Streamlining research processes by organising, coordinating and analysing medical test data and video material

- In the context of CLE testing and ILO research

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Abstract

After many years of research, the condition Induced Laryngeal Obstruction (ILO) recently became an official diagnose. However, a lot is yet to be explored regarding the condition and its role in the respiratory system [1]. A Continuous Laryngeal Exercise (CLE) test is performed in order to be able to diagnose, research and determine treatment for ILO. Bergen ILO Group's current research process for studying cardiopulmonary data and video material collected from CLE tests involves a lot of time consuming, and possibly erroneous, manual data plotting and processing. There are even some areas of investigation that are possible to explore, but due to lack of resources, this is not carried out. Software engineering can create efficient and useful research tools for streamlining such a process. This thesis proposes a generalised software system that can be applied in both the research process of ILO, and those of other disciplines and institutions. The system provides organisation and handling of time-based medical test data, statistical analysis and coordination of test data and video material. The development process and the resulting software system will be described, and contributions it potentially can bring to any research process that entails studying medical test data will be presented.

Acknowledgements

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Acronyms

AWS Amazon Web Services.

BF Breathing Frequency.

CLE Continuous Laryngeal Exercise.

COVID-19 Coronavirus Disease.

CPD Cardiopulmonary Disease.

CPET Cardiopulmonary Exercise Test.

ECG Electrocardiography.

EILO Exercise-Induced Laryngeal Obstruction.

GC Google Cloud.

GDPR General Data Protection Regulation.

HF Heart Frequency.

ILO Induced Laryngeal Obstruction.

IS Information System.

LAN Local Area Network.

MVP Minimum Viable Product.

RCT Randomised Control Trial.

RMSE Root-Mean-Square Error.

SARS Severe Acute Respiratory Syndrome.

SARS-CoV-2 Severe Acute Respiratory Syndrome Coronavirus 2.

UWP Universal Windows Platform.

WPF Windows Presentation Foundation.

Chapter 1

Introduction

The fields of medicine and technology have made great advances during the last 30-40 years. Several modern areas of research have appeared following this development [2]. An example of this is the long term survival prospects for premature borns, which has improved drastically [3]. This has exposed a need for research of the long term consequences to prematurity [2]. We can also look at this from another side, and see that people these days live longer, but also with more long term conditions [4]. This is yet another example of a modern need for more research.

Bergen ILO Group is a research group at Haukeland University Hospital that studies the respiratory system as a whole with a focus on the role of the larynx (see section 2.1). This research is conducted in the context of prematurity, among others. They are, therefore, part of a multidisciplinary collection of collaborating research groups called WestPaed Research [5], who all contribute to the research of prematurity with findings from their crossing fields. Bergen ILO Group's area of research has remained relatively unexplored until quite recently, and their innovative solution for studying the larynx during activity has enabled a new technique for investigation. However, as they collect large amounts of data for their studies, their research process is quite complex.

The field of medicine is becoming increasingly automated, and health information systems is a continuously evolving discipline emerging from the intersection between information science, computer science, and health care. Digital healthcare technologies should be part of solving the healthcare challenges of the 21st-century [4]. Health information systems can make way for more efficient and rigorous medical research, as the research can be conducted in a more structured and efficient way by automating parts of the process of collecting, organising and analysing data. The topic of this thesis is *coordination, processing, and analysis of diagnostic cardiopulmonary test data and associated video and audio material*.

This thesis aims to support and enhance research processes by proposing a software system containing features that work together to fulfill these goals. The software system is first and foremost applied to Bergen ILO Group's research process, which studies the condition Induced Laryngeal Obstruction (ILO) by performing Continuous Laryngeal Exercise (CLE) tests and analysing the results. The larynx is an organ situated in the top of the lower airway system. ILO is a condition where the patient experiences difficulty breathing caused by dynamic obstructions of the larynx. The current research process is quite complex, and this thesis aims to streamline it. The resulting impact on their research is presented and evaluated, and the system's ability to be applied within other disciplines and institutions is explored. The proposed software system consists of two components which together work as a complete system for importing, organising, visualising, analysing, and exporting medical test data.

1.1 Context

This thesis and its associated work were conducted for the research group Bergen ILO Group at Haukeland University Hospital [6]. Associate Professor, MD Hege Clemm was part of the main contact group together with physiotherapists Haakon Kvidaland, MSc Lars Peder Bovim, and Professor Ola Røksund. As mentioned, the topic of Bergen ILO's research is Induced Laryngeal Obstruction (ILO). According to Bergen ILO Group, the larynx has traditionally been overlooked in studies of the respiratory system. Their goal is to view the respiratory system as a whole and investigate its components with a focus on Induced Laryngeal Obstruction (ILO).

Figure 1.1: An overview of the setup of a CLE test

The current gold standard method for diagnosing ILO is a Continuous Laryngeal Exercise (CLE) test, which forms the basis of research and treatment of ILO patients. The CLE test includes a Cardiopulmonary Exercise Test (CPET), where the participant runs on a treadmill until exhaustion (see figure 1.1). In addition to the CPET, some video and audio material is displayed and recorded. There is one camera situated at the end of a flexible laryngoscope, filming the larynx of the participant. Another camera is directed from the front so that the upper body and face are in focus. There is also a microphone which purpose is to record the breathing and vocal sounds of the participant. [7].

Today's solution for gathering and showing video material from the CLE test is a software program developed by Profitek AS. In addition to the video material from the CLE test, it receives a screen capture of the user interface of an application called SentrySuite [8] that gathers, analyses, and shows the data from the CPET. A 0.7-second delay is added to the video streams to compensate for the calculation delay for the CPET data. The Profitek program shows the video streams while simultaneously recording a screen capture of the computer it is running on. The

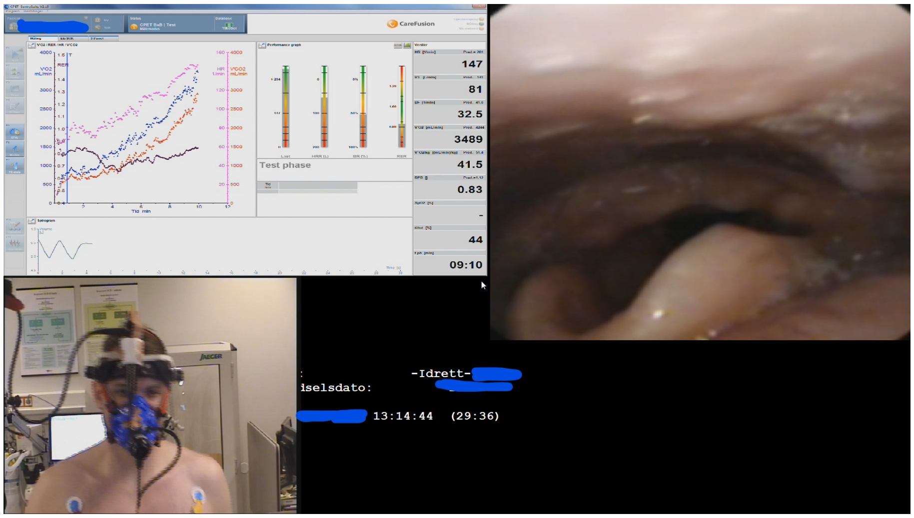

Figure 1.2: Screenshot of the Profitek application showing video streams from a real CLE test

result is one single video containing all the streams. In addition to the functionality for gathering and showing video, the Profitek application lets the user input the date of birth and the research number of the participant. This information is then displayed on the user interface of the application while a test is running. Figure 1.2 shows a screenshot of an actual test conducted in the Profitek application. Personal data in the image has been redacted in blue.

However, the Profitek program is far outdated, concerning both usability and output quality. The resolution of the streaming and the video it produces is very poor, and video lag can occur frequently. The resolution issue is a significant problem concerning the screen capture of the SentrySuite application, as it is usually not possible to read accurate values from the graphs. In addition, the meta-information about the participant is partly covered by the videos. This also leads to a different problem; this data should not be visible in this way at all. Anonymity plays a big part in medical research, and showing these data creates an obstacle to achieve that. This also goes for the screen capture of SentrySuite, where personal data is also displayed.

Another issue is that the program only shows data from one single CLE test at a time. It is clinically useful, but when it comes to conducting research on several tests, the solution is inadequate. During the last 15 years, over 3000 CLE tests have been conducted at Haukeland University Hospital [9], and this points to an apparent need of structure and statistics. The hardware requirements for the Profitek program are also extensive, including a need for a specific, local cable setup and a seemingly arbitrary video format requirement that has appeared quite recently. Ideally, the program should be completely flexible and be able to read any video stream coming from any input. A program with the purpose of collecting and presenting medical data should be stable, intuitive and easy to use.

Due to deficiencies of the Profitek program, Bergen ILO wants a new solution to replace it. They also want a number of new features, including functionality for saving each video stream individually, saving the CPET data directly in the new solution, and to be able to see, compare and analyse several tests at once. As of today, they are using a separate application for analysing the course of individual tests, but if they want to analyse tests on group-level, they have to do this manually. A long-term goal is to make the new solution into a product that can be distributed to both other areas of research and other institutions. This means that the solution should be possible to use in the context of a CLE test and for any other use where medical test data and video material are involved.

In cooperation with VIS Innovasjon, who had the role of managing and funding the development of the application, Bergen ILO gave the task of developing this new solution that would replace the Profitek application to the software consultancy company Rainfall. Rainfall proceeded to develop a Windows application that would work as a Minimum Viable Product (MVP) for the new solution that Bergen ILO requested. The MVP can show and save video streams individually, associate a set of videos and data to a client and show a set of graphs per test session.

1.2 Problem description

This thesis proposes a software system which purpose is to be used as a tool in streamlining research processes. Bergen ILO Group's research process functions as an initial use case, and all implemented features are based on their needs. However, the superior goal was to create an innovative product that could also be used within other disciplines and possibly other institutions. The following challenges regarding the design and implementation of the software system were identified.

The workflow of moving the medical test data from its source to CleDashboard should be optimised considering both user-friendliness, safety, and efficiency. Therefore, access to the SentrySuite application was requested at the beginning of the project so that this whole workflow could be completely automated. However, this was denied. The medical-technical department of Haukeland University Hospital could not grant access to the data, as this theoretically could lead to privacy breaches. Hence, other solutions had to be explored regarding transferring of data.

A CLE test collects video material, audio material, and medical test data in the form of time series. Therefore, these elements have to be synchronised, which is problematic as SentrySuite is running on its own, separate computer. SentrySuite can put a time stamp on the test start, but this only accounts for the computer where SentrySuite runs. This makes the task of synchronising the data with its associated video material quite complex, which again can be problematic for the subsequent data and video analysis.

Another significant challenge is creating good design and high usability. Considering that the software system's target user group is hospital workers and researchers, user experience is an aspect that requires focus throughout the entire development process. Presenting the functionality with an appropriate vocabulary and following a recognisable and intuitive structure is essential.

When developing a complex software system, some challenges arise concerning the planning, structuring, and implementation of the system. A solution to this is to divide the system into artifacts by applying design science methodology and behavioural science (see section 3.1) as the research framework, which also fits an agile development method.

The following research questions were identified:

RQ: How can a software system streamline and enhance research processes that involve coordination, statistical analysis and synchronisation of medical test data and associated audiovisual material?

- **a)** How should data be organised to allow for a structure well fit for statistical analysis covering several selectable medical tests, and what value does this create for Bergen ILO Group?
- **b)** How can statistical analysis be performed and visualised based on data from selected CLE tests, and what impact will the new insight gained from doing so have on the research of ILO?
- **c)** How can the software system be developed in such a general way that it also can be applied within other disciplines and institutions?

1.3 Thesis outline

This thesis will first present the theoretical background knowledge that was necessary to possess in order to develop the proposed software system, see chapter 2. Chapter 3 explains the research and development method utilised in the thesis project. Chapter 4 describes the design and implementation of all the components and features of the system. Chapter 5 presents the system as a whole by applying it to an actual use case by Bergen ILO Group, and then evaluates it based on an interview with a key target user. A discussion of the generality of the system and answers to the research questions are to be found in chapter 6. The conclusion, which gives a summary of this thesis and its contribution, is found in chapter 7, together with a listing of further work that should be conducted in the future.

Chapter 2

Theoretical background

The domain of this thesis' research is of an interdisciplinary nature. First of all, we need a thorough understanding of the diagnostic tools and research process of ILO. We also need to be supported by a strong background in software development and to know how to use statistical analysis. In order to enhance the ILO research, we need to combine the knowledge from all these domains. As the proposed software system is aimed at researchers, we also need to keep a focus on user experience to efficiently streamline their research process.

2.1 Induced Laryngeal Obstruction

To understand the ILO condition, we first need some knowledge of the larynx and its role in the respiratory system. We also need to know how a malfunction of the larynx interferes with an individual's health. Then, we will consider the current research process of ILO.

2.1.1 Larynx

The vocal cords are part of the larynx, so one function of the larynx is to produce the vocal sounds. The other function is to protect the lower respiratory tract from any aspiration of food or other foreign objects. To perform this protection, both supraglottic structures and glottic structures in the larynx can narrow and fully enclose. However, during exercise, both supraglottic structures and glottic structures are normally standing wide open both during inspiration and expiration. See figure 2.1 for an overview of the larynx anatomy.

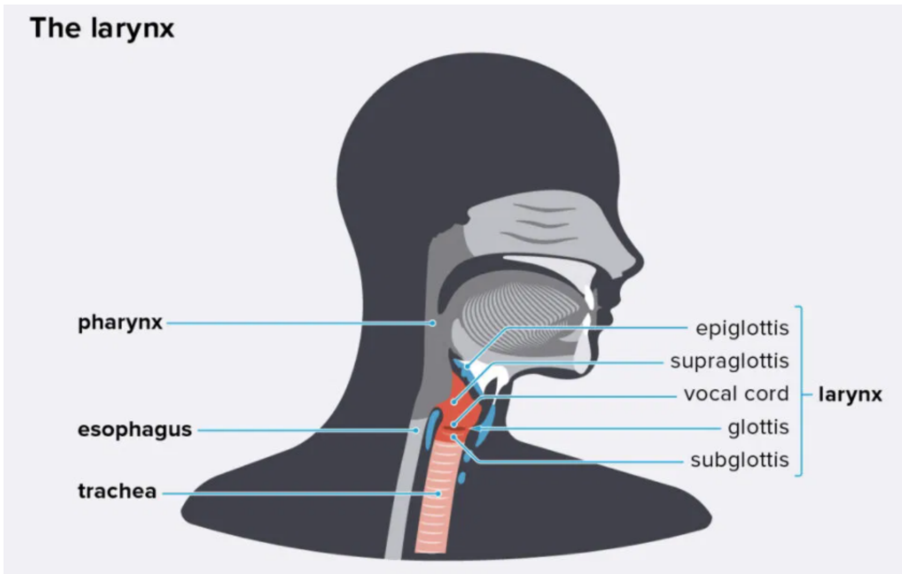

Figure 2.1: Anatomy of the larynx, image from [10].

A patient with ILO has a normal functional larynx at rest. However, with increased exercise, either the supraglottic structures, glottic structures or both are obstructing during inspiration. Most commonly, the obstructions seem to originate from the supraglottic structures during inspiration [11]. This narrowing or enclosing is most commonly induced by exercise, but emotional stress or irritants can also induce ILO. The narrowing typically peaks at maximum distress [1]. As the severity of ILO varies, a visual grade scoring system as demonstrated in figure 2.2 has been introduced by airway scientists to classify patients.

A prevalence and symptom study conducted in Copenhagen showed that 7.5 % of the 556 randomly selected subjects aged 14-24 years had Exercise-Induced Laryngeal Obstruction (EILO) [12]. EILO can contribute as a driving force to stop activity, which again leads to reduced health and a lower quality of life.

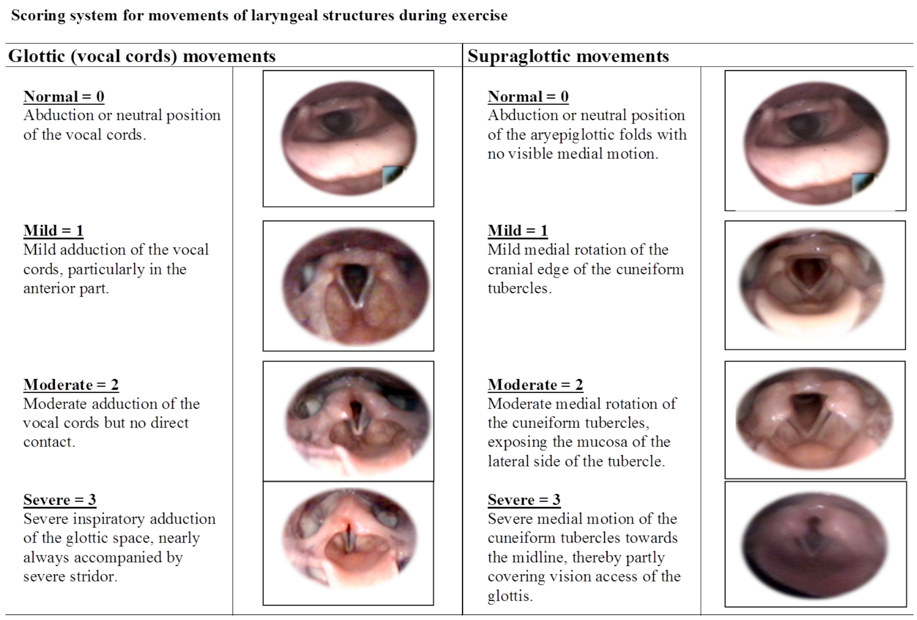

Figure 2.2: ILO grade scoring system

2.1.2 Current research process

When conducting research, Bergen ILO Group is interested in looking at the development in breathing pattern crossing several CLE tests. They might want to look at differences between some populations whose characteristics vary. They might also want to see the development before and after some intervention, for example, a treatment. They are looking for similarities and differences, both on an individual and group level. Their current research process is quite complex and consists of the following workflow:

1. Collect cardiopulmonary data and audiovisual material through CLE-tests.
2. Process, plot and analyse the cardiopulmonary test data.
3. Consider the video and audio material in the light of data analysis results.

In order to collect the medical test data and video- and audio-material from each CLE test, Bergen ILO Group has to follow the workflow displayed in figure 2.3. The green dotted arrows symbolise manual operations, while the black ones are operations that occur automatically. Suppose they are going to analyse more than one

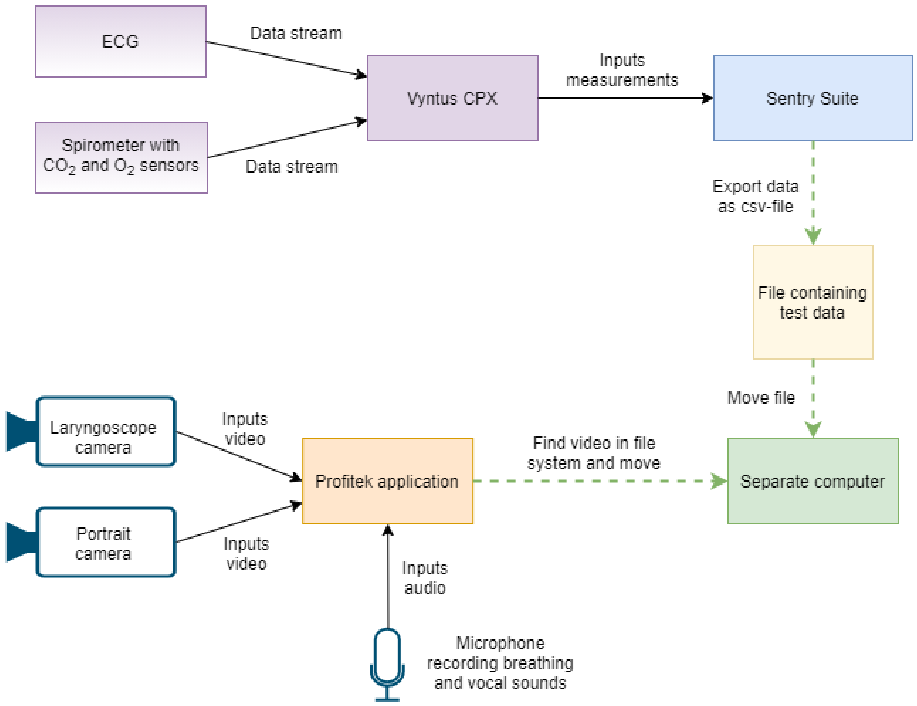

Figure 2.3: Current workflow for conducting a CLE-test and collecting all the test data and video-and audio-material in one computer.

CLE-test. In that case, they have to follow the workflow in figure 2.5, which occurs after finishing the one in figure 2.3 in order to process and analyse the data. After all the data is ready, the workflow loop in figure 2.6 can start if they also wish to study events in the video material.

As previously mentioned, a CLE test involves a Cardiopulmonary Exercise Test (CPET). The CPET is performed using a Vyntus CPX, which is a stationary CPET-system [13]. The CPET measures both respiratory and cardiac data. It has an instrument connected to a mouthpiece that contains sensors for measuring the content of O_2 (oxygen uptake) and CO_2 (carbon dioxide output) per breath, and a flow sensor (spirometer) measuring the volume of each breath. The heart rate is also measured using an Electrocardiography (ECG) unit. [7] The Vyntus CPX machine inputs the measured data into a software program called SentrySuite, which runs on a separate computer. This program visualises the data to the user, and calculates derived values from the original measurements. The values are measured per breath, and the calculation of derived values takes 0.7 seconds. SentrySuite has a feature that lets the user export the measured data from one CPET to a file, and to add meta-information on the top of that file. This can be age, name, test date, test start time and so on. See appendix A for an example of such a file from a real CLE-test. The CLE test also includes 3 phases; *rest*, *test* and *recover*. These phases can also be added to the exported file, plotted next to their start time. After selecting the data the file should contain, it is exported to the file system. From there, it can be moved onto the computer where the researcher wants to use it.

The other part of a CLE-test is the recording of video and audio. The participant's laryngeal movements are filmed using a fiber-optic laryngoscope that is linked to a video camera. The laryngoscope is threaded into the throat of the participant, first through a hole in the mask and then through the nose. The connected part is mounted on a special, patented head rack. See figure 2.4 for demonstration. The camera filming the participant from the front is referred to as the portrait camera, and a microphone is placed on the participant to record breathing and vocal sounds.

Figure 2.4: Participant wearing the laryngoscope mounted to the head rack.

As previously explained, the Profitek application exports each test as one video file containing all the material (as seen in figure 1.2). The location and name of this video file are dependent on the user. Bergen ILO Group uses a system where they put all the files into the same folder, and they use the file name as an identifier for that test. They try to follow a file name convention. When this video file is to be used in some analysis, it is usually copied into the computer where the analysis is conducted.

After all the data and video material is collected into one computer, the workflow in figure 2.5 initiates. As the SentrySuite application can only export data from one individual test at a time, analysis covering several tests has to be done manually by following this procedure.

Step 1 involves opening the exported file from SentrySuite in Excel. This is because it is necessary to convert it into a CSV file and possibly clean some details. This

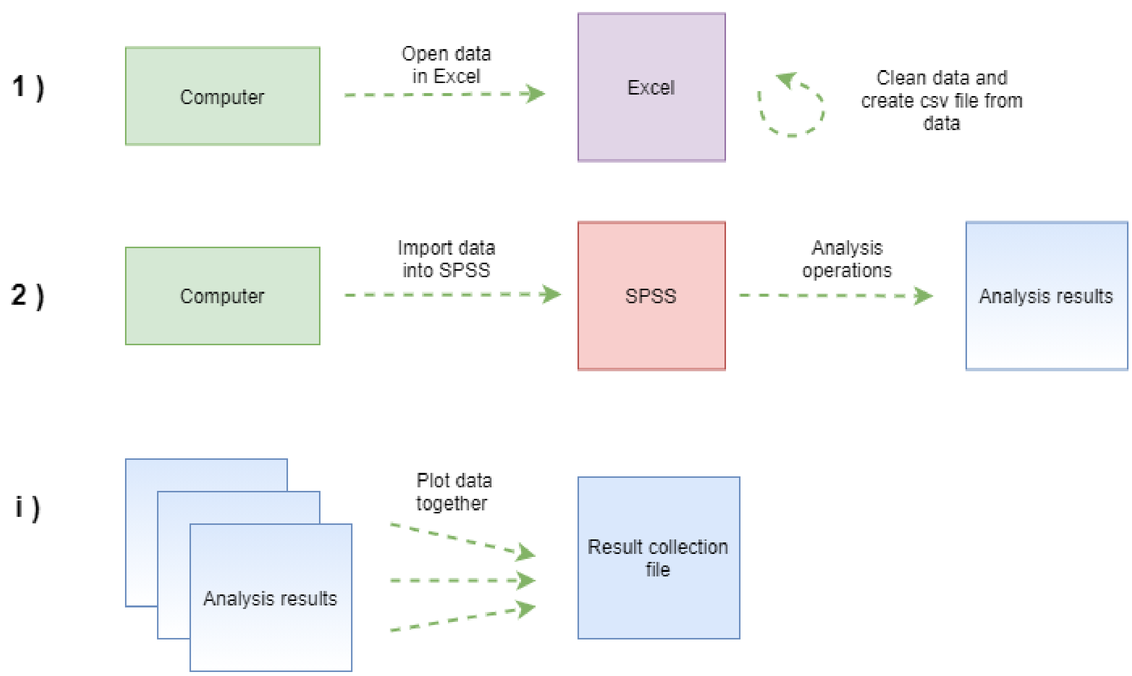

Figure 2.5: Workflow for processing and analysing data once it is collected into a computer

means that there sometimes are some comma-signs that need to be replaced with a period-sign, and sometimes there are other issues as for example, symbols appearing in the data tables. After finishing the preparation of the file, step 2 can commence. The file can be imported into an application for data analysis, and the one Bergen ILO Group usually utilises is SPSS by IBM [14]. Steps 1 and 2 have to be conducted until all analysis results are ready, and then they get plotted together into a file where all results are collected in an organised manner as step i. This whole process is quite time-consuming, and as the plotting is conducted manually, it can be erroneous. There is clearly potential to automate this process.

To connect the data analysis from one or many CLE tests with events in the belonging video and audio material is a complex task. After going through the workflows in figure 2.3 and 2.5, Bergen ILO Group has the information they need in order to study the video material. Whenever a researcher of Bergen ILO Group sees an event of interest in the graphs or analysis results, it is sometimes relevant to also observe that same event in the associated video and audio material. This is because they want to see which state the laryngeal structures are in, if the participant has any visible reaction and if they can hear vocal wheezing sounds or constrained breathing caused by ILO in the audio. See figure 2.6 for a visualisation of the procedure for doing so. To find the time of the event, the researcher first has to find the start time of the test. Then, she has to find out how much time had passed in the test at the time of the event. That is because the time series that the SentrySuite application produces starts at 00:00, not at the actual start time of the test. When she adds

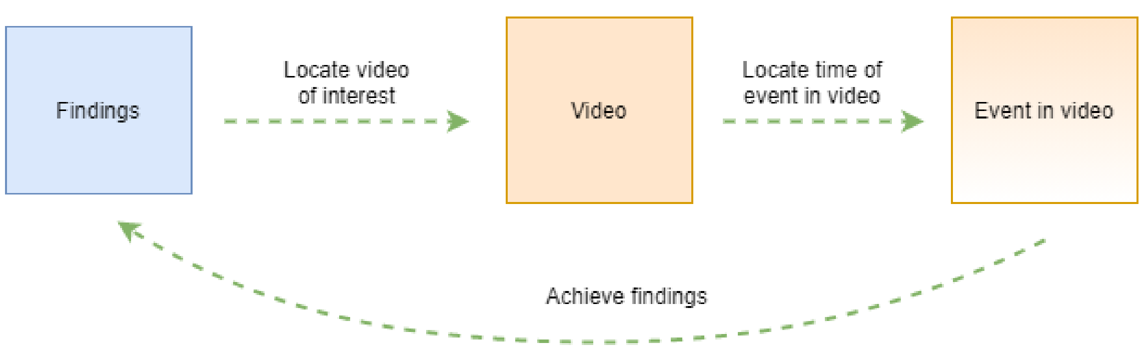

Figure 2.6: Workflow for coordinating event of interest in test data analysis with associated video material

this amount of passed time to the starting time of the test, she gets the time of the event in question. After the correct file is located for the test they want to study, the remaining task is to find the correct time in the video. As a certain delay caused by the Vyntus-machine is set, this has to be taken into account when setting the correct time in the video. Also, they base the event time on the time display in the Profitek application. However, the displayed time reflects the time set on the computer where the Profitek application is running, which is not necessarily the same as the local computer clock where SentrySuite is running. Observations are made when the event is finally located in the video or audio, which again adds value to the findings.

2.2 Statistics

2.2.1 Smoothing

Smoothing a data set is a technique that can be applied when the measurements are noisy, and we are looking for the general trend of the data. During CLE-tests, the respiratory data is measured per breath. However, the breath-by-breath pattern usually contains disturbance for some of the measurements. One uses either a set sample size or a set time interval as a smoothing value when smoothing a data set.

For example, say we have a set of 40 measurements over time of the oxygen uptake per breath from a CLE-test. Each measurement corresponds to a breath and has both an x- and a y-value. The x-value is the oxygen uptake per breath, and the y-value is the time passed since the test start. If we smooth this dataset with a sample size of 4, we divide the dataset into 10 subsets, each containing 4 samples. We then make a new dataset of size 10, which contains the average values from the data points in each of these 10 intervals. As the data points both have an x- and y-value, the new data points are on the form (average x, average y). See figure 2.7 for a visualisation of this procedure. The same procedure is applied if we use a time interval as a smoothing value, except the new subsets contain data points with a time value (x-value) within the set time interval. This alternative produces a result where an uneven number of data points might make up the average values.

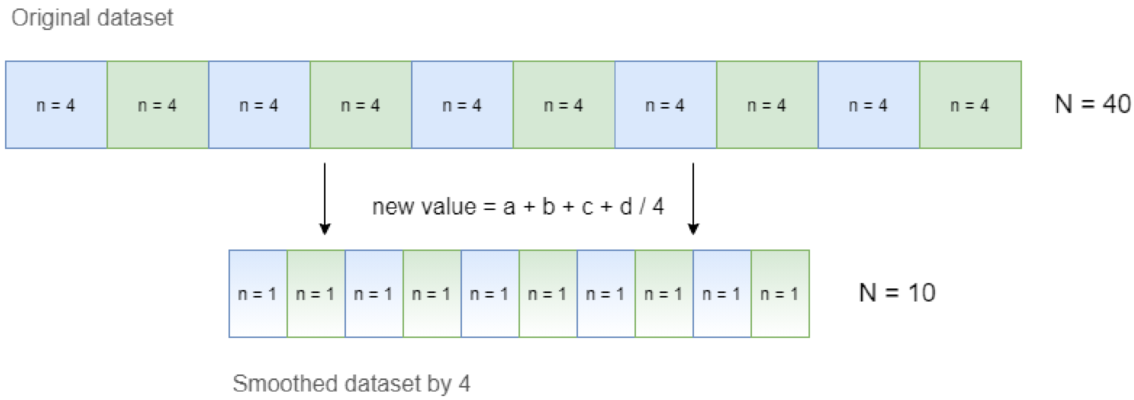

Figure 2.7: Procedure for smoothing a dataset with a sample size 4.

By applying the smoothing technique, the data appears cleaner and is easier to read. As for now, Bergen ILO Group exports data that is already smoothed by SentrySuite. However, if they later want to change the interval of the smoothing, this is not possible. Therefore, the optimal solution is to always export the full raw data and then rather smooth it in the analysis application. This way, there is no data loss.

2.2.2 Regression

Regression is a statistical method for finding the relationship between one dependent and one or more independent variables [15]. An essential part of conducting a CLE-test is to look at the relationship between certain measurements. When it is assumed that there is an existing relationship between some given measured variables X and Y, it can be helpful to find a function that approximates the set of data points emerging from these variables. The nature of this relationship will differ depending on the context, and both a linear and a polynomial approach can be applied to approximate it. Therefore, selecting the optimal regression model for calculating a function to present the relationship between the variables correctly is a challenge.

In this thesis, the method of least squares is used as the regression method. Suppose we have a line that that predicts y using x. n denotes the number of points in our set of measurements. The error made in each point in our set is equal to the vertical distance of the point to the line. Let the average distance be defined as the Root-Mean-Square Error (RMSE) of the line. The goal is to find the line (or polynomial) that gives us the least RMSE. The function of any line is as follows:

$$y(x) = ax + b$$

This means that we have to minimise the RMSE of y by tweaking the values of a and b. However, if we want to use polynomial regression of nth degree, the following function is replacing the former. In this case, n is input as the degree we want to use, and the constants a_0 - a_n are tweaked in order to minimise the r.m.s. error [16].

$$y(x) = a_n x^n + a_{n\text{-}1} x^{n\text{-}1} + ... + a_1 x + a_0$$

2.2.3 Average and standard deviation

The average of some n variables is equal to their sum divided by n [16]. When conducting research and dealing with large amounts of data, the average is useful as one can present a whole population's values by a single one. However, the accuracy of the presentation varies. Standard deviation is a kind of descriptive statistics, as it is a measure of the spread around the average. A low standard deviation indicates that most measurements were around the average, and a high one indicates that the measurements are more spread. In a normal distribution, all measurements are symmetrically distributed around the average, as shown in figure 2.8. The more normally distributed a dataset is, the more a reliable metric is the standard deviation for that dataset [16]. The formula to calculate the standard deviation for a sample is as follows. X is each value in the sample, $\bar{x}$ is the mean value, and n is the number of values in the sample.

$$SD = \sqrt{\frac{\sum (X - \bar{x})^2}{n - 1}}$$

2.2.4 Slope

When investigating measurements from a CPET, it is of interest to know at which rate some variable a increases or decreases in relation to another variable b. This

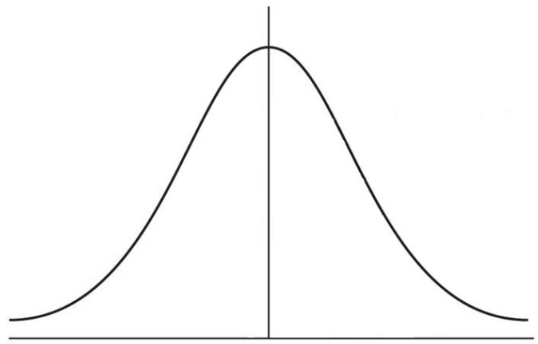

Figure 2.8: Normal distribution

rate is called the slope of a and b. It is equal to the ratio between the change from the first to the last included measurement of a, and the change from the first to the last included measurement of b [16]. See equation, where the numbers 1 and 2 denotes the first and last included values of the variable:

$$slope(a, b) = \frac{a_1 - a_2}{b_1 - b_2}$$

2.3 GDPR and medical technical equipment

The purpose of General Data Protection Regulation (GDPR) is to protect people's fundamental rights and freedoms concerning their personal data, as an EU data protection law. GDPR states that just adequate personal data should be collected for specified and legitimate reasons, and the data should be processed in a lawfully, fairly, and transparent manner that ensures security. The data should be kept with integrity and be up to date [17]. Health-related data are personal data considered sensitive by article 9 GDPR [18]. However, GDPR should not be perceived as an obstacle for research but rather as guidelines for conducting ethic-legal investigation. Innovation is encouraged by GDPR, as it provides some exemptions from its rules enabling scientific research [19]. As this thesis focuses on the development of software research tools, it has to be kept in mind that medical-technical equipment has to be compliant with GDPR. Developing a robust, secure software system is therefore vital.

2.4 User experience

As the overall goal for this project is to develop a software system that will automate any research project, it is important to keep in mind that the target group is hospital workers and researchers. Usability is a metric that tells us to which extent a system, product, or service lets the user achieve some set goals in a set context while providing effectiveness, efficiency, and satisfaction [20]. Usability and design were initially not a direct goal for this thesis, but in order to create a quality product, it is important to keep the user in mind while developing and designing it. Data visualisation is also an important subject in this thesis, and the objective is for the visualisation to be clear and provide an overview for the user.

Chapter 3

Methodology

3.1 Design science

Design science research is a problem-solving paradigm that emerges from engineering and computer science, and it seeks to improve an environment and expand the capabilities of humans and organisations through innovation [21]. Its overall goal is to innovate real solutions based on ideas, practices, technical capabilities, and products [22]. Design science partitions the product into artifacts. Knowledge and understanding of each problem domain are highly valued, and are encountered in the building and application of an artifact which acts as a designed solution to that problem. An artifact can be in the form of a model, construct, method, or instantiation.

The nominal development process of a solution to each artifact is called an iteration. The iteration is partitioned into two processes, building and evaluating the associated artifact. Guidelines have been proposed in order to conduct systematic and high-quality design science research. In summary, they encourage to utilise all available means to design relevant and viable artifacts that create verifiable contributions to their domain. The utility, quality, and efficacy of each artifact should be demonstrated through well-executed evaluation methods. Lastly, the research should be communicated to all relevant parties. These guidelines and the cycles in which they apply are demonstrated in figure 3.1 [23].

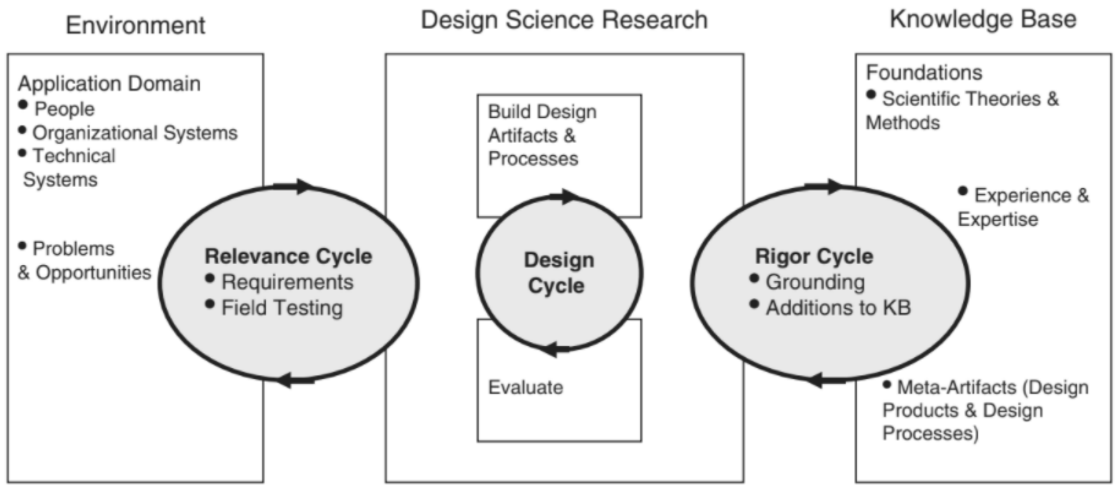

Figure 3.1: The cycles of design science research, figure from [23].

When conducting design science research, it is important to keep in mind that a strong theoretical background is crucial to achieving valid results. Behavioural science research is a paradigm that predicts or explains both human (individual) and organisational interaction with information systems. It explains this behaviour through the development and verification of theories. The behaviour concerns analysis, design, implementation, and use of information systems. The goal is for these theories to be used in order to improve efficiency and effectiveness within an organisation.

Together, the behavioural and design science research work as a cycle. Behavioural science research provides knowledge and understanding (truth) to design science research. In turn, design science brings utility to the behavioral science research. The research result and its practical relevance should be equally valued as the research's quality, methods, and trustworthiness [22].

Innovation and research make way for technological advances, and both are present in this thesis. A systematic approach to conduct research is key, and in this context, it was well-fitting to apply this qualitative method in order to answer the research questions. Design science and behavioural science was therefore used as the framework for the conducted Information System (IS) research.

Acquiring domain knowledge

As the research of this thesis is of an interdisciplinary nature, we consider two domains; the domain of ILO-research with its research process including CLE-testing, and the domain of software engineering. Prior to the start of the thesis project, a base of knowledge of both domains already existed. My classmate and I wrote our bachelor thesis *"Software for collecting and presenting lung test data at Haukeland University Hospital"* [24] for Bergen ILO Group, and with it we developed a Windows Presentation Foundation (WPF) application as a proof of concept to a replacement for the Profitek application. In fact, Rainfall's MVP was developed after the approval of this proof of concept. I also took part in Rainfall's development of the MVP, which gave me knowledge of the codebase. This was later on important when I was developing CleDashboard as an upgraded version 2 to that MVP.

I also had a lot of ideas, inspiration, and knowledge from participating in meetings regarding ILO research. I was included in both Bergen ILO Group's semi-monthly meetings and their meetings for HelpILO with their regional treatment network for difficult-to-treat respiratory problems. Furthermore, I created two websites for Bergen ILO, `https://www.westpaed.com` and `https://www.helpilo.com`. The work to create these websites was done independently of this thesis and its project. However, as their purposes are to inform about respectively WestPaed Research and the research project HelpILO, the information they provide is quite relevant for my collection of domain knowledge and the planning and designing of the proposed software system.

3.2 Development method

The proposed software system was developed using an agile development method, which fit the project well since the development was continuous throughout the year and meetings with the Bergen ILO group took place when planning was needed. The most recent work was evaluated in these meetings, and requests and ideas for new features were made. As these requests came from the actual basis target users, the development was primarily user-story driven [25]. The main requirement artifacts originated from Bergen ILO Group's descriptions of the capabilities they wanted to have. This development method corresponded with the Design Cycle demonstrated in figure 3.1. Independent, logical thinking and planning of how the features should emerge from artifacts was then conducted after the meetings. Each feature was given a priority based on the wishes of the product owner or its requirements. Which feature was being developed at a given time switched continuously depending on the overall state of the application. This means that even though a feature may not be optimally working after finishing a certain task, it was better to focus on the development of more crucial features rather than finishing the rest of the tasks for the current feature right away. This led to an agile way of working, where the priority order of tasks making up features would change dynamically.

The proposed software system was implemented using incremental development, where each increment corresponded to an improved artifact in the system. There was a continuous focus on having a working solution. As the application grew and got more complex with each increment, it became important to have a structured manner of designing each artifact and planning its implementation. Therefore, a Kanban board was taken into use, as it is a well-fitting approach to both planning and creating an overview of a development process. The Kanban board allows the user to create tasks with a title, description, and priority in a hierarchical structure, meaning that each task can have sub-tasks. The top-level of the hierarchy is made of epics, which normally are used for a whole component or module and works as a superior goal to its tasks [26]. So, each module of the proposed software system was presented as an epic, and its features as collections of tasks. New ideas for functionality were immediately put on the board, which made planning easier.

As mentioned earlier, the superior goal for the project was to innovate a product that could be used in other settings than just CLE-testing. It was, therefore, always kept in mind that each feature should not be too specific to any part of Bergen ILO Group's research and rather be as general as possible. For example, this meant that a broad perspective of the structuring of data was necessary. The domain knowledge of the Bergen ILO Group's position as a sub-group of WestPaed Research served as a good example for this perspective. This superior purpose actually benefited other parts of the application, as it led to a structure that allowed for several research projects to utilise the software system and was also the most sensible and general solution for structuring the data to be able to perform statistical analysis on it.

Chapter 4

Design and implementation

This section will explain and demonstrate all the features that make up the proposed software system, and how the features were implemented, and the process of designing them will be elaborated. The system consists of two components. The first one is a program called MedDataWatcher, which aims to gather and coordinate medical test data. The second component is an application called CleDashboard. It contains functionality for showing and recording video and audio material from a CLE-test and organising that material and belonging medical test data together with its associated participant into a hierarchy of research projects. It provides statistical analysis for any selected tests and synchronises it with the video and audio material. Also, both raw and processed data can be exported for selected research projects or participants, containing data the user can mark for export.

The development process of CleDashboard started by contributing to Rainfall's MVP. The MVP was completed relatively early in the thesis project, so the next step was to build version 2 based on it. That version 2 is CleDashboard, and it has diverged quite a lot from its original codebase by altering, restructuring, and adding to it. CleDashboard includes a more extensive organisation of data and carries many new features with its additional 10 000 lines of code.

The general requirements that were identified for the proposed software system are summed up in figure 4.1, meaning these are elements that all had to be incorporated into the software system for it to meet the goals that were set for it. The require-

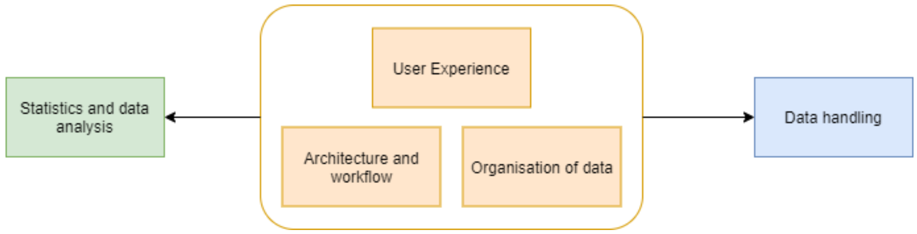

Figure 4.1: The requirements of the proposed software system

ments of user experience, architecture and workflow, and organisation of data are marked in yellow to communicate that they all work together as the foundation of the solution and affect the other parts.

4.1 Technical resources

The CLE test application was written in the programming language C# in Universal Windows Platform (UWP), as the goal was to develop a Windows application. The .NET library OxyPlot was used for plotting graphs [27]. The NMath package built on the .NET Standard Library 2.0 by CenterSpace Software was used for regression and statistical analysis [28]. MedDataWatcher is written using JavaScript, and ran in a Node-project [29]. The package Chokidar is used for file watching [30].

4.2 User experience

As previously mentioned in section 1.2, the development of CleDashboard consisted of alterations, improvements, and additions to Rainfall's MVP. As the MVP's only purpose was to reach a set of goals for some core functionality, user experience naturally was not a priority in its development process. However, as the overall goal was to streamline research processes, the user experience was considered part of achieving this. Good and efficient user interaction adds value to the streamlining.

4.2.1 User workflow

The user workflow is a key part of the user experience. In order to enhance user workflow and allow for statistical analysis in CleDashboard, a restructuring of the application architecture was necessary. The architecture refers to both the structuring of data in the database and the codebase. This restructuring resulted in a better workflow for the user, reduced the risk of user error, and generally improved the user experience. The two main workflows within CleDashboard are to perform a CLE test and to see data from one or more selected tests. The goal was to minimise the number of necessary clicks to carry out these workflows. As some parts of the existing workflows in the MVP could be automated, there was potential to reduce the number of clicks. An example of this is that initially, the user had to manually select all the video and audio sources that should be included in a test. However, usually, a user wants to use all available sources. This was therefore automated so that all sources are automatically selected in CleDashboard. This is also the most common practice for media streaming services, so this characteristic makes CleDashboard more intuitive to the users.

4.2.2 Visual design

The visual design, layout, and feature communication together formed an artifact introduced as a vital part of the user experience. The objective was for the application to provide a good overview of all medical test data with associated video material, and all features should be easily located and visible. The application should be intuitive and organised in a sensible way considering the target user group consisting of hospital workers and researchers. Even though the design does not provide any direct value to the research process, it is a way of gaining the user's trust. A light beige and white theme with a lot of space was applied, to match the modern conventions and keep a professional impression as the software is meant to be used by serious institutions. Some green and blue details were also applied, which respectively matched the color palette of the website `https://www.helpilo.com/` associated with Bergen ILO Group's research project HelpILO, and the website `https://www.westpaed.com/` associated to WestPaed Research, which Bergen ILO Group is part of. This was done to infer a red thread to the work of the research group.

4.2.3 Visualisation of data

Visualisation of medical test data is a core functionality for CleDashboard. For each CLE test, several measurements are exported by SentrySuite and will then be imported into a test entity in CleDashboard. The user can choose to see statistics for all the data within either a research process, a single project participant, or a single test. Every type of measurement gets its own plot in an overview, and all data of that type of measurement gets plotted there. This meaning that the same measurement from several tests ends up in the same plot.

Figure 4.2 shows an additional, upgraded plot view that is implemented. Several features for performing operations on the graphs and analysis were introduced, which appear in this new plot view. As we see, the graphs are colour coded. Each colour corresponds to the test the data belongs to. In this case, we are viewing the measurements of oxygen uptake from 4 separate tests.

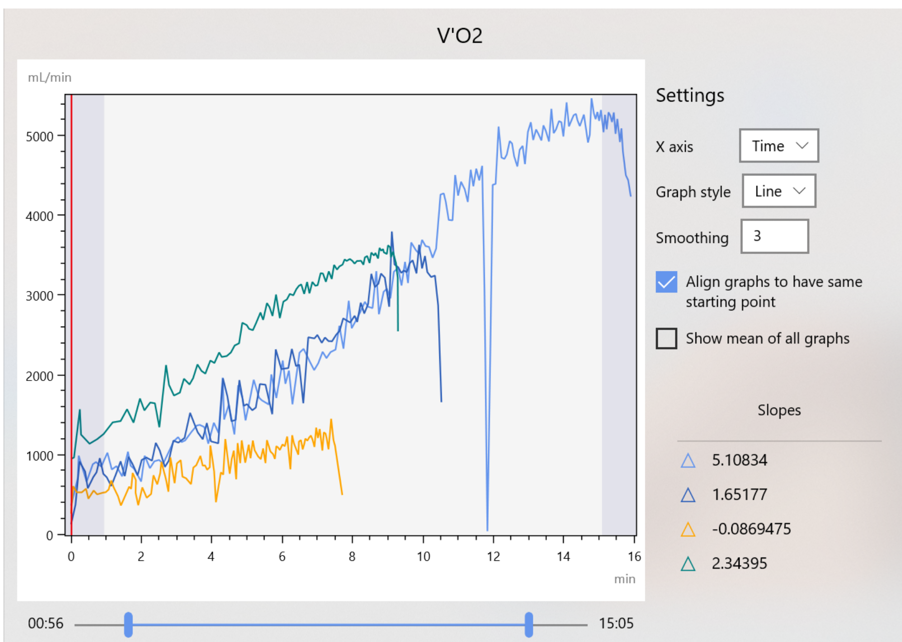

Figure 4.2: Plot view containing features for performing operations on the data sets and some analysis.

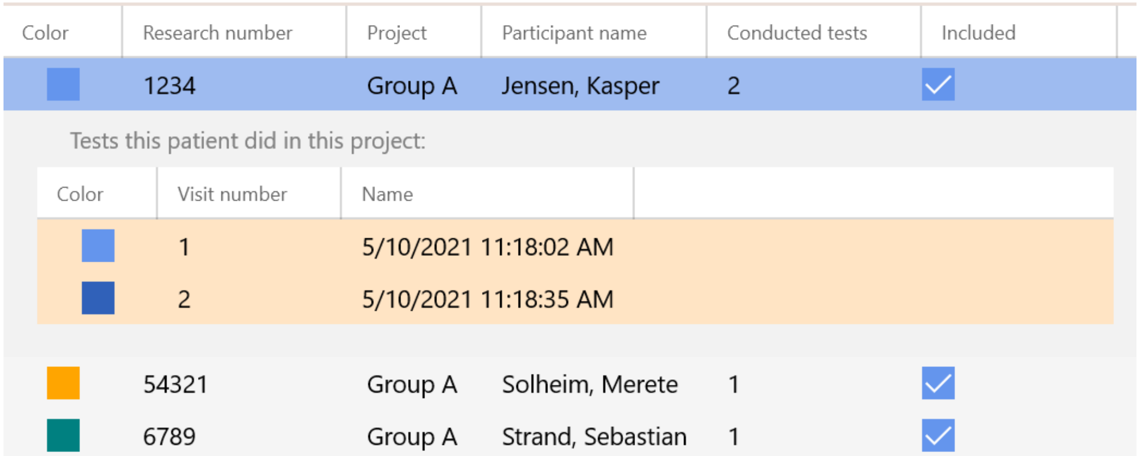

Figure 4.3: An overview of the selected tests containing information of the tests and their colour coding. Clicking one participant expands the nuance view, which the nuance per test for the selected participant.

An overview of the tests and their colour coding is also implemented, as demonstrated in figure 4.3. As we see, two graphs are blue but in different nuances. This is a way to inform the user that these are separate tests conducted by the same participant. This way, we can also see the development for one participant over the span of time. Concerning the visualisation aspect of the plot view, let's look at the presentation of the data itself. There are two methods for plotting the data; either using scatter plot or line plot. See figure 4.4 for demonstration.

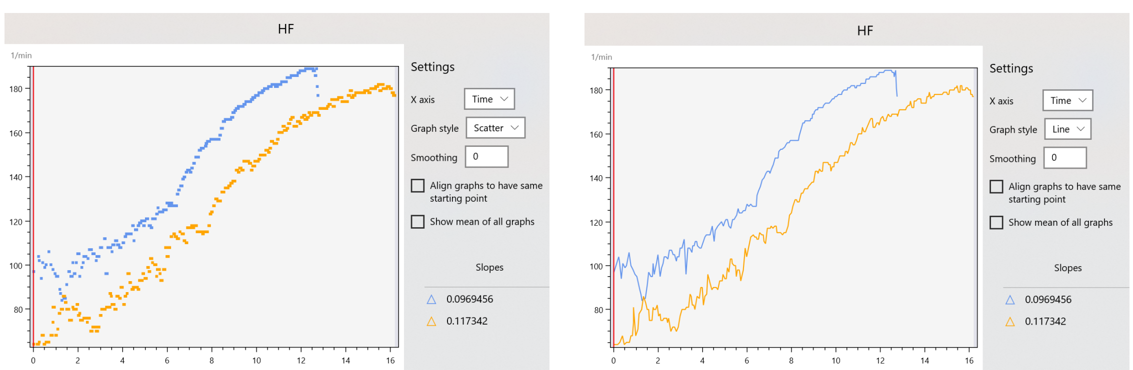

Figure 4.4: The left plot presents the graphs using scatter, and the right plot presents graphs using line.

4.3 Architecture and workflow

The workflow in figure 4.5 is proposed as a solution that will enhance the current workflow of Bergen ILO Group's research process. CleDashboard has replaced the Profitek application, and gathers all the video and audio material and test data in an organised manner so that a separate computer for data collection is no longer needed. MedDataWatcher automatically collects the exported test files from Sentry-Suite, and inputs the test data into the correct location in CleDashboard's database.

In software engineering, an ideal for code structure is high cohesion and low coupling. The codebase for any software system should be easy and safe to add modules to. The MVP was designed by mainly focusing on the video streaming and recording functionality. However, once this functionality was in place, the opportunity for enhancing the workflow, structure, and design presented itself. It was clear that a new architecture for CleDashboard was necessary to make way for statistical data analysis. The user should be able to organise data in such a way that it is easy to

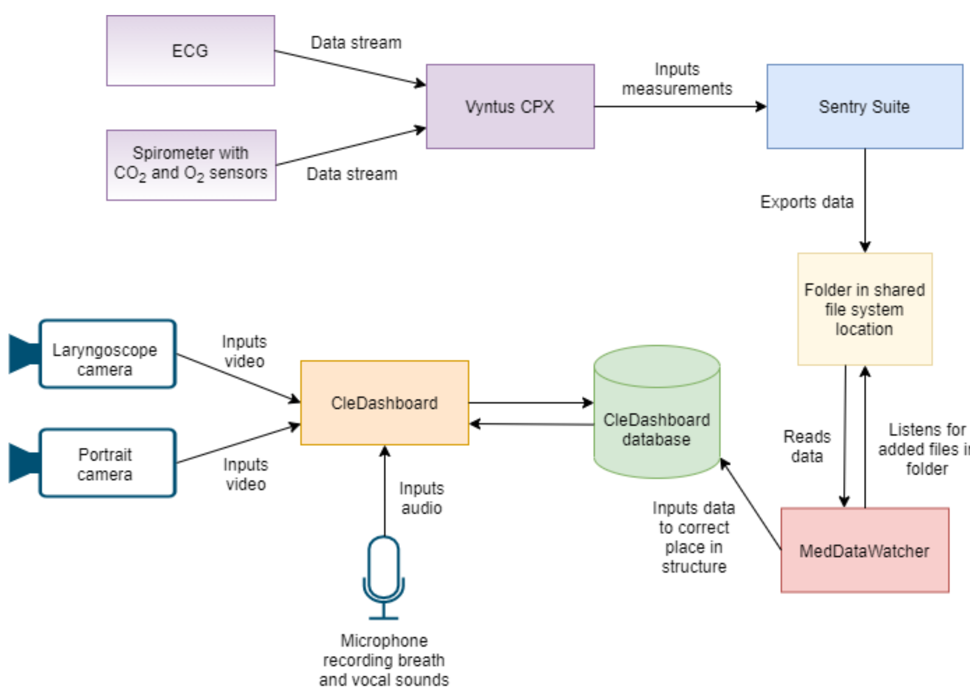

Figure 4.5: Diagram of the new workflow the proposed software system introduces.

select data for inclusion in an analysis, and the data structure should fit being analysed. Therefore, the application architecture, database structure, and workflow had to be altered to meet the requirements. This alteration also leads to an improved user experience considering the new workflow and a general application structure that can fit any research project.

The data organisation pattern demonstrated in figure 4.6 was implemented. Each research project can contain any number of sub-projects. Any number of participants can be added to a research project. Any number of tests can be added to a participant, and the tests receive a visit number equal to the order in which they were conducted.

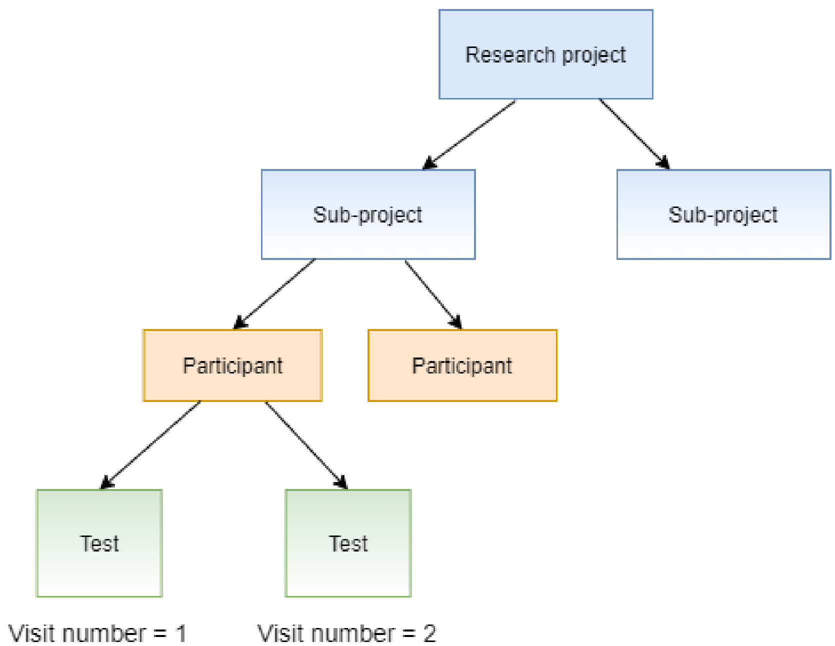

Figure 4.6: The data structure in CleDashboard.

4.4 Organisation of data

A main requirement for the software system is to organise data. As Bergen ILO Group is dealing with large amounts of test data, organisation of it will add significant value to their research. The data has to be stored safely, and the participants' personal information has to be protected.

4.4.1 Database structure and ID protection

The database was altered and expanded to allow the new structure. See appendix C for the full database diagram. Anonymity protection is important both considering the rules of Haukeland University Hospital and for being compliant with GDPR. Thus, personal identification numbers are not used by the database. It rather produces a unique ID number per participant for storage in the database. The user can input a research number for each participant when he or she is added to a research project. This is a safe solution that keeps track of all participant data.

4.4.2 Coordination of video and test data

Each CLE test contains both CPET data and video and audio material. CleDashboard itself has the functionality for recording the video and audio. However, it is the SentrySuite application that collects and exports the medical test data. The MedDataWatcher program imports the medical test data into the correct test in CleDashboard's database (see section 4.5.1). As of yet it does not take into account that the same CLE test is started at different times for the SentrySuite and CleDashboard and that the time setting on the two separate computers might differ. A theoretical solution to this is demonstrated in section 4.5.3, as this is a key challenge for the proposed software system. As for now, we assume that the video and audio material is already synchronised with the associated medical test data. This means that the time 00:00 should be the starting time of all the elements.

A feature that was requested by Bergen ILO Group was to be able to coordinate the video material with the medical test data. This included adding a time marker on the plots and a timeline controller to each video. As a user clicks the button to see statistics for a selected research project or participant, the screen in figure

4.7 appears. The statistics tab automatically coordinates all data with the video material from all the selected tests. When the user clicks a point in a graph, the time marker in all plots and videos moves to this point in time. It is also possible to set the timeline controller in any video to a certain point in time, and the time marker for all the plots will move to that point in time.

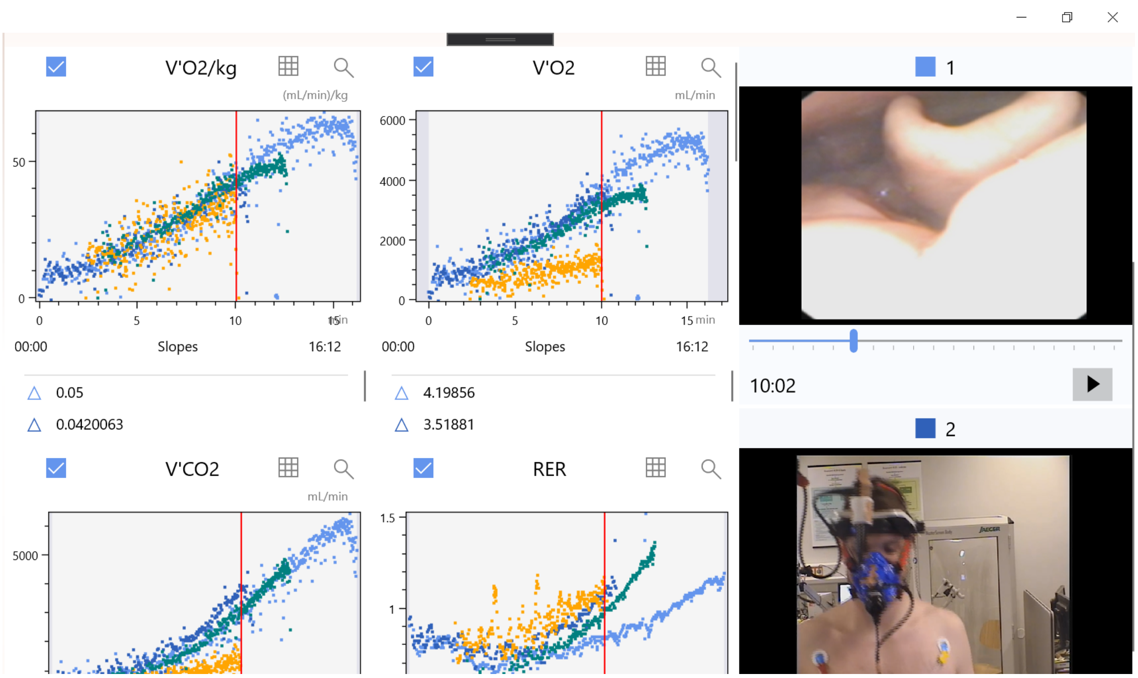

Figure 4.7: Time set to 10:02 for plots and videos.

4.4.3 Aligning test data

As previously mentioned, CLE-tests contain 3 phases; *rest*, *test* and *recover*. The *test* phase is of special interest, and it would therefore be beneficial for the user to be able to align the start of the *test* phase to x = 0. As for now, functionality for aligning all graphs in a plot to start at x = 0 is implemented as a proof of concept to this idea. See figure 4.8 for a demonstration.

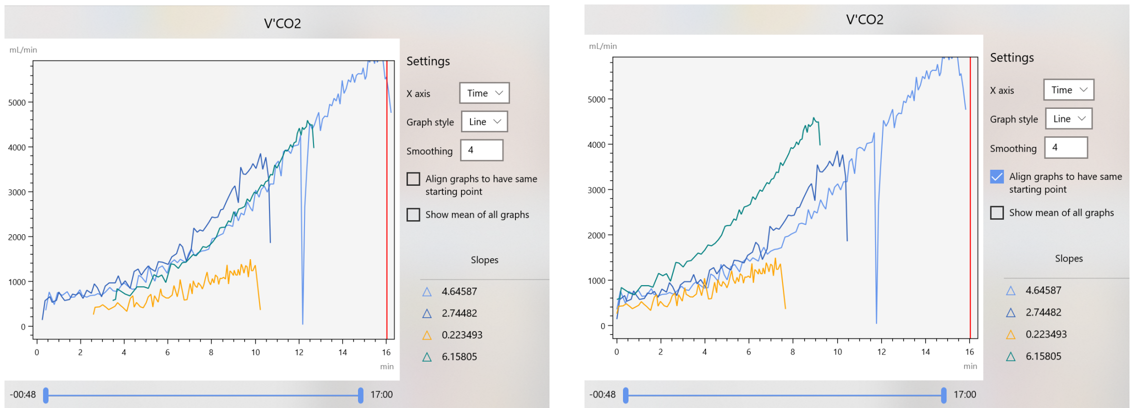

Figure 4.8: Demonstration of aligning graphs. The graphs in the plot to the left are at their original positions in time. The graphs in the plot to the right are aligned to start at x = 0.

4.4.4 Changing x-axis value

All data series that are imported by MedDataWatcher are initially time series. However, it is beneficial for Bergen ILO Group to be able to plot some data against other. Functionality was implemented to make way for this. The user can click the drop-down menu for each plot, and an algorithm checks which other measurement types are available for the tests in the plot. Figure 4.9 shows an example of this. V'E (minute ventilation) is plotted against time, and the user has clicked the menu to the right. We can see which other measurements are available for the yellow and blue tests. When clicking another measurement type, that one is used for the x-axis, and the graph adjusts.

4.5 Data handling

The proposed software system is to be used to streamline the research process of Bergen ILO Group, and an overall goal is for the solution to be transferable to other disciplines and institutions. The streamlining happens in the form of automating as many parts of a research process as possible. In order to fit any research process, the system should be agile and work just as well as the endpoint that produces all necessary results as just part of the way of achieving wanted results. It is therefore essential that the solution can import medical test data from any source and that

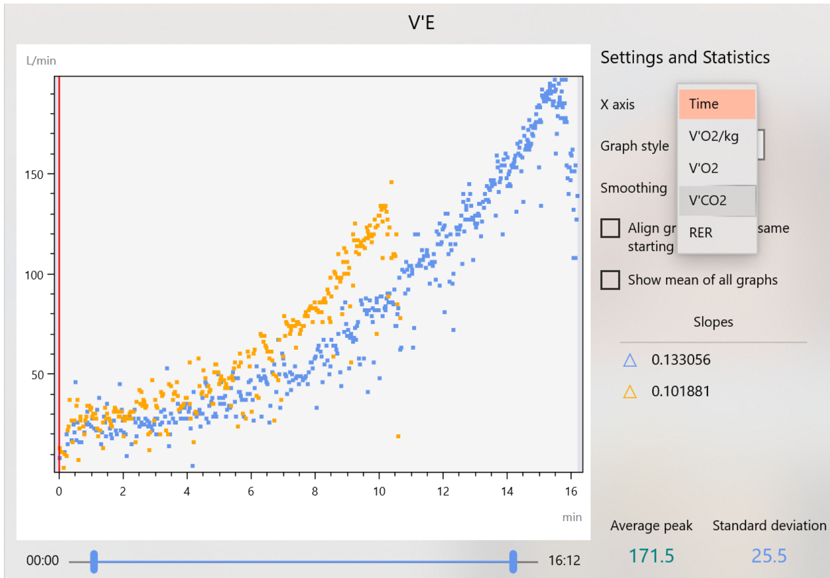

Figure 4.9: Plot of the V'E from two tests. The x-axis drop-down menu is open, and we can see which other measurements we can put on the x-axis to replace time.

it is able to export it again after processing it. This way, it can be placed anywhere in a research process and thereby achieve generality.

4.5.1 Importing data

The overall goal of the development project is to streamline and enhance the research process for Bergen ILO Group. This goal includes automating some steps in the researchers' workflow during and after conducting a CLE test. In the proposed workflow, SentrySuite is running on a different computer than CleDashboard. This creates a challenge regarding how to get the data from SentrySuite to CleDashboard's database in an orderly manner. There are many possible solutions to this, and the one that is considered to require the least user effort is to handle it in a separate software program called MedDataWatcher. MedDataWatcher is a Node.js program that works as a bridge to transfer medical test data between a source and CleDashboard. It contains a file watcher, which is a tool that raises events when the file system has a change in the file or folder that it has subscribed to. It can then run any code as a response to the event.

The idea is that a folder can be created on a shared file area, for example, through a Local Area Network (LAN), between the computer where the SentrySuite application is running and the computer where CleDashboard is running. Then MedDataWatcher will be configured to watch this folder. This makes way for a simple workflow where after finishing a CLE-test, the user has to export the test data in a certain format to a file in the shared folder. The file watcher program then runs code for reading the newly added file and inserting the data it contains into the database belonging to CleDashboard. It inserts it into the newest session, which is the database entity dedicated to each CLE-test.

This solution for a workflow comes with the benefit that it is general. It can be used to connect any device with access to the shared LAN, as long as it exports files containing data in the correct format. Appendix A contains an example of data from a real CLE-test exported by SentrySuite. As previously mentioned, permission to read data directly from SentrySuite's database was requested but denied. This would have made it possible to automate the research process of Bergen ILO Group even more. However, it would not have been a solution that could have been applied to other contexts. Therefore, importing the data from SentrySuite's export is a more general solution. Furthermore, the MedDataWatcher program can be configured to read any data structure in the files added to the shared folder. It is for now written to fit a format that SentrySuite can produce. However, the solution also comes with some downsides. Suppose a user forgets to export the test data from a CLE test before starting the next one. In that case, the test data can no longer be imported into the correct session in CleDashboard's database by being put into the shared folder.

The MedDataWatcher program was, as mentioned in the Resources section, developed as a separate application using Node. All of its functionality could have been implemented into CleDashboard itself as it is also supported by UWP. But in that case, CleDashboard would have to run at all times. This would take up unnecessary resources compared to the Node program that can run silently in the background. Additionally, the Node program can be automatically run from a startup script. This minimises the risk of user error.

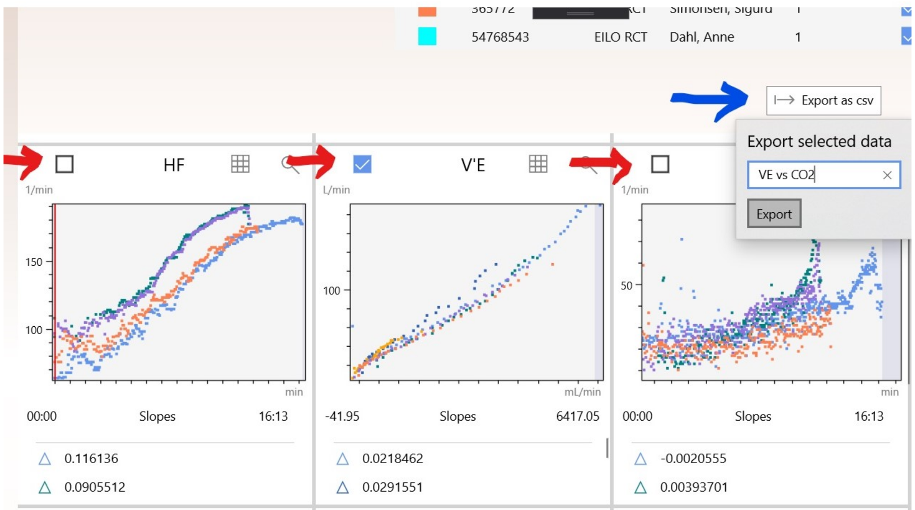

Figure 4.10: Location of the export button and the check boxes for marking data for the export indicated by red arrows.

4.5.2 Exporting data

The statistical aspect of CleDashboard creates a lot of value, and one could go on adding statistical features. However, there already exists a great number of powerful statistical tools. SPSS by IBM is widely used, and the main contact group frequently uses this program for research purposes. To bridge the gap between CleDashboard and other statistical software such as SPSS, it is possible to export test data from selected tests as a CSV file. If the user has processed the data, the processing operations are included in the exportation. Otherwise, raw data is exported. The possible processing operations include setting another value at the x-axis, smoothing the data, and aligning starting points of all graphs to x = 0. The statistics tab of CleDashboard has an export-button, as seen in in figure 4.10. The user has to go through the following workflow steps in order to export data:

1. Check the boxes of the desired measurements for including them in the file to be exported. This refers to the boxes the red arrows are pointing at.

2. Click the button "Export as csv", which the blue arrow is pointing at.

3. Enter the name of the file to be exported.

4. Click "Export". When this is done, a file picker opens that allows the user to select which folder the file should be exported to.

The file format of the exported file is shown in figure 4.11. See appendix D for an actual export of real, processed test data of V'E plotted against V'CO2.

Y-measurement			
	Test-ID A	Test-ID B	Test-ID C
Slopes	Slope A	Slope B	Slope C
X-measurement			
x-value 1	y-value A 1	y-value B 1	y-value C 1
x-value 2	y-value A 2	y-value B 2	y-value C 2
x-value 3	y-value A 3	y-value B 3	y-value C 3

Figure 4.11: Format of exported file containing medical test data covering example tests A, B and C.

The labels in figure 4.11 represent the following information:

- **Y-measurement:** This is the measurement checked for exportation. It is stated by name and unit.
- **Test-ID:** Research project name - research number - visit number
- **X-measurement:** This is the variable that the measurement is plotted against on the x-axis. It is stated by name and unit. By default, all measurements are plotted against time, as they initially are time series. However, the user can choose to plot it against any other available value, as previously explained in section 4.4.4.
- **Slopes:** All slopes get automatically calculated for all plots. These slopes are included per test in the exported file.

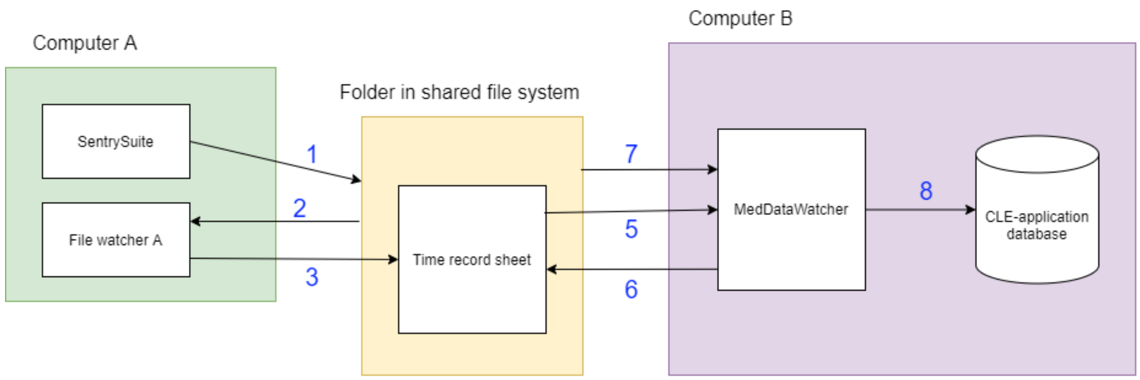

Figure 4.12: Diagram of proposed, theoretical solution to synchronising data between two separate computers A and B

4.5.3 Synchronising data

For each conducted test using CleDashboard, the medical test data has to be synchronised with its associated video and audio material. As the test data is imported after the test is recorded, this is a challenge. Furthermore, the researchers will not be able to start the test in CleDashboard at the same time as they start the test in the SentrySuite application, which is the application that gathers the medical test data that is measured by the Vyntus CPX (as described in section 2.1.2).

In order to solve this synchronisation challenge, the following theoretical solution is proposed and should be implemented as further work. In figure 4.12, a procedure is shown that should occur every time a test is exported from SentrySuite. It is possible to put a time stamp onto the exported file, which shows the local computer clock of computer A when the test was started by SentrySuite. CleDashboard on the other side keeps a timestamp for when the test was started there. Therefore, the goal is to use these two timestamps to synchronise the medical test data from SentrySuite with the video and audio material recorded by CleDashboard. The following system should be implemented:

1. SentrySuite runs on computer A and exports a file into a set folder in a shared file system between computer A and B. The file contains both medical test data and the test start timestamp.

2. A file watcher A is also running on computer A, which listens to changes in the folder in the shared file system. When a change occurs, the file watcher checks in the current time on computer A into a specified time record sheet in the shared folder.

3. MedDataWatcher also contains a file watcher, which listens to changes in the time record sheet. Upon a change, it checks in the current time of computer B next to the one of computer A. This creates a time record, where we can see an entry of the time setting difference between computer A and B for every time a test was exported into the shared folder. As the synchronisation will be based on the timestamps SentrySuite and CleDashboard puts on the test, we need to keep track of any possible difference in time setting on their two respective computers.

4. MedDataWatcher calculates the time difference between computer A and B at the time directly after the test has been exported.

5. MedDataWatcher now uses the time difference between the two computers for the current test that is about to be imported into CleDashboard. It reads the test file from the shared folder and adjusts the timestamp in it so that it is matched with computer B.

6. MedDataWatcher imports the medical test data exported from SentrySuite into the database of CleDashboard.

This solution is optimal if the user exports the medical test data file from SentrySuite right away after conducting the test. However, the time setting of a computer is not likely to diverge very much within just a few hours or days, and as Bergen ILO Group usually conducts tests quite often, it should not be a problem. With the proposed software solution of this thesis, it is necessary to export the test data before starting a new test. So, in the case of using it, the time between the conducted test and exporting it would not exceed days. As the SentrySuite application can only put the timestamp with accuracy on second-level, this proposed system is not 100% accurate. However, it is the most accurate solution found at the time being. A simpler solution could have been to use either an online or hardware time synchronisation solution that would allow us to skip the use of a time record sheet.

But as the least amount of dependencies as possible was wished for the software system, this was not considered.

4.6 Statistics and analysis

4.6.1 Average graph

When a lot of separate CLE tests have each their own measurements for the same variable, it can be helpful to the user to see a graph that presents the mean value between all those tests. However, calculating the most representative mean graph possible turned out to be a complex task. This is because each test has a graph that presents the measurements of a given variable made up by its own set of data points, and the datasets from different tests usually do not match time-wise (or for any other value that would be used on the x-axis). In order to solve this problem, polynomial regression was implemented to find approximate values for each variable at any given point in time and not just the times when actual measurements had taken place. So, an approximate value is calculated for each variable for each second within the time span of all the graphs combined. The mean graph is made up of the average of each of those calculated data points. This method had the advantage of creating a smooth mean graph, referred to as the inclusive mean graph. See figure 4.13 for an example of an inclusive mean graph of Heart Frequency (HF) measurements.

However, one issue remained. Some measurements can potentially start earlier than others, and some can also finish earlier than others. This means that if we use the function for a given graph using a time input that takes place before or after any actual measurements have taken place, the output is a predicted value. And since we use simple regression with no regard to what the given measurement is in fact of, our prediction is not trustworthy at all. So the question is, should we then use the output from a function that is placed in time where we have no basis of actual measurements to justify that output? The objective of finding the functions for the n graphs from n tests was not to predict anything, as this is a whole other area of research, but to approximate the actual measurements. So, an experiment was done where outputs from functions where the time input was not within the belonging

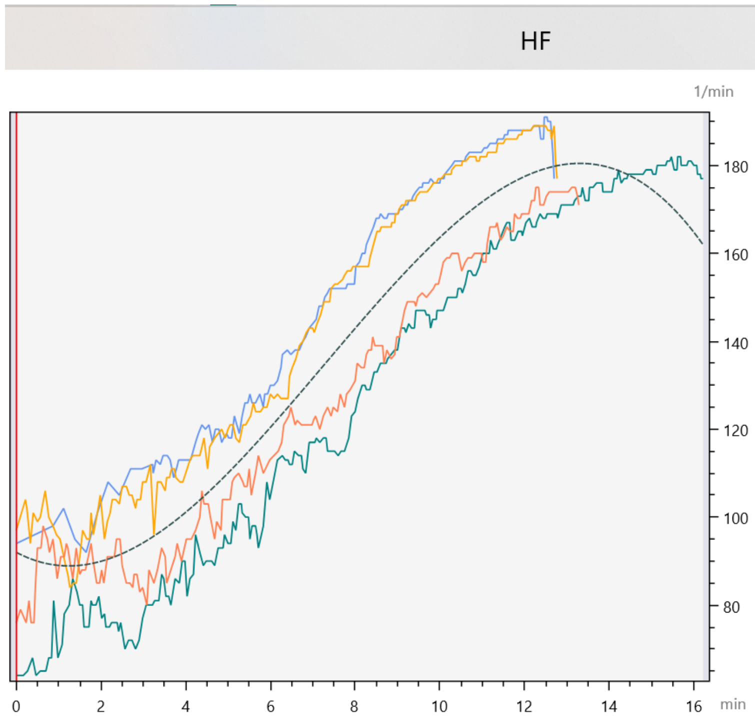

Figure 4.13: A plot of Heart Frequency (HF), showing inclusive mean graph in gray.

graphs' timespan were disregarded. This means that the mean graph could have some parts that were only affected by a few of the original graphs. This lead to a quite different mean graph referred to as the exclusive mean graph. This graph was less smooth and did not demonstrate the trend of its source graphs very well. Figure 4.14 shows an example of an exclusive mean graph of Heart Frequency (HF) measurements:

The exclusive mean graph was concluded not to be ideal. As the objective was to present an average of the graphs as realistically as possible, it was not a good fit. Even though it was more affected by real values, the trends of the graphs were not well represented and resulted in a confusing graph. Therefore, it was disregarded, even though it was the method that gave the least amount of squared error regarding the distance to each of the measurements. The inclusive graph was chosen instead.

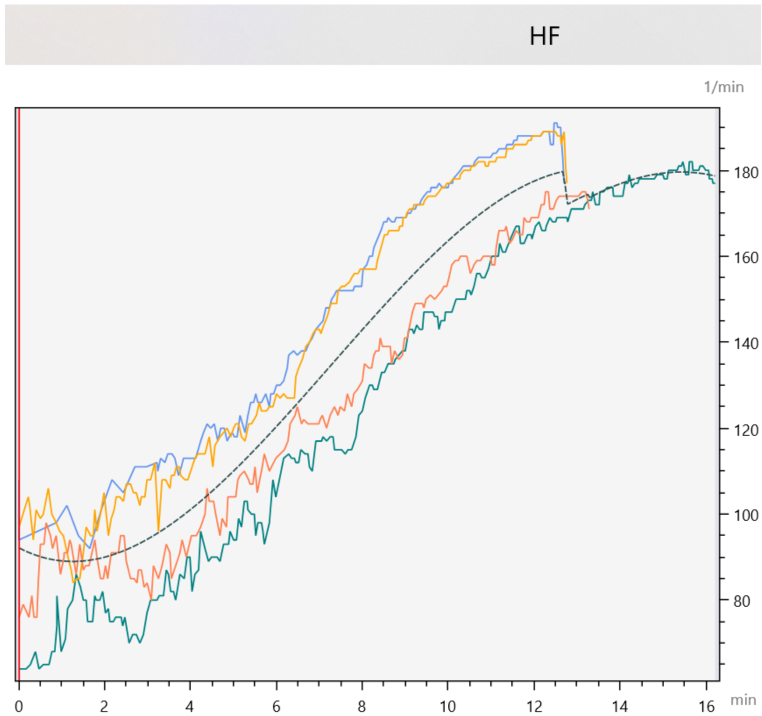

Figure 4.14: A plot of Heart Frequency (HF), showing exclusive mean graph in gray.

The goal was for the application to dynamically adjust the degree of the polynomial regression to what fit the current data best. However, in some cases, this lead to overfitting as some predicted values are used in the solution. Therefore, the optimal result seemed to be to statically set second-degree polynomial regression. For achieving better results, we could allow the user to input the degree in the future.

4.6.2 Smoothing graphs

Smoothing of graphs was specifically requested by Bergen ILO Group. The medical test data can be noisy, so it can be helpful to smooth the graphs to see the actual trends in data. As for now, functionality for smoothing graphs by user input sample size is implemented. The input field is located to the right of the plot, as seen in figure 4.15. We see the effect that the smoothing has on the graph, as the noise decreases depending on the smoothing sample size.

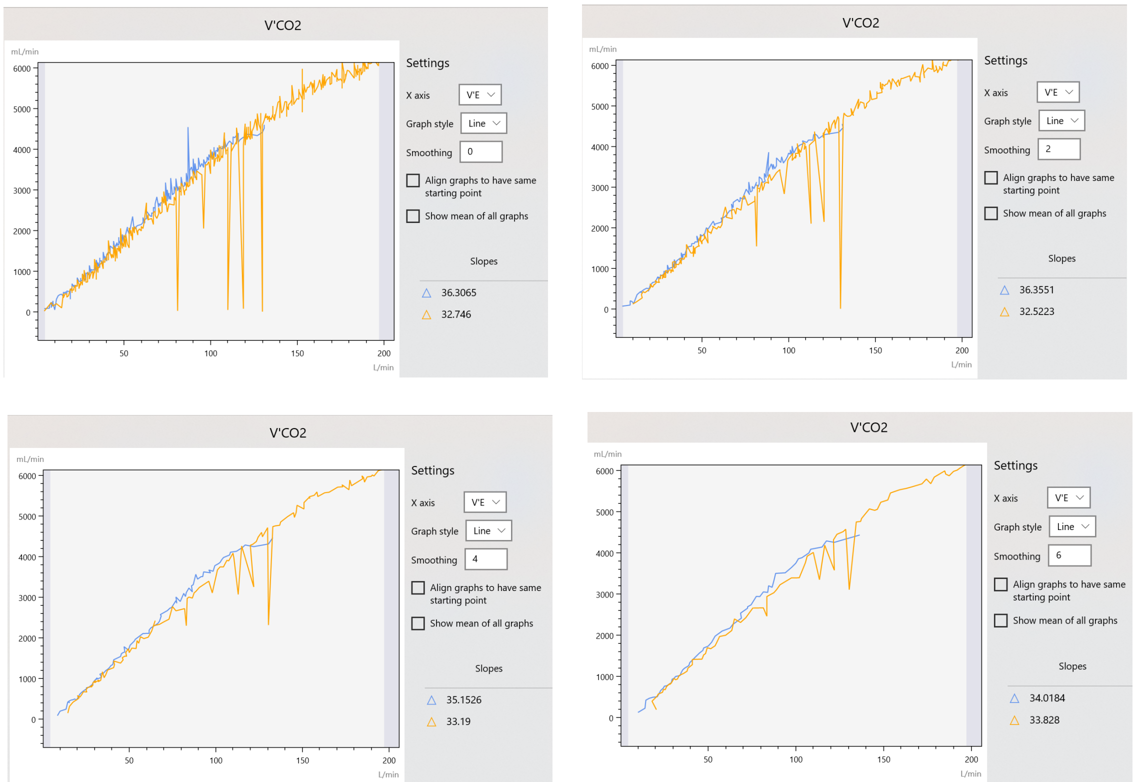

Figure 4.15: Applying smoothing to a graph using an increasing sample size.

4.6.3 Slope

The slope is calculated automatically for every graph in the plot, as specifically requested by Bergen ILO Group. All points within the limits of the marked area is included in the calculation, and the user can adjust that area by using the control below the plot. Figure 4.6.3 shows an example to demonstrate this, where V'E, minute ventilation, is plotted against V'CO_2. To the right of each plot, we see the slope for the graph marked by a delta sign. The whole graph is included in the slope calculation in the left plot, where the slope is 0.03. In the right plot, we limit the sample inclusion to the middle part of the graph, which results in a slope equal to 0.04. This feature can be useful for several reasons, including cutting away noise in the measurements in the beginning and at the end of the test.

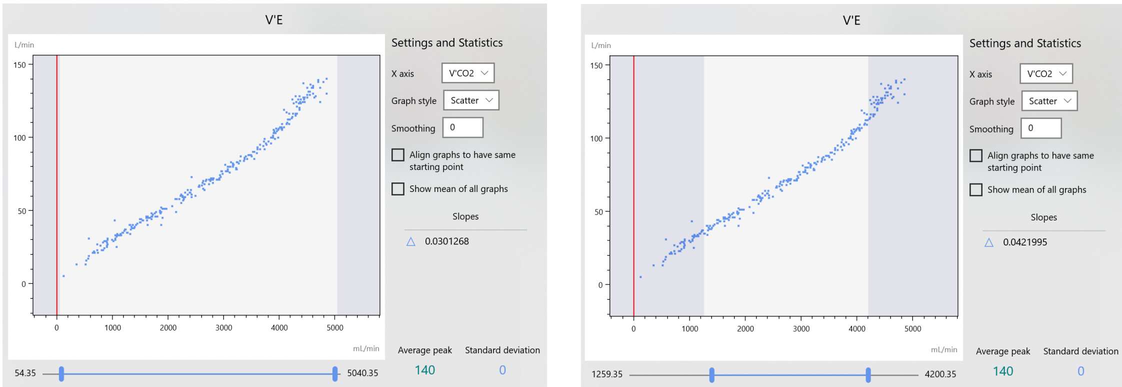

Figure 4.16: See that the slope of the same graph varies when using different inclusion limits.

4.6.4 Average peak and standard deviation

Calculating average peak and standard deviation was a functionality that was added to CleDashboard as the last artifact in the development process. Bergen ILO Group requested to be able to see the average maximum y-value for any variable and the corresponding standard deviation. See figure 4.17 for an example, where carbon dioxide output is plotted on the y-axis against time on the x-axis. The average peak (maximum) value is automatically displayed, which in this case is 3755.14 mL/min. The standard deviation is 1508.9 mL/min.

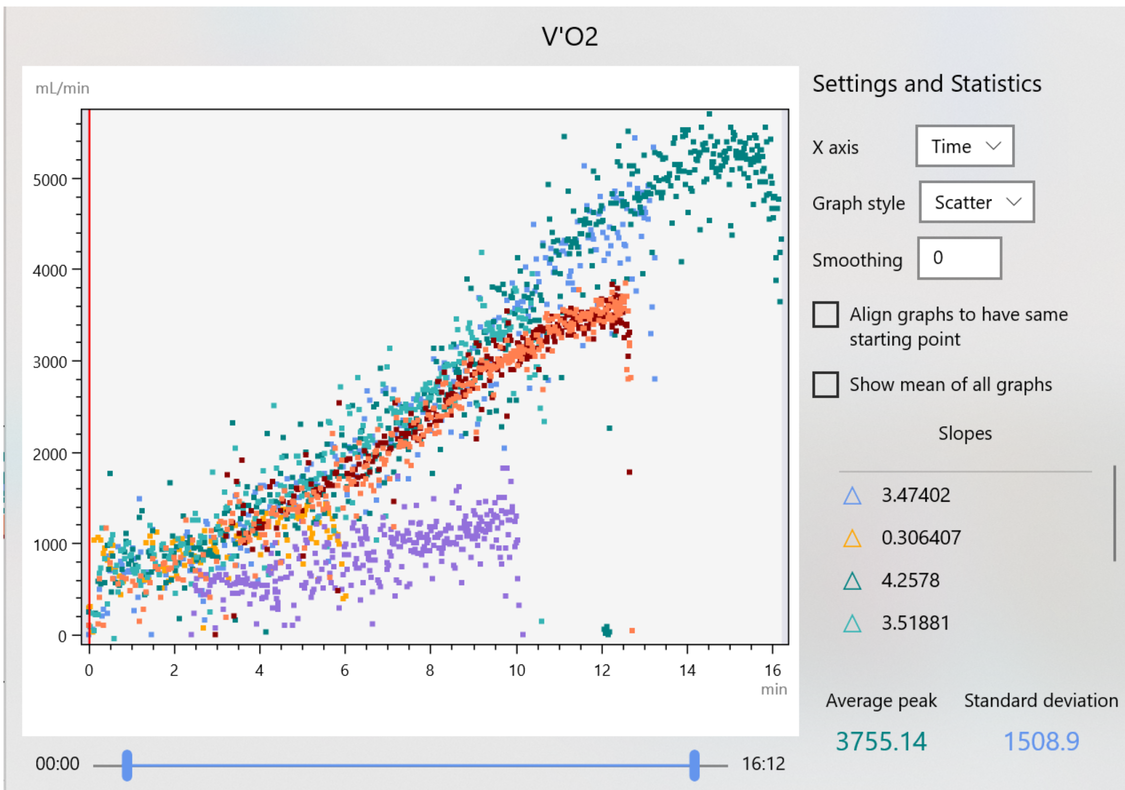

Figure 4.17: Plot view with average peak and standard deviation

Chapter 5

Results and evaluation

This chapter will demonstrate the resulting software system and its value by applying it to an actual use case. It will thereafter present an evaluation through an interview with Hege Clemm, the leader of Bergen ILO Group. Compatibility with the MVP and the consequences of the time limitation will then be evaluated.

5.1 Demonstration of a use case

In order to demonstrate and evaluate CleDashboard, it was set to simulate an actual, highly relevant use case. The research project HelpILO by Bergen ILO Group was selected as that use case. Random sample test data from 8 individual, real CLE-tests were collected. As the data had to be anonymous, the displayed names connected to it are all fictional. Two videos from a real CLE-test were also collected in order to get a realistic demonstration of CleDashboard.

5.1.1 Dashboard module

The module called Dashboard was introduced into CleDashboard to create an overview of all the data and its structure. It allows the user to organise participants into research projects, and associate tests with the participants. The research projects can also contain sub projects, creating a nested structure. This organises the medical tests in a sensible hierarchy, while allowing for statistical analysis covering several tests. This architecture plays a central role in the generalisation of CleDashboard.

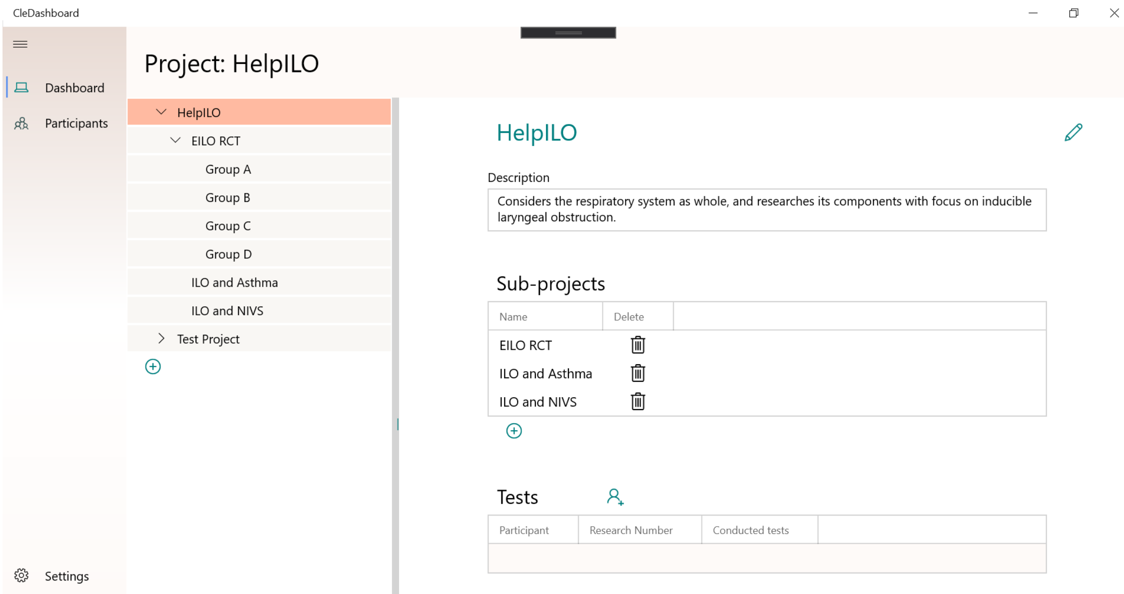

Figure 5.1: The Dashboard module containing the research project HelpILO.

For the sake of this demonstration, projects were added into the project hierarchy in Dashboard so that it matched the actual structure of HelpILO. Figure 5.1 shows a screen capture of the projects added to CleDashboard. The HelpILO project was added to the top layer of the project structure and its three work packages as sub-projects of it. Work package 1: EILO and Randomised Control Trial (RCT) is focused on to demonstrate data. See figure 5.2 to see its course of study. As it contains three groupings of participants, projects A, B, C, and D were added as sub-projects to work package 1.

The application structure allows one patient to conduct several CLE tests for the same research project. They then get listed within the project under *Tests*, as demonstrated in figure 5.3. As each participant in the EILO and RCT work package contains phases 1 and 2 per participant, these are reflected in CleDashboard in the visit number; see figure 5.1. As phase 3 initiates, the participants are regrouped depending on their needs. These groups would then be added as sub-projects to work package 1.

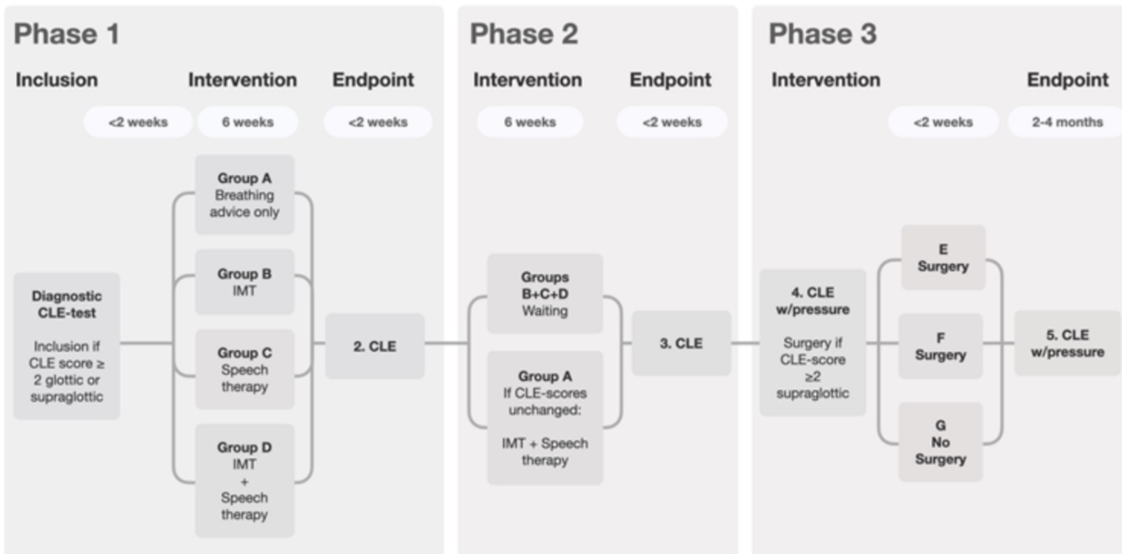

Figure 5.2: Course of study for HelpILO's work package EILO and RCT.

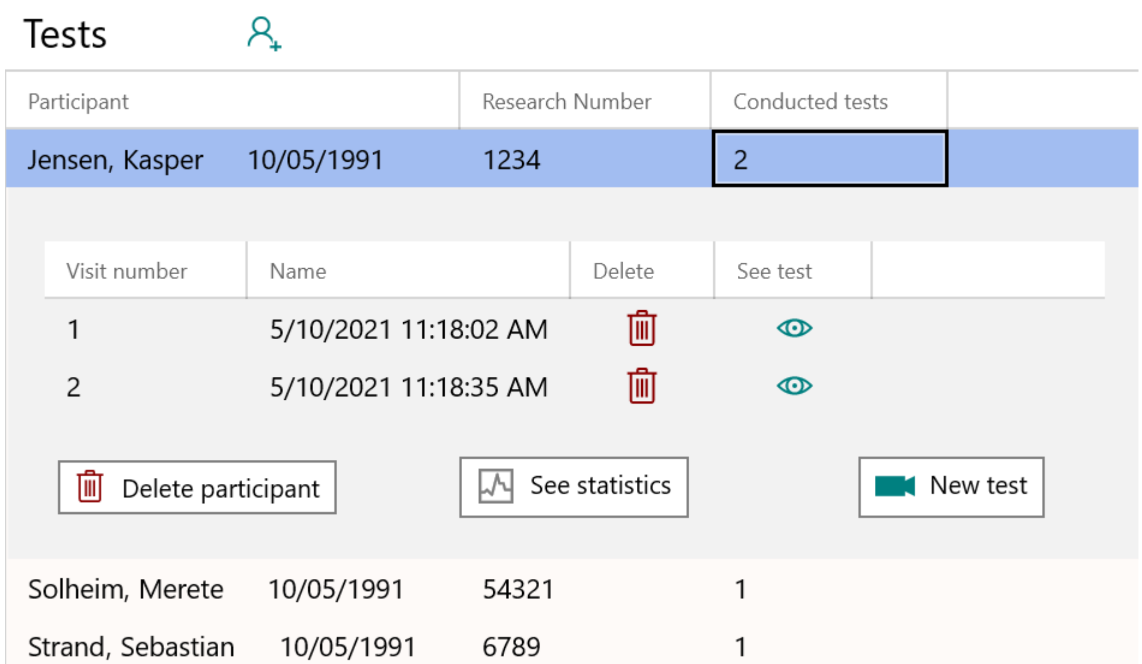

Figure 5.3: Overview of the participants and their data within Group A.

5.1.2 Statistics module

The statistics module has an overview of all the test data and shows and coordinates it with the associated video and audio material. The module is displayed, dividing the screen into three sections, each dedicated to showing different elements. Figure 5.4 shows a screen capture of the statistics tab, and the three sections are marked by the colors blue, green, and red.

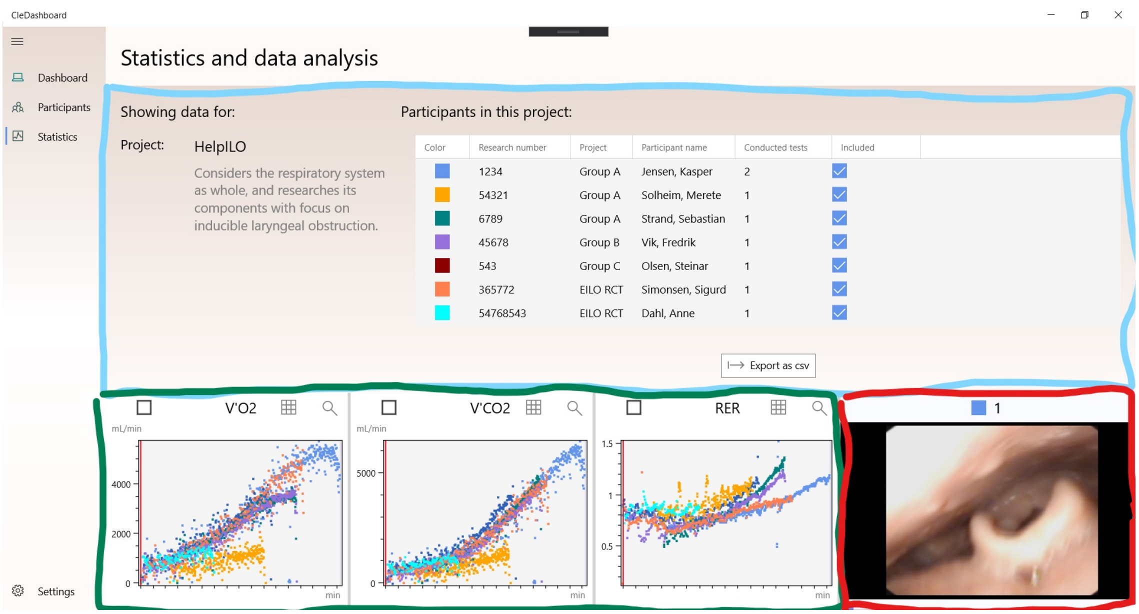

Figure 5.4: Statistics module displaying research project HelpILO and its sub-projects.

The blue section gives information about the selected project, or in some cases, the selected participant. The project name and description is displayed to the left, and an overview of the participants in the project is situated to the right. The green and red sections are both scroll views.

The green section is an overview of all the test data and collects all measurements of the same type from different tests into one plot. Therefore, the result is one plot per measurement, and the user can then easily compare the measurements of the same type from different tests. When clicking the magnifier-button, a large fly-out appears containing the view explained in section 4.2.3, which shows a bigger version of the plot, contains several features for performing operations on the graphs, and offers some statistical analysis.

The red section in the module displays the associated videos from the tests. As for now, it picks the first video in the list of videos belonging to the test. A feature for switching between the videos should be implemented. Each video has an identifier on the top, where it has the color code for its test and the visit number. The videos are coordinated with the plots, meaning when a user plays a video, a red time marker dynamically moves along the x-axis of the plots showing the user where the current time in the video is located in the plot. Also, the user can click a point in the graph, and the videos all jump to that point in time. This coordination is very valuable to Bergen ILO Group, as it makes it easier for them to compare the videos with the cardiopulmonary test data.

5.2 Evaluation

As Bergen ILO group is the product owner and intends to be the initial user of CleDashboard, evaluation by them was a natural step in the evaluation of the final CleDashboard. The evaluation was conducted in the form of a qualitative, semi-structured interview of Hege Clemm at the 10th of May 2021, as she is the leader of Bergen ILO Group. In addition to this interview, Haakon Kvidaland, Lars Peder Bovim and Ola Røksund gave continuous feedback during the whole development process, which was also considered regarding the evaluation.

A thorough demonstration was given as an introduction just before the interview. Hege, the subject, was encouraged to ask questions and to navigate and test CleDashboard herself. The interview then contained questions regarding the user experience of CleDashboard, the generalisation of it, and what value could be created for the user by utilising the plots and the statistical analysis. See appendix E for the full interview. The questions, summations of the answers, and additional comments are listed below:

Q1: Is the structure with nested research projects easily understandable and useful?
The answer was that it is intuitive and useful. CleDashboard is the further development of their current solution that Bergen ILO Group was looking for. The structure fits their research method very well. They now wish for functionality for making the structure more flexible by being able to move participants into different research projects as it becomes clear where they belong after some consideration.

Q2: Is the workflow logical, and how is the usability and design?
It was responded that the workflow is good and logical. The design is also very nice, and the color-coding of tests conveys the necessary information and gives a good user experience.

Q3: Is the application generalised enough and correctly?
The answer to this question confirmed that the application is in fact general enough. It is transferable to other research groups in WestPaed Research.

Q4: Do you have any examples for other disciplines or institutions where the application could be used?
It was answered that all exercise test labs that measure test data both for clinical and research purposes could use CleDashboard. A list of examples was given for use cases, as follows:

- *"To compare data from before and after a heart or cancer-operation."*
- *"COVID-centres who test people after they have had the disease. This is also done by a CPET-test."*
  The ongoing global pandemic of the Coronavirus Disease (COVID-19) is predominantly a Severe Acute Respiratory Syndrome (SARS). However, it has shown potential for provoking multi-organ damage which impairs cardiopulmonary function and reduces cardiorespiratory fitness. Together with a reduction on physical activity, this can accentuate risk for Cardiopulmonary Disease (CPD) [31]. In order to diagnose CPD, a Cardiopulmonary Exercise Test (CPET) is conducted. The CPET therefore plays an important role in both the clinical assessment of convalescent COVID-19 patients and the re-

search of the long-term health effects of Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) infection. As the proposed software system is developed using a CLE-test as a basis, which includes a CPET, it is perfect for this use case. When researching the long-term effects, it is advantageous to compare data before and after infection to see the development. The system contains functionality specifically designed for this purpose.

Furthermore, a large proportion of patients that have been affected by COVID have been reported to have underlying CPD [32]. This means that these patients are likely to have conducted at least one CPET already. This data can be imported into CleDashboard and placed into a patient's test. This shows that the application is adaptive and supports data from several sources, even from any previous test from any institution, as long as it is imported in the correct format.

- *"In all kinds of premature research. For example, we want to see how the oxygen consumption varies between premature and term born populations. So, the application could be used by any of the research groups in WestPaed Research."*
  A study on 81 extremely prematurely born individuals in their teenage years was conducted where the results showed that the slope of ventilation (V_E) - carbon dioxide output (VCO_2) relationship is steeper in those born extremely prematurely compared to those born on-term. This indicates lower ventilatory efficiency. [3]. As we will see demonstrated in section 6.1, it is possible to study relationships such as this using CleDashboard.

- *"CPET on lying-down cycle ergometer with heart ultrasound."*

- *"It could be used by many in different context in Haukeland University Hospital. It also has the potential to be made into a product and sold to other institutions, but we as a hospital cannot be the ones to distribute it."*

- *"Research in sports. Athletes follow their health very accurately, and it would be very valuable for them to be able to see their own development like this."*

Bergen ILO Group is in general interested in studying both test-to-test and group-to-group differences. This can include the development from tests before and after some intervention for the same patient or to see the collective differences between groups. Their method of conducting studies can for example consist of comparing test data from a group with some condition with the test data from a healthy control-group, including some intervention as logopedic exercise treatment.

Q5: How many CLE-tests have you conducted here at the test lab?
This question was asked to get a perspective on how large the data amount that the software system should be able to handle is. The answer was that around 3000 CLE-tests had been performed during the last 20 years, and with the HelpILO project, they will perform around 1500 more. This answer clearly states the importance of handling and organisation of data.

Q6: You earlier mentioned that the big medical technology companies are less lenient to innovate. How did you experience that?
This question was asked in order to find out more about Bergen ILO Group's motivation for developing this software system in-house, rather than asking their supplier for it. The interview revealed that Bergen ILO Group had made several requests during the last 15 years for the functionality that the software system proposed by this thesis provides, and representatives from their supplier have promised to do so but have not yet followed through. Enterprise companies have close to a monopoly in the medical information system industry in Norway today. Once they have reached this enterprise stage, many end up only tweaking and optimising their existing products like the company in question when they rather should keep creating new value for their customers and their business by consistent product innovation [33]. This shows that in-house software development can be beneficial in this context, as it allows for more agile product development and for the product to be specialised to specific needs concerning the discipline or institution.

Q7: What value do you get from seeing the data from these 8 CLE-tests being visualised and analysed in the same plots?
While asking this question, the subject was shown several plots in the statistics module of CleDashboard. The ones that was mentioned by her will be demonstrated in figures 5.5, 5.6, 5.7 and 5.8. Keep in mind that different colors indicate different

tests. It was answered that being able to compare the data creates a lot of value, as it allows the researcher to see if the measured variables demonstrate normal development in relation to time. The time series indicate how the CPET went, how the subject performed, and his/her physical state.

Figure 5.5: Plot of Breathing Frequency (BF). The BF will increase heavily when the subject running is on maximal effort

Q8: What does the proposed system do for your research?
This question was asked to gain an understanding of the value that the proposed software system has the potential to add to Bergen ILO Group's research. The answer said that it could be a complete data management system for them. It creates new opportunities for their research, as they do not have the resources to always use all their data since it would take too much time to organise and plot. The system will support their research process, make way for new research and save them a lot of time. An example was mentioned of an article written about prematurity, where they spent two months plotting data. In the end, they just showed the data from two different tests in each its own plot. Their results are compared to the results produced by CleDashboard in section 6.1.

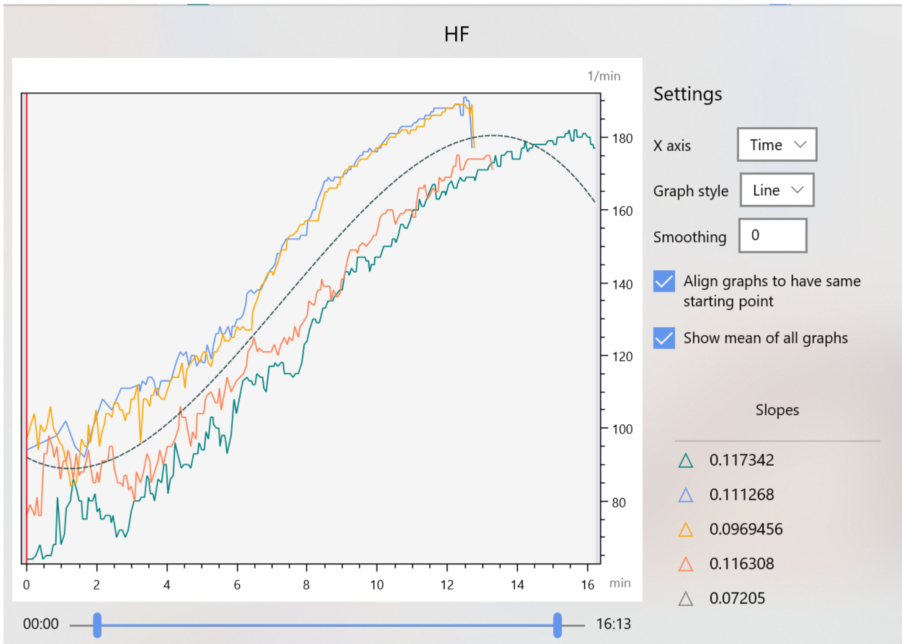

Figure 5.6: Plot of Heart Frequency (HF), and showing average between all graphs as a grey line. HF can vary a lot at the beginning of the test but should increase as the test goes on and then flat out when the subject reaches maximal heart rate. However, as the last few data points of some graphs seem to be decreasing in this example, this trend is reflected in the average graph instead of flatting out.

Q9: As you have previously told me, CLE-testing is conducted by institutions around the world. This is creating a world-wide research community. Would it make sense to develop a web-based application similar to this one, where any scientist could upload the data from their CLE-tests, creating a big database available to everyone?

It was responded that this is a great idea. However, the data would have to be anonymised following the GDPR-rules. As explained in section 2.3, health-related data are sensitive and have to be handled in a secure way. For developing a web-based solution, data integrity and safety have to be a top priority.

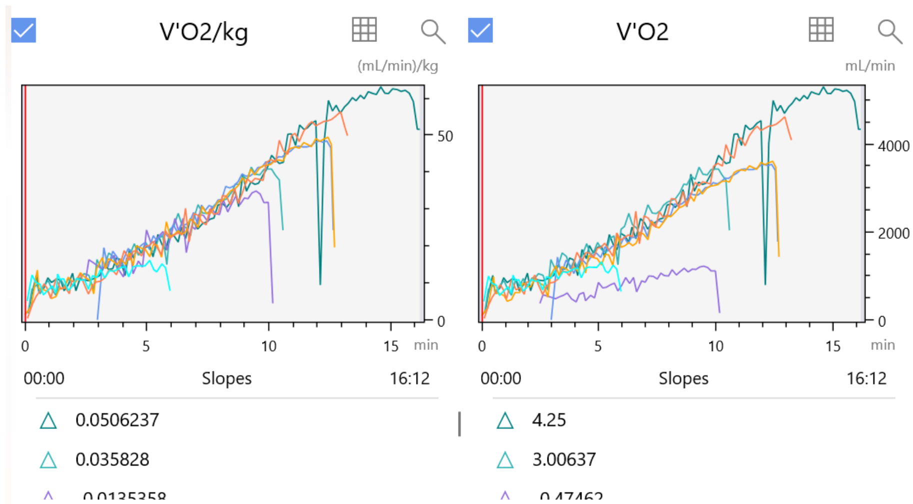

Figure 5.7: Plots of respectively oxygen uptake per kilo (V'O_2/kg) and oxygen uptake (V'O_2) alone. (V'O_2) tells us something about physical fitness, measured as consumed oxygen in one minute, per kilogram of body weight (ml/min/kg). The green subject is performing well and is most likely a well-trained young man. The turquoise and purple subjects are most likely children.

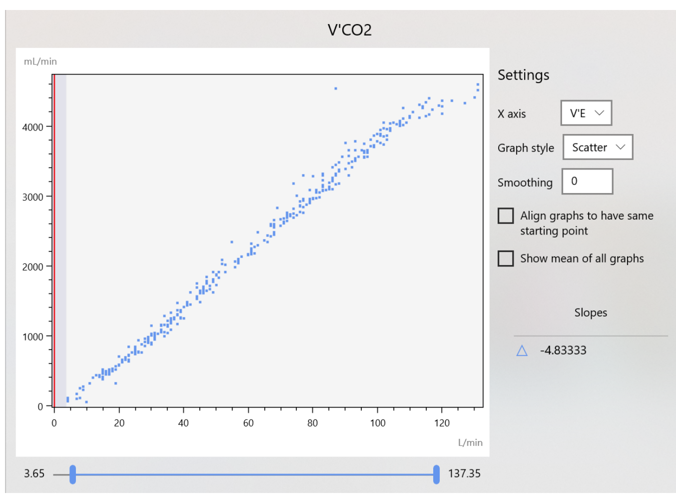

Figure 5.8: Being able to see the development in the relationship between two variables creates insight for Bergen ILO Group's research. They are, for example, interested in the exchange of carbon dioxide in relation to the volume of breathed air.

Q10: Would it be beneficial to train a machine learning model to classify the ILO-patients into the CLE-scoring system?
The subject confirmed this and said that someone has already been trying to use machine learning to analyse laryngoscopic videos to find out how big the opening of the larynx is at any time. Although, the results of this were not clear.

5.3 Compatibility with Rainfall's MVP

Full compatibility was attempted at first, but the benefits of the restructuring of both the database and CleDashboard outweighed this ideal. However, the functionality itself for viewing and recording video and audio was not altered at all. As the plan is for Bergen ILO Group to try out the MVP for some time before migrating fully to CleDashboard, their testing of said functionality will still be valuable. These are also the most critical features involving the most significant risk, as important video and audio material from a CLE-test could be lost if an error occurred. The statistical analysis and structuring of data into nested research projects does not carry a big risk if something should cause the application to crash.

Regarding the MedDataWatcher program, the MVP is dependent on it to gather the medical test data automatically. The code that makes up MedDataWatcher is designed only to input the data with dependencies to a test-id, so it is still compatible with the MVP.

5.4 Consequences of the time limitation

The opportunities of features to add to CleDashboard are endless, and during the development process, it was necessary to prioritise some functionality over others due to the time limitation. Therefore, some features are implemented to the point of demonstrating some useful functionality but would need further development to reach their full potential. However, the architecture of the system is already as good as optimal for its purpose. This makes it easy to develop the features further and to add new ones. Section 7.2.1 lists examples of possible improvements and additions of features.

Chapter 6

Discussion

In the previous section, a possible use case for Bergen ILO Group was simulated. Using the project structure of their research project HelpILO together with cardiopulmonary test data and video material from some CLE tests demonstrated the application's functionality. In this section, we will consider what value that functionality can bring to the field and confirm its validity by comparing its analysis results to a prematurity study. The research questions will also be answered.

6.1 Generality

Bergen ILO Group uses cardiopulmonary test data to analyse the breathing pattern of their participants. When conducting research, they look at similarities and differences mainly on group-level. They are interested in which characteristics affect the participants' results. This thesis has a key focus on the functionality of CleDashboard to organise, coordinate and analyse that data. As such, we can use any other population's cardiopulmonary data analysis in order to confirm the validity of the analysis results CleDashboard produces. In order to do so, we consider a study conducted within a related field to the one of Bergen ILO Group, namely ventilatory efficiency in extremely premature born adolescents and children [3]. This will clarify the advantages, and disclose any disadvantages, that the proposed software system can bring to the field. Furthermore, it will demonstrate the generality of the solution, as it is applied to another context than the one of Bergen ILO Group's research.

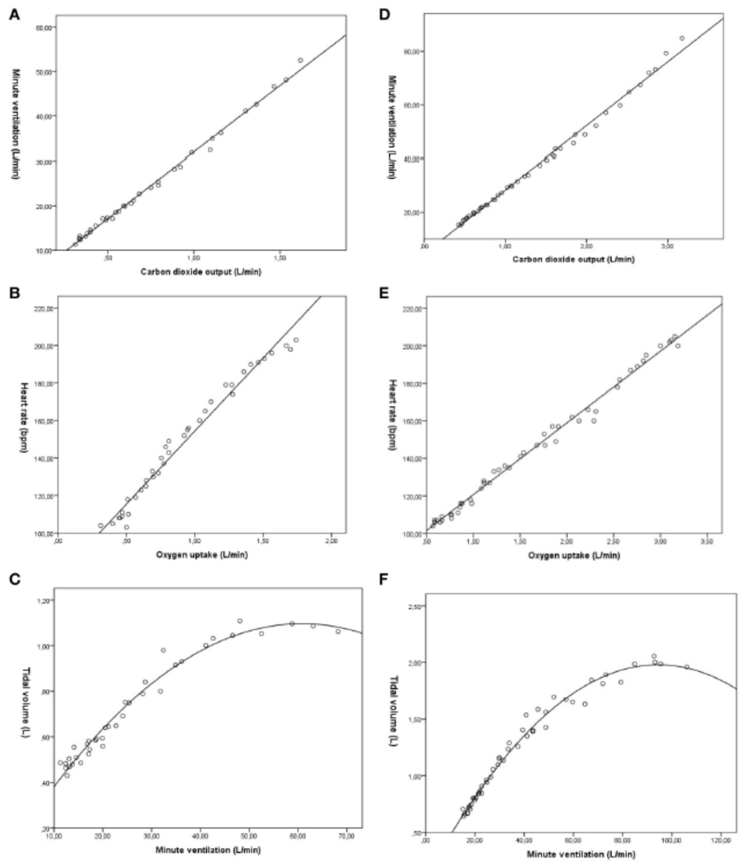

Figure 6.1: Respiratory development in study by [3].

According to the study, extremely prematurely born children and adolescents have proven to have poorer ventilatory efficiency and different breathing pattern compared to normal-term born individuals. The study was conducted to verify this and explore the impact of some variables on their CPET-results. It included two population-based cohorts where all participants were born at gestational age ≤ 28 weeks or their birth weight was ≤ 1000 grams. The participants in the first cohort were born between 1982 - 1985, and the participants of the second were born between 1991 - 1992. They all underwent CPET-tests at the respective average ages of 18 and 10 years. Afterward, one random participant from each group was selected, and some relationships between selected measurements from their CPET-tests were plotted. Regression was also utilised to show the pattern in the measurements [3]. The plots of the two participants are shown below in figure 6.1. Both linear and quadratic regression models were used to approximate the data sets.

Figure 6.2 is a screen capture of CleDashboard, where data of the same type as plot A and D in figure 6.1 from two randomly selected tests were plotted. On the y-axis, we have volume of ventilation in liter per minute. On the x-axis, we have volume of carbon dioxide in milliliter (mL) per minute (although this is measured in liter per minute in figure 6.1). In CleDashboard, we get the advantage that the two graphs are in the same plot. Hence, they are easier to compare. A smoothing with sample count 4 was put on the data to be more similar to the data in 6.1, which also seems to be smoothed. The slopes for the data are also displayed for the selected area of the graphs. The first part of the area was excluded from this, as the points in it seem to be outliers.

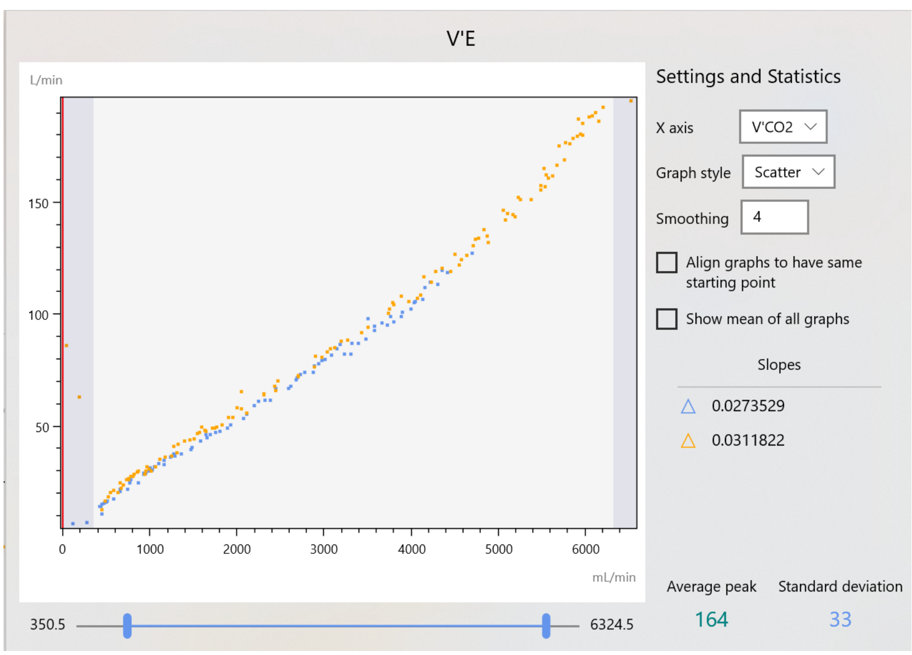

Figure 6.2: Respiratory development of two participants

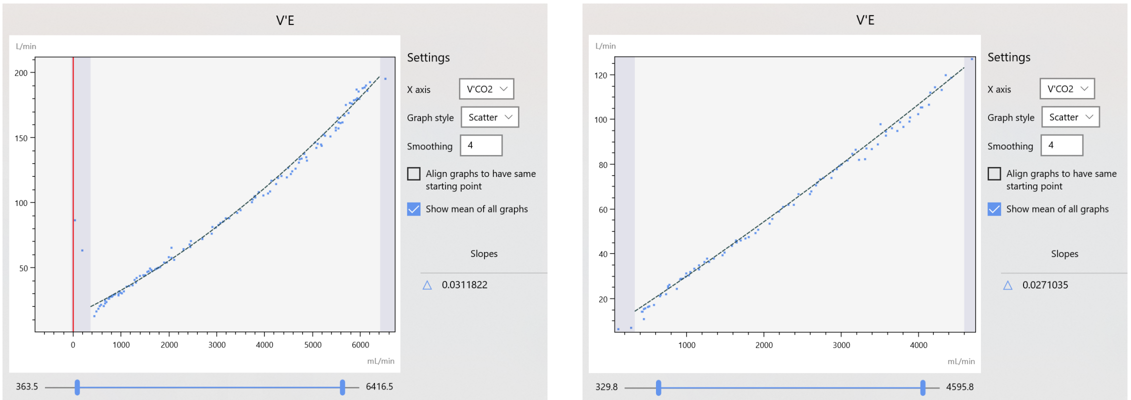

Figure 6.3: Plots of the respiratory development of two participants, showing approximated graphs to the measurements.

The same data is shown in figure 6.3, also using CleDashboard. The plot to the left displays the data with the same data set source as the yellow graph seen in figure 6.2, and the plot to the right displays data with the same dataset source as the blue graph. In this case, we see the consequences of the time limitation that was set for the thesis. The box "Show mean of all graphs" is checked, which does not reflect the button's function very well in the context of when data from just one single test is showing. As this button makes the system perform regression on the data sets in the plot to find functions for each of the graphs and then uses those graphs to find an average, in this case, it directly shows the one graph it finds from the regression of the data from this one graph.

Therefore, it is applicable in this case and leads us to exactly what we were looking for; approximation to the data points in the plots. In figure 6.1, linear regression had been performed in order to get the line shown in the plots A and D [3]. CleDashboard uses quadratic regression, but we see that the result is quite similar in this case. An idea would be for the user to input the polynomial degree, where 1st degree would cause linear regression. As for now, 2nd-degree polynomial regression is statically set in the codebase for reasons that are previously explained in section 4.6.1.

The data shows the same trends in all figures. Let's take plot D in figure 6.1 as an example and compare its axes values to the ones of the plots produced by CleDashboard. It seems that the data plotted in D are only a few data points from the beginning of the test, which implies that smoothing has been applied to the dataset. Its minute ventilation goes as far as around 60 L/min, and the carbon dioxide output to around 3 L/min. In our plot, the minute ventilation goes up to 200 L/min, and the carbon dioxide output to around 6 L/min.

Let's also look at the table produced from the same study, shown in figure 6.4. We observe that average peak values for some selected measurements along with their standard deviation are of interest. These values automatically appear in the plot view in CleDashboard, as demonstrated in figure 6.2.

TABLE 1 | Participant characteristics and peak responses to progressively incremental exercise test on treadmill.

	EP-born participants		**Term-born participants**	
	Male (n = 11)	**Female (n = 20)**	**Male (n = 12)**	**Female (n = 22)**
	Male (n = 20)	**Female (n = 17)**	**Male (n = 25)**	**Female (n = 20)**
1982–1985 birth-cohort (age 18 years)				
Birth weight (gram)	1,011 ± 189	1,029 ± 201	3,423 ± 307	3,490 ± 338
GA at birth (weeks)	27 ± 1.3	27 ± 1.2	**	**
Height (cm)	176 ± 6	164 ± 4*	177 ± 6	168 ± 6
Body mass (kg)	68 ± 15	59 ± 9	68 ± 8	67 ± 15
FVC (L)	4.79 ± 0.80	3.60 ± 0.46	5.04 ± 0.75	3.96 ± 0.62
FEV_1 (L)	3.93 ± 0.59*	3.03 ± 0.42*	4.47 ± 0.68	3.52 ± 0.47
$\dot{V}O_{2peak}$ ($L \cdot min^{-1}$)	3.50 ± 0.62	2.41 ± 0.37	3.79 ± 0.57	2.68 ± 0.47
$\dot{V}CO_{2peak}$ ($L \cdot min^{-1}$)	3.80 ± 0.70	2.63 ± 0.46*	4.17 ± 0.64	3.00 ± 0.51
$\dot{V}_{Epeak}$ ($L \cdot min^{-1}$)	109.8 ± 23.9	76.1 ± 16.3	120.2 ± 25.3	82.9 ± 9.8
HR_{peak} (min^{-1})	197 ± 16	193 ± 11	198 ± 9	195 ± 10

Mean ± 1 standard deviation.
**Significantly different from term-born participants of same sex $p < 0.05$.*
GA gestational age, FVC forced vital capacity, FEV_1 forced expired volume in 1 s, $\dot{V}O_{2peak}$ peak oxygen uptake, $\dot{V}CO_{2peak}$ peak carbon dioxide output, $\dot{V}_{Epeak}$ peak minute ventilation, HR_{peak} peak heart rate.
***GA in term–born participants were > 37 weeks, exact number not applicable*

Figure 6.4: Table of characteristics from the prematurity study by [3].

In summary, we see that we have reached more inclusive and reliable results of the same nature as in figure 6.1 and 6.4 using CleDashboard. The analysis was performed by a few keystrokes, as opposed to in the study, where they spent extensive time plotting and analysing the data. The matching results confirm the validity of CleDashboard's analysis. The plotting is performed automatically, and the solution provides strong data integrity. CleDashboard also adds possibilities to the research by easily plotting the data in the same plot, providing the user with good insight by the comparison. The easily visible and adjustable slopes and mean graph adds additional value.

6.2 Answers to research questions

RQ: How can a software system streamline and enhance research processes that involve coordination, statistical analysis, and synchronisation of medical test data and associated audiovisual material?

It has been proven by the master thesis project that gathering and organisation of data and video and audio material can be streamlined, partly automated, and thereby much more efficient. Bergen ILO Group's current research process has been mapped into three consecutive procedures with their own workflows. In this context, we can replace the elements in these procedures within the red rectangles in figure 6.5, 6.6 and 6.7 with the proposed software system. The yellow rectangle indicates parts of the research process that, in some cases, can be automated.

Streamlining the collection of data

CleDashboard can receive video and audio from any source, show, and record it. MedDataWatcher can import any data from a selected folder that it has access to into the database of CleDashboard. This allows us to skip the manual operation of moving the file to a separate computer. CleDashboard automatically organises the test data and the video and audio material together, enabling us to skip the manual step of finding that material in the file system and put it together with the associated test data. Figure 6.5 demonstrates which elements of Bergen ILO Group's current research process become replaced by the proposed software system.

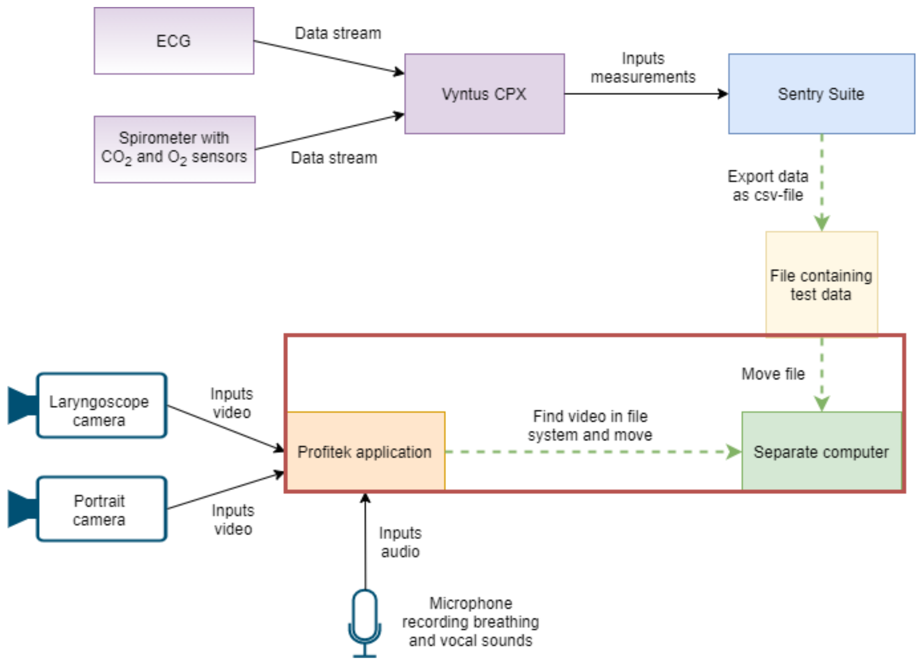

Figure 6.5: Bergen ILO Group's current setup: the red box implies the part of the research process that is automated

Automating parts of processing and analysis of test data

The red rectangle in figure 6.6 indicates that CleDashboard can fully cover step *1* in Bergen ILO Group's current procedure for processing and analysing data. As CleDashboard has functionality for both processing and then exporting data, we no longer need to do this manually. The yellow rectangle indicates that step *2* and *i* can be automated by CleDashboard in some cases, as it contains some functionality such as regression, smoothing graphs, finding slopes, and finding average peak together with standard deviation. However, the feasibility of implementing functionality in CleDashboard that will fully cover all of Bergen ILO Group's needs for statistical analysis is a question we have to ask ourselves. Ideas to how this task could be carried out are explored in section 7.2.3.

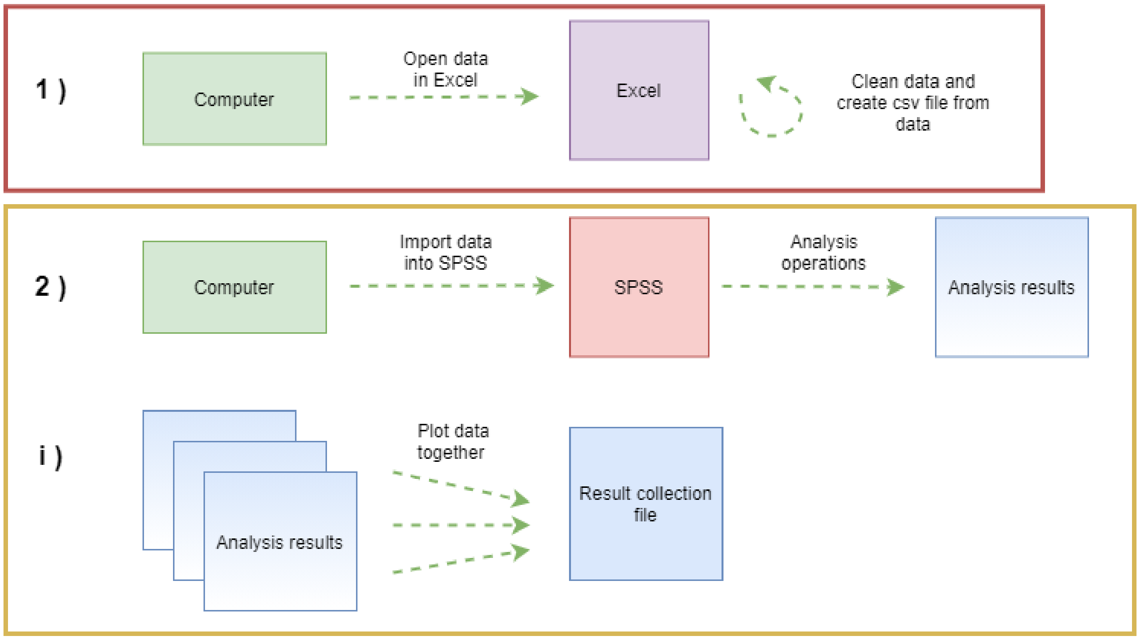

Figure 6.6: Bergen ILO Group's data processing and analysis procedure after data is collected. The red box indicates the part of the research process that is automated, and the yellow indicates indicates that its content can be automated in some cases.

Automating coordination of test data and video material

As we see in figure 6.7, the proposed software system aims to fully automate the Bergen ILO Group's current workflow for comparing data analysis results with video and audio material. This is a key part of Bergen ILO Group's research process that, as of now, is quite time-consuming. The coordination functionality in CleDashboard is already working, however, the automatic synchronisation of video- and audio-material and test data is yet to be implemented. However, a valid theoretical solution for it has been devised in section 4.5.3.

A: How should data be organised to allow for a structure well fit for statistical analysis covering several selectable medical tests, and what value does this create for Bergen ILO Group?

The solution for this was to create a nested structure of research projects, where the user can add participants to any project and add consecutive tests associated with

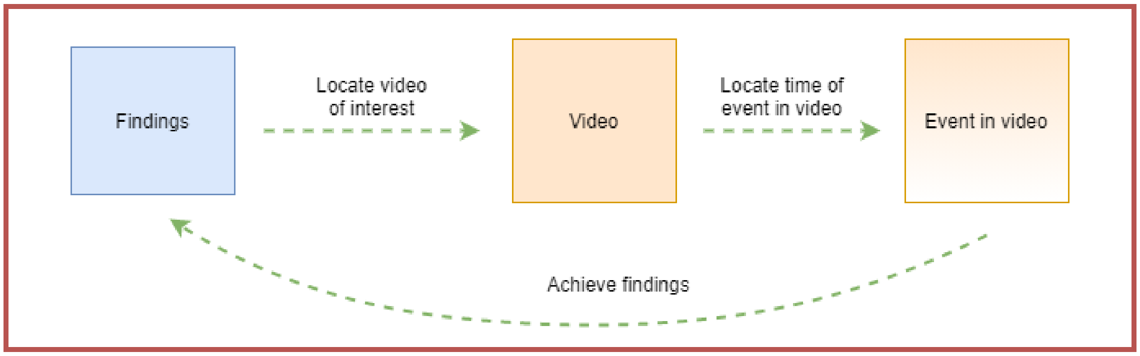

Figure 6.7: Bergen ILO Group's current workflow for comparing data analysis results with video and audio material. The red box implies the part of the research process that is automated.

that user. This is a natural, hierarchical structure that is applicable to any research project and provides an organisation that facilitates statistical analysis and selection of tests. The solution creates great value to Bergen ILO Group as it organises their test-data, saves them a lot of working time and and minimises risk of error in their research.

B: How can statistical analysis be performed and visualised based on data from selected CLE tests, and what impact will the new insight gained from doing so have on the research of ILO?

Several tools for statistical analysis have been implemented to give Bergen ILO Group insight into their test data. As for now, Bergen ILO Group does not have the resources to explore all their data as they have no tool for doing it efficiently enough. The proposed software system solves this problem. It gives the user an overview of their measurements; both plotted against time or any other matching measurement. This allows them to see the relationship between their variables.

C: How can the software system be developed in such a general way that it also can be applied within other disciplines and institutions?

Keeping a general application architecture for CleDashboard and its database was prioritised during the development process of the system. It was designed to organise the data into a nested structure of research projects, and tie the data to participants thereunder. As this organisation fits the standard way of conducting research, it is applicable to other disciplines and institutions. It has been demonstrated in section 6.1 that the proposed software system can be applied in other contexts of test lab data, thereby achieving the goal of generality. CleDashboard successfully demonstrated the same plots as the prematurity study presented, included more data, and thus presented a more accurate and inclusive solution. As for now, the analysis functionality that is included in CleDashboard is based on the requirements for research and clinical evaluation of CPET-data. However, the analysis applies to any other data, and the software system accepts data of any kind.

Chapter 7

Conclusion

This chapter will provide a conclusion to the research conducted in this thesis by summarising the work done, the resulting software system, and its contribution to the field. Further work will then be proposed.

7.1 Thesis and contribution

This thesis proposes a software system that streamlines the research processes of Bergen ILO Group, and it contributes with efficiency, data integrity, and new possibilities to extend that research. It has also been shown that the system is transferable to other disciplines. The new solution saves time in terms of work time spent on manually gathering and organising the medical test data. It also minimises the risk of errors originating from manual processes, which by experience can be significant. The solution can also be transferred to other fields and institutions, as it is generalised. Design science was applied to design relevant and useful artifacts based on a solid basis of continuously evolving domain knowledge throughout the development of the software system. The final solution was able to demonstrate clear contributions to the field of research.

7.2 Further work

7.2.1 Improvements of CleDashboard

As previously mentioned in section 5.4, some work still remains to finish details in CleDashboard to enhance the user experience, make the application more flexible, and extend the existing features. Examples of this follow.

Import buttons

The only way to import medical test data, for now, is to use the MedDataWatcher program. In CleDashboard, there should be import buttons on every test. The user should be able to both import test data and video and audio material. This would allow for skipping the step of using MedDataWatcher, making CleDashboard independent. Also, CleDashboard would be more flexible this way, as the user could collect test material in many ways, and recording of video and audio would not need to be live. That would also allow users to enter tests done before taking the proposed software system in use.

Aligning test data

As explained in section 2, the user can check a box for each plot to align all the graphs it contains to start at x = 0. Ideally, the user should be able to drag the graphs back and forth, thus achieving a flexible alignment. The video and audio material should also follow this alignment, meaning their timeline should be shifted to match the time alignment for its test data. Furthermore, for the time being, only the data for the variable in the plot is aligned. As tests usually contain measurements for several variables, they should all be aligned by the same value in all plots.

Universal design

Universal design and accessibility are two requirements when the goal is for an application to be a product. However, as CleDashboard is still under development, this part was left with the status of future work.

Phases

CleDashboard is already capable of showing phases as red marker lines in the data plots, as it is possible when showing data from single tests. However, even though the phase start times can be printed onto the data export file from SentrySuite, MedDataWatcher does not read that data as of yet due to the time limitation set for the project. Furthermore, to show phases in a plot containing data from several tests is a challenge considering the user experience aspect. A creative solution for marking the graphs with phases has to be found, as a plot would get confusing if it were to contain marker lines for every phase for every graph.

7.2.2 Adding measurement to plot

As for now, each measurement gets its own plot and is automatically plotted against time on the x-axis in CleDashboard. Functionality already exists for letting the user switch the x-axis measurement to another available one, but a missing feature is to also allow the user to plot the values of another measurement on a new y-axis. This feature already exists in SentrySuite, see an example of this in appendix A. This would be a great advantage for Bergen ILO Group when comparing measurements and has already been requested but not prioritised in the development process.

7.2.3 Further statistical analysis

Looking at the study of extremely prematurely born individuals and their CPET data, we see that they used descriptive statistics to characterise the study population. They were using categories such as extremely prematurely born versus term-born, height, weight, gender, and more. They were interested in seeing which of these variables were independent or explanatory [3]. This type of functionality should be incorporated into CleDashboard. The database should be expanded to include variables like these connected to tests, and the user should be able to see whether or not and to which degree any variable seems to affect any measured data. As SentrySuite can include this type of data in the file it exports containing test data, MedDataWatcher should be able to read that data and input it to CleDashboard's database. Functionality for this should therefore be implemented.

By including these categories in the tests in CleDashboard, we could also implement a filter algorithm that both could sort out tests from a selection based on for example, a height, age or weight interval, gender, extreme premature versus term-born, and so on. This would allow for visualisation of those variable's effects on the data and reveal any impact. One could also implement a comparison algorithm that matches tests based on the user's choice. For example, the user could choose to show "the average graph for each measurement from all male participants", and "the average graph for each measurement from all female participants" in the plots. In the previously mentioned study on extremely premature-born individuals, these types of comparisons were performed [3]. Figure 7.1 shows an overview of extreme premature versus normal term-born and male versus female effects on some relationships. It clearly states the relevance of this hypothetical functionality.

7.2.4 Simulating airflow through larynx

As the application is model-based, one can easily implement any other functionality and add that as a module. An example of such a model, and something that is sought after by Bergen ILO Group, is a simulation of airflow through the larynx. A model for doing so has been developed recently [34], and it would be possible to implement a simulation module based on this. The model requires air volume and pressure parameters over and under the larynx per breath, which Bergen ILO Group already has the equipment to measure. The CLE-test already gathers air volume data through the CPET, and Bergen ILO recently started using pressure measurement during CLE-tests after it was proven both feasible and tolerable to do so [35]. Pressure measurement to register the airflow resistance over the larynx has recently been introduced as a reliable diagnostic tool to be used during CLE tests. Two measurement devices are inserted via a laryngoscope and placed above and under the larynx, thereby measuring the tracheal and supraglottic pressure [36]. The simulation would be very useful for several reasons. For example, it could be used to simulate the outcome of surgery, which can be hard to predict.

TABLE 2 | Curve parameters (a, b, and c) describing the relationships between $\dot{V}_E$ and $\dot{V}CO_2$, between HR and $\dot{V}O_2$ and between V_T and $\dot{V}_E$.

	EP-born participants		Term-born participants	
	Male ($n = 11$)	**Female ($n = 20$)**	**Male ($n = 12$)**	**Female ($n = 22$)**
1991–1992 birth-cohort (age 10 years)				
$\dot{V}_E = a + b \cdot \dot{V}CO_2$				
a	2.4 ± 1.5	2.2 ± 1.4	2.3 ± 1.3	2.1 ± 1.6
b	32.8 ± 2.1*	32.1 ± 2.8	29.5 ± 2.2	30.7 ± 3.4
$HR = a + b \cdot \dot{V}O_2$				
a	75 ± 12	70 ± 10	74 ± 13	77 ± 16
b	93 ± 10*	100 ± 15*	79 ± 9	82 ± 18
$V_T = a + b \cdot \dot{V}_E + c \cdot \dot{V}_E^2$				
a	0.17 ± 0.09	0.17 ± 0.10	0.14 ± 0.10	0.22 ± 0.20
b ($\cdot 10^{-2}$)	2.4 ± 1.0	2.6 ± 0.6	3.0 ± 0.9	2.8 ± 0.8
c ($\cdot 10^{-4}$)	−2.0 ± 1.6	−1.9 ± 1.0	−2.1 ± 1.1	−2.1 ± 1.4
	Male ($n = 20$)	**Female ($n = 17$)**	**Male ($n = 25$)**	**Female ($n = 20$)**
1982–1985 birth-cohort (age 18 years)				
$\dot{V}_E = a + b \cdot \dot{V}CO_2$				
a	2.7 ± 1.7	3.3 ± 1.9	2.3 ± 2.0	4.2 ± 1.6
b	25.4 ± 2.0	26.2 ± 3.9	25.1 ± 2.8	25.2 ± 3.1
$HR = a + b \cdot \dot{V}O_2$				
a	65 ± 11	68 ± 13	68 ± 12	75 ± 14
b	40 ± 8	57 ± 9	39 ± 5	51 ± 12
$V_T = a + b \cdot \dot{V}_E + c \cdot \dot{V}_E^2$				
a	0.24 ± 0.20	0.09 ± 0.17	0.29 ± 0.16	0.17 ± 0.16
b ($\cdot 10^{-2}$)	3.7 ± 0.9	4.5 ± 1.2	3.8 ± 0.9	4.0 ± 1.1
c ($\cdot 10^{-4}$)	−1.8 ± 0.8	−3.5 ± 1.9*	−1.7 ± 1.0	−2.4 ± 1.1

Mean ± 1 standard deviation.
** significantly different from controls of same sex $p < 0.05$*
$\dot{V}O_2$ oxygen uptake, $\dot{V}CO_2$ carbon dioxide output, $\dot{V}_E$ minute ventilation, HR heart rate.

Figure 7.1: The impact by gender and extreme premature versus term-born on the development of the relationship between selected measurements from the study in [3].

Another model that could be introduced into CleDashboard is ILO assessment. With only the imaging and CPET-data to rely on, the assessment using the ILO scoring system can be subjective [37]. However, by using both pressure and air volume measurement, one might be able to assess the degree of ILO in a more objective way. This might even allow for CleDashboard itself to determine the ILO score automatically, which would come in handy when grouping a population for research purposes.

7.2.5 Migrate the SQLite database onto cloud

As for now, the application has a local database, which means that the data is not accessible from other computers. For example, by using cloud technology, one could reach the data from anywhere. Such a solution would not only make the application data more accessible, but it would open up possibilities for combining research results from anywhere. As the application is designed for containing any type of research project, this could create an international medical data database. And as the application has functionality for combining related data and tweaking that data to fit together, it would be possible to visualise and analyse data from the same tests conducted at different hospitals.

This was not done in the first place due to strict rules concerning personal data protection. Although, this can be solved by proving that one can safely upload data to cloud, and by using secure user authentication and authorisation the data would be at least as safe on cloud as on a hospital server. The second solution could be to make the data anonymous before uploading it to cloud. For example, the true identity of the patients whose data is obtained can only be found locally where the application is run. This would be an ideal solution, as the subjects' identities would not be relevant in a large data collection for research purposes.

7.2.6 Cloud computing

As CleDashboard is used for handling, processing, and analysing medical test data while showing video and audio material, it requires a quite powerful computer to work fast enough. One of the wishes of Bergen ILO Group was for CleDashboard to be able to run on any computer. This is where cloud computing comes in. By uploading the data to a cloud vendor such as Amazon Web Services (AWS) [38] or Google Cloud (GC) [39], it can both easily be stored and efficiently processed and analysed [40]. This would also open up possibilities for analysis of medical images and video, which is very heavy for normal personal computers. This could be useful to apply to videos from CLE tests.

7.2.7 Machine learning

Machine learning is a powerful technology that can be utilised for solving classification problems. The grade scoring system of Induced Laryngeal Obstruction (ILO) is, in its essence, a classification problem. As the scoring system is purely visual, one could argue that it might be useful also to consider the CPET data in the assessment. CleDashboard allows for gathering a large amount of data, which can be utilised as training data. For example, a fuzzy neural network could be trained to assess a probability score for each category within the ILO grading system based on laryngoscopic video analysis for each participant. When the model's performance is sufficiently high, the medical test data that belongs to each video can be considered in the context of the score that the patient received. An algorithm can then look for patterns in the data and see if there are trends that can be linked to the score. A new grade scoring system can be invented using this pipeline based on the laryngoscopic video and the related test data.

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Appendix A

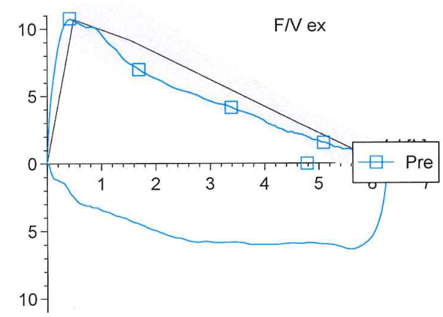
CPET-data analysis by SentrySuite

This is a report exported by SentrySuite of a real CLE-test, used as an example.

Hjerte-lunge Belastningstest

Spirometri

	Pred	Pre	%	Z-skåre	Post 1	%
FVC	6.18	6.78	110			
FEV1	5.27	4.78	91			
FEV1%F	84.31	70.54	84			
PEF	10.68	10.78	101			
FEV6		6.72				
BF MVV		»				
MVV	169.49	197.63	117			
PIF		6.39				
FIV1	5.60	5.39	96			
FVC IN	6.09	6.25	103			
Substans						
Dose						
Målingsdato		16.04.18				
Målingstid		12:45				



Cardiovascular Responses

Oppsummering (30 - sek)		Rest	Aerob grenseve...	Anaerob grenseve...	Peak (R)	Peak (R) [Pred.]	Peak (R) [%...
V'O2/kg	[(mL/min)/kg]	8.2	28.9	33.1	62.7	51.4	122
V'O2	[mL/min]	689	2428	2778	5263	4244	124
V'CO2	[mL/min]	528	1822	2129	5920	-	-
Belastning	[W]	-	245	245	570	294	194
HR	[1/min]	68	124	133	181	201	90
O2puls	[mL]	10.1	19.6	20.9	29.1	20.0	145
Psys	[mmHg]	-	-	-	-	177	-
Pdia	[mmHg]	-	-	-	-	76	-
HRR (L)	[1/min]	133	77	68	20	-	-

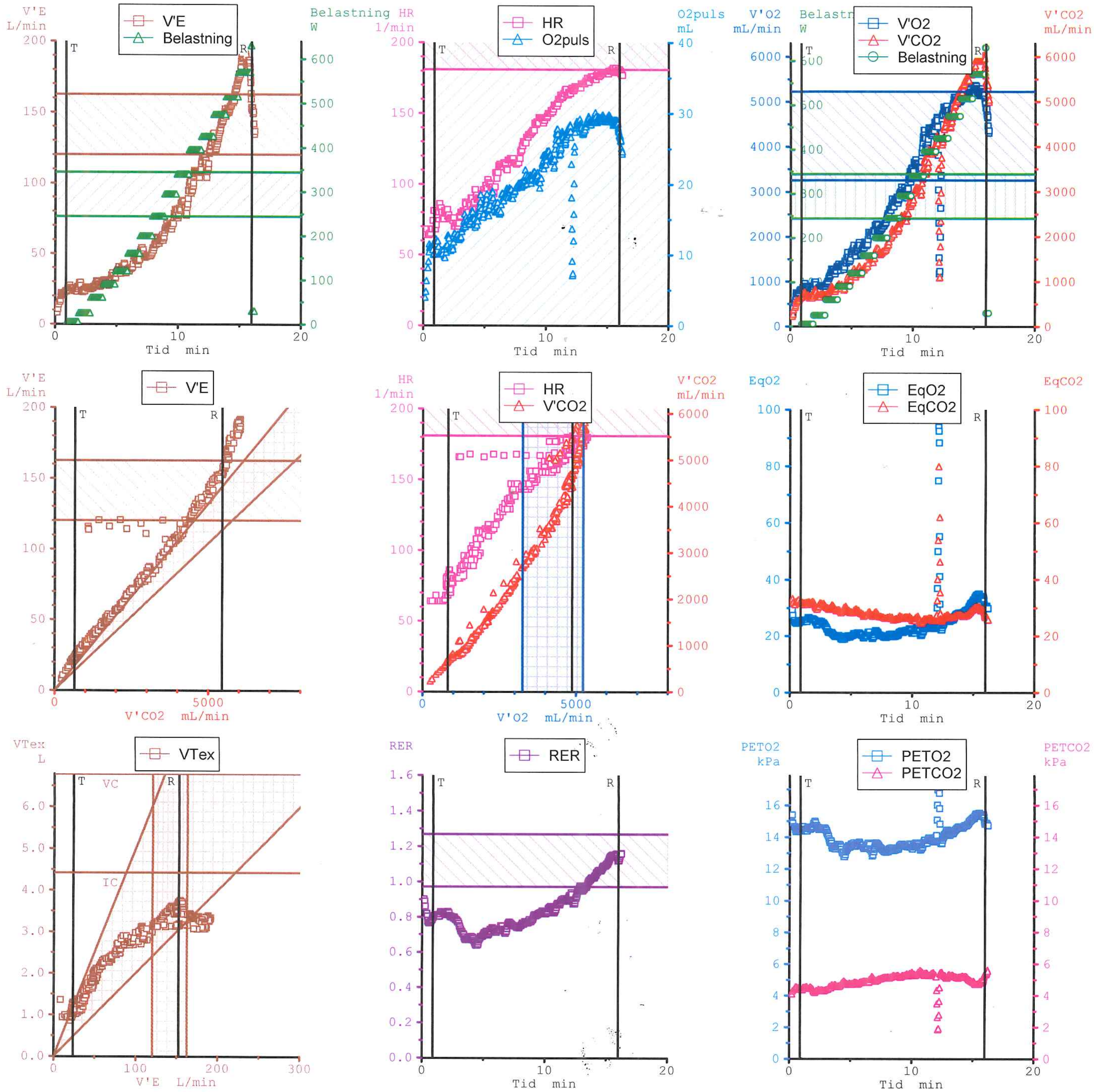
Ventilatory Response

V'E	[L/min]	20	52	58	187	141	132
VTex	[L]	1.017	2.060	2.253	3.329	-	-
BF	[1/min]	19.3	25.3	25.9	56.0	41.6	135
BR (%)	[%]	88	69	65	-11	27	-42
BR MVV%	[%]	90.05	73.59	70.43	5.59	-	-

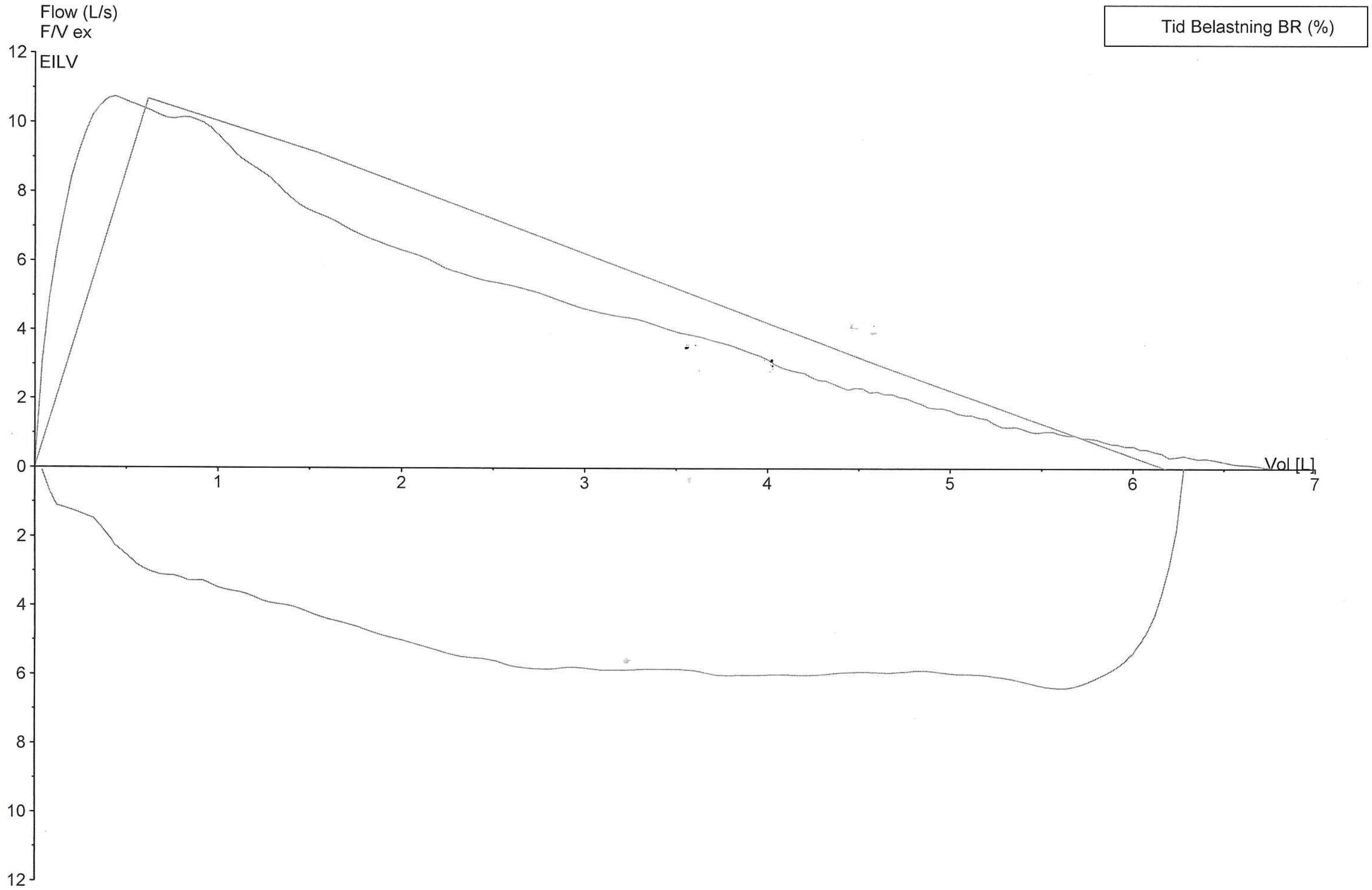
Gas-Exchange Response

PETCO2	[kPa]	4.58	5.16	5.27	4.80	-	-
PEO2	[kPa]	15.92	14.59	14.59	16.39	-	-
EqO2		24.6	20.0	19.7	34.0	-	-
EqCO2		32.1	26.7	25.7	30.2	-	-
VDc	[mL]	127	152	134	167	-	-
RER		0.77	0.75	0.77	1.12	1.12	100
SpO2	[%]	-	-	-	-	-	-

CardioPulmonary Exercise Graphs: 9-Plot



Oppsummering (30 - sek)		Aerob grenseve...	Anaerob grenseve...	Peak (R)	Peak (R) [Pred.]	Peak (R) [%...
V'O2	[mL/min]	2428	2778	5263	4244	124
Belastning	[W]	245	245	570	294	194
HR	[1/min]	124	133	181	201	90
O2puls	[mL]	19.6	20.9	29.1	20.0	145
RER		0.75	0.77	1.12	1.12	100
V'E	[L/min]	52	58	187	141	132
BR (%)	[%]	69	65	-11	27	-42


Tid Belastning BR (%)
Flow (L/s)
F/V ex
EILV
12
10
8
6
4
2
0
2
4
6
8
10
12
1
2
3
4
5
6
7
Vol [L]

Kommentar

Tid [min]	HR [1/min]	Belastning [W]	V'O2 [mL/min]	V'O2/kg [(mL/mi…	V'CO2 [mL/min]	RER	V'E [L/min]	EqO2	SpO2 [%]	ti/tot [%]
00:00 Rest										
00:30	64		520	6.2	426	0.82	16	25.6		34
00:50	68		717	8.5	553	0.77	21	25.2		27
00:53 Test										
01:00	81	5	1013	12.1	812	0.80	28	24.5		38
01:30	86	5	850	10.1	689	0.81	25	25.9		34
02:00	80	25	843	10.0	690	0.82	25	26.0		30
02:30	76	25	874	10.4	711	0.81	25	24.8		45
03:00	72	60	887	10.6	695	0.78	25	24.1		44
03:30	87	60	1186	14.1	840	0.71	29	21.3		38
04:00	90	90	1244	14.8	845	0.68	28	20.0		37
04:30	89	90	1322	15.7	873	0.66	29	19.3		43
05:00	96	120	1473	17.5	994	0.68	33	19.7		40
05:30	100	120	1740	20.7	1225	0.70	39	20.3		40
06:00	108	160	1704	20.3	1245	0.73	39	20.6		44
06:30	113	160	1908	22.7	1403	0.74	43	20.5		44
07:00	117	200	2060	24.5	1490	0.72	45	19.9		39
07:30	115	200	2220	26.4	1693	0.76	50	21.0		45
08:00	118	245	2340	27.9	1732	0.74	49	19.6		46
08:30	129	245	2632	31.3	2007	0.76	57	20.1		44
09:00	138	295	2893	34.4	2233	0.77	62	20.2		44
09:30	143	295	2936	35.0	2380	0.81	68	21.6		45
10:00	145	340	3278	39.0	2702	0.82	76	22.0		46
10:30	152	340	3625	43.2	3052	0.84	84	22.1		46
11:00	157	395	3930	46.8	3303	0.84	88	21.1		44
11:30	162	395	4206	50.1	3726	0.89	103	23.3		46
12:00	165	425	4447	52.9	4001	0.90	109	23.4		46
12:30	168	425	3347	39.8	2990	0.89	112	31.9		45
13:00	171	475	4785	57.0	4553	0.95	129	25.7		46
13:30	172	475	4906	58.4	4733	0.96	132	25.8		46
14:00	174	515	5089	60.6	5156	1.01	148	27.9		46
14:30	178	515	5145	61.3	5426	1.05	154	28.7		47
15:00	179	570	5239	62.4	5668	1.08	169	31.0		47
15:30	182	570	5243	62.4	5922	1.13	187	34.1		48
15:57	181	630	5144	61.2	5902	1.15	180	33.3		47
15:59 Gjenoppr										
16:00	181	630	5429	64.6	5972	1.10	153	27.2		53
16:30	177		4523	53.8	5180	1.15	142	30.1		46

Appendix B

Data series export by SentrySuite

An example of data from a real CLE-test exported by SentrySuite. As of yet, it is only the data series that is imported into CleDashboard's database by MedDataWatcher. The data is from a real CLE-test, and the measurements comes per breath. As the amount of data is quite large, the example is cut in order to fit into one page.

mann
22 år
189 cm
84,0 kg
24 kg/m^²
13:03
1006 mB
23 °C
34%

Tid	V'O2/kg	V'O2	V'CO2	RER	HF	V'E	BF	EqO2
min	(mL/min)/	mL/min	mL/min		1/min	L/min	1/min	
00:00	Rest							
00:10	3.0	253	228	0.90	64	8	6	28.8
00:13	2.8	238	203	0.85	64	11	19	34.0
00:16	7.0	589	519	0.88	64	20	22	28.4
00:23	6.7	559	453	0.81	65	15	8	25.2
00:26	6.9	576	443	0.77	68	17	23	24.0
00:28	11.7	980	737	0.75	68	25	27	21.7
00:30	8.5	711	540	0.76	64	21	28	24.7
00:31	21.1	1771	1316	0.74	64	46	46	22.4
00:34	5.7	475	363	0.76	64	17	21	30.5
00:37	10.3	863	685	0.79	65	26	23	26.7
00:42	6.8	569	444	0.78	65	16	11	25.0
00:46	6.5	547	418	0.76	65	16	16	24.9
00:50	8.5	712	557	0.78	68	21	16	26.5
00:53	10.7	901	708	0.79	68	25	19	25.0
00:53	Test							
00:56	12.2	1021	814	0.80	74	26	21	22.2
00:59	13.2	1112	909	0.82	81	31	18	25.8
01:02	9.3	780	654	0.84	81	25	20	28.0
01:05	9.8	825	678	0.82	68	24	24	25.3
01:08	11.2	937	776	0.83	68	28	21	26.7
01:11	9.1	762	629	0.83	71	23	20	26.7
01:15	10.1	846	658	0.78	78	22	16	22.9
01:18	15.2	1279	1002	0.78	78	32	18	23.0
01:20	16.2	1358	1059	0.78	80	38	27	24.8
01:23	5.1	433	347	0.80	80	15	22	27.5
01:26	7.9	662	540	0.81	86	21	20	27.9
01:28	10.8	908	738	0.81	86	29	33	26.5
01:30	10.3	867	714	0.82	83	26	21	26.6
01:34	8.1	682	567	0.83	83	19	20	23.1
01:36	13.6	1145	967	0.84	80	35	29	26.8
01:39	8.8	737	618	0.84	80	23	18	28.4
01:43	8.7	734	606	0.83	75	20	14	24.8
01:46	6.2	517	401	0.78	75	18	22	29.4
01:48	11.1	930	746	0.80	75	27	24	25.7
01:53	10.3	862	670	0.78	81	22	14	23.9
01:55	6.9	576	468	0.81	80	20	31	27.0
01:57	19.8	1666	1351	0.81	80	45	27	24.8
01:59	7.1	600	496	0.83	80	22	34	28.1

Appendix C

Database of CleDashboard

The database of CleDashboard, in order to demonstrate the data structure.

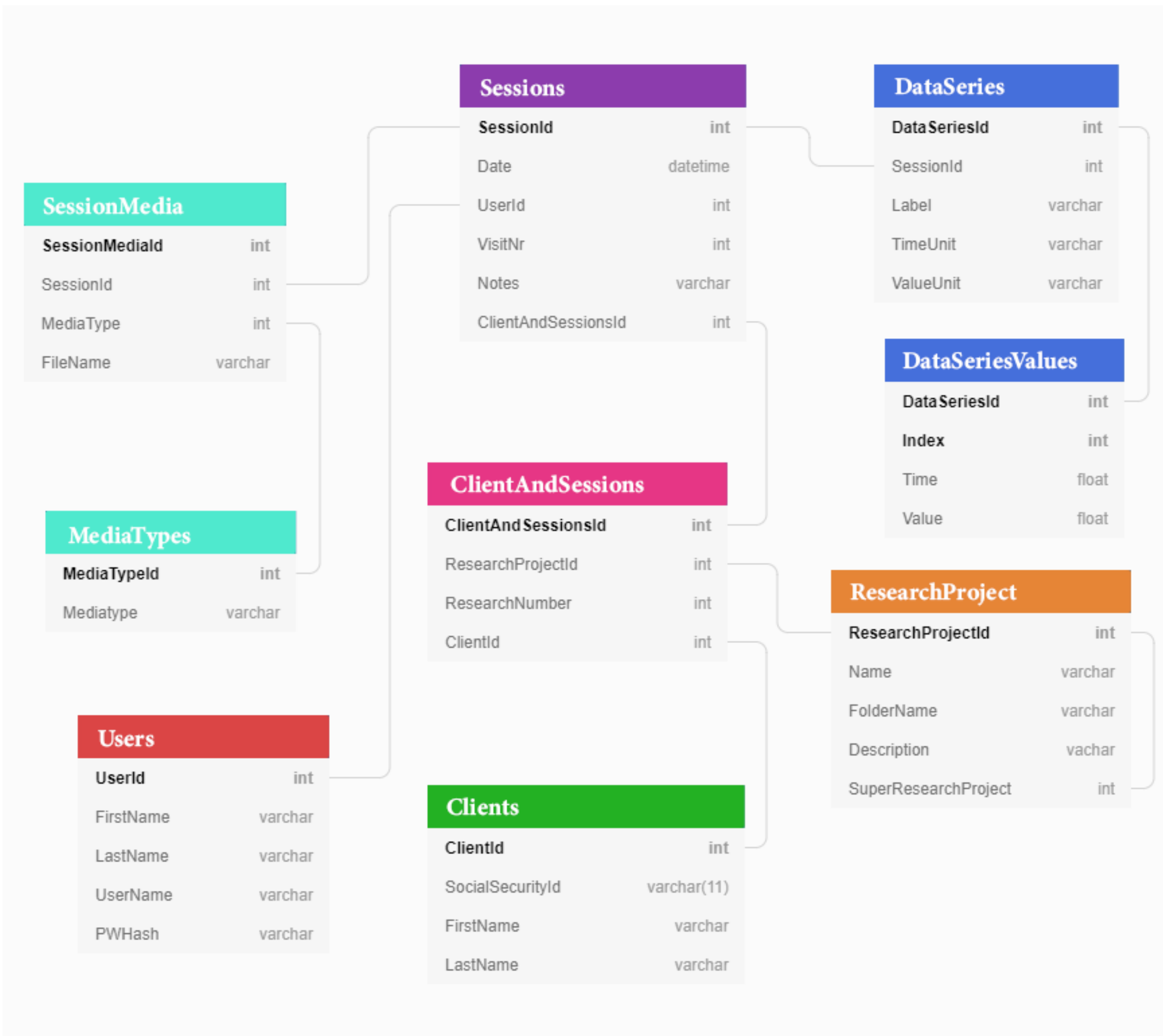


Figure C.1: Database diagram of CleDashboard

Appendix D

Data export by CleDashboard

The data in this export example is on the format described in section 4.5.2, and the colour coding has been applied using Excel to match the one in figure 4.11. It contains processed data from real CLE-tests. The example shows V'E (air volume per breath) in liter per minute plotted agains V'CO_2 (volume of carbon dioxide output per breath) in milliliter per minute. A smoothing of sample size 10 has been applied to the data. The original data sheet is much longer, this version was cut to fit into one page.

V'E L/min				
	Group A-1234-1	Group A-1234-2	Group A-54321-1	Group A-6789-1
slopes	0.022	0.029	0.029	0.03
V'CO2 mL/min				
332			5.6	
338.5	61.6			
379				
383			16.3	
396.5			11.4	
435.5			13.5	
458.5			15.3	
481.5			16.4	
482.5				
495				
503.5			16.2	
512				
518				
532			18.6	
567		11.3		
570.5	17.1			
573				
579.5			18.4	
587				
615.5				
619		20.7		
641.5		24.1		
647.5			20.9	
649.5	20.6		19.9	
654.5				
680			26.2	
685.5	23			
717				
723.5		27.3		
749.5	24.9			
752.5				
753.5		28.5		
770.5	26.5			
773			25.1	
787				
806.5			26	
820.5		31.4		
827	27.6			
845.5		30		
854.5				
863.5	29			

Appendix E

Interview

A qualitative, semi-structured interview of Hege Clemm, the head of Bergen ILO Group, conducted the 10th of May 2021.

Question	**Answer**
Usability	
Is the structure with nested research projects easily understandable and useful?	Yes, it is intuitive. I think CleDashboard is a further development from the Profitek application, and I am very happy with it. I also like that we can add tests to any research project even though it has sub-projects. A lot of times we initially do not know which sub-project a participant belongs to, because we find that out later on. We would therefore like to be able to dynamically move the participant into the research project he or she belongs to after finishing the CLE-test and making some considerations.
Is the workflow logical and how is the usability and design?	The workflow is good and logical, and the design is very nice. The colour coding makes the overview easy and pretty."
Generalisation	
Is the application generalised enough and correctly?	Yes.
Do you have any examples for other disciplines or institutions where the application could be used?	In all exercise test labs that measure test data, both for clinical and research purposes. Examples: - To compare data from before and after a heart or cancer-operation - COVID-centres who test people after they have had the disease. This is also done by a CPET-test. - In all kinds of premature research. For example, we want to see how the oxygen consumption varies between premature and term born populations. So, the application could be used by any of the research groups in WestPaed Research - CPET on lying-down cycle ergometer with heart ultrasound. - It could be used by many in different context in Haukeland University Hospital. It also has the potential to be made into a product and sold to other institutions, but we as a hospital cannot be the ones to distribute it. - Research in sports. Athletes follow their health very accurately, and it would be very valuable for them to be able to see their own development like this. In general, we are interested in the development from test to test for the same patient, or to see the collective differences between groups. These groups can for example be a group with some condition and one healthy control-group. If we look at one patient, we are interested in the development after any kind of intervention. An intervention can be a kind of treatment for something, as for example use of medicine.
EILO research	
How many CLE-tests have you conducted here at the test lab?	Around 3000 during the last 20 years. With the HelpILO project we will test around 1500 more.

You earlier mentioned that the big medical technology companies are less lenient to innovate. How did you experience that?	Our supplier is the world leading company in this field, and they are the ones who provides our laboratory with software and equipment. We have asked for some of the functionality that your master thesis' project has provided for 15 years. We wanted to be able to export tabular data, and to show data from different groups in one plot. We have made several requests to the representatives from our supplier, but even if they have promised to help with this, they have not yet followed it through.
Plots	
What value do you get from seeing the data from these 7 CLE-tests being visualised and analysed in the same plots?	Being able to compare the data creates a lot of value. The time series gives us an idea of how the CPET-test went, how the subject performed and his/her physical state. It shows us if the measured variables had a normal development in relation to time. For example, the breathing function (BF) will increase heavily when the subject running is on maximal effort. The heart frequency (HF) can vary a lot in the beginning of the test depending on whether the subject is nervous and should increase as the test goes on and then flat out when the subject reaches maximal heart rate. The volume of oxygen uptake ($V'O_2$) tells us something about the physical fitness, measured as consumed oxygen in one minute, per kilogram of bodyweight (ml/min/kg). We see here that the green subject is performing well and is most likely a well-trained young man. The turquoise and purple subjects are most likely children. However, for our research on ILO, the most important part is to see the development in the relationship between two variables. The exchange of CO_2 in relation to volume of breathed air (V'E) is important to us.
Contribution	
What does this system do for your research?	What this application can be is a complete data management system. It creates opportunities for our research that was not there before, as we did not have the resources to always use all our data since it would take too much time to organize and plot. There is an example of an article written about prematurity, where they spent two months plotting data. In the end they just showed the data from two different tests in each its own plot. Since your application does that automatically with any number of tests, it is going to support our research process, make way for new research and save us a lot of time.
Further work	
As you have previously told me, CLE-testing is conducted around the world. This is creating a world-wide research community. Would it make sense to develop an application similar to this one, where any scientist	That would be amazing. However, the data would have to be anonymised and the GDPR-rules would have to be followed.

could upload the data from their CLE-tests, creating a big database available to everyone?	
Would it be beneficial to train a machine learning model to classify the ILO-patients into the CLE-scoring system?	Definitely. In fact, someone has already been trying to use machine learning to analyse the laryngoscopic videos in order to find out how big the opening of the larynx is at any time. I am not sure if they had good results, though.