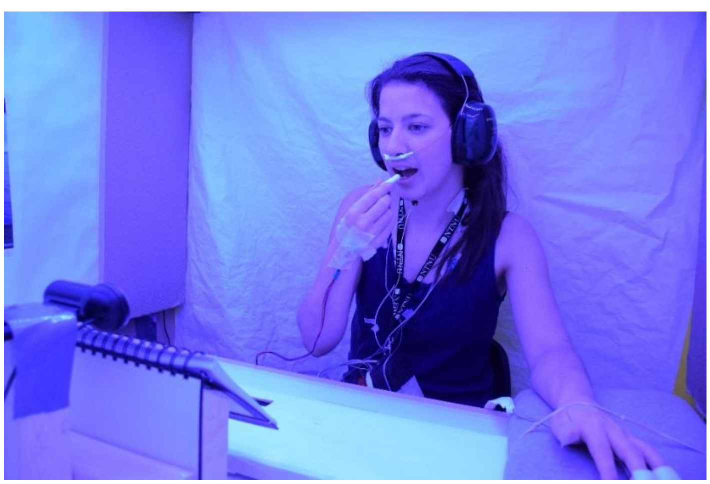

Figure 5. Participant inserting saliva probe

3.3 Experimental tasks

3.3.1 Ship conducting tasks

The Ship Simulator 2008 software[1] was chosen after considering trial versions of the various commercial ship simulation games available, most of which are developed by VSTEP. Although considered our best option, the game has considerable limitations in terms of design options of the experimental tasks, as the game is essentially developed for recreational use. Consequently, we had to apply a healthy dose of experimentation and creative usage of the software's features to create experimental simulation tasks suitable for our purposes. For the pilot experiment, three experimental tasks were custom-made using the Mission Editor application in the Ship Simulator 2008 software package:

1. A trial run to familiarize the participant to the game's controls and appearance.
2. A cruising mission with the intent of being a "non-stressful", baseline ship-handling scenario.
3. A racing mission with the purpose of creating a "high stress", increasingly demanding ship-handling scenario.

A similar strategy was employed for the design of both the trial run and the cruising mission. Both tasks are intended to be low on action, while still providing enough stimulation to avoid inducing frustration. To achieve this both missions are set in scenic environments for the participant to explore freely. (1) For the one-minute trial run, the environment is set to "Marseilles". No traffic or obstacles are added to the environment, nor is there any player objective to the game. Weather conditions are set to the software's default "Good weather" settings, time is set at noon and the "VSTP7" vessel is set as the player object. Overall, the task is designed to be a simple introduction to the dynamics of the game, with a minimum of taxing elements. (2) Likewise, the aim of the cruising mission design is to minimize any taxing elements in the participants gaming experience. Weather conditions are set to the software's default "Good weather" settings, time is set at noon and the "VSTP7" vessel is set as the player object. The "Phi Phi Islands" environment is chosen to provide some stimulation to the task, in the form of a scenic coastline to explore. No player objective is given, as the participant is simply instructed to enjoy cruising around for the duration of the task, which last for five minutes.

Figure 6. Cruising mission screen shot

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[1] http://www.shipsim.com/products/shipsimulator2008

(3) To induce stress in the test subjects a combination of strategies was implemented for the racing task. The first strategy assumed that increasing the degree of difficulty of the game is likely to help create a more stressful gaming experience. The adjustable in-game variables directly linked to the difficulty of the gaming experience were mapped through pilot testing and a creative usage of the features to overcome the software's considerable limitations. As a result, a course of increasing difficulty was designed by manipulating the density of various obstacles such as ships, ramps and icebergs, and weather condition variables; "Rain", "Thunder", "Fog" and "Waves & wind". Furthermore, the participant is set to play the course with the "Hydrojet", combining low weight, high speed and aggressive steering dynamics, to be what we consider the game's most difficult vessel to maneuver. The course is set in the "Atlantic Ocean" environment, where rows of stationary "Supertanker" vessels are used to confine the straight-lined course area. The course was designed to be impossible to finish within the fixed task duration of five minutes. The second strategy was to prime the test subjects to consider the task to be important and worthy of their best effort, to ensure that the increased difficulty of the game actually affected them. To achieve this, the participants were informed in the pre-game instructions (see Appendix D and E) that the best performer receives a gift card of 500 NOK for the university cafeteria, to encourage a competitive mindset. Also, it is informed that they will be able to check their performance on the class website, implying that the performance will be publicized and comparable, to encourage a competitive mindset also for the participants who perceive their gaming skills to be deficient in taking away the top prize.

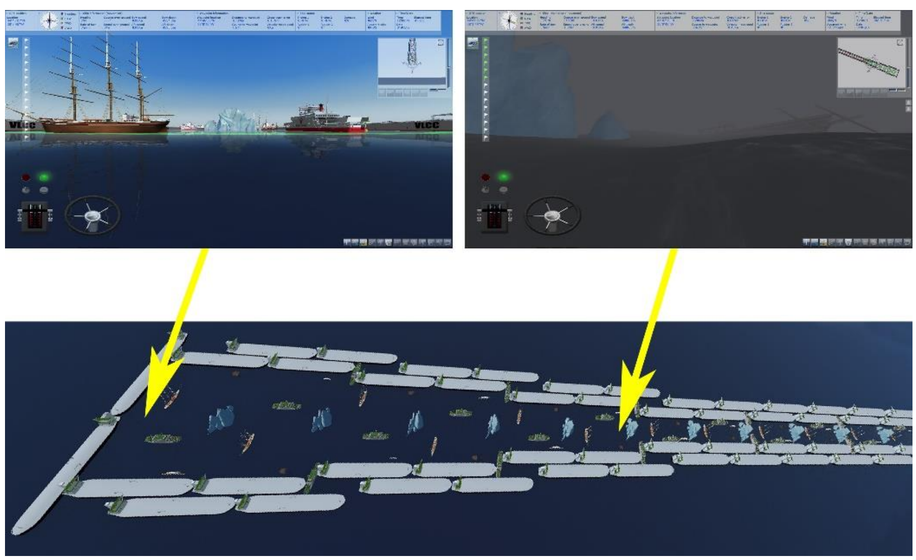

Figure 7. Racing mission screen shots and course layout

3.3.2 Secondary task

Simultaneously to performing the racing task, the participants are instructed in the pregame information slide to solve calculations as they appear on the instruction screen (see Figure 18 for example). The information slide states that executing these calculations is equally important to their overall performance score to encourage the participant to pay attention to the task. The calculations are implemented to analyze how the increasing difficulty of the racing task affects the performance of a secondary task. The time is measured from a math problem appear on the instruction screen until the moment the pen left the answering sheet after an answer was given (copying the problem without providing an answer does not meet the requirement). In the case where a problem is answered, after preforming a subsequent calculation, the answer is disregarded. The first math problem appears 24 seconds into the task. In total, nine math problems appear on the screen for 6 seconds each, with 24 second blank screen intervals between them.

3.4 Areas

The areas occupied by the experiment are situated in close relative proximity on the third floor of the Verkstedteknisk facility at NTNU Gløshaugen, as pictured in Figure 8. A designated waiting area is situated in the hallway by the elevator and stairway area to intercept both routes to the third floor. A preparation room is occupied for the pre- and post-experimental procedure. The experimental room is situated at the end of the hallway.

3.4.1 Preparation room

Two similar partitions are installed in the preparation room, as depicted in Figure 9, to be able to handle two participants simultaneously without them interacting. The partitions are constructed from tall sheets of honeycomb cardboard blocking the view. Partition A is used to isolate the participant during the pre-experimental procedure, whereas partition B is designated for the post-experimental procedure. The equipment used by experimenter 1 to facilitate each procedure (usage explained in section 3.5.3) is organized on tables neighboring the partitions, listed in Table 1. A refrigerator is installed for short-term storage of saliva samples taken prior and after the experiment.

Equipment E1a	***Equipment E1b***
• Experimenter 1 checklist (laminated) • Instruction cards • Consent forms • Pre-experimental questionnaires • Participant box • Post it's • Pens • Hearing protectors • Earplugs • Saliva probes • Stop watch • Permanent marker to label saliva probes • Disposable ECG electrodes • Participant sign • Disinfection fluid (ethanol) • Cotton pads • Tape • Cellphone (on silent mode)	• Instruction cards • Post-experimental questionnaires • Pens • Saliva probes • Stop watch • Permanent marker • Stapler • Tape

Table 1. Preparation room equipment

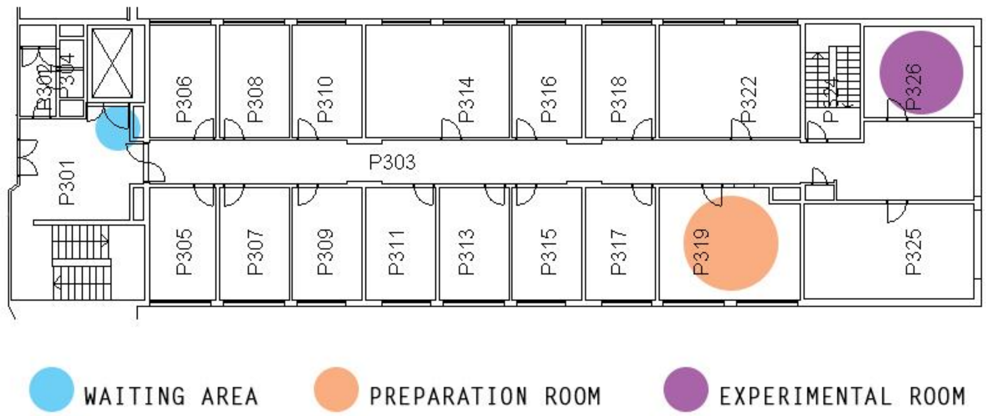

Figure 8. Floor plan

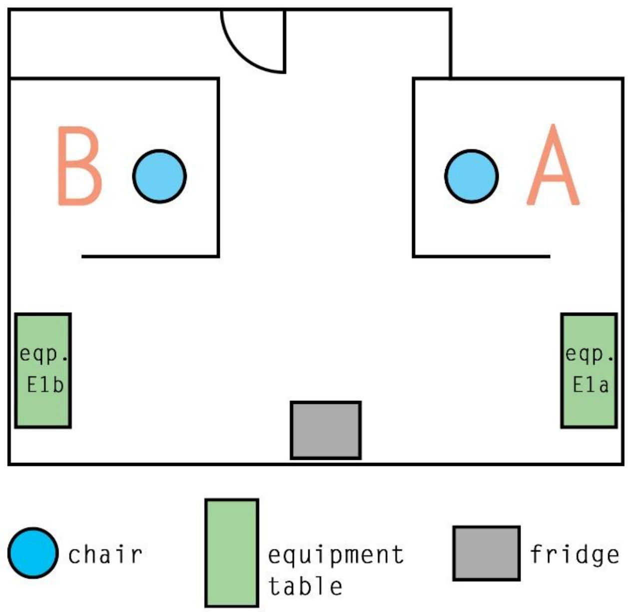

Figure 9. Preparation room

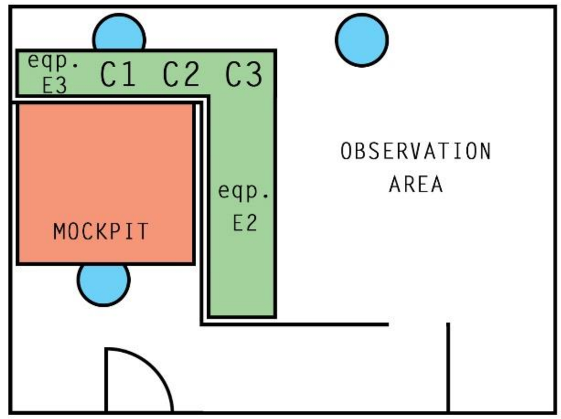

Figure 10. Experimental room

3.4.2 Experimental room

The experimental room (Figure 10) is divided into an observation area for the experimenters and an experimental area with the ship simulator environment. Walls of honeycomb cardboard sheets divide the room to conceal the observation area as the participant enter and exit the experiment room. The three computers needed to run the experiment (see Table 2) are installed on a table behind the Mockpit, depicted as C1, C2 and C3 in Figure 10. The additional equipment used by experimenter 2 and experimenter 3 (usage explained in section 3.5.3) is organized in the observation area, listed in Table 3.

	CPU	**RAM**	**Software**	**Screen setup**
Computer 1 (C1)	1.80 1.80 GHz	8 GB	iMotions v5.6 Arduino (IDE) v1.0.5-r2	Multiple displays / Show desktop only on 1 1. 15" LED operator monitor 2. 17" LCD Mockpit instruction screen
Computer 2 (C2)	3.60 3.60 GHz	16 GB	Ship Simulator 2008	Multiple displays / Duplicate these displays 1. 24" LED operator monitor 2. 24" LED Mockpit gaming screen
Computer 3 (C3)	1.86 1.86 GHz	3 GB	Windows Movie Maker (scene camera recording)	24" LED operator monitor

Table 2. Computer setup

Equipment E2	***Equipment E3***
• Checklist • Affect grids • Saliva probes • Instruction card • Clothespins • Rubber bands • Pen • Tape • Note sheets • Cell phone (on silent mode)	• Stopwatch • Schedule • Note sheets • Pen

Table 3. Observation area equipment

Figure 11. Participant filling out pre-experimental questionnaire in partition A

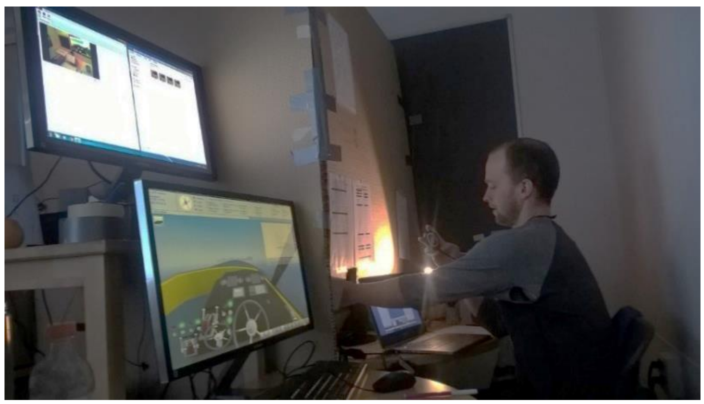

Figure 12. Third experimenter facilitating experiment in observation area

3.4.3 Ship simulator environment - Mockpit

The Mockpit is the simple ship simulator environment where the experimental tasks are carried out depicted in Figure 13. The main part of the box construction is made from honeycomb cardboard sheets, mounted onto a desk. The interior is covered in white lining paper for a clean appearance and to enhance lighting conditions for the camera recordings. A 24" gaming screen is integrated in the rear wall. Combined with the "At the helm"-POV camera angle of the simulation game, the aim is to mimic the experience of looking out of a cabin window, rather than onto a computer screen. Furthermore, a 17" instruction screen is installed to provide instructions during the experiment (see Appendix D and E). The four arrow-keys on a regular keyboard were used for maneuvering in the ship-handling tasks, with all other keys disabled by a physical barrier cover (see Figure 14). Importantly, the simple keyboard solution facilitates one-handed ship-handling, necessary because of the movement restrictions imposed by the GSR sensor. A designated answering sheet setup is fixed in the center of the mockpit for the execution of the secondary task. It consists of a blank sheet notepad bolted onto a wooden mount, where the top sheet is secured with a rubber band. The reason for the centralized mount is to provide a common, ergonomically suitable solution for both right-handed and left-handed participants, to avoid having to rearrange the setup. Furthermore, raising and tilting the sheet, enables capturing the execution of the secondary task and the math problems appearing on the instruction screen, both within the frame of the scene camera. This solution allows us to measure the problem-solving time of each calculation from the scene camera recording. An armrest pillow to restrict non-dominant hand movement and the affect grids change places according to handedness. A box to collect the affect grids is placed underneath the instruction screen. A saliva probe is prepared in a container in the rear, with the lid half opened to facilitate one-handed operation during the experiment. A white curtain is pulled down from the roof of the Mockpit, enclosing the simulator environment during the experiment.

Figure 13. Mockpit layout (right-handed setup)

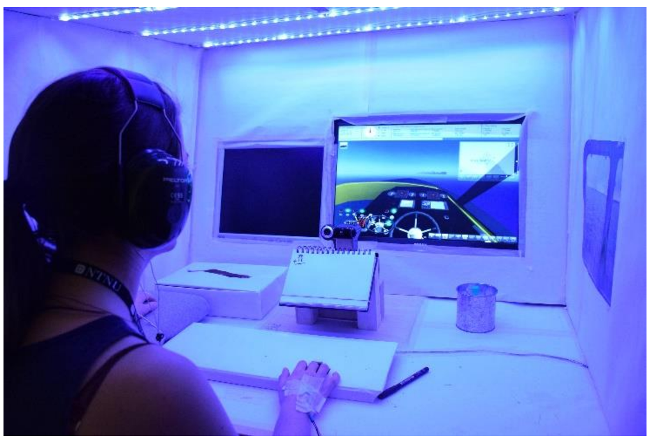

Figure 14. Participant preforming simulation task

3.5 Experimental procedure

3.5.1 Participants

34 mechanical engineering students preformed the experiment as an introduction to interaction design experiments in the TMM4280 Advanced Product Development class. The students were invited through *itslearning*, the student intranet portal, and provided with a link to select a suitable time slot for participating. In addition, six engineering department employees agreed to partake in the experiment, resulting in a total of 40 participants. The participants were informed that participation was voluntary. This was informed both orally and stated in the consent form. The consent also stated that the participant was free to discontinue the experiment at any time if necessary. Half of the participants (17 students and 3 employees) were randomly drafted to subgroup "condition A" and the other half to subgroup "condition B", to compare if and how the order of the experimental tasks affected the results. Condition A performed the undemanding

cruising task prior to the taxing racing task, whereas condition B performed the tasks in the reversed order, as depicted in Figure 15.

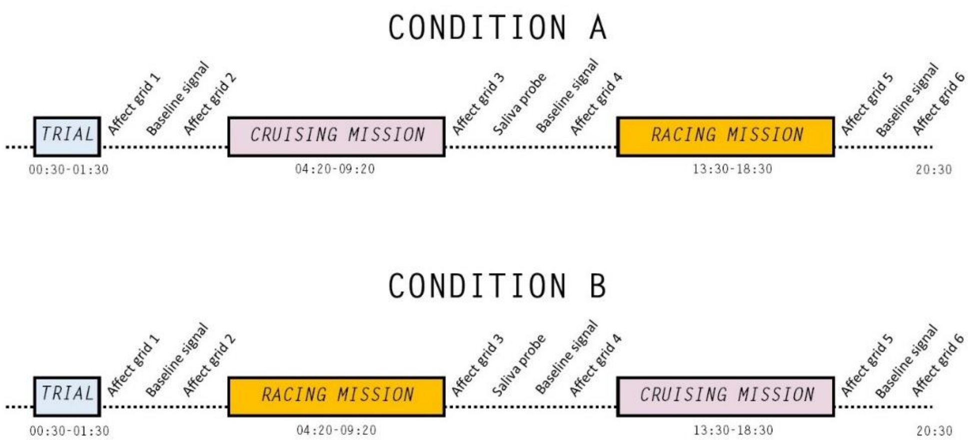

Figure 15. Order of experimental tasks for the two subgroups

3.5.2 Scheduling

The experiments were distributed over a course of five days between the hours of 10:00 and 18:00. The participants were scheduled in timeslots of 70 minutes, including 10 minutes preparation time for the experimenters to reset for the subsequent participant. The timeslots were scheduled to be partially overlapping to increase the number of experiments per day, as illustrated in Figure 16. This was achieved by experimenter 1 semi-simultaneously facilitating the post-experimental and pre-experimental procedure of consecutive participants, described in detail in Table 4.

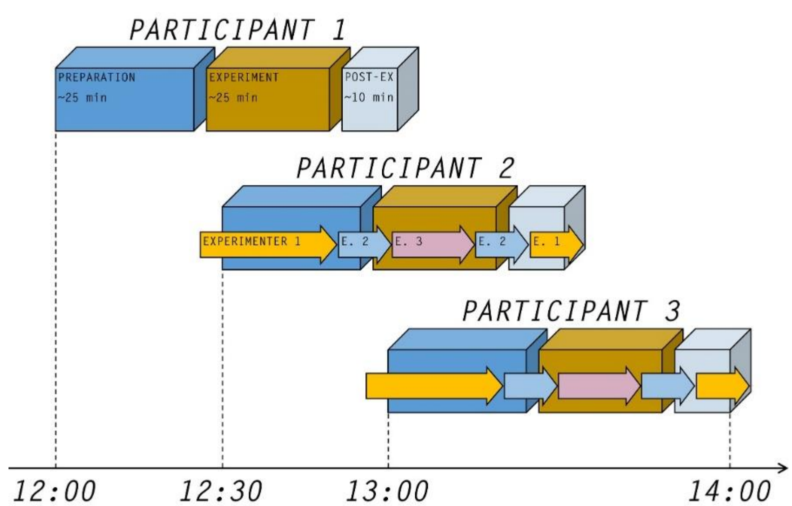

Figure 16. Scheduling

3.5.3 Protocol

Three experimenters are needed to operate the experiment. Experimenter 1 is responsible for greeting the participants upon arrival and conducting the pre-experimental and post-experimental procedures taking place in the preparation room, depicted as orange arrows in Figure 16 and described step-by-step in Table 4. This includes handing out the consent form and the questionnaires, as well as assisting a saliva sample before and after the experiment. Furthermore, experimenter 1 prepares the participant with the physiological sensors and detach the sensors after the experiment. Experimenter 2 transits the participant between the preparation room and the experimental room, depicted as blue arrows in Figure 16 and described step-by-step in Table 5. This includes installing the participant in the Mockpit and resetting the Mockpit between subjects. Experimenter 3 is responsible for operating the experiment from the observation area in the experimental room, depicted as purple arrows in Figure 16 and described step-by-step in Table 6. This includes initiating data capturing and experimental tasks, as well as monitoring the subjects during the experiment.

Step	**Subject**	**Experimenter 1 action**
1.	PARTICIPANT A	Greet the participant in the waiting area. Let them know that this is a good time if he/she wants to use the restroom.
2.		Walk with participant to preparation room. Avoid small talk.
3.		Let participant hang up coat/jacket and place personal belongings in a designated area. Ask if they can put distracting things like cell phones and watches in jacket/bag.
4.		Guide them to sit in partition A.
5.		Explain that participation is voluntarily and give them consent to read through. Let them take their time on this and let them know it is okay to ask questions about consent.
6a.		If they don't accept the consent, let them know “that’s okay” and discontinue the preparation process
6b.		If they accept the consent, continue the preparation process.
7.		Inform that they will be outfitted with physiological sensors; ECG, GSR, thermometer, airflow and accelerometer, while pointing to the placement on the body (use our own to demonstrate).
8.		Ask participant to place ECG electrode pads on chest as demonstrated.
9.		Inform: • How to answer affect grid • Where to place filled out forms • To try to relax while waiting for instructions
10.		Ask if they are left or right handed, note this either by placing and L or R on the checklist.
11.		Inform of the use of hearing protectors during the experiment and that all further instructions will be given in written form.
12.		Outfit the participant with earplugs and put on hearing protectors.
13.		Give first instruction card. “Relax”.
14.		Wait 5 minutes.
15.		Give instruction card “Please fill out document”.
16.		Give pre-experimental questionnaire and pen.
17.		Wait until participant has put the document in the box.

18.		Give instruction card “Please place cotton pad inside mouth until it’s covered in saliva. (30 seconds)”
19.		Put on disposable gloves, remove green lid from saliva tube with correct participant number and saliva probe no. 1.
20.		Give the saliva tube to participant. Wait and see that participants put the cotton pad inside mouth and time 30 seconds.
21.		Let participant put cotton pad back inside tube. Put lid on. Mark HH:MM. Place in fridge or freezer straight away.
22.		Remove disposable gloves.
23.		Give instruction card “Relax”.
If this is first participant of the day, skip to step 29.		
24.	PARTICIPANT B	Wait for the previous participant to return from the experiment and guide them to partition B.
25.		Detach sensor kit. Signalize no talking. Leave earplugs and hearing protectors on.
26.		Give instruction card "Please fill out document".
27.		Give post-experimental questionnaire and pen. Show the multiple pages.
28.	PARTICIPANT A	Bring sensor kit and return to participant in partition A.
29.		Give instruction card "I will now hook you on to the sensor kit".
30.		Begin with thermometer because this needs 5 minutes to stabilize. Disinfect it. Attach it with tape in a cross.
31.		Then let the participant place ECG. Signalize which is left and right on chest by pointing.
32.		Disinfect and place GSR on the non-dominant hand, see checklist for handedness.
33.		Place accelerometer on the dominant hand. Use tape and shape the wires, so that the accelerometer does not loosen.
34.		Put on gloves to disinfect airflow sensor and place airflow sensor. Temporarily remove hearing protectors while attaching sensor.
35.		Remove disposable gloves.
36.		Put on sign with participant number around neck.
37.		Give instruction card “Relax”.
38.		Text-message second experimenter that participant X is ready for transit, notify if left-handed.
If this is the first participant of the day, return to step 1.		
39.	PARTICIPANT B	Return to participant in partition B.
40.		Give instruction card “Please place cotton pad inside mouth until it’s covered in saliva. (30 seconds)”
41.		Put on disposable gloves, remove green lid from saliva tube with correct participant number and saliva probe no. 3.
42.		Give the saliva tube to participant. Wait and see that participants put the cotton pad inside mouth and time 30 seconds.

43.		Let participant put cotton pad back inside tube. Put lid on. Mark HH:MM. Place in fridge or freezer straight away.
44.		Remove hearing protectors
45.		Thank the participant for participating and ask for confidentiality. Let the participant collect their belongings and see them out.
46.		Collect the paper from his/her box. Staple it together and place in storage.
47.		Collect saliva probe no. 2 from the box and tape it together with no. 1 and no. 3. Place all in freezer.
Return to step 1.		

Table 4. First experimenter procedure

Step	**Experimenter 2 action**
1.	Go through checklist after receiving text message from experimenter 1 (E1-38): • Clean secondary task answering sheet • 2 pens • New saliva probe with correct participant number and lid open • New affect grids 1-6 • Monitors switched off
2a.	If informed of left-handedness, move armrest to the right side and affect grids and pens to the left side.
2b.	If not notified of left-handedness, make sure armrest is on the left side and affect grids and pens are on the right side.
3.	Ask experimenter 3 "Please confirm, next participant is participant X".
4.	Notify experimenter 3 "I will now leave the room and come back with the participant".
5.	Move from the experiment room (close the door) to the preparation room.
6.	Collect the participant box and gesture to the participant in partition A to follow along.
7.	Open the door of the preparation room and let the participant exit (close the door after).
8.	Guide the participant through the corridor to the experiment room.
9.	Open the door of the experiment room and let the participant enter (close the door after).
10.	Indicate for the participant to sit down inside the Mockpit.
11.	Place the participant box directly underneath the instruction screen.
12.	Give instruction card X.
13.	Plug USB and Ethernet cables into sensors kit, additionally secure cables with a clothespin to sensor kit pouch.
14.	Indicate to place non-dominant hand onto armrest and attach.
15.	Show the "breathing reminder tape" and place it onto the lips of the participant.
16.	Point at the affect grids, saliva probe, pens, secondary task answering sheet, keyboard and monitors.
17.	Pull down the curtain behind the participant.
18.	Open the door of the experiment room and close it audibly (without leaving the room).
19.	Tiptoe over to the observation area.
20.	Three minutes before the end of the experiment, text message first experimenter "3 min".

21.	After the experiment, tiptoe back to the door, open and close it audibly.
22.	Pull up curtain, place hand on the shoulder of the participant to indicate your presence.
23.	Close the saliva probe and put it in the participant box.
24.	Pull off the answering sheet and put it in the participant box.
25.	Put any affect grids remaining on the desk into the participant box.
26.	Remove the clothespin and unplug USB and Ethernet cables from the sensor kit.
27.	Release non-dominant hand from armrest.
28.	Indicate for the participant to follow and bring the participant box.
29.	Open the door of the experiment room and let the participant exit (close the door after).
30.	Guide the participant through the corridor to the preparation room.
31.	Open the door of the preparation room and let the participant enter.
32.	Give participant box to first experimenter.
33.	Return to experiment room.
34.	Reset Mockpit: • Clean secondary task answering sheet • 2 pens • New saliva probe with correct participant number and lid open • New affect grids 1-6 • Monitors switched off
Return to step 1.	

Table 5. Second experimenter procedure

Step	**Experimenter 3 action**		
1.	Initiate Trial run.		
2.	Select "At the helm" camera angle.		
3.	Check next participant number and Cruising mission/Racing mission order (condition A/B) in schedule and create new participant iMotions labeled with participant number.		
If the participant belongs to subgroup "Condition A", follow steps XXa – Xxa. *If the participant belongs to subgroup "Condition B", follow steps XXb – XXb.*			
4a.	Place condition A experiment schedule on cardboard wall (remove condition B schedule).	4b.	Place condition B experiment schedule on cardboard wall (remove condition A schedule).
5a.	Monitor second experimenter installing participant in Mockpit through respondent camera viewer and wait for sensor kit to be connected.	5b.	Monitor second experimenter installing participant in Mockpit through respondent camera viewer and wait for sensor kit to be connected.
6a.	Run Arduino initiation code.	6b.	Run Arduino initiation code.
7a.	Confirm that iMotions is receiving signals in "Incoming events API viewer".	7b.	Confirm that iMotions is receiving signals in "Incoming events API viewer".

8a.	Wait for second experimenter to close door when leaving the participant.	8b.	Wait for second experimenter to close door when leaving the participant.
9a.	Initiate scene camera recording.	9b.	Initiate scene camera recording.
10a.	Start stopwatch (SW 00:00)	10b.	Start stopwatch (SW 00:00)
11a.	Initiate iMotions study "Mockpit cruise first".	11b.	Initiate iMotions study "Mockpit race first".
12a.	Confirm that iMotions study is running on instruction screen in scene camera monitor.	12b.	Confirm that iMotions study is running on instruction screen in scene camera monitor.
13a.	Confirm that Trial run is initiated and "At the helm" camera angle is set.	13b.	Confirm that Trial run is initiated and "At the helm" camera angle is set.
14a.	At SW 00:30 move hand over to gaming screen switch.	14b.	At SW 00:30 move hand over to gaming screen switch.
15a.	At blue slide signal initiate gaming screen.	15b.	At blue slide signal initiate gaming screen.
16a.	Confirm that Trial run is running on gaming screen in scene camera monitor.	16b.	Confirm that Trial run is running on gaming screen in scene camera monitor.
17a.	At SW 01:30 move hand over to gaming screen switch.	17b.	At SW 01:30 move hand over to gaming screen switch.
18a.	At blue slide signal switch off gaming screen.	18b.	At blue slide signal switch off gaming screen.
19a.	Confirm that gaming screen is switched off in scene camera monitor.	19b.	Confirm that gaming screen is switched off in scene camera monitor.
20a.	Restart Ship Simulator 2008.	20b.	Restart Ship Simulator 2008.
21a.	Initiate Cruising mission.	21b.	Initiate Racing mission.
22a.	Select "At the helm" camera angle.	22b.	Select "At the helm" camera angle.
23a.	Confirm that Cruising mission is initiated and "At the helm" camera angle is set .	23b.	Confirm that Racing mission is initiated and "At the helm" camera angle is set.
24a.	At SW 04:10 move hand over to gaming screen switch.	24b.	At SW 04:10 move hand over to gaming screen switch.
25a.	At blue slide signal initiate gaming screen.	25b.	At blue slide signal initiate gaming screen.
26a.	Confirm that Cruising mission is running on gaming screen in scene camera monitor.	26b.	Confirm that Racing mission is initiated and "At the helm" camera angle is set.
27a.	Make notes on participant behavior and/or technical issues.	27b.	Make notes on participant behavior and/or technical issues.
28a.	At SW 09:10 move hand over to gaming screen switch.	28b.	At SW 09:10 move hand over to gaming screen switch.
29a.	At blue slide signal switch off gaming screen.	29b.	At blue slide signal switch off gaming screen.

30a.	Confirm that gaming screen is switched off in scene camera monitor.	30b.	Confirm that gaming screen is switched off in scene camera monitor.
31a.	Restart Ship Simulator 2008.	31b.	Record number of waypoints reached by participant in Racing mission.
32a.	Initiate Racing mission.	32b.	Confirm that correct number of waypoints reached is recorded.
33a.	Select "At the helm" camera angle.	33b.	Restart Ship Simulator 2008.
34a.	Confirm that Racing mission is initiated and "At the helm" camera angle is set.	34b.	Initiate Cruising mission.
35a.	At SW 13:20 move hand over to gaming screen switch.	35b.	Select "At the helm" camera angle.
36a.	At blue slide signal initiate gaming screen.	36b.	Confirm that Cruising mission is initiated and "At the helm" camera angle is set .
37a.	Confirm that Racing mission is running on gaming screen in scene camera monitor.	37b.	At SW 13:20 move hand over to gaming screen switch.
38a.	Make notes on participant behavior and/or technical issues.	38b.	At blue slide signal initiate gaming screen.
39a.	At SW 18:20 move hand over to gaming screen switch.	39b.	Confirm that Cruising mission is running on gaming screen in scene camera monitor.
40a.	At blue slide signal switch off gaming screen.	40b.	Make notes on participant behavior and/or technical issues.
41a.	Confirm that gaming screen is switched off in scene camera monitor.	41b.	At SW 18:20 move hand over to gaming screen switch.
42a.	Record number of waypoints reached by participant in Racing mission.	42b.	At blue slide signal switch off gaming screen.
43a.	Confirm that correct number of waypoints reached is recorded.	43b.	Confirm that gaming screen is switched off in scene camera monitor.
44.	After the completion of the iMotions study, save scene camera recording labeled with participant number.		
45.	Restart scene camera recording program.		
46.	Restart Arduino software.		
47.	Restart Ship Simulator 2008.		
Return to step 1.			

Table 6. Third experimenter procedure

3.6 iMotions

iMotions Biometric Software Platform is a specialized software solution for conducting human experiments[1]. iMotions version 5.6 was used for data synchronization of the sensor signals, along providing automated instructions and stimuli for the participant as a slide show presentation.

3.6.1 Instructions and stimuli

Separate iMotions studies were custom made for condition A and condition B. The same study settings, described in section 3.6.2, applies to both. The only difference is the arrangement of the slides in the slide show presentation, to reverse the order of the cruising task and the racing task between the two conditions, as pictured in Figure 15. The complete slide show presentations are included in Appendix D (condition A) and Appendix E (condition B).

The slide shows consists of the six following types of slides: (1) Mission information slides provides instructions of the following ship-handling task. The trial run and cruising task information slide (Figure 17) appear for 30 seconds each, whereas the racing task appear for 45 seconds to account for the longer instructions. (2) The secondary task slides presents math problems as depicted in Figure 18. A total of nine different math problems appear for six seconds each during the racing task at 24 second black slide intervals. (3) Baseline slides provide instruction and a stimulus for collecting a one minute baseline signal after each ship-handling task (Figure 19). (4) Affect grid instruction slides, depicted in Figure 20, provides instructions and 30 second timeslot for filling out affect grids. The six affect grids filled out over the course of the experiment, distributed as depicted in Figure 15. (5) Two saliva probe instruction slides (Figure 21) instruct and provides a 75 second timeslot for executing a saliva probe between the cruising task and the racing task. (6) Two second blue signal slides (Figure 22) are included directly prior and directly after the ship-handling task to notify experimenter 3 to manually switch the gaming screen on and off.

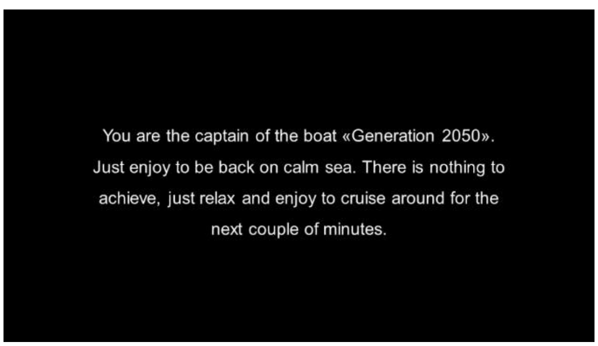

Figure 17. Cruising task information slide

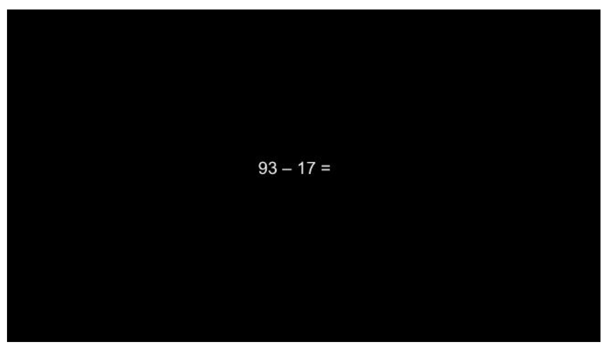

Figure 18. Math problem slide

[1] http://imotions.com/

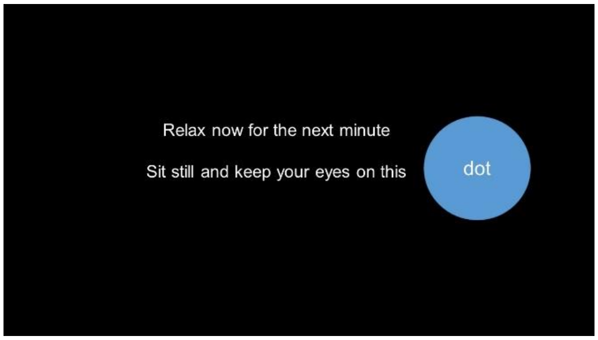

Figure 19. Baseline instruction slide

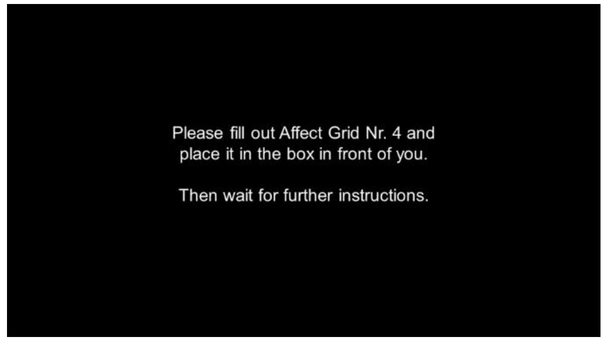

Figure 20. Affect grid instruction slide

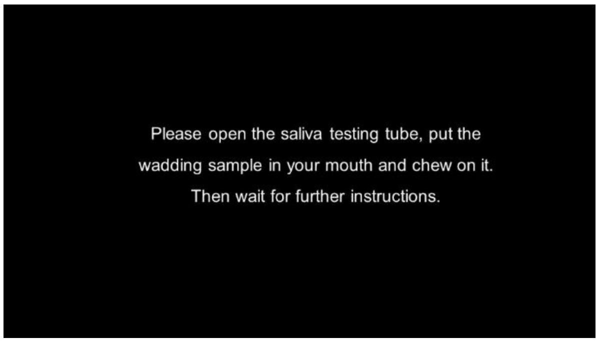

Figure 21. Saliva instruction slide 1 of 2

Figure 22. Blue slide signalizing gaming screen switch

3.6.2 Settings

The sensor signals were integrated via the software's API platform. The API solution enables iMotions to connect and stream the data output from the sensor kit via the Ethernet connection. This is achieved by adding the sensor kit is added as an *Event Source* (Appendix G) in *Preferences > Global Settings > API* and selecting *Enable External Events API* in the *Sensors* menu. After the sensor kit is initiated via the Arduino program (Appendix F), the sensor signals will appear in the *Incoming Events API* window, confirming successful connection. The respondent camera was integrated via a USB connection by selecting *Enable VideoCam Capture* in *Preferences > Global Settings > Video* and by selecting *Enable Camera* in the *Sensors* menu. Furthermore, the software's *Enable FACET* feature was selected in the *Sensors* menu, to extract and collect facial expression data automatically from the respondent camera recording. The operator screen and instruction screen were kept independent by selecting *Use secondary screen* in *Preferences > Global settings > Slide Show*, to allow the operator to supervise the experiment in the software interface on the operator monitor, while the slide show presentation is running on the participant instruction screen.

4 Data analysis

4.1 Pre-processing

The dataset generated by iMotions for each participant was pre-processed in Matlab to prepare it for statistical analysis in SPSS. In the pre-processing code, included in Appendix H, the ECG signal is detrended and filtered to remove signal noise. A peak detecting function is used to find the indices of the local maxima (i.e. heartbeats) of the processed signal. The processed signal and the detected peaks are plotted and checked visually to ensure the quality of the data. From the time locations of the detected peaks, the heart rate is then calculated for every 10 second interval and exported as variable "BPM". The GSR signal and the temperature signal was resampled by decimation to remove noise components as the high sampling rate (57600 baud) required to detect heart beats in the ECG signal is not necessary for the much slower variation in these signals. The resampled signals are exported as variables "GSR" and "TEMP". The absolute values of the accelerometer data in the x- y- and z-direction were added together and exported as variable "ACC". Due to a suspected hardware malfunction, the airflow sensor did not produce continuous measurements and was dismissed from analysis. Furthermore, the some markers in the datasets were relabeled and the pre-processed datasets were exported in .xslx format for compatibility with statistical analysis in SPSS.

In SPSS, the means of the variables "BPM", "GSR" and "TEMP" for the cruising task and the racing task were calculated from each dataset. These means were imported as dependent variables into a comprehensive sheet including the results of the self-report task and the secondary task for each participant. The dependent variables were organized by the two groups; condition A (cruising task → racing task) and condition B (racing task → cruising task) and subjected to Shapiro-Wilk's test for normal distribution, as a prerequisite for parametric testing.

4.2 Results

The variables; heart rate, skin conductance and temperature was subjected to a paired samples t-test comparing the measurements during the racing task and the cruising task:

There was found significantly higher heart rate during the racing task ($M = 80.90$, $SD = 11.18$) compared to the cruising task ($M = 74.19$, $SD = 10.79$) in condition A; $t(15) = 8.26$, $p < .01$, two-tailed. Similarly, there was found a significantly higher heart rate during the racing task ($M = 85.14$, $SD = 10.76$) compared to the cruising task ($M = 80.00$, $SD = 9.19$) in condition B; $t(13) = 5.67$, $p < .01$, two-tailed. These results suggest that the heart rate was higher during the racing task than during the cruising task, regardless of the order of the tasks.

There was found a significantly higher skin conductance during the racing task ($M = 7.24$, $SD = 3.92$) compared to the cruising task ($M = 5.26$, $SD = 3.61$) in condition A; $t(15) = 8.31$, $p < .01$, two-tailed. In contrast, there was found a slightly lower (not significant) skin conductance during the racing task ($M = 6.48$, $SD = 3.79$) compared to the cruising task ($M = 6.63$, $SD = 4.00$) in condition B; $t(13) = -.58$, $p > .05$, two-tailed. These results suggest that the order of the cruising task and the racing task affected the corresponding skin conductance measurements. Specifically, the participants sweated more during racing task, compared to the cruising task, when performing this task last, whereas the participants performing the racing task first showed no significant variation in sweating between the two tasks.

There was found a significantly higher body temperature during the racing task ($M = 39.07$, $SD = .42$) compared to the cruising task ($M = 38.83$, $SD = .45$) in condition A; $t(15) = 12.37$, $p < .01$, two-tailed. In contrast, there was found a significantly lower body temperature during the racing task ($M = 39.13$, $SD = .40$) compared to the cruising task ($M = 39.33$, $SD = .34$) in condition B; $t(13) = -7.89$, $p < .01$, two-tailed. These results suggest that the order of the cruising task and the racing task affected the corresponding body temperature measurements. Specifically, the body temperature is higher during the racing task, compared to the cruising task, when performing this task last, whereas the body temperature is higher during the cruising task, compared to the racing task, when performing this task last.

A paired-samples t-test was conducted to compare the subjective arousal rating from the affect grids directly prior to and directly after the ship conducting tasks:

There was found significantly higher self-reported arousal after the racing task ($M = 7.00$, $SD = .88$) compared to before the task ($M = 4.50$, $SD = 1.51$) in condition A; $t(13) = 5.24$, $p < .01$, two-tailed. Similarly, there was found significantly higher self-reported arousal after the racing task ($M = 6.36$, $SD = 1.01$) compared to before the task ($M = 4.50$, $SD = 1.51$) in condition B; $t(13) = 3.88$, $p < .01$, two-tailed. These results suggest that the subjective arousal level increased during the racing task. There was found no significant variation in self-reported arousal after the cruising task ($M = 5.00$, $SD = 1.41$) compared to before the task ($M = 5.21$, $SD = 1.19$) in condition A; $t(13) = -.46$, $p > .05$, two-tailed. Neither was there found any significant variation in the arousal ratings after the cruising task ($M = 4.07$, $SD = 1.44$) compared to before the task ($M = 4.50$, $SD = 4.07$) in condition B; $t(13) = -1.147$, $p > .05$, two-tailed. These results suggest that the cruising task had no significant influence on the subjective arousal level.

4.3 Findings

4.3.1 Does the order of the experimental tasks affect the outcome?

It was found that the order of the experimental task had a strong effect on the results for both the GSR and temperature measurements. Contrary to the results of condition A, participants in condition B show significantly higher body temperature measurements during the cruising task compared to the racing task. Similarly, the GSR measurements shows contradictory results in the cruising task and the racing task between the two groups. While participants in condition A show a significant increase in skin conductance for the "stressful" task compared to the "relaxing" task, group B show an unexpected lower (not significant) skin conductance for the racing task compared to the cruising task. These results lead us to suspect that some unexpected factor related to the order of the experimental task has affected the measurements, as the task design was identical for both conditions. The most plausible explanation to these results is considered to be the temperature within the Mockpit rising throughout the experiment due to radiated heat from the participant being trapped inside the confined Mockpit space. This heat buildup will in turn directly influence the body temperature measurements. Upon closer inspection, the datasets for both conditions A and B show a near linear increase in body temperature for the duration of the experiment, supporting this explanation. Furthermore, this can explain the increased GSR measurements in the cruising task compared to the racing task for condition B, as an increasing temperature increases sweating as a response for regulating the body temperature (Havenith, 2001).

4.3.2 Does the racing task induce stress?

While the contradictory body temperature and skin conductance results are unable to confirm the physiological response effect of the racing task, the heart rate measurements clearly show an increase compared to the cruising task. Furthermore, the self-reported affect grids showed a significant increase in subjective arousal rating after performing the racing task for both conditions. In contrast, the subjective arousal rating showed no significant variation after performing the cruising mission. Thus, both physiological response and subjective response suggest that the arousal level increases during the racing task as a potential stress indicator. In addition, the post-experimental questionnaires provides participant feedback in support of the intended task design (Appendix I). Further analysis is still undertaken for the forthcoming master thesis dedicated to cortisol (saliva samples) and heart rate variability as potential indicators of stress.

5 Learnings

In the extended wayfaring model, we emphasize merging system components early, testing the global solution for integration issues before optimizing local solutions. The pilot experiment was the first probing cycle including the final components to our experimental setup: handling unbiased test subjects and performing a comprehensive analysis of unbiased data. While we were able to get a good understanding of our setup probing within the development team, we needed real participants to verify our solutions. This chapter illustrates the importance of conducting a full-scale pilot experiment by highlighting flaws in the experimental design discovered in the process, much like how we use prototyping in the early product development process. Admittedly, some issues discussed in the following sections might have been avoided given more time available prior to the pilot experiment. However, our best option for running a full-scale experiment, using the TMM4280 students as test subjects, was fixed according to the course schedule. Furthermore, the intense learning speed and agility of the wayfaring approach is fueled by facilitating fast and early failures. We believe that the early pilot experiment was the most efficient approach for managing the high degree of uncertainty in the early development stage. Providing us with clear feedback on all aspects of the setup, pointing out the most critical areas for improvement and interrupt spending unnecessary resources developing into a disadvantageous direction.

5.1 Physiological measurements

The solution we used for overcoming the interference issue between the ECG and GSR signals by disabling the grounding electrode of the ECG, as described in section 3.1.2, resulted in some expected ECG signal noise that had to be removed in pre-processing. While mostly providing usable data from which reliable heart rate could be extracted, some signal glitches occurred in a couple of our participant datasets, likely due to the brute solution employed to be able to measure ECG and GSR simultaneously. Although this solution was deemed acceptable for our transitory "proof-of-concept" pilot experiment, it is not considered a viable option for providing robust, high-resolution ECG and GSR measurements. Therefore, it is highly recommended to look into other alternatives (Table 7) to overcome the electrical interference issue.

The airflow sensor failed to produce continuous measurements for all of our participants, the reason for this failure remains uncertain. In the post experimental interview, all the subjects claimed to have been breathing through the nose as instructed, thus it seems likely to be caused by a hardware malfunction. As a result, no analysis on respiratory data was possible. The initial plan right up until the start of our pilot experiment was to have two sensor kits available, to have the opportunity to change sensors in case of any malfunction. However, the synchronization software did not operate correctly when interchanging, by not collecting any sensor signals after switching sensor kit. Unable to resolve this software issue in the limited time we had available, we had to stick to one sensor kit for the pilot experiment, consequently eliminating the backup solution. Resolving this issue to allow for a replacement sensor kit would drastically reduce the setup's vulnerability towards hardware malfunction and should be prioritized in the further development.

Physiological measurement tool	*Advantage*	*Disadvantage*	*Alternatives*
GSR sensor	Easy to attach/detach Comfortable to wear Good measure for arousal	Electrical interference with ECG measurement Sensitive to movement Finger placement hinders execution of two-handed task	Toe placement to avoid hand movement restriction
ECG sensor	Non-obstructive to task execution Comfortable to wear Good stress indicator	Electrical interference with ECG measurement No neutral electrode solution causes noisy signal Uncomfortable to remove	3-electrode solution at different frequency range than GSR Photoplethysmogram (PPG) Eulerian video magnification (EVM)
Airflow sensor (temperature transducer)	Easy data analysis	Experienced malfunction Requires only breathing through nose Uncomfortable to wear Needs thorough disinfection between participants	Respiratory transducer
Thermometer	Easy to attach/detach Comfortable to wear Good quality data recording	Sensitive to room temperature Requires 5 minutes on skin before reliable measurements Requires several measurement points in cold environments	Thermographic camera
Accelerometer	Easy to attach/detach Comfortable to wear	Not wireless 2g settings does not capture speed of movement	4g settings to measure speed of movement

Table 7. Overview of sensor solutions

5.2 Self-report tasks

A few subjects reported the affect grids by marking the "grid", overlooking the instruction to place a mark inside the appropriate "box". To analyze these cases, we decided to convert the 9x9 affect gird scales, accounting for the additional notch introduced by the 10x10 "grid-scale". However, measures should be taken to better facilitate correct execution of this task for all participants. Additionally, the box for collecting the affect grid sheets during the experiment was not optimally designed. The slender slot for inserting affect grids proved cumbersome to handle for several subjects, when only allowing one-handed operation, due to the movement restrictions imposed by the GSR sensor. For the post-experimental questionnaire, the first three participants failed to fill out the last page of the form, as they were not informed that the document was printed double-sided. Informing the remaining subjects of the double-sided printing prior to filling out the questionnaire prevented any more mishaps, although a single-sided printout is likely to be a more robust solution.

5.3 Ship conducting tasks

Executing the cruising task, four participants, seemingly on purpose, landed their vessel onto the beach, rendering them immobile for the remainder of the task. As one participant comments; "*During the cruise I was bored and began trying things out and explore the display and wanted to see what happens if you drive the boat on the beach. I expected to get a second chance, but I was stuck on shore instead*". Similarly, an additional six participants damaged their vessel and sank during the cruising task. In turn, this is likely to have altered the supposedly relaxing, "low stress" inducing experience into an experience of frustration. The possibility for stranding and/or damaging the vessel could have been avoided had the task been set to an open ocean environment. However, this option was abandoned in the development process as the task became, in our opinion, too monotonous and pointless without any coastline to explore. Going forward, the distinction between an undemanding "baseline" task and a frustratingly boring task should be considered when improving the task design.

Figure 23. Stranded participant

5.4 Secondary task

The purpose of the secondary task was to analyze the number of correct answers and the time between a calculation appeared on the instruction screen to an answer had been written down on the answering sheet setup. However, some participants would copy the math problem onto the sheet only to solve it later, whereas others would write down the answers directly. Consequently, the different calculation strategies undermines our ability to compare problem-solving performance for these instances. Secondly, the calculations were not presented in a randomized order. Although we put effort into making these calculations of similar difficulty, some calculations are likely to have been less difficult than others. This inhibits our ability of running a valid repeated measures test for secondary problem-solving performance. Thirdly, two of the participants flipped the answering sheet, disregarding the rubber band clamping down the sheet to prevent this from happening. As a result, this caused the flipped sheet to block the respondent camera mounted on top of the answering sheet setup. Finally, implementing the secondary task for the racing task imposed different movement conditions for the racing task compared to our other experimental tasks, due to the action of writing down answers for the calculations. Although the additional movement imposed by the secondary task was not very substantial, it impairs our ability to compare physiological measurements during the "stressful" condition with the "low stress" condition, as movement affects body temperature, heart rate, skin conductance (sweating), acceleration of dominant hand and respiration in varying degrees (Balters and Steinert, 2015).

5.5 iMotions

A bug in the iMotions software (version 5.6) required manually switching hot-key configurations when initiating a new participant study, causing reconfiguration delays for the commencement of each experiment. When a hot-key configuration had been set for one participant, this configuration was not reusable, meaning we had to keep track of which configurations had been used previously to be able to do successful reconfigurations quickly. When contacting iMotions, they were aware of the problem, but unable to provide a solution at that time. At some point, this issue would have prevented us from running any more participants, as we would have had no more possible reconfigurations. Luckily, we did not run out of unique configurations at 40 participants. After the completion of our pilot study, an update to the iMotions software was made available (version 5.7). From testing this version, the hot-key issue seems to have been resolved, no longer requiring reconfiguration for each participant. However, if the same problem should occur it is important to go through the different configurations in a systematic manner to keep track of the depleted ones.

Not much consideration was put into naming the different slides for the experiment in iMotions. This caused unnecessary time spent identifying and renaming the slides to access the relevant parts of the experiment when entering the analysis phase, as the labels of these slides function as the markers in the datasets. This could easily have been avoided by giving systematic, meaningful labels compatible with the analysis tool, when naming slides in the iMotions study. Avoiding spaces and mixing letters and numbers to create easily importable and understandable data sets, e.g. "Baselineone", "Affectgridthree", "Raceinstructions".

5.6 Scheduling

At the time of scheduling, the envisioned setup only required two experimenters operating the experiment, allowing the three-person team to alternate positions and take breaks interchangeably. However, as the evolution of the experimental setup continued after this point (see section 4.3 in the IDC paper) all three team members were required to run the pilot experiment. As a result, the premature scheduling did not leave any room for lunches and there was no replacement experimenter to step in if another was prevented to show up. Furthermore, the approximately 10 minutes resetting time between participants left little room for delays and unexpected technical issues. Although the tight scheduling was possible in the pilot experiment, a looser time schedule is strongly advised for the next round. If possible, the team should also consider recruiting at least one additional person to facilitate the experiment to increase the robustness towards unforeseen events.

6 Further work

6.1 Suggested measures for improving physiological measurements

A suggestion for overcoming the electrical interference issue between the ECG and the GSR signals, is replacing the ECG measurement with a PPG (photoplethysmogram) measurement, using a pulse oximeter. The pulse oximeter consist of two light-emitting diodes sending red and infrared light onto the skin, commonly via a finger clip or ear clip. As the heart pumps blood out to the periphery, the amount of red and infrared light absorbed by the blood pulsates according to the heart rate. A photodiode then measure the amount of light either transmitted through or reflected from the skin. This enables deriving noninvasive heart rate measurements optically, to avoid encountering electrical interference with the GSR signals. Figure 24 shows a test measurement comparing an Arduino based pulse oximeter[1], to the e-Health ECG sensor with all three electrodes connected. Importantly, no signal disturbance was detected for the PPG signal when initiating the GSR sensor, which is the case for the ECG signal. Furthermore, the PPG solution is much less intrusive than the ECG sensors, easing the process of attaching and detaching the sensors considerably.

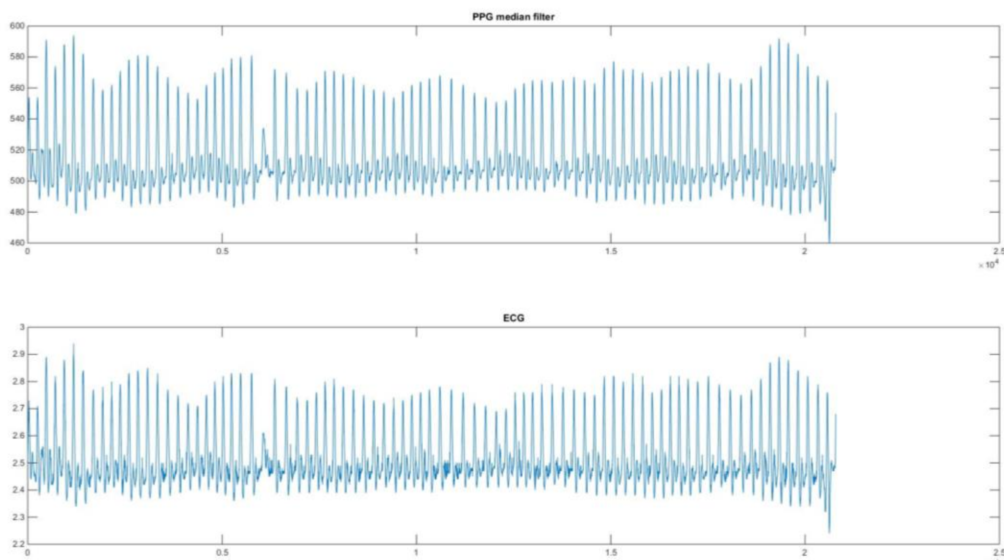

Figure 24. PPG (top) and ECG (bottom) signal comparison (57600 baud)

6.2 Suggested measures for improving the secondary task

The hurriedly implemented secondary task features several flaws uncovered by conducting the pilot experiment, as discussed in section 5.4. Therefore, some alterations are suggested to improve upon the task design. To counter-effect difficulty variations between calculations and enable a valid repeated measures test, the math problems should be presented in a randomized order. This can be achieved in iMotions by selecting *Randomize stimuli except for the locked stimuli* in *Study Settings* while keeping the secondary task problem slides unlocked. The order of the other slides in the study is controlled by selecting *Position fixed* for each slide. Additionally, it is suggested to implement

[1] http://pulsesensor.com/

the secondary task during the cruising mission as well as the racing mission. This would enable a comparison of secondary task performance between the stressful condition and the baseline condition. Importantly, the math problems should be randomly drafted for both conditions from one shared pool of calculations made of similar difficulty/structure for the validity of a repeated measures between the two conditions. Furthermore, this would impose the similar additional movement from performing the secondary task for the two conditions, strengthening our ability to compare the physiological measurements. However, it needs to be evaluated to which degree a secondary task would induce stress in the in the "low stress" condition by probing this solution.

As an option to eliminate additional movement and prevent the possibility of copying the calculations for solving them later, the participant could be instructed to provide the answers orally. The iMotions software readily features synchronization of an audio recording (*Include Audio* in *Preferences < Global Settings < Video),* which could be used for analyzing problem-solving time. In addition to removing the need of the secondary task answering setup, this would enable simultaneous execution of the primary (ship conducting) and secondary task, as the participant would not need the dominant hand to perform the secondary task. However, this would interfere with the temperature transducer measurements and the "breathing reminder" tape. An alternative technology to the temperature transducer, deployed unsuccessfully in the pilot experiment, is a respiratory transducer for measuring the breathing pattern. This alternative airflow sensor is a piezoelectric device integrated into a chest belt, measuring the breathing pattern from the variation of the circumference of the thorax. This alternative would replace the defective airflow sensor while simultaneously allowing oral execution of the secondary task.

6.3 Suggested measures for improving the Mockpit

As discussed in section 4.3, the current design of the Mockpit, as a confined "box", is likely to trap the heat produced by the participant causing a temperature increase during the course of the experiment. Although the temperature of the experimental room was monitored and controlled, the local temperature within the Mockpit was not considered in the pilot experiment. Necessarily, a digital thermometer should be integrated into the Mockpit to keep track of the local temperature of the experimental area. Various solutions could be implemented as a countermeasure to heat buildup. A thermostat solution implementing heating and cooling units could be installed in the current design to maintain a setpoint temperature. Another solution would be to remodel the current Mockpit structure to allow the heated air to escape. Removing parts of the roof and/or the curtain closing the Mockpit can decrease the sensitivity for local temperature variations.

6.4 Suggested measures for improving self-report tasks

It is suggested to consider investing in the iMotions' survey module[1], to integrate the self-report tasks digitally. The add-on module could be used to present the affect grids on the instruction screen and compile the information directly through the iMotions software. As a survey, the affect grid would be presented as separate scales (1-9) of pleasure (valence) and arousal. As a digital input, the possibility of marking outside of the scale (as discussed in section 5.2) would be eliminated.

[1] http://imotions.com/software/add-on-modules/attention-tool-survey-module/

Furthermore, the pre-experimental and post-experimental questionnaires can readily be integrated digitally through iMotions using this solution. While requiring adding a computer mouse to the Mockpit for answering the self-report tasks, the solution would eliminate the need of physical copies and the collection box. Therefore, it is suggested to consider this investment to increase the robustness of the experimental setup and ease the experimental procedure.

6.5 TMM4280 input

The four weeks after the experiment was spent sharing the experiences from our process and aiding the TMM4280 students in setting up their own small-scale interaction design experiments. Specifically, the project assignments were devised to explore potential improvements to the experimental setup. This included investigating the impact of various external factors (e.g. smell, vibration and electromagnetic interference) on physiological measurements and/or emotional response. Others focused on implementing additional measurement techniques, such as stroke volume and posture analysis. Finally, improvements for the simulator environment and the experimental tasks was explored, including a 180 degree projector screen for the simulation tasks and an alarm system task as a potential secondary task. The result of these projects have been handed in to the project owner for consideration.

7 Some concluding personal remarks

As product developers, we are trained to identify the user's needs and improve our designs to enhance the user's experience. Capturing affective response and physiological measurements allows us to quantify this experience and access crucial feedback on our user interaction scenario we cannot otherwise. Yet, the theme of this thesis is largely outside what is included in the curriculum. Having to accumulate this large amount of new expertise is what inspired us to look for an alternative development strategy. Using our background as product developers, we introduced a prototyping approach for developing a pilot experiment. Our rapid progress we solely attribute to the intense learning process enabled by the wayfaring mindset. Facilitating fast and early failures through probing allowed us to manage the high degree of uncertainty while gaining practical experience immediately. Merging the experimental components from the beginning and testing our system at large enabled us to address the full scope of an experiment. Thus, we are able to present a comprehensive list of solutions towards capturing affective response in a controlled ship-handling scenario based on empirical evidence. Introducing the extended wayfaring model for the development of human experiments, we hope to lower the threshold for affective engineering and inspire fellow product developers to venture into unknown territory to decode user behavior and enable better user interaction design.

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Request for participation in research project

"TMM4280 Experiment"

Background and Purpose
The purpose of this project is to 1) introduce the students of the course TMM4280 (Autumn 2015) to Interaction Design Experiments (IDE) and to 2) give the students insights in how to set up and conduct physiological experiments. This experiment is part of a PhD at IPM, Norwegian University of Science and Technology.

What does participation in the project imply?
The participant will be hooked up with a variety of non-invasive physiological sensors and the raw data will be stored. After being introduced to the task, the participant will be guided through the experiment. The participant will be ask to fill out questionnaires as part of the experiment. The participant will be ask to give saliva probes to test cortisol levels only. Audio and video data will be recorded throughout the experiment.

What will happen to the information about you?
All personal data will be treated anonymously. No name is connected to the gathered data.
The only persons having access to the data are the PhD candidate and her supervisor.
In case of a publication, participants will therefore not be recognizable.
The project is scheduled for completion by 31.12.2017. After this date the personal data will be stored encrypted.

Voluntary participation
The participation of this experiment is part of the course content TMM4280. It is voluntary to participate in the project, and you can at any time choose to stop and withdraw from the experiment.

If you would like to participate or if you have any questions concerning the project, please contact Stephanie Balters, +47 936 120 26 or Martin Steinert .

Consent for participation in the study

I have received information about the project and am willing to participate. I agree that the recorded data is completely anonymously stored and handled for further publications. I further agree to be confidential about the experiment to provide non-biased conditions for every participant.

Name & student number of the participant

Place & date, Signature

Martin Steinert Stephanie Balters

APPENDIX B – PRE-EXPERIMENTAL QUESTIONNAIRE

Participant ID

1. What is your age? years
2. Gender Female ☐ Male ☐
3. Are you right or left handed? Right ☐ Left ☐
4. Do you see correctly? Yes ☐ No ☐
5. Did you exercise today? If yes how many hours ago? ______ hours

6. How tired do you feel right now? (set a cross inside space)

Very Tired Energetic

7. What is your general tendency to sweat?

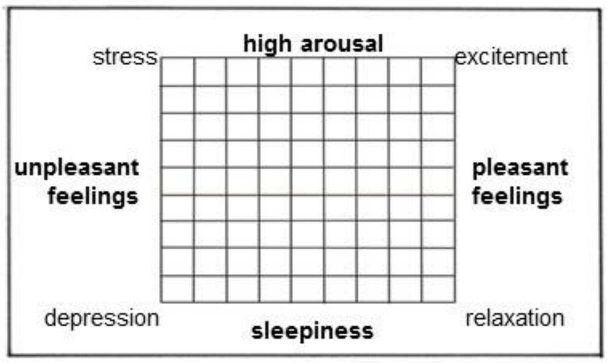
Very Low Very High

8. Can you breathe smoothly through your nose today? Yes ☐ No ☐

9. How many coffees did you drink today?

10. Are you on any specific diet?

11. Please grade your current emotional state by marking a box in the grid below (place a cross inside box).



APPENDIX C – POST-EXPERIMENTAL QUIZ

Participant ID ☐

12. Have you played this game or another ship simulator game before? Yes ☐ No ☐

13. How experienced are you with computer gaming? (put a cross inside space)

Novice Professional

14. How experienced are you with driving a real boat?

Novice Professional

15. How mentally demanding were the tasks?

cruise

race

Very Low Very High

16. How physically demanding were the tasks?

cruise

race

Very Low Very High

17. How hurried or rushed was the pace of the task?

cruise

race

Very Low Very High

18. How successful were you in accomplishing what you were asked to do?

cruise

race

Failure Perfect

19. How hard did you have to work to accomplish your level of performance?

cruise

race

Very Low Very High

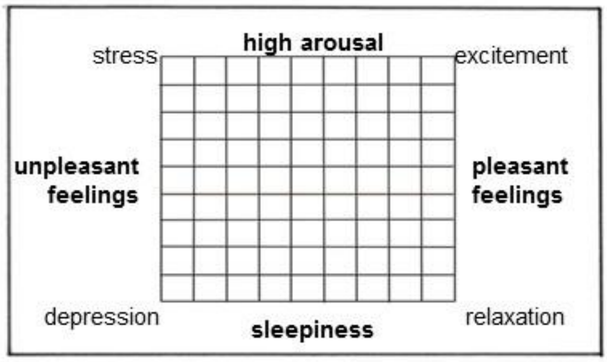
20. How clearly were the tasks defined?

cruise

race

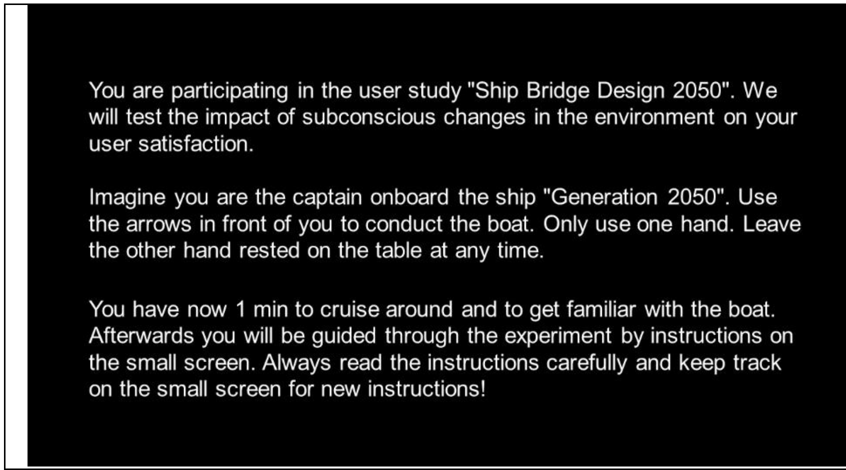
Unclearly Clearly

21. Please grade your current emotional state by marking a box in the grid below (put a cross inside one of the squares).



22. Suggestions & comments for the experiment:

APPENDIX D – IMOTIONS STUDY CONDITION A



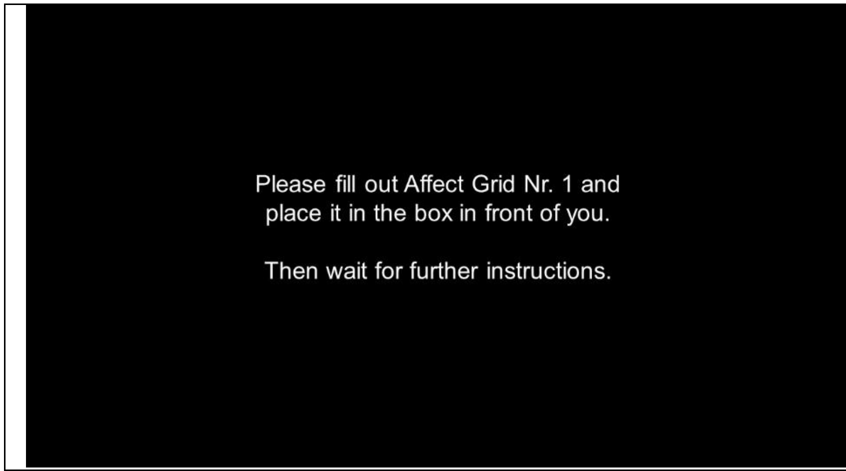
SLIDE 1 – 30 SEC

SLIDE 2 – 2 SEC

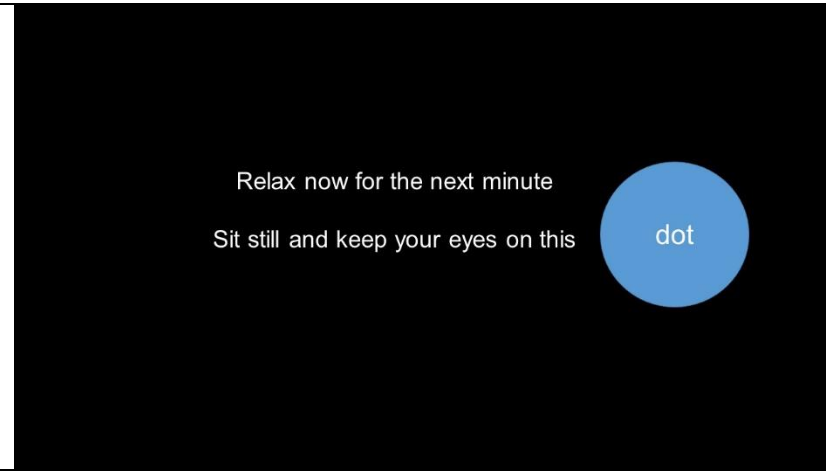
SLIDE 3 – 1 MIN

SLIDE 4 – 2 SEC

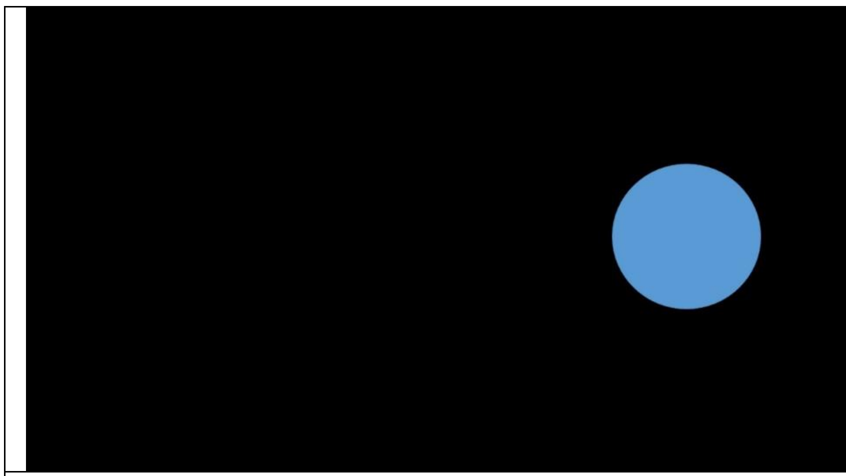
APPENDIX D – IMOTIONS STUDY CONDITION A



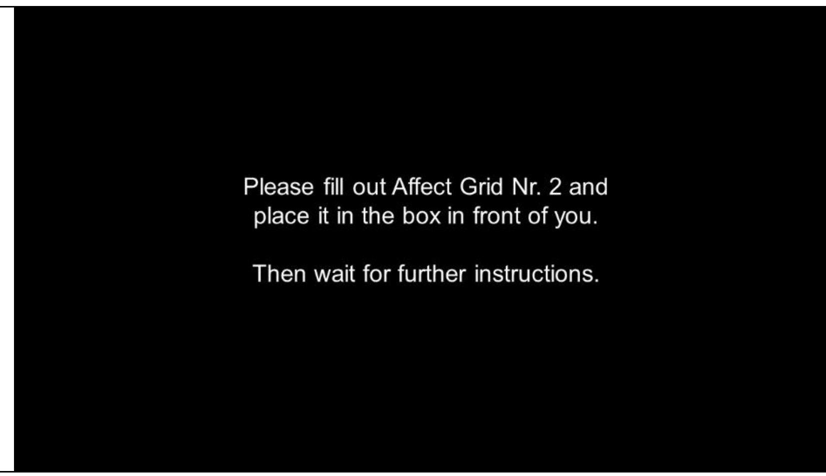
SLIDE 5 - 30 SEC



SLIDE 6 – 10 SEC

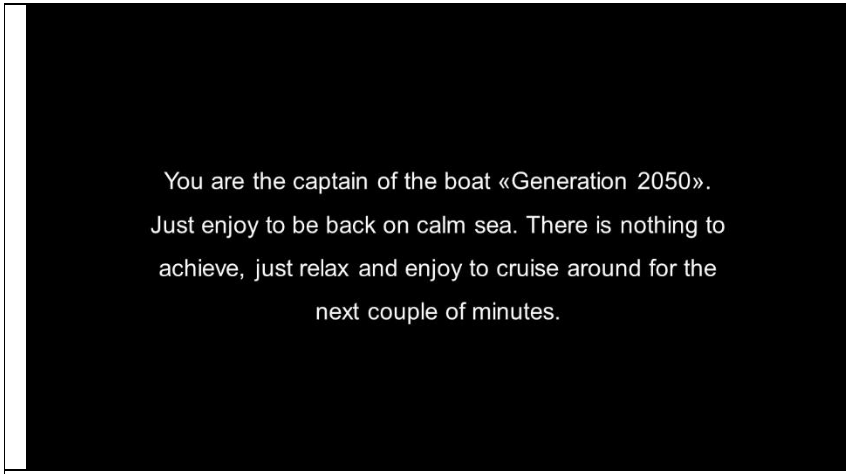


SLIDE 7 – 1 MIN

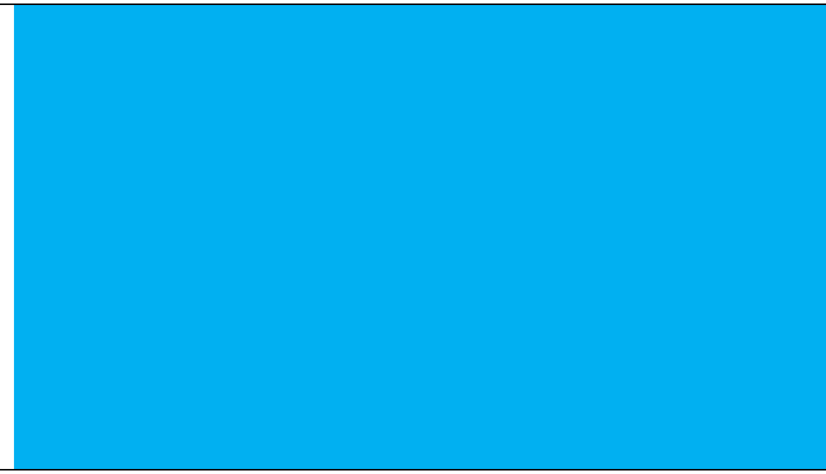


SLIDE 8 – 30 SEC

APPENDIX D – IMOTIONS STUDY CONDITION A



SLIDE 9 – 30 SEC

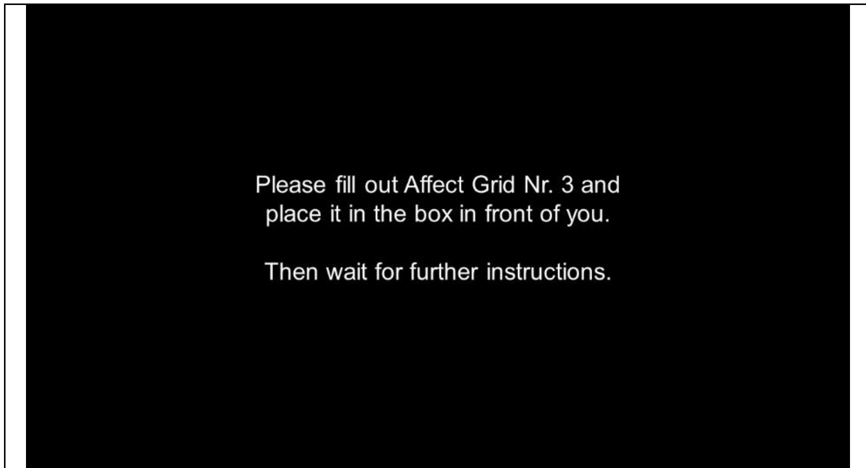


SLIDE 10 – 2 SEC

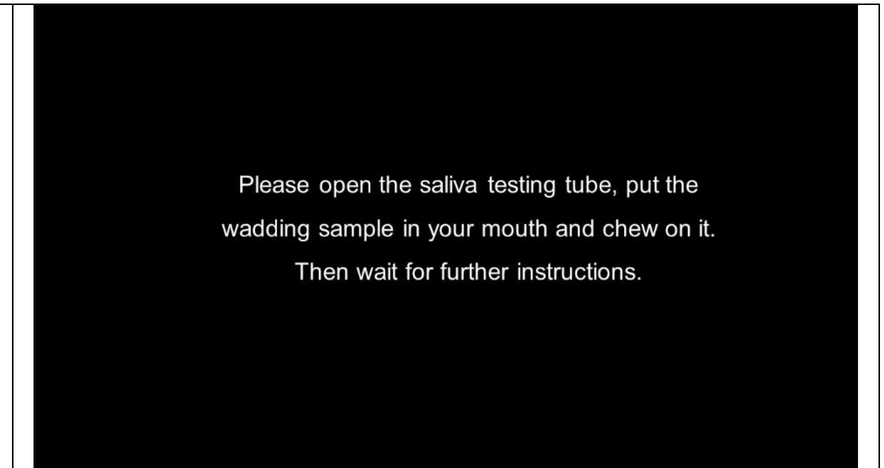
SLIDE 11 – 5 MIN

SLIDE 12 – 2 SEC

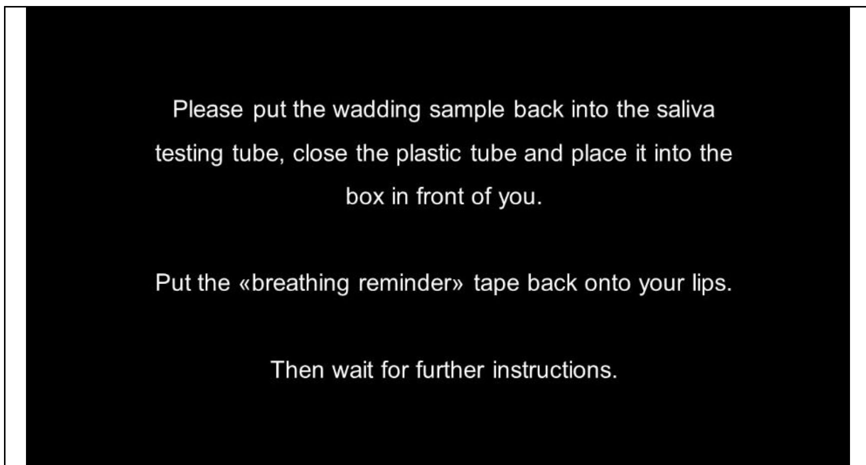
APPENDIX D – IMOTIONS STUDY CONDITION A



SLIDE 13 – 30 SEC



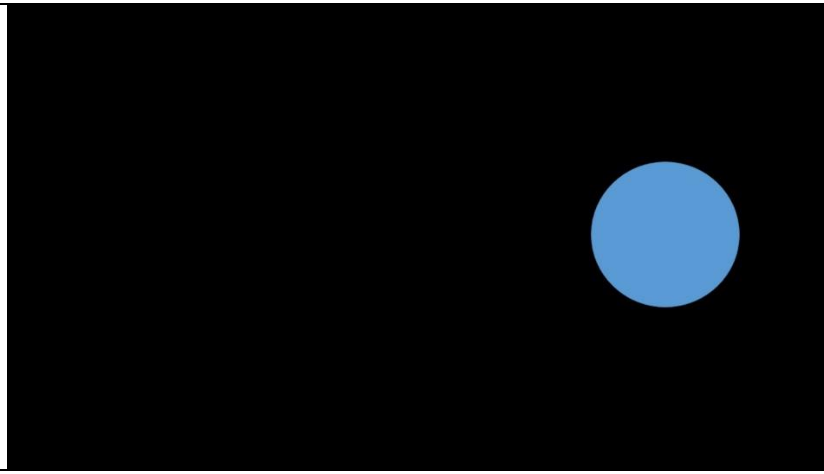
SLIDE 14 – 45 SEC



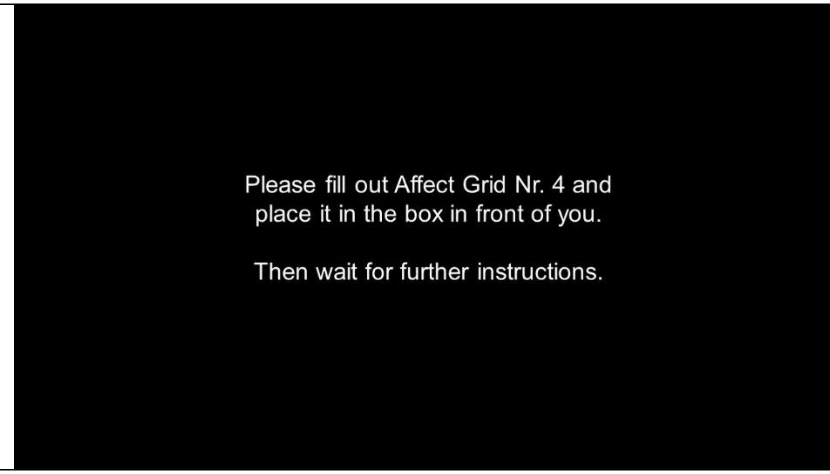
SLIDE 15 – 30 SEC

SLIDE 16 – 10 SEC

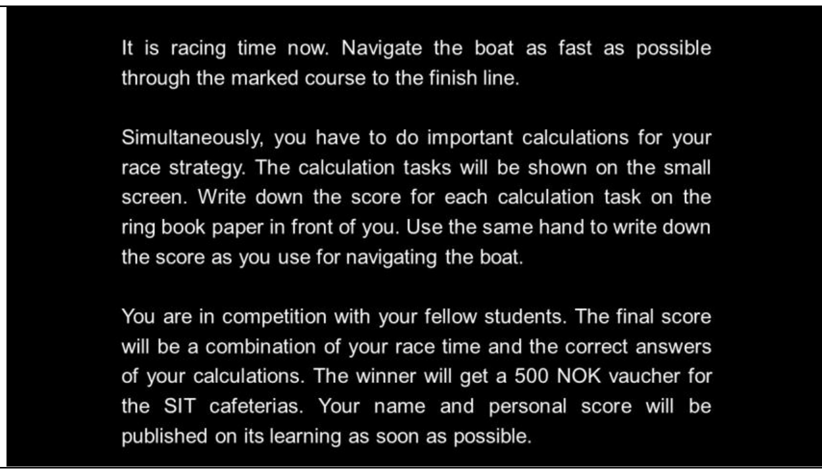
APPENDIX D – IMOTIONS STUDY CONDITION A



SLIDE 17 – 1 MIN



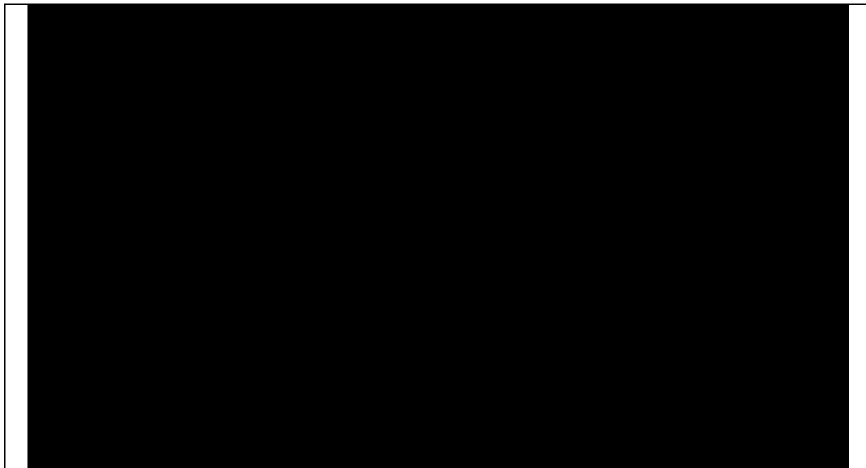
SLIDE 18 – 30 SEC

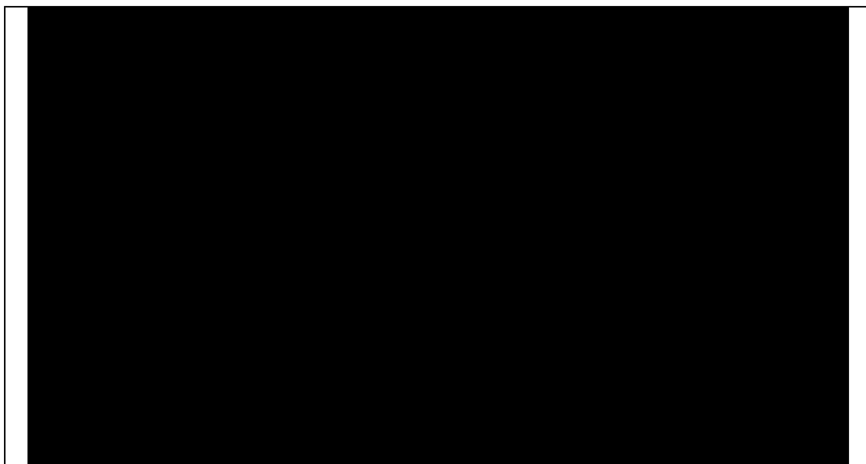
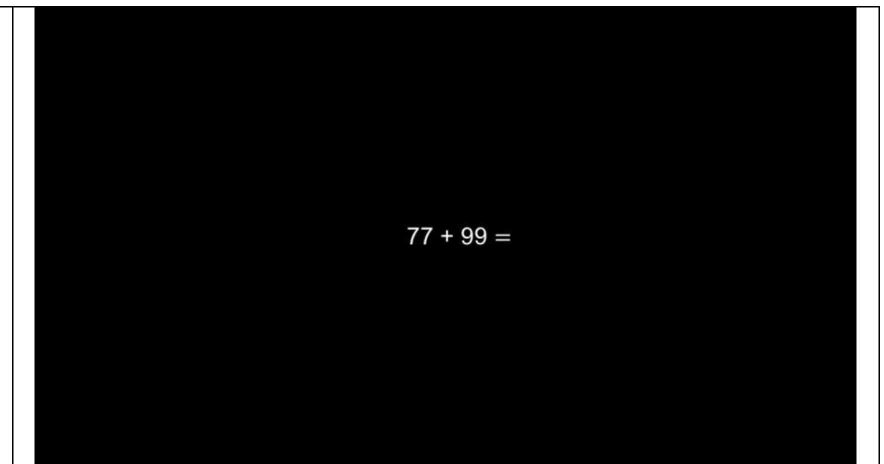


SLIDE 19 – 45 SEC

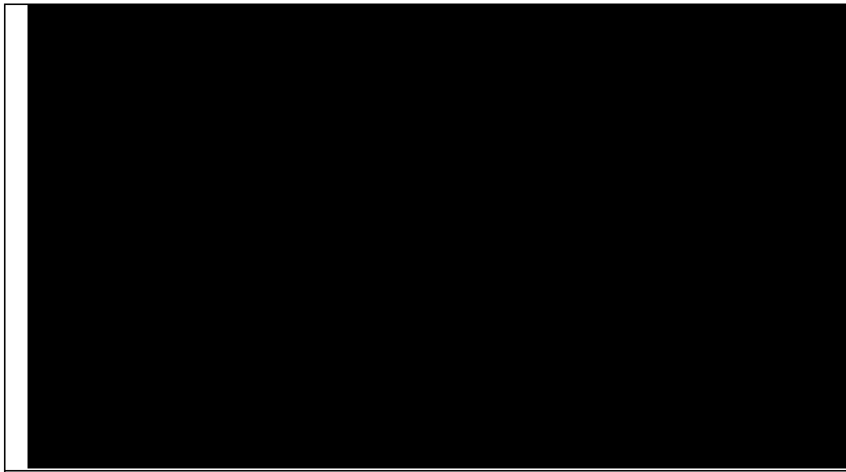
SLIDE 20 – 2 SEC

APPENDIX D – IMOTIONS STUDY CONDITION A

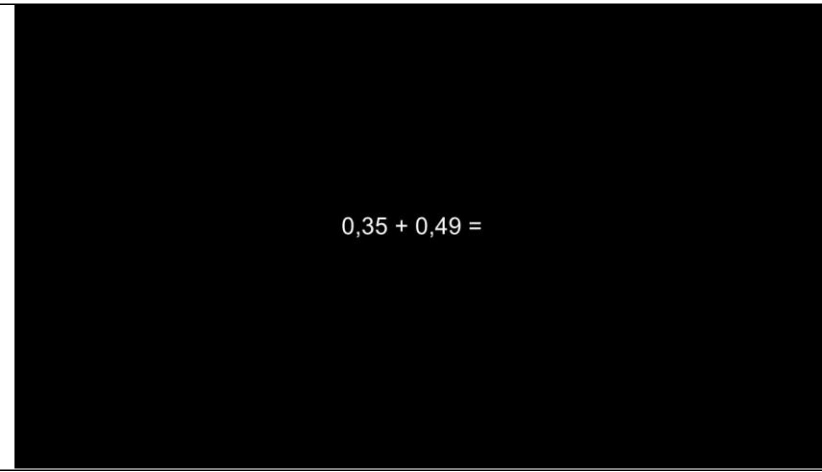
	
SLIDE 21 – 24 SEC	SLIDE 22 – 6 SEC

	
SLIDE 23 – 24 SEC	SLIDE 24 – 6 SEC

APPENDIX D – IMOTIONS STUDY CONDITION A



SLIDE 25 – 24 SEC

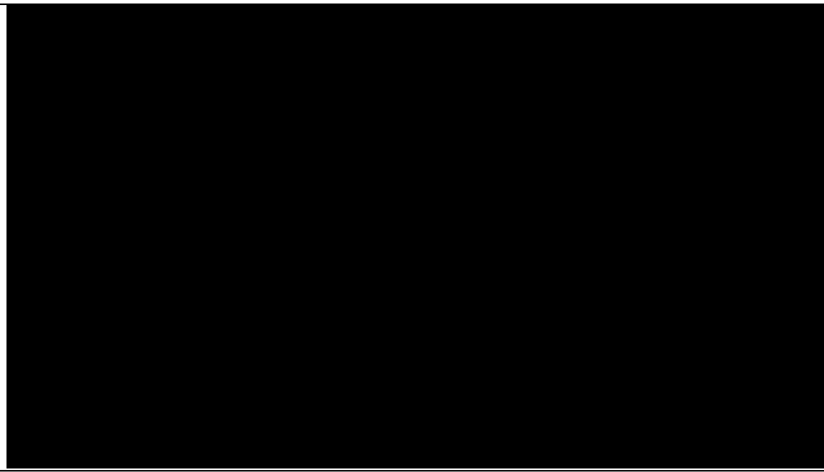
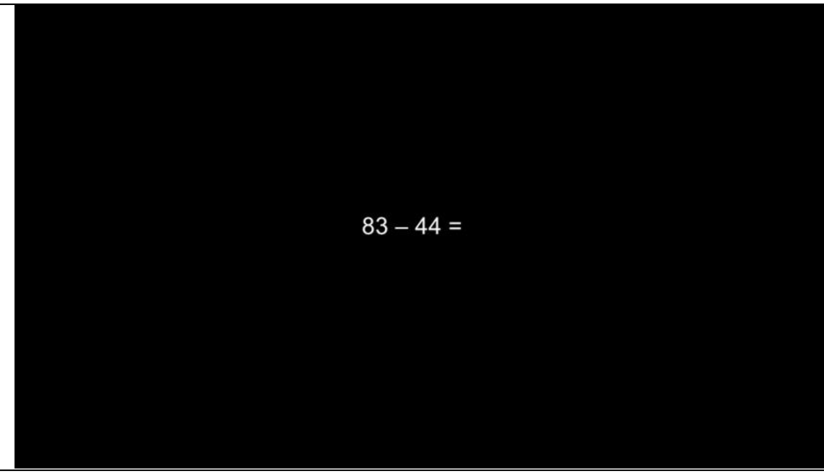
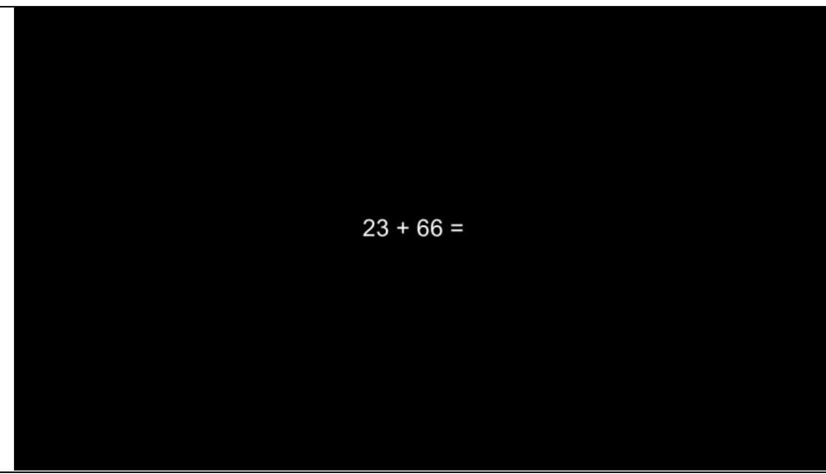


SLIDE 26 – 6 SEC

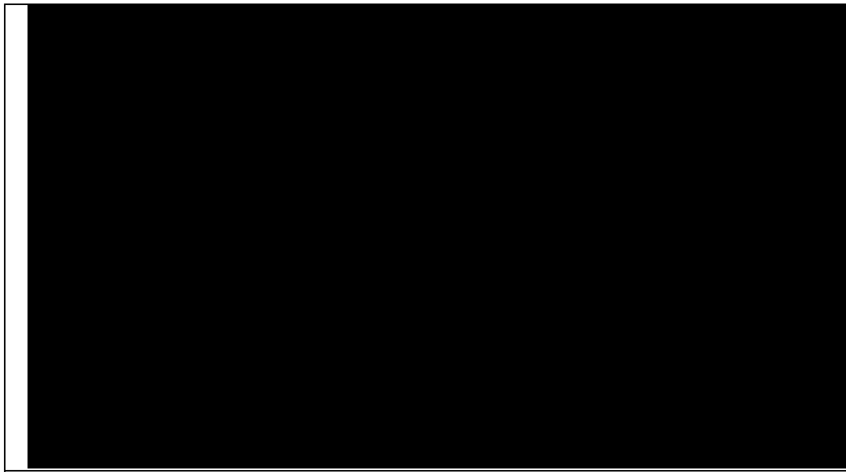
SLIDE 27 – 24 SEC

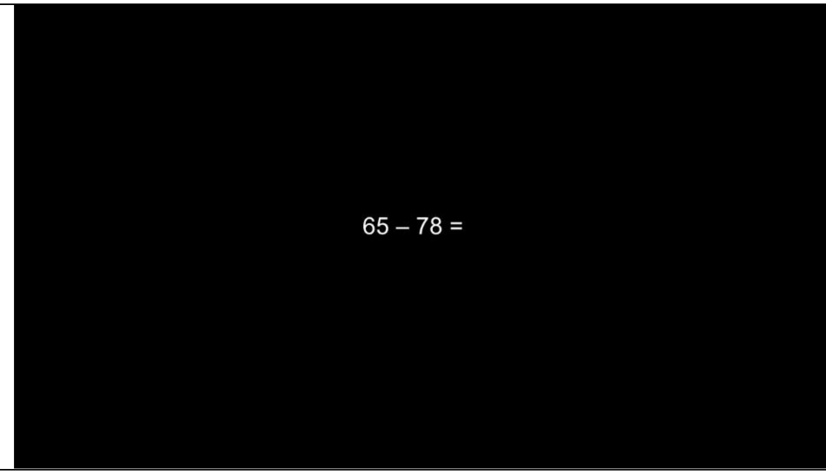
SLIDE 28 – 6 SEC

APPENDIX D – IMOTIONS STUDY CONDITION A

	
SLIDE 29 – 24 SEC	SLIDE 30 – 6 SEC
	
SLIDE 31 – 24 SEC	SLIDE 32 – 6 SEC

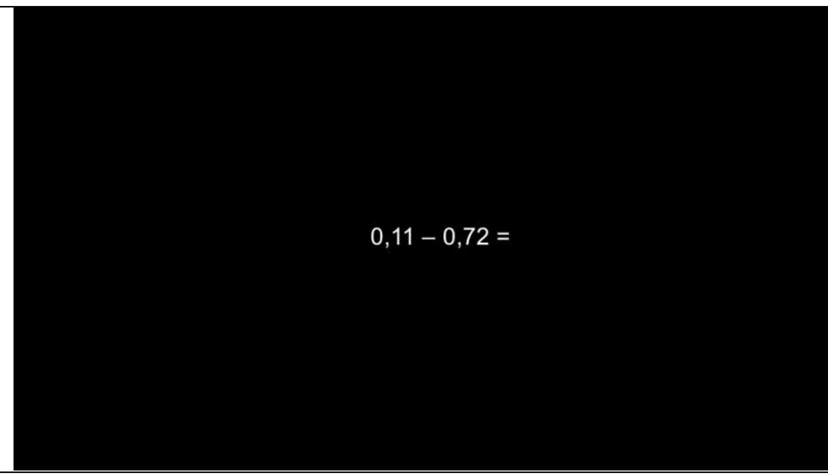
APPENDIX D – IMOTIONS STUDY CONDITION A


SLIDE 33 – 24 SEC



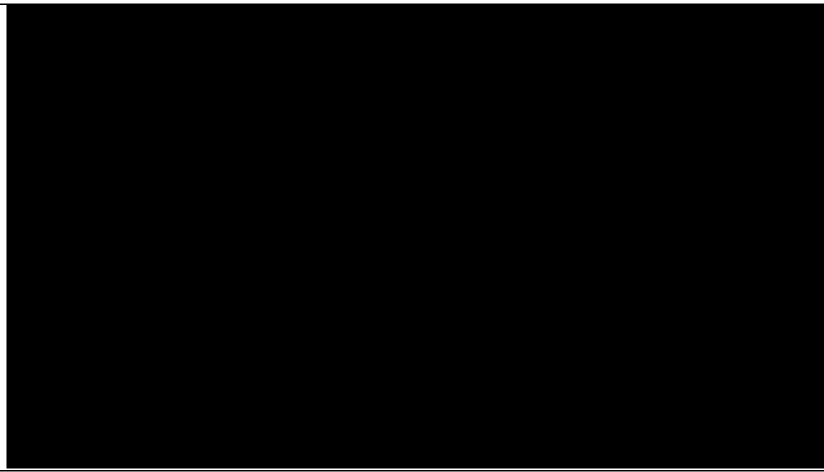
SLIDE 34 – 6 SEC


SLIDE 35 – 24 SEC

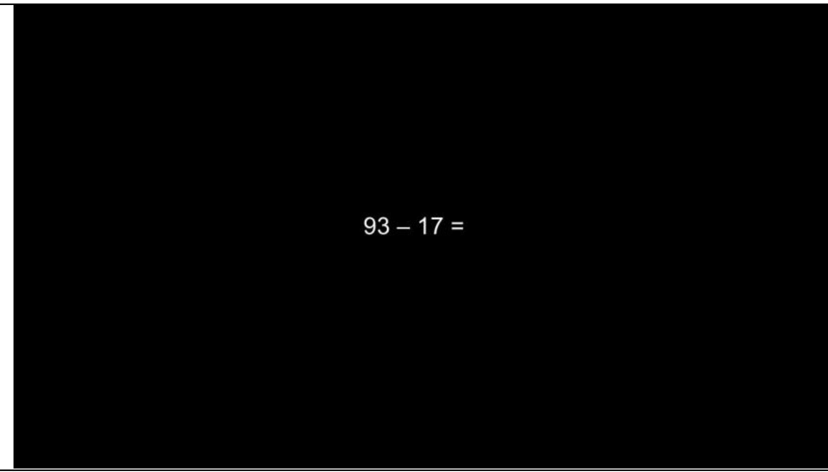


SLIDE 36 – 6 SEC

APPENDIX D – IMOTIONS STUDY CONDITION A



SLIDE 37 – 24 SEC

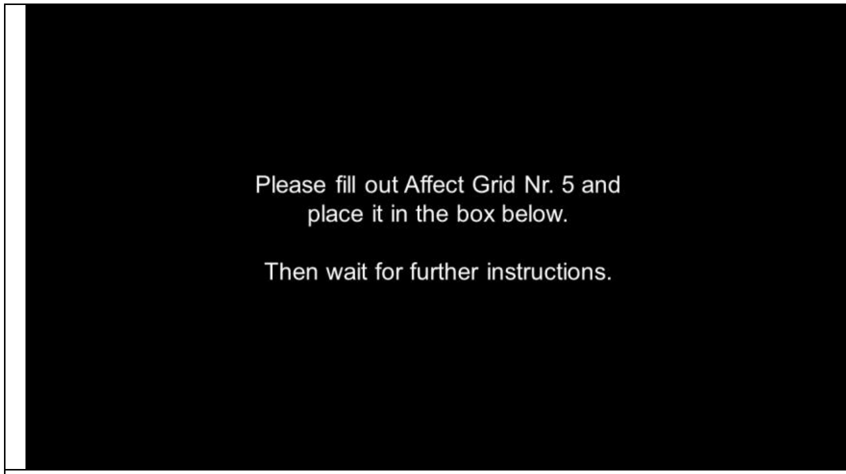


SLIDE 38 – 6 SEC

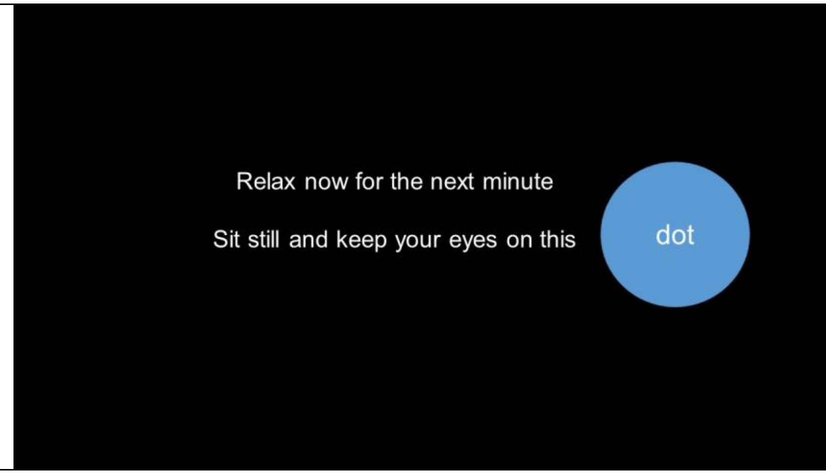
SLIDE 39 – 30 SEC

SLIDE 40 – 2 SEC

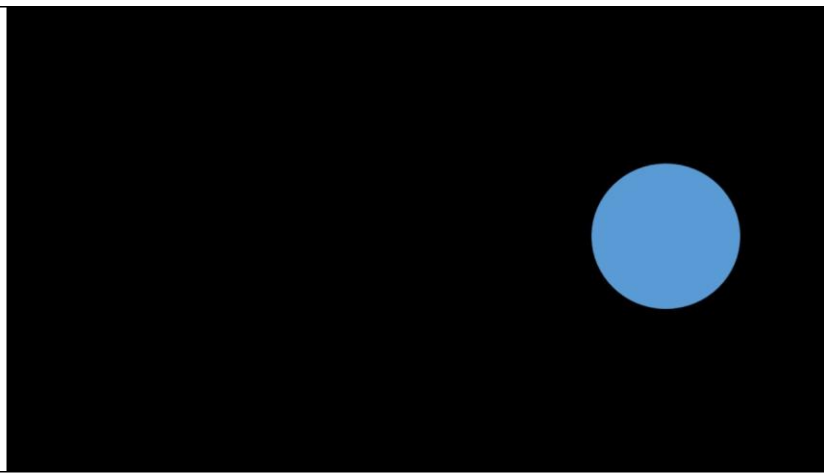
APPENDIX D – IMOTIONS STUDY CONDITION A



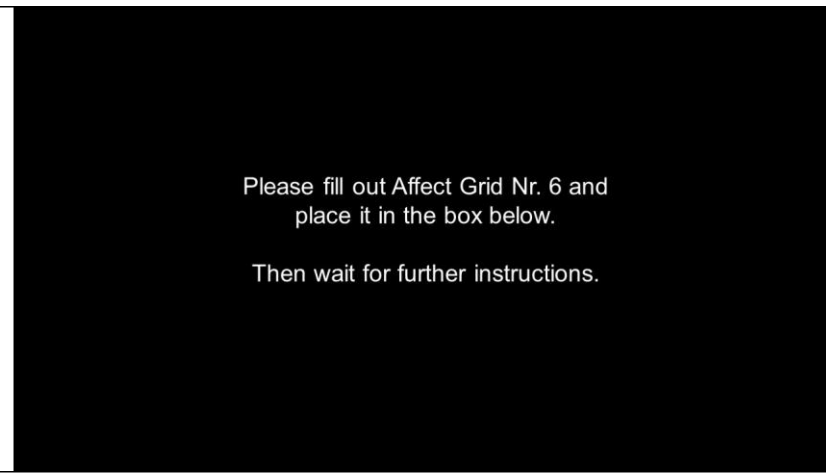
SLIDE 41 – 30 SEC



SLIDE 42 – 10 SEC

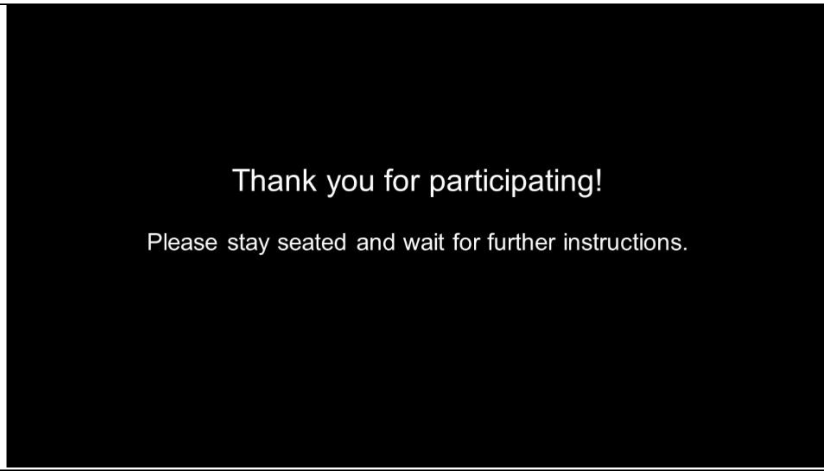


SLIDE 43 – 1 MIN



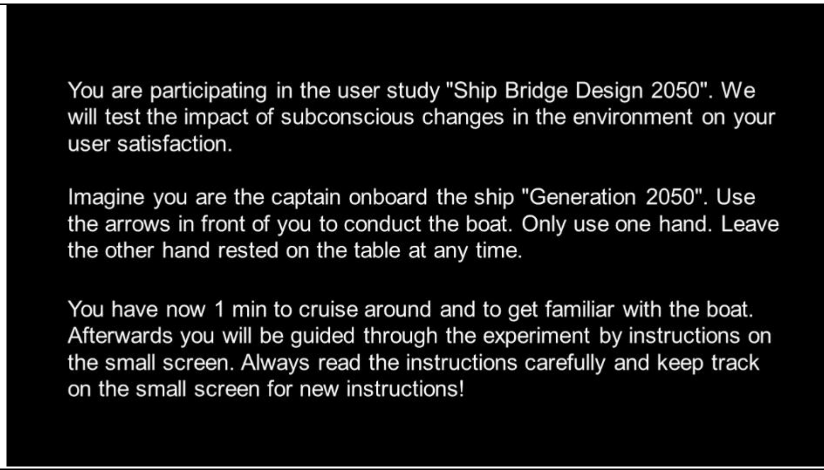
SLIDE 44 – 30 SEC

APPENDIX D – IMOTIONS STUDY CONDITION A



SLIDE 45 – 10 SEC

APPENDIX E – IMOTIONS STUDY CONDITION B



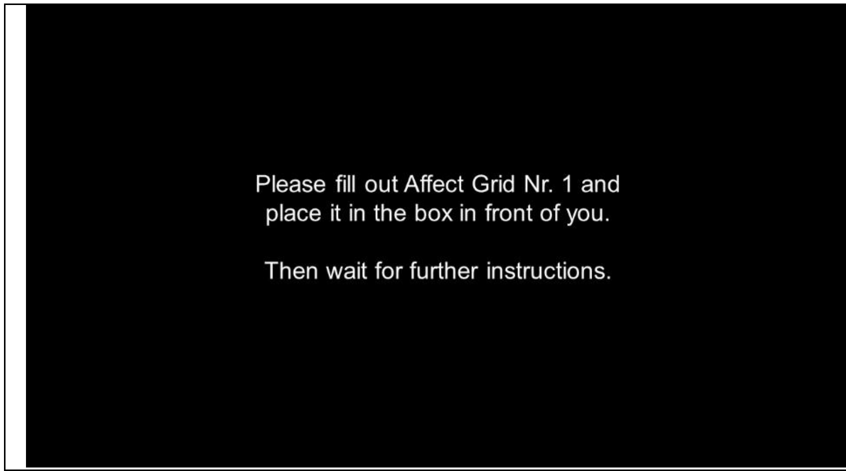
SLIDE 1 – 30 SEC

SLIDE 2 – 2 SEC

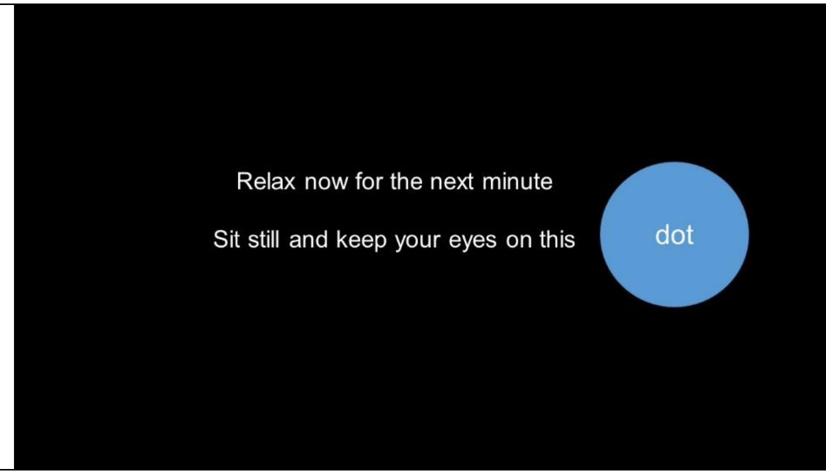
SLIDE 3 – 1 MIN

SLIDE 4 – 2 SEC

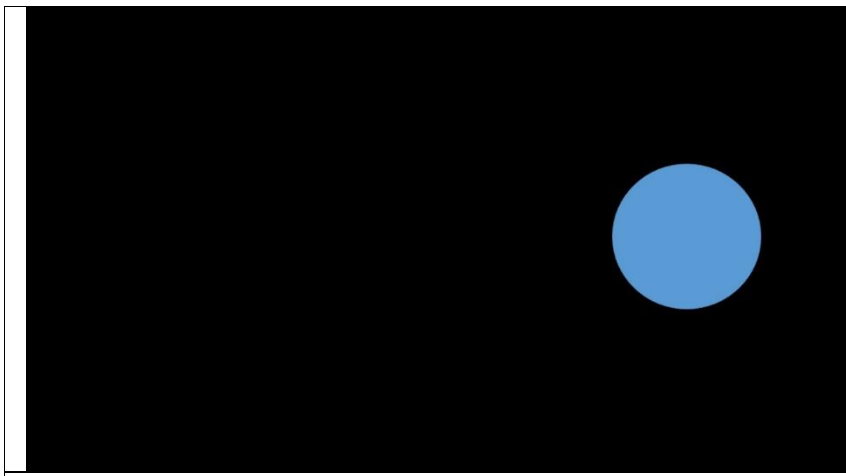
APPENDIX E – IMOTIONS STUDY CONDITION B



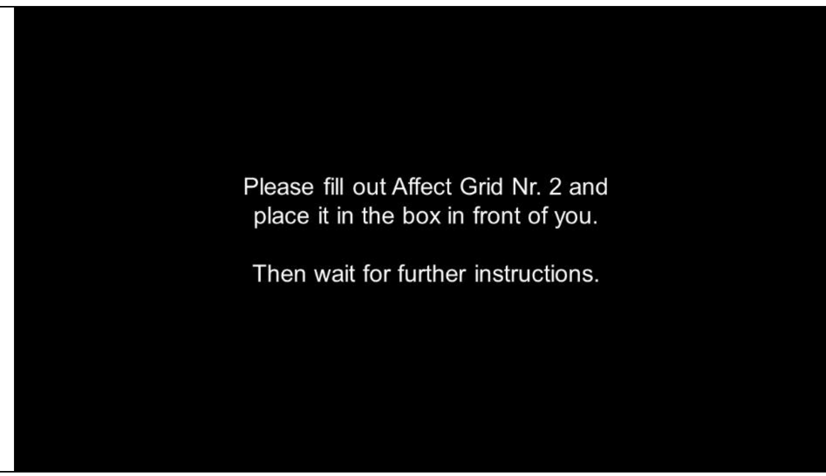
SLIDE 5 - 30 SEC



SLIDE 6 – 10 SEC

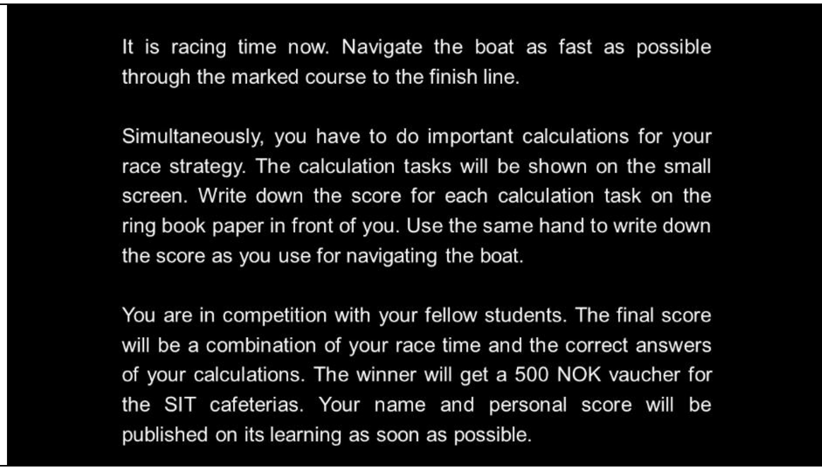


SLIDE 7 – 1 MIN

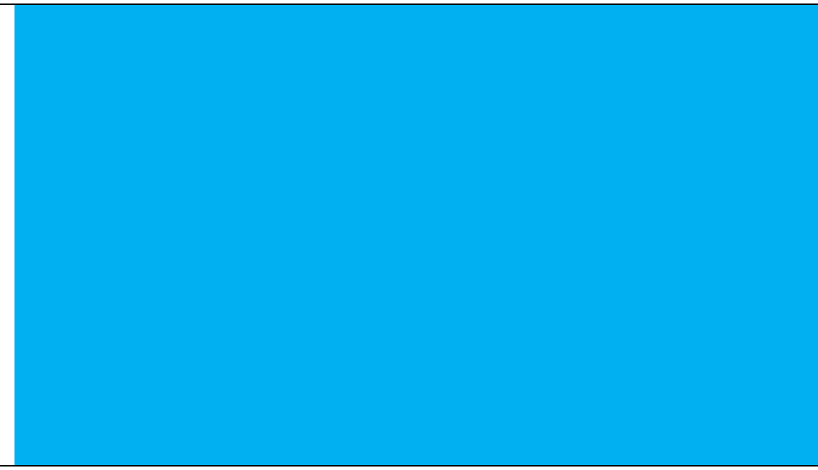


SLIDE 8 – 30 SEC

APPENDIX E – IMOTIONS STUDY CONDITION B

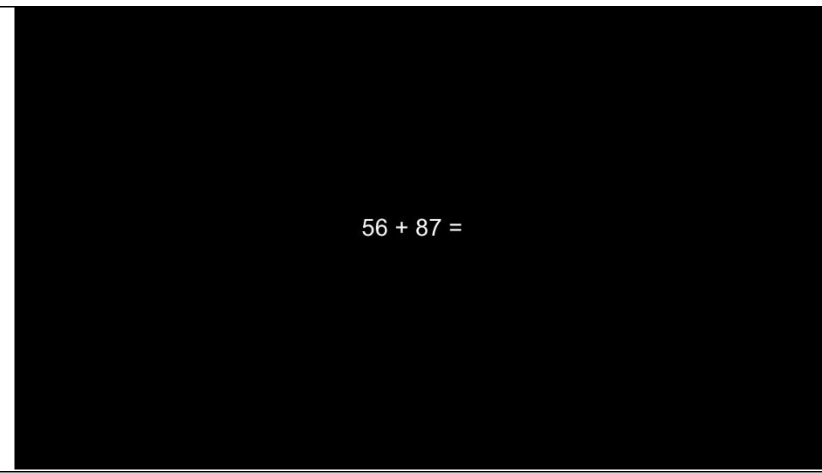


SLIDE 9 – 45 SEC



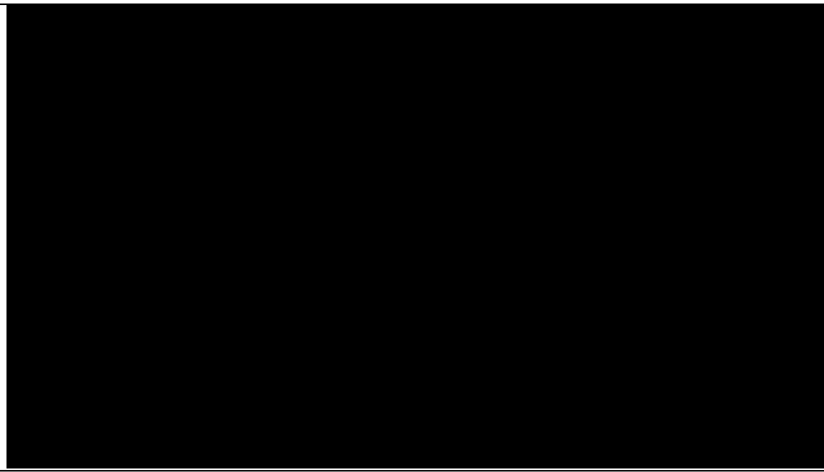
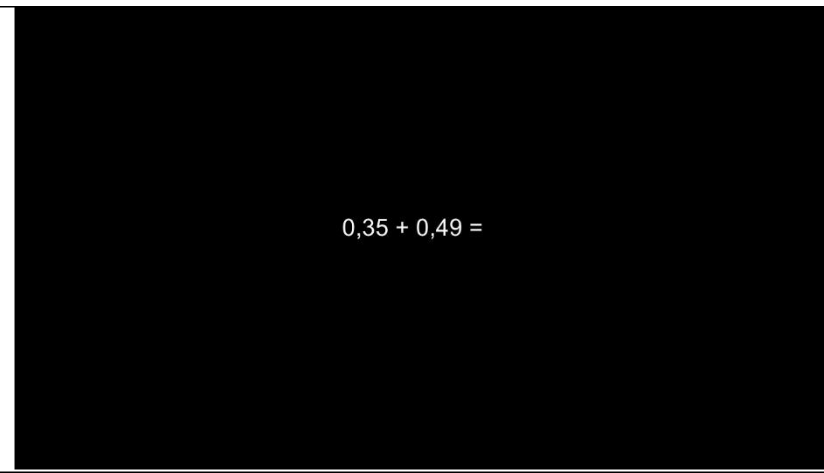
SLIDE 10 – 2 SEC

SLIDE 11 – 24 SEC

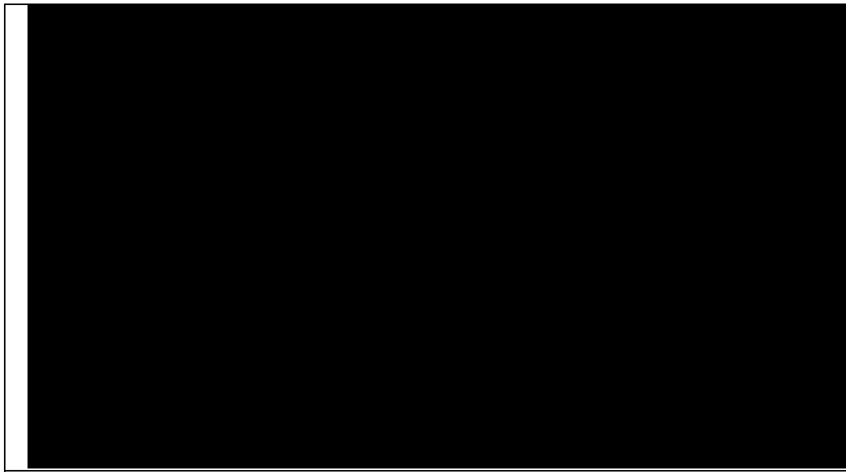


SLIDE 12 – 6 SEC

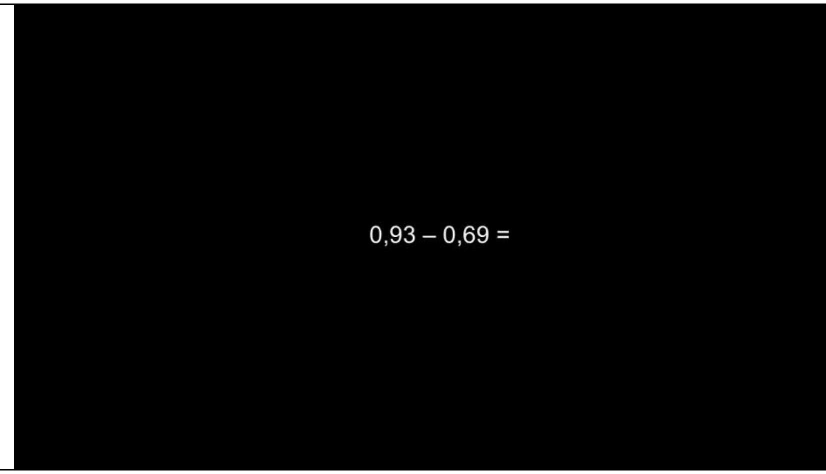
APPENDIX E – IMOTIONS STUDY CONDITION B

	
SLIDE 13 – 24 SEC	SLIDE 14 – 6 SEC
	
SLIDE 15 – 24 SEC	SLIDE 16 – 6 SEC

APPENDIX E – IMOTIONS STUDY CONDITION B

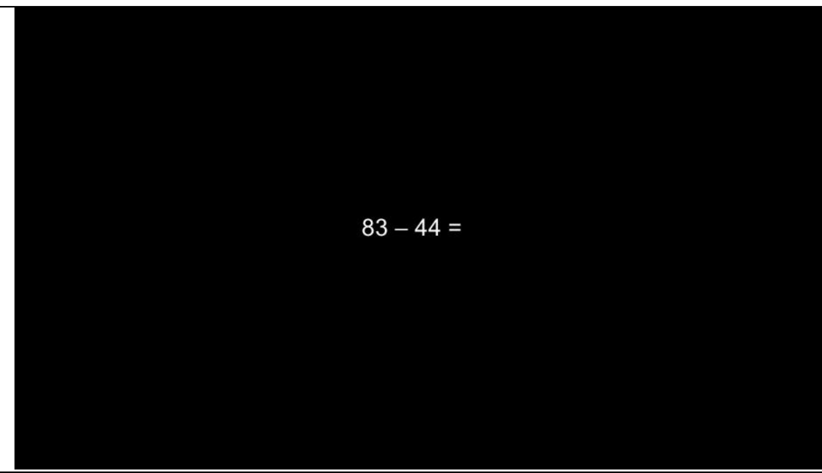


SLIDE 17 – 24 SEC



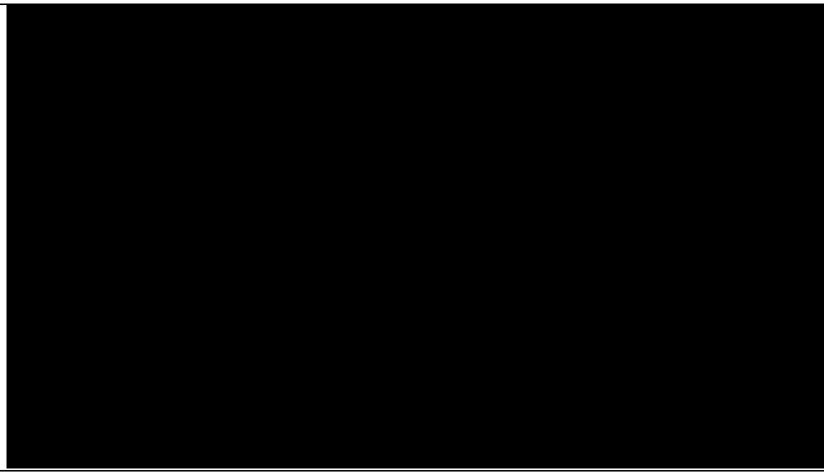
SLIDE 18 – 6 SEC

SLIDE 19 – 24 SEC

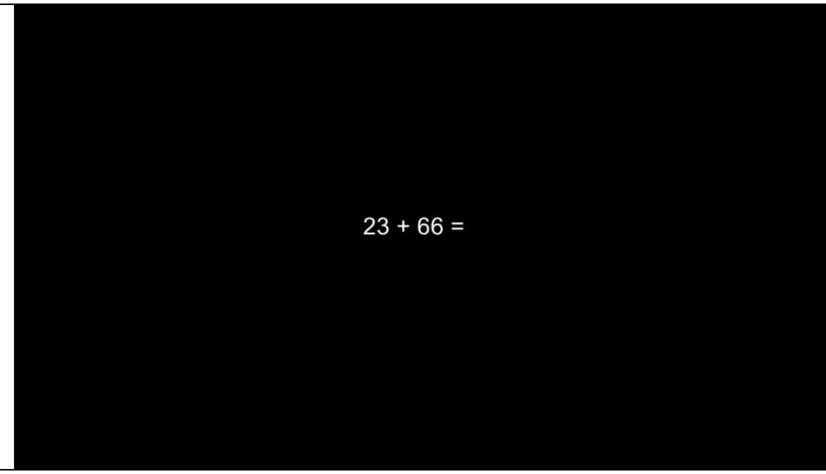


SLIDE 20 – 6 SEC

APPENDIX E – IMOTIONS STUDY CONDITION B

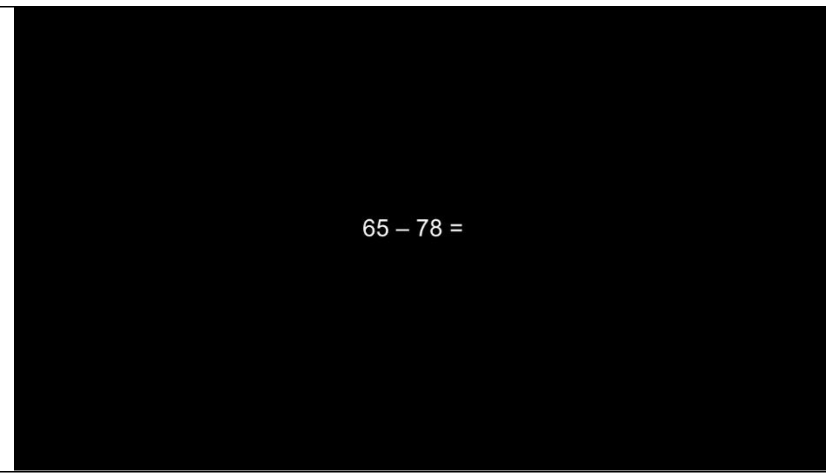


SLIDE 21 – 24 SEC



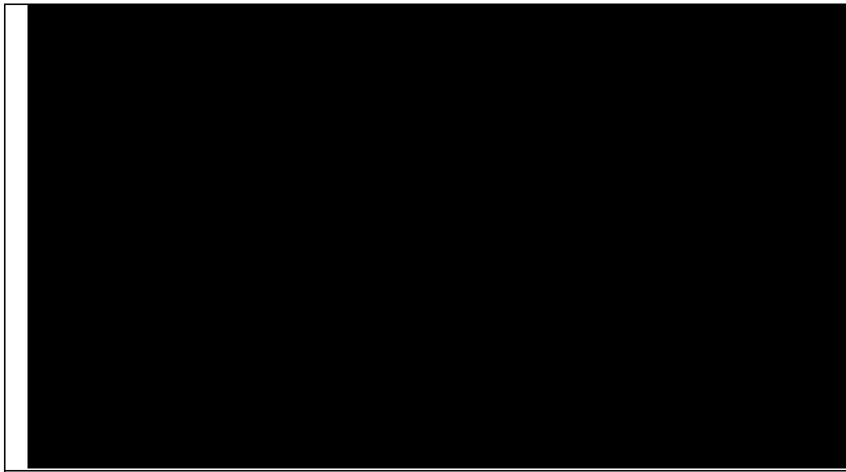
SLIDE 22 – 6 SEC

SLIDE 23 – 24 SEC

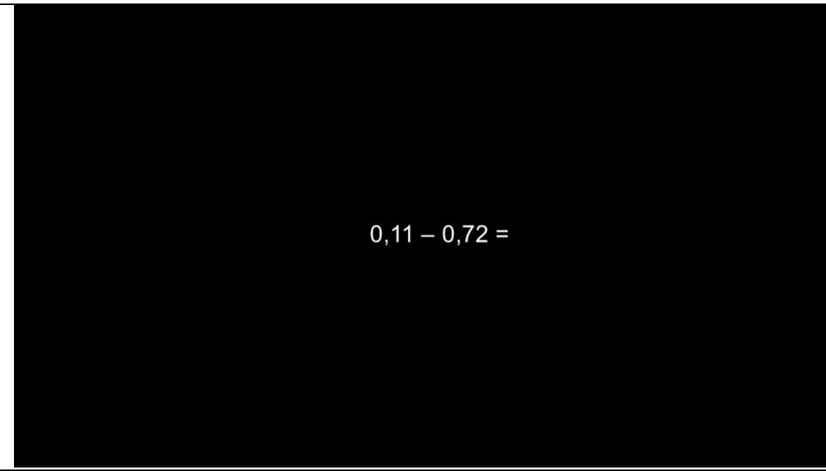


SLIDE 24 – 6 SEC

APPENDIX E – IMOTIONS STUDY CONDITION B

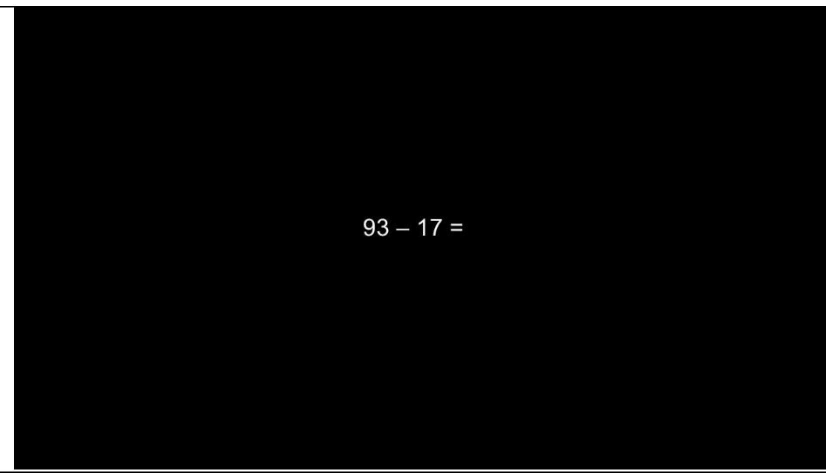


SLIDE 25 – 24 SEC

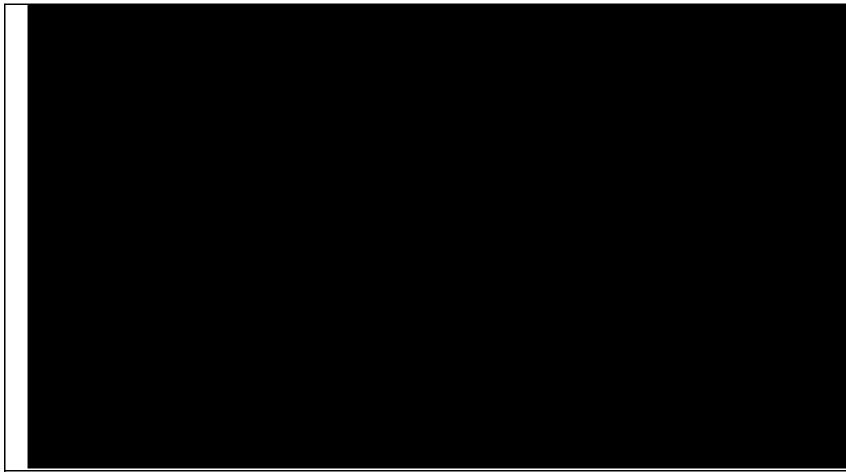


SLIDE 26 – 6 SEC

SLIDE 27 – 24 SEC

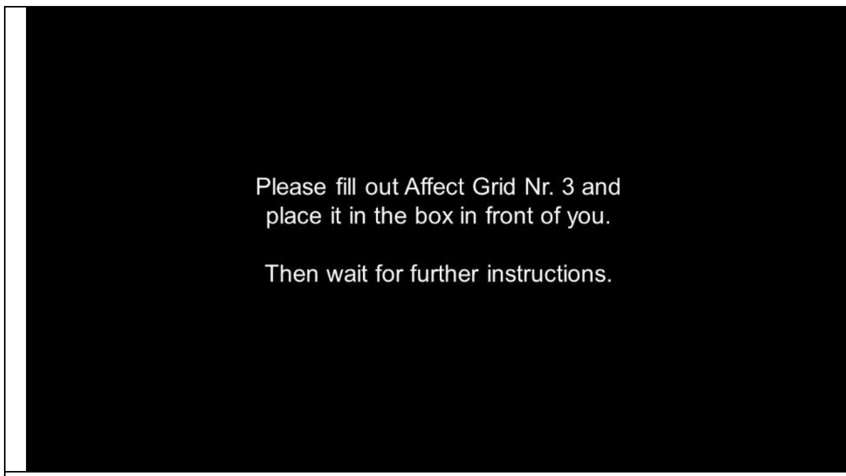


SLIDE 28 – 6 SEC

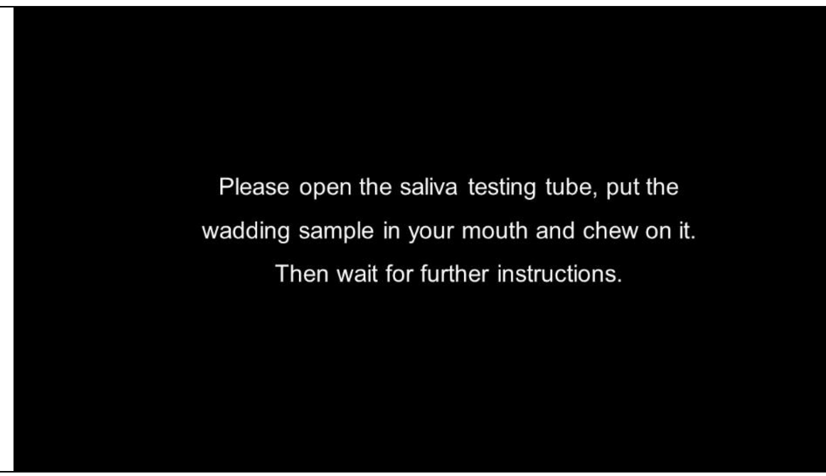


SLIDE 29 – 30 SEC

SLIDE 30 – 2 SEC

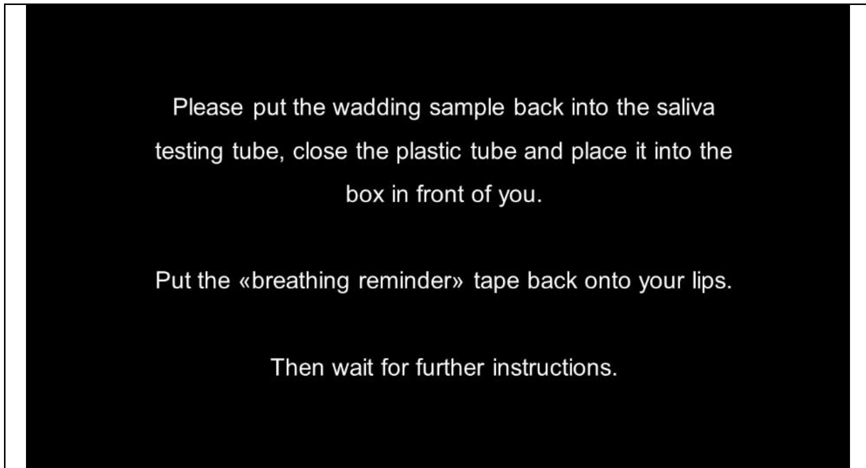


SLIDE 31 – 30 SEC



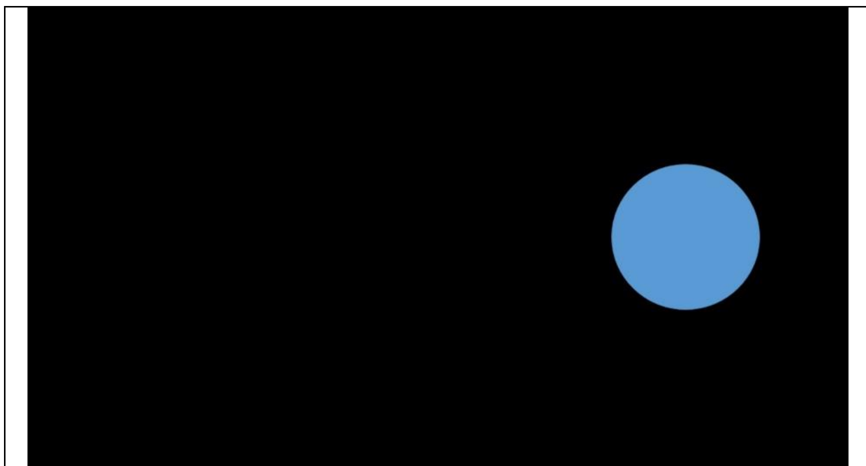
SLIDE 32 – 45 SEC

APPENDIX E – IMOTIONS STUDY CONDITION B

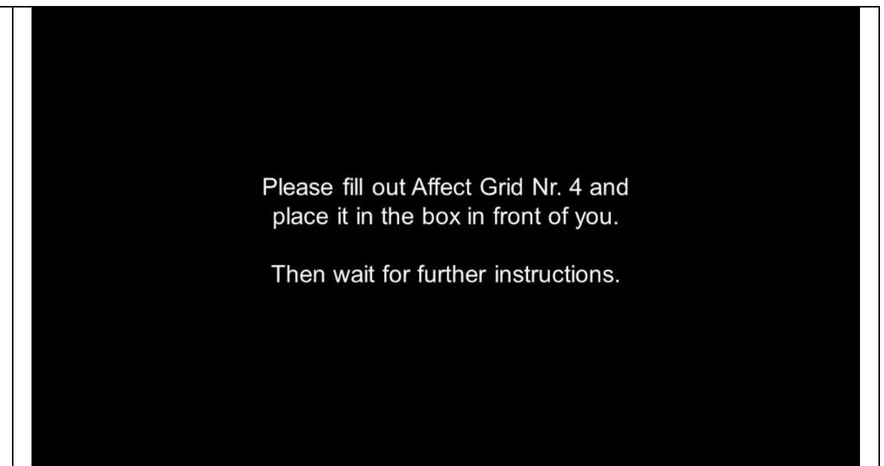


SLIDE 33 – 30 SEC

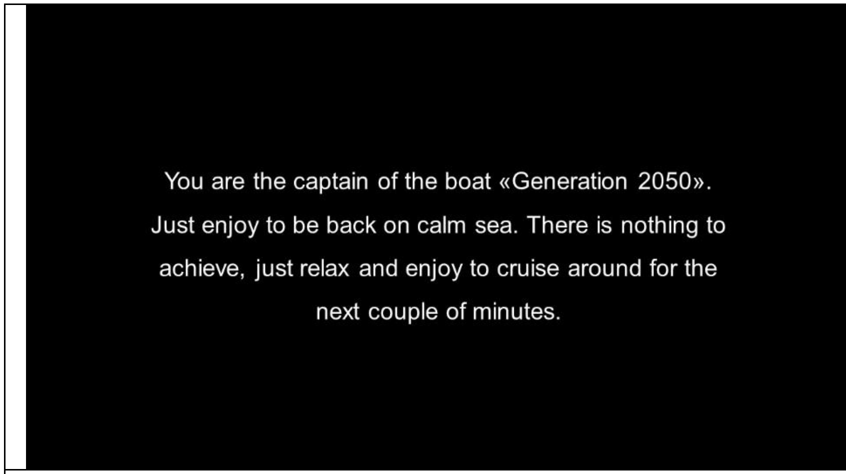
SLIDE 34 – 10 SEC



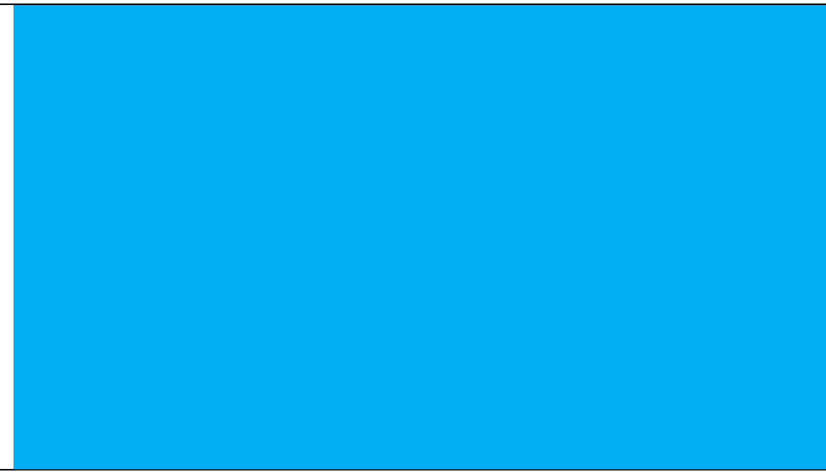
SLIDE 35 – 1 MIN



SLIDE 36 – 30 SEC



SLIDE 37 – 30 SEC

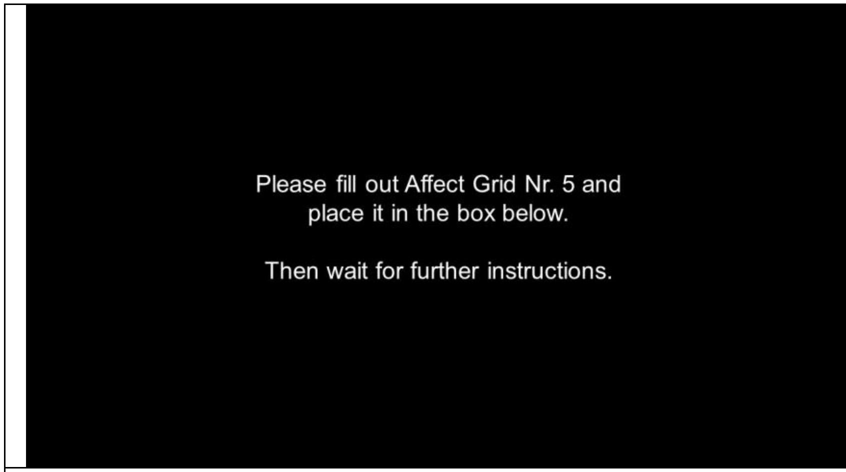


SLIDE 38 – 2 SEC

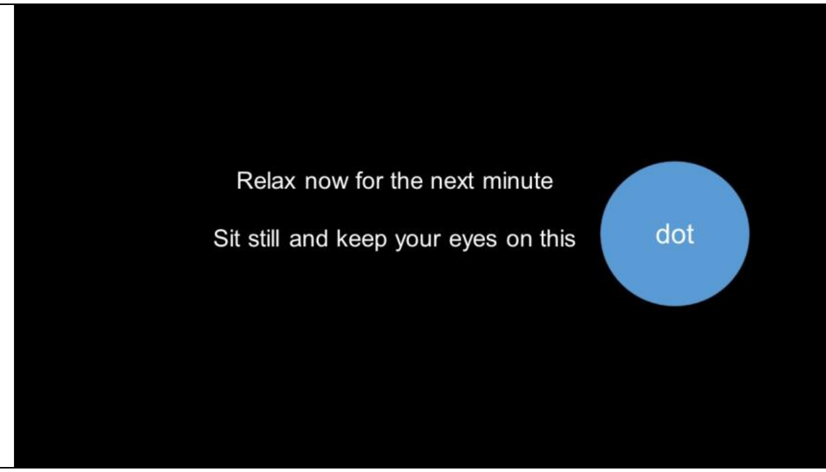
SLIDE 39 – 5 MIN

SLIDE 40 – 2 SEC

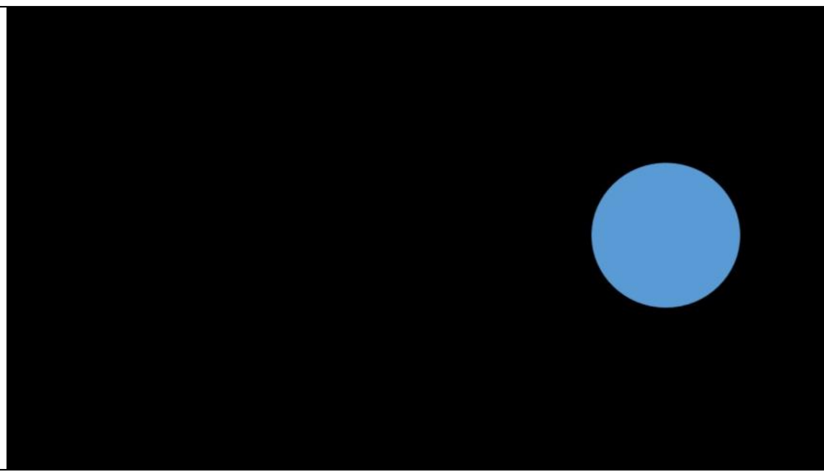
APPENDIX E – IMOTIONS STUDY CONDITION B



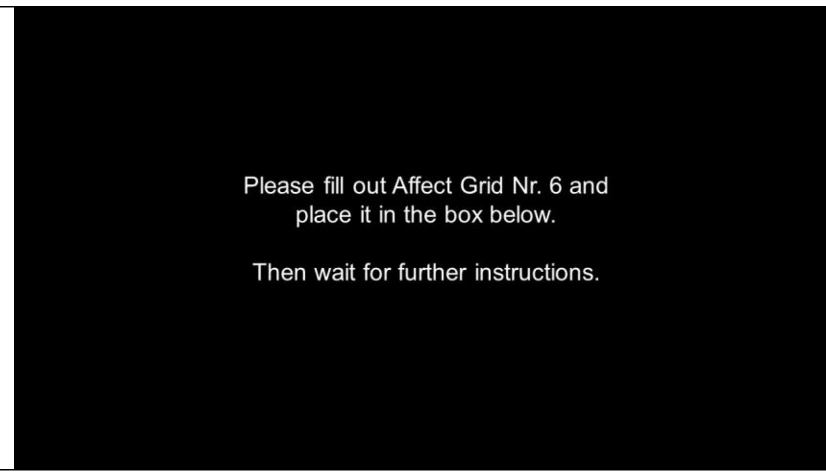
SLIDE 41 – 30 SEC



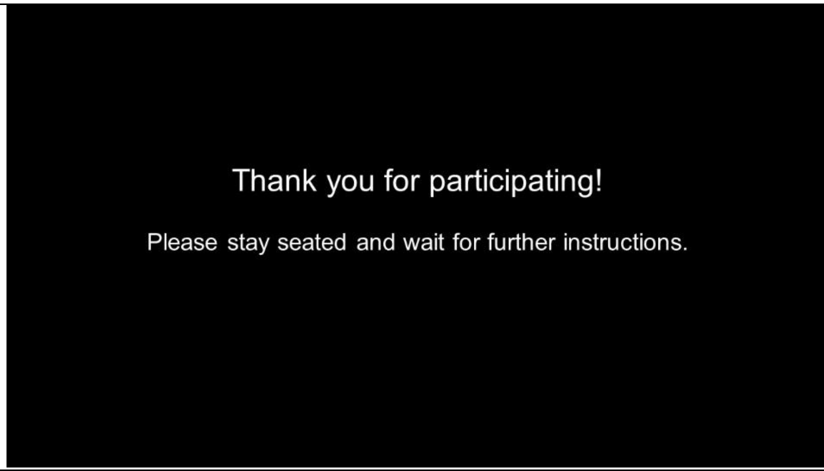
SLIDE 42 – 10 SEC



SLIDE 43 – 1 MIN



SLIDE 44 – 30 SEC



SLIDE 45 – 10 SEC	

APPENDIX F – ARDUINO INITIATION CODE

```
connecting the Arduino (Arduino Ethernet) with iMotions software via Ethernet cable (no switch box r
Arduino eHealth platform sends physiological sensor data to Attention Tool (iMotions software)
*/

#include <SPI.h>
#include <Ethernet.h>
#include <eHealth.h>

////==================Libraries for Accelerometer
////Activate if using accelerometer
#include <Wire.h> // Must include Wire library for I2C
#include <SFE_MMA8452Q.h>// Includes the SFE_MMA8452Q library
MMA8452Q accel;
////===================================

extern  volatileunsigned longtimer0_overflow_count;

float fanalogECG;
float fanalogGSR;
float fanalogAirflow;
//float fanalogEMG;
int analogECG;
int analogGSR;
int analogAirflow;


//int analogEMG;
unsigned long time;
byte serialByte;


byte mac[] = {  0x90, 0xA2, 0xDA, 0x0D, 0x54, 0x46 };//physical mac address of ethernet shield

IPAddress arduino_ip(192,168,1,20);//IP address arduino
IPAddress server_ip(192,168,1,30);//IP address PC
//byte ip[] = { 192, 168, 1, 102 }; // arduino ip in lan

//byte gateway[] = { 78, 91, 48, 1 };//internet access via router
byte subnet[] = { 255, 255, 255, 0 };//OK subnet mask

  EthernetClient  client;
//EthernetServer server(80);//server port

void setup() {
  Serial.begin(57600);
  //===================== Accelerometer function
   accel.init();

  //=====================
  // start the Ethernet connection and the server:
 //  Ethernet.begin(mac,  ip,  gateway,  subnet);
  Ethernet.begin(mac, arduino_ip, subnet);
   //server.begin();

   Serial.println("start");

     // if you get a connection, report back via serial:
  if (client.connect(server_ip, 8089)) { // Port is defined in Attention Tool as 8089
    Serial.println("connected");
   }
```

APPENDIX F – ARDUINO INITIATION CODE

```
  else {
    // if you didn't get a connection to the server:
    Serial.println("connection failed ");
  }
}


void loop() {

  //if (client.available()) {
    while (client.connected()) {


      //client.print("<?xml version='1.0' encoding='utf-8' ?><EventSource Version='1' Id='evadevice


        fanalogECG=eHealth.getECG();
        fanalogGSR=eHealth.getSkinConductance();
        float temperature =eHealth.getTemperature();
        fanalogAirflow=eHealth.getAirFlow();
        accel.read();
        client.print("E;1;eHealth46experiment;1;;;;eHealth46experiment;");
        client.print(fanalogECG,5);
        client.print (";");
        client.print(fanalogGSR,5);
        client.print (";");
        client.print(temperature,2);
        client.print (";");
        client.print(fanalogAirflow,5);
        client.print (";");
        client.print(accel.cx, 3);
        client.print(";");
        client.print(accel.cy, 3);
        client.print(";");
        client.print(accel.cz, 3);
        client.println(";end\r\n");




     Serial.println("sending");
//delay(100);
/*
///         fanalogECG=eHealth.getECG();
        fanalogGSR=eHealth.getSkinConductance();
//         fanalogAirflow=eHealth.getAirFlow();
//        fanalogAirflow=eHealth.getEMG();
//        accel.read();
        // Use the timer0 => 1 tick every 4 us
            time=(timer0_overflow_count << 8) + TCNT0;
        // Microseconds conversion.
           time=(time*4);
        //Print in a file for simulation
        client.print(time);
        client.print(";");
//        Serial.print(fanalogECG,5);
//        Serial.print(";");
       client.print(fanalogGSR,5);
       client.println(";");
//        Serial.print(fanalogAirflow,5);
//        Serial.print(";");
```

APPENDIX F – ARDUINO INITIATION CODE

```
//       Serial.print(fanalogEMG,5);
//       Serial.print(";");
//       Serial.print(accel.cx, 3);
//       Serial.print(";");
//       Serial.print(accel.cy, 3);
//       Serial.print(";");
//              Serial.println(accel.cz,  3);

  */
    }
    client.stop();
//  }
}
```

APPENDIX G – XML CODE FOR IMOTIONS EXTERNAL EVENTS API

```xml
<?xml version='1.0' encoding='utf-8' ?>
<EventSource Version='1' Id='eHealth46_all' Name='eHealth46_all'>
  <Sample Id='eHealth46_all' Name='eHealth46_all Data'>
    <Field Id='ECG' Range='Variable' Min='0' Max='10'></Field>
    <Field Id='GSR' Range='Variable' Min='0' Max='400'></Field>
<Field Id='temperature' Range='Variable' Min='0' Max='45'></Field>
<Field Id='Airflow' Range='Variable' Min='0' Max='400'></Field>
<Field Id='AccX' Range='Variable' Min='-10' Max='10'></Field>
<Field Id='AccY' Range='Variable' Min='-10' Max='10'></Field>
<Field Id='AccZ' Range='Variable' Min='-10' Max='10'></Field>
    <Field Id='End' Range='Variable' Min='0' Max='8000'></Field>

  </Sample>
</EventSource>
```

APPENDIX H – MATLAB PREPROCESSING CODE


```
clear all
close all

txtFiles = dir('*.txt');
numfiles = length(txtFiles);


for g = 2
inputname=txtFiles(g).name;
fileID = fopen(inputname);
formatSpec = '%s %f %f %f %s %s %s %s %f %*s %*s %*s %f %f %d8 %*f %*f %*f %*f %*f %*f
%*f %*f %*f %*f %*f %*f %*f %*f %*f %*f %*f %*f %*f %*f %*f %*f %*f %*f %f %f %f %f %f
%f %f %*[^\n]';
RAWDATA = textscan(fileID, formatSpec, 'headerlines', 7, 'delimiter', '\t');
fclose(fileID);

filename = inputname(9:11);

%% DEFINE COLUMNS
VERSION = RAWDATA{1};
DATE = RAWDATA{2};
ID = RAWDATA{3};
SLIDE = RAWDATA{6};
T = RAWDATA{9};
ECGraw = RAWDATA{13};
GSRraw = RAWDATA{14};
TEMPraw = RAWDATA{15};
AIRraw = RAWDATA{16};
ACCraw = [RAWDATA{17},RAWDATA{18},RAWDATA{19}];

ECGraw(1:2)=0; GSRraw(1:2)=0; TEMPraw(1:2)=0; AIRraw(1:2)=0; ACCraw(1:2,:)=0;
%% TIMESTAMP CONVERSION
T =T-T(1);                          %start time @ zero
T = T./1000;                        %milliseconds to seconds conversion
n = length(T);                      %number of datapoints

%% SLIDES CONVERSION
black = strfind(SLIDE, 'bla');
calc = strfind(SLIDE, 'cal');
for h=1:n
    if black{h,1}==1
        SLIDE{h,1}='Race';
    elseif calc{h,1}==1
        SLIDE{h,1}='Race';
    end
end

%% ECG
%Remove noise components
ECG_de = detrend(ECGraw);           %removes baseline wanderers
ECG_mean = mean(ECG_de);            %mean component
ECG = ECGraw - ECG_mean;

ECG_smooth = smooth(ECG, 3);        %smootening of the curve
ECG = ECG - ECG_smooth;
```

```
[pks locs] = findpeaks(ECG,'MinPeakDistance',30, 'MinPeakHeight', 0.08);
m = length(pks);                            %Number of peaks

plot(T,ECG);
hold on
scatter(T(locs),ECG(locs),20,'filled'); %Visualize detected peaks
hold off

fprintf('Check ECG peaks for dataset %s. Press any key to continue.\n',filename);
pause
%% Calculate BPM average of time intervals
duration = T(end) - T(1);
int = 10;                                   %desired approximate slice size (seconds)
nr_slice = round(duration/int);             %number of slices
slice_int = duration/nr_slice;              %slicesize

beat=T(locs);                               %time location of heart beats
t1=T(1);                                    %slice start
t2=t1+slice_int;                            %slice end

bpmslice = zeros(nr_slice,1);               %allocate memory
BPM = AIRraw;
SS=1;
SL=0;
for j = 1:nr_slice
    slice = beat(beat>=t1 & beat<=t2);      %find peaks within interval
    SL = SL+length(T(T>=t1 & T<=t2));       %find number of datapoints within interval

    bpmslice(j)=length(slice)*60/(slice(end)-slice(1));

    BPM(SS:SL) = bpmslice(j);
    t1=t1+slice_int;
    t2=t2+slice_int;
    SS=SL;
end

%% GSR
p = 1;
q = 20;
GSR = resample(GSRraw, p, q);               %resample GSR signal at p/q times original
sample rate
GSR = imresize(GSR, [n 1], 'bilinear');

%% TEMPERATURE
r = 1;
s = 10;
TEMP = resample(TEMPraw, r, s);             %resample temperature signal at r/s times
original sample rate
TEMP = imresize(TEMP, [n 1], 'bilinear');

%% ACCELEROMETER
ACC = abs(ACCraw(:,1))+abs(ACCraw(:,2))+abs(ACCraw(:,3));

%% WRITE
```

APPENDIX H – MATLAB PREPROCESSING CODE


```
DATE = num2cell(DATE);
ID = num2cell(ID);
T = num2cell(T);
BPM = num2cell(BPM);
GSR = num2cell(GSR);
TEMP = num2cell(TEMP);
ACC = num2cell(ACC);
M = [{'VERSION','DATE','ID','SLIDE','T','BPM','GSR','TEMP','ACC'};VERSION,DATE,ID,↙
SLIDE,T,BPM,GSR,TEMP,ACC];
form = '.xlsx';
filename = strcat(filename,form);
xlswrite(filename, M);
fprintf('%s succesfully exported!\n',filename)
end
% S=[VERSION,DATE,ID,SLIDE,T,BPM,GSR,TEMP,ACC];
% T = cell2table(S,'VariableNames',↙
{'VERSION','DATE','ID','SLIDE','T','BPM','GSR','TEMP','ACC'});
% writetable(T,'250.txt');
```

The second saliva container was sort of stuck, so I put it in the container it came in. Maybe put the swab in the one it is supposed to be delivered in. Fun experiment! **– 220**

I didn't chew on the first saliva test, just had it in my mouth. The other one didn't taste very good. **– 225**

I had the flu during this period (just thought you might want to know). If the purpose of the "secrecy" beforehand was to build excitement, then, well done. If this is unwanted, consider sharing more info. I liked it! Thanks. **– 226**

I get stressed out from looking at dots on a computer screen. **– 227**

I was stuck on another boat during the race, is it supposed to be like this? **– 228**

The additional problem solving made the gaming part more challenging but at the same time more interesting. **– 229**

Just want to tell about that I daily use medicine which affects my blood, and then also maybe my spit. **– 231**

The boat game made me lost, and I didn't understand the map due to lag and low resolution. Felt a bit hopeless. **– 236**

I crashed the cruise boat immediately and couldn't do anything about it. Fix it. The cotton thing tasted like shit. **– 237**

Hard to see that I should follow the green line in the race when the boat wasn't lined up with it from the beginning. I assume the jetski in the race when the cruise part was with a boat, was intended. I was surprised I had to ride a jetski, it turned so quickly. I got stressed. **– 240**

Very nice setup. During the cruise I was bored and began trying things out and explore the display and wanted to see what happens if you drive the boat on the beach. I expected to get a second chance, but I was stuck on shore instead. **– 246**

Very cumbersome sensory equipment. Should inform about filming during exp. Professional walkthrough/exec. **– 250**

I didn't like the dot. It made me feel dumb. I didn't see the equations right away. I thought they would show up on the right screen. Beside that it was well set up. I am also a little hungover which might be the reason for not feeling that great in the tiny room. **– 254**

Second saliva test gave a funny taste. Kind of put me off. **– 255**

Not only math tasks on the side, maybe some memory tasks? **– 256**

I don't know what the experiment is about, so I can't really make any good suggestions. In cruising I wanted to figure out how the boat worked. Maybe this could be explained beforehand. In the math puzzles I was unsure if you could use the sheet for notes or just for answers and if the ordered mattered. Also, is time or math more important, I would also like to use both hands, and I kept focusing on other things like the tri-colored LED's, webcam or weeing my lips. **– 257**

Taste of cotton was sour, could affect physiology. The second boat (jetski) was far more sensitive to throttle and steering inputs. The map refresh rate was much slower than the sensitive boat input (race). **– 258**

Funny experiment. Good guidance through the experiment and surprising events. :) **– 259**

It was interesting. I enjoyed it; The time of some of the instruction on the screen could be more; those that have more details like race. Thanks! :) **– 260**

Please fill out the document.

When you are done, place it in your box.

Then wait for further instructions.

Relax in the meantime.

Please sit down and relax.

Then wait for further instructions.

I will connect you now to the sensor kit.

Please breathe only through your nose during the experiment. As "physical reminder" I will put a tiny tape onto your lips (in case of panic you can open your mouth easily).

I will close the curtain behind you and then leave the room.

Please follow the instructions on the small screen in front of you. It will guide you through the experiment.

NTNU HMS	Risikovurdering	Utarbeidet av	Nummer	Dato
		HMS-avd.	HMSRV2601	22.03.2011
		Godkjent av		Erstatter
		Rektor		01.12.2006

Enhet: IPM **Dato:** 01.09.2015

Linjeleder: Torgeir Welo

Deltakere ved kartleggingen (m/ funksjon): Martin Steinert /supervisor

Risikovurderingen gjelder hovedaktivitet: Master thesis for student: 716035. Setting up and conducting interaction design experiment

Signaturer: *Ansvarlig veileder:* *Student:*

ID nr	Aktivitet fra kartleggings-skjemaet	Mulig uønsket hendelse/ belastning	Vurdering av sannsyn-lighet	Vurdering av konsekvens:				Risiko-Verdi (menn-eske)	Kommentarer/status Forslag til tiltak
			(1-5)	Menneske (A-E)	Ytre miljø (A-E)	Øk/ materiell (A-E)	Om-dømme (A-E)		
1	Interaction design experiment exposing students to stress/nonstress conditions	Subjects could faint because of being stressed from being in a cardboard box and playing stressful game.	1	A1	A1	A1	A1	A1	Students are always monitored/supervised. The supervisor and consent paper also inform that they are free to stop the experiment at any time if wanted.
2	Connecting Airflow sensor	With airflow sensor, they can infect others if they have a cold or flu.	2	A2	A1	A1	A1	A1	It is important to disinfect sensors between subjects.
3	ECG	The students are volunteering to have disposable electrodes fitted to chest (Students put these on themselves). Students could be allergic to the disinfection fluid (ethanol) or the electrodes.	1	A1	A1	A1	A1	A1	Inform the students about this beforehand and supervise the students.
4	Saliva probes	Students can be allergic to the saliva probes equipment.	1	A1	A1	A1	A1	A1	Inform about saliva probes beforehand.

5	Epilepsy	In the ship simulator box, there is the possibility to adjust the LED lights in the roof and the light from the computer screens will vary. There might be subjects with epilepsy and that these factors might trigger an epilepsy seizure.	1	D1	A1	A1	C1	D1	The students are always supervised during the experiment and have the option to leave at any point. Also possible to ask the subjects if they are in this risk category beforehand, i.e. in the questionnaire.
6	Building the ship bridge simulator.	Possiblity of injuries during the construction of the ship bridge mockup.	1	A1	A1	A1	A1	A1	We use “safe" materials such as light-weight cardboard, and stable parts such as tables and chairs.