UNIVERSITY OF CAPE TOWN

DEPARTMENT OF COMPUTER SCIENCE

CS/IT Honours
Final Paper 2019

Title: **A visualization front-end for the analysis and display of physiological measurements**

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Project Abbreviation: **VRFEAR**

Supervisor(s): **James Gain**

Category	*Min*	*Max*	Chosen
Requirement Analysis and Design	*0*	*20*	
Theoretical Analysis	*0*	*25*	
Experiment Design and Execution	*0*	*20*	
System Development and Implementation	*0*	*20*	
Results, Findings and Conclusion	*10*	*20*	
Aim Formulation and Background Work	*10*	*15*	
Quality of Paper Writing and Presentation	*10*		10
Quality of Deliverables	*10*		10
Overall General Project Evaluation (*this section allowed only with motivation letter from supervisor*)	*0*	*10*	
Total marks		**80**	

A visualization front-end for the analysis and display of physiological measurements

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ABSTRACT

Information or data visualization is a critical part of research and communication of results due to its ability to synthesize large amounts of data into effective graphics, visualization aids in the understanding data from experiments. This is way visualization is utilized in emotion inducing experiments that measure physiological signals, done by the University of Cape Town's psychology department. The researchers (involved in emotion inducing experiments) have access to two visualization tools: AcqKnowledge and Excel. But these visualization tools have drawbacks. AcqKnowledge is expensive, significantly restrictive and can only work on one data set at a time. Excel is a general use tool and not made specifically for handling physiological data. The main aim of this project is developing an alternative visualization tool for the researchers, the tool will not have drawbacks of other visualization tools. The visualization tool be will be a desktop application. A user-centred design was used to develop the application. Design ideas were taken from the information/data visualization literature and user requirements. After the development a heuristic evaluation using Nielsen's ten usability heuristics, for user interface design, was done using three evaluators. The evaluators had to identify at least six problems using the heuristics and also had give the problem a severity level .The evaluators had to also rate the overall usability of the application using a 5-level Likert-like scale (1- very poor to 5 - very good, 3- reasonably usable). The application had an average usability rating of 3.33 and the heuristic with the most critical problems was error prevention and the heuristic with the most problems was flexibility and efficiency of use.

KEYWORDS

Visualization, physiological data, desktop application, heuristic, user-centered design.

1 Introduction

An objective method for determining the emotional state of person is measuring signals from the sympathetic branch of the Autonomic Nervous System (ANS) [1]. The ANS is responsible for involuntary body functions such as heartbeat, blood-flow and digestion [2]. The ANS contains a sympathetic branch, linked to emotional responses (regulating sweat, heartrates etc.), and a parasympathetic branch linked to digestion, attention and effort [1].

This objective method was used in the Virtual Reality (VR) Fear project. The VR Fear project was undertaken in-conjunction with this project. The VR Fear project focuses on creating a virtual environment that will elicit fear in participants without any phobias. The VR Fear project is done in collaboration with the psychology department. The department provided equipment to measure emotional responses in participants and guided the experimental design.

The signals, from the ANS sympathetic branch, measured ,in the VR Fear experiment, are: conductivity produced in the skin due to the activity of sweat glands(Electrodermal activity or EDA), electrical activity of the heart(Electrocardiography or ECG), blood volume changes in the microvascular bed of tissue(Photoplethysmogram or PPG) and Respiration (breathing or RSP).

Having a system/tool that can visualize data or information is important, a visual representation of data/information can make it more understandable and discernable [3]. So, having a visualization tool for visualizing the physiological data described above is useful. The psychology department currently makes use of two visualizing tools, for this type of data, but these tools have several drawbacks.

The main aim of this project is creating an alternative visualization tool for the psychology department. The tool will be very usable. The tool will not have the drawbacks of the currently used visualization tools. The tool will give researchers, from the psychology department, more options when doing data analytics and provide better understanding of data correlations.

The visualization tool will be a desktop application. The desktop application will have to perform four functions: reading in physiological data, visualizing the data, displaying the data, and exporting the data out of the application. Transformations performed on the data will be based on the requirements gathered from clients and literature. The clients will be representatives of the psychology and computer science department.

The clients are: James Gain (computer science professor and project supervisor), Timothy Gwynn (computer science master student) and Siphumelele Sigwebela (psychology master student)

2 Background and Related Works

2.1 Background

Information or data visualization is a critical part of research and communication of results due to its ability to synthesize large amounts of data into effective graphics [3]. Visualization makes it easier for people to analysis and understand the data/information, because it is easier for the brain to comprehend an image versus words or numbers [4]. A standard definition of information or data visualization does not exist, but attempts have been made to define information visualization. Few et al. defined information/data visualization as any graphic that examines or communicates data in any discipline [5]. And Chen et al. defined information/data visualization as visual representations "of the semantics of information" [6]. There has also been attempts to define an information visualization system. Yi et al. stated that a visualization system has two main components: representation and interaction [7]. From our research there seems to be no standard way of creating an effective visualizing system, but numerous guidelines on how to make effective visualizing system have been created.

Shneiderman. [8] developed a set of guidelines, called Shneiderman's Mantra, for creating an effective visualization system. The Shneiderman's Mantra guidelines consist of: "Overview first", "zoom and filter", "details on demand." [8]. "Overview first" means showing the entire dataset in a summary fashion [8]. "Zoom and filter" means focusing on a subset of the dataset and potentially removing certain data to focus on relevant data [8]. "Details of demand" means providing information on a data point/specific dataset when requested by a user [8]. According to the Shneiderman's Mantra the first step is "Overview first", then "Zoom and filter" and after zooming or filtering the user will then have detailed information [9].

Yi et al. [7] conducted an extensive review of the interaction techniques used by the visualization systems/tools in the market. They discovered that the most widely used categories of interaction techniques were Select, Explore, Reconfigure, Encode, Abstract/Elaborate, Filter and Connect [7]. Select interaction techniques allow users to highlight areas of interests [7]. Explore interaction techniques allows the user to view a different subset of the data, the most common explore interaction technique is panning [7]. Reconfigure interaction techniques allow users to change the arrangement of data items or change the alignment of the data items, this will give the user a different perspective on the data [7]. Encode interaction techniques allows the users to change the fundamental visual representation of the data, e.g. changing a Line graph to a pie chart [7]. Abstract/Elaborate allows users to alter "the representation from an overview down to details of individual data cases and often many levels in-between" [7]. Filter interaction techniques allows the users to select specific data to be presented based on some condition, e.g. selecting data within a specific time range. Connect interaction techniques highlight relationships and associations between data items. Also, they identified that undo/redo buttons were widely used.[7]

Kelleher et al. [10] developed ten guidelines for effective scientific data visualization. The ten guidelines are:
1)Create the simplest graph for your data. [10]
2)Consider the "type of encoding object (points, lines, and bars) and attribute used to create a plot"[10].
3) Focus on visualizing patterns [10].
4) Select the best axis range for your data [10].
5) graph aspect ratios and data transformations can be used to highlight rates of change in the data [10].
6) When plotting overlaying points (scatter plot) show the density differences between points [10].
7) Use lines when connecting sequential data in time-series plots [10].
8) Summarize large data sets [10].
9) Keep axis ranges as similar as possible to compare variables
10) Select appropriate colour scheme based on the type of data [10].

2.2 Related Works

In this section we examined the two visualization tools already being used by the psychology department. AcqKnowledge and Excel are the visualization tools currently being used by the psychology department.

To measure the signals from the ANS wireless sensors attached to participants. The signals detected by the sensors are then sampled by a digital converter system MP150 (Biopac Systems). Acqknowledge, a desktop application with a graphical user interface, is then used to visualize each signal. There is a plot area for each signal, signals are plotted as line graphs. Users can also perform data analysis via the numerous data transformations functions provided by the software. The main problem with AcqKnowledge is that it is expensive, and usage is very restrictive, you need a special dongle to operate the software. Also, it is difficult to switch between different data sets (participant data set), because AcqKnowledge only allows one data set to be loaded and plots cannot be superimposed (line graphs cannot be over-layered with each other, separate plot areas). Our visualization desktop application will not suffer from these failings, it will be free, simply, easy to use, load multiple data sets and it will not require special hardware to operate. Another alternative visualization tool researcher from the psychology department use is Excel. The main issue with using Excel is that it is a general use tool and not made specifically for handling physiological data. Also, with Excel interactivity is not automatically provided, the user has to manually create an interactive visualization. This is time consuming.

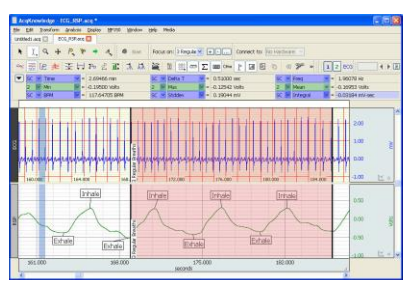

Figure 1. The user interface of AcqKnowledge. The line graphs have separate plot areas.

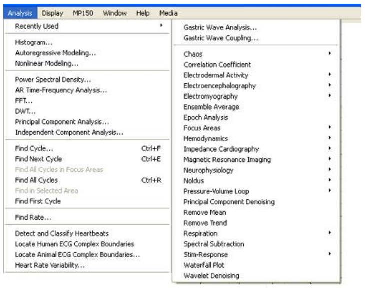

Figure 2. The numerous data transformation provided by AcqKnowledge

3 Design and Implementation

3.1 Brief overview of the design of the VR Fear experiment and virtual environment used in it

As stated, this project was done in-conjunction with the VR Fear project, the physiological data collected from the VR Fear project was visualized using the desktop application. The design of the virtual environment and experience in it was important to the success of the VR Fear project and this project. The virtual environment created was a dark and damp underground canal. In the virtual environment a participant is stationary on a “boat” that is moving through the environment, the participant is given a torch for exploring. As the participant moving through the environment a water monster will stalk the participant and make noises with the goal of scaring the participant. At the end of the experience the monster will appear and attack the participant. The experience has five triggers, a trigger is an occurrence in the experience that grabs the participants attention. A trigger could be when a participant sees the water monster or when the experience starts. Refer to Figure 3 for a map of the virtual environment and when the triggers happen.

Siphumelele provided the experiment design and procedure for the VR Fear experiment. In the experiment a participant first signs a consent form, and electrodes and sensors were then attached to the participant in order to detect the physiological signals. The sensors communicate with the BIOPAC system wirelessly and the BIOPAC system records the physiological signals. Too see where the placement electrodes and sensors on the body refer to Appendix B. The baseline is then collected, and the VR experiences starts. Each project partner conducted half of the experiments.

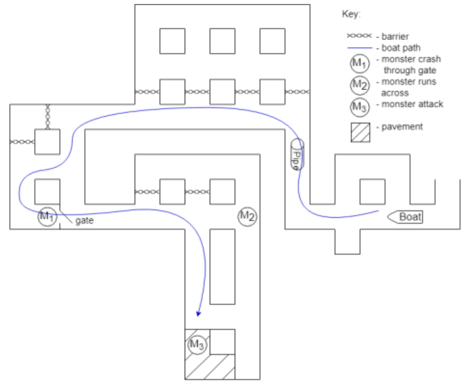

Figure 3. Design of the virtual environment and the location of the triggers. Created by Hama Mathivha

3.2 Design and Implementation of the desktop application

3.2.1 Methodology

User Centered Design (UCD) was used to develop the visualization desktop application. UCD is an iterative design process where users are central to the development of the product, the users influence how the design takes shape [13,14]. At every iterative step in UCD, a prototype based on user evaluation of the previous version is produced [14]. The prototype is then tested by users and the feedback informs the design for the next iteration of the prototype [14].

We used UCD because of the following reasons: UCD is flexible and can handle changing requirements and uncertainty [14]. User involvement, in the development of the product, leads to more effective, efficient and safer products [11]. User involvement in the development process ensures that the final product is suitable for its intended purpose in the environment in which will be used [13]. Also, users who are involved in the development process fill a sense of ownership for the final product, this results in user satisfaction and easy” integration of the product into the environment” [11,12].

Our development process had five iterations. Three software prototypes and one paper prototype were produced. At each iteration available clients (not all clients) provided the requirements and evaluated the design, for evaluation clients used the application, suggested features and approve the design. Also, the design ideas, for the desktop application, came from the information visualization literature. After the five iterations a heuristic evaluation, of the desktop application, was done by all of the clients.

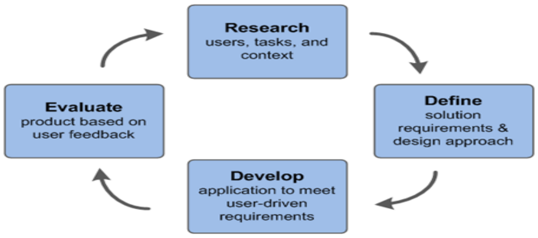

Figure 4. A simple representation of the user-centered design approach

3.2.2 Iterations

3.2.2.1 Iteration 1

For our initial design idea, we envisioned a SQL like application. Where users would query information like average heart rate and then display the information in graphical format (line or bar graph etc.). Timothy and James suggested that the application should mainly focus on visualization and that SQL like application could be to advance for people without a computer science background. Timothy also suggested that the application should render the line graphs of the different physiological signals on the same plot area and not on different plot areas like AcqKnowledge software. We were then tasked, by Timothy and James, to create a paper prototype.

3.2.2.2 Iteration 2

The paper prototype was then developed. The application has only one main screen. The screen is divided into five sections: section one(left area) has list of participant data sets, section two(middle area) has list of the physiological signals(channels) from a particular participant, section three(right area) has the plot area, section four(bottom area) has a slider that is used to select the x-axis range(Time range) of the plot area and section five(top area) contains buttons for adding new participant data sets, undo,redo,saving the plot area, zooming in and zooming out for rendering the line graph(s).

Shneiderman’s Mantra [8] influenced our initial design. The user first selects one particular participant (particular data set). After selecting a participant (particular data set), a user can then select which physiological signals(channels) to plot, this is filtering it is widely used in other information visualization systems [7] ,forms part of the Shneiderman’s Mantra [8] and allows for reconfiguration(showing different arrangements of the participant’s data) which is widely used in visualization systems[7] . Initial the “whole” line graph(s) are visible, because it is important to give an overview first according to Shneiderman’s Mantra [9]. The user can then select a subset of the plot area by either zooming in or selecting the time range, according to Shneiderman’s Mantra this is “Zoom and Filter” [9]. Also, when a user hovers a mouse pointer over a graph, detailed information about the graph appears. This is called a tooltip, and this type of interaction wildly used in other visualization systems, Yi et al. [7] categories this type of interaction as Abstract/Elaborate.

The prototype was evaluated by all of the clients. Timothy suggested that we remove the slider and allow the user to use the mouse for filtering by time. The prototype was then approved, refer to Appendix A for the paper prototype.

3.2.2.3 Iteration 3

We then used the design from the paper prototype to develop the desktop application with minor differences. The application does not have a button for rendering, rendering was done automatically. The section that has the buttons for zooming, redo, undo and downloading the plot is under the plot area. But the buttons for uploading data, starting a new project and opening a project were still in the same place. Also, a button for modifying the title, x-labels and y-labels of the plot area was added under the plot area. The slider button for selecting the time range was not included. If a user wants to filter the time range the user can the zoom-in button or the panning button. The zoom-in button allows the user to focus on a specific subset of the plot. The panning button allows the user to grab the plot area and move it with a mouse, this functionality is widely used in many visualization systems [7]. The prototype reads in excel data.

The prototype was then evaluated by Timothy and Siphumelele. Siphumelele suggested that we could improve on the application if we added visual aids to identify the triggers and a way to visually show the correlation between the difference data types (time and physiological data)

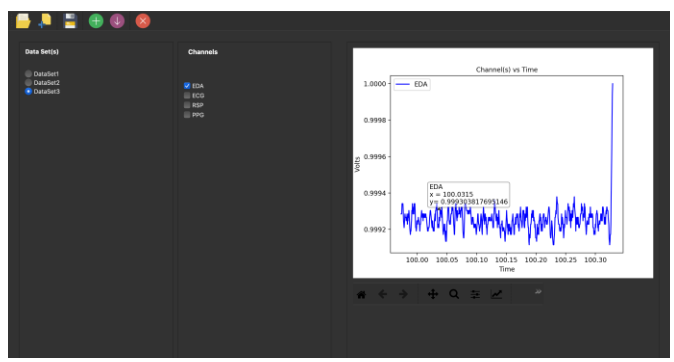
Figure 5. The user interface after iteration 2.

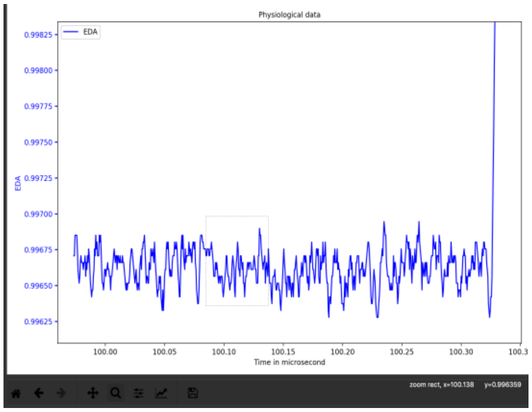

Figure 6. Selecting an area to zoom into

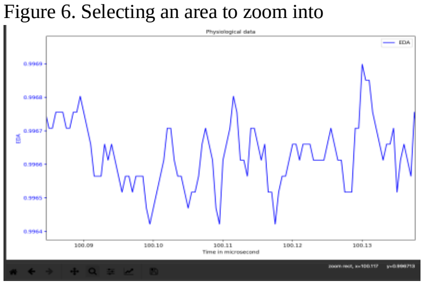

Figure 7.The zoom-in function is applied

3.2.2.4 Iteration 4

In this iteration we tested the prototype with actual data from the VR Fear experiment, we previously generated random numbers. Using actual data exposed problems. Having the different physiological data sets on the same plot was a challenge, the challenge was with the y-axis (the x-axis was the time, which is constant for all the different data types). The different physiological data were measured in different units of measurement, some data were measured in volts other data measured in microvolts. And also, the different physiological data had wildly different ranges, some range between 0 and 100 and others between -10 and 0. And it is usually considered good practice for the different data sets to have similar axis ranges, if not it becomes difficult to do data comparison [10]. If the different data sets have wildly different ranges it is best to separate the data sets some way, usually a having subplot that share a similar axis [10]. So, the best solution for our application was to have multiple y- axis and just overlay the graphs. Also, the data is normalized between 0 and 1.

Visually showing which actions are possible is very important for usability [13]. So, in our application if an action is available, the button that controls that action is highlighted and can be clicked. A way to visually identify the triggers was implemented, a user has to press a button then vertical lines will appear on the plot area. To visually show the correlation between different physiological signals (data sets) a heatmap was used. A heatmap uses colours to show if datasets correlate, red is used to show correlation and blue is used to show contrast. A heatmap was used because it is very useful when you want to search for patterns or compare values [10]. Showing a different visual representation of the data set, e.g. from line graph to heatmap, is common in visualization systems [10]. It is common because it enhances user understanding of the data [10]. An additional section was added to the application that stores the buttons for activating the triggers, line graphs and the heatmap.

The prototype was evaluated by James and Siphumelele, they approved it. James suggested a way of adding annotations on the plot area, and Siphumelele suggested we add visual aids to identify the peaks and trough on the different line graphs.

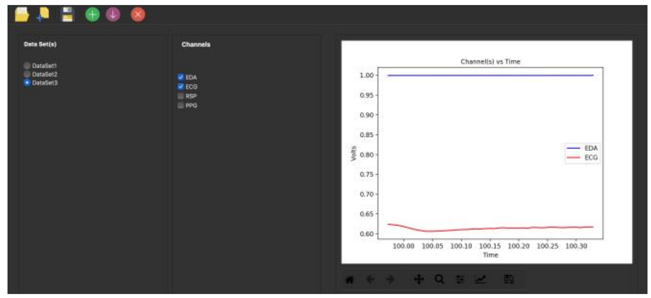

Figure 8. When the different data share the same y-axis. It is hard to visually compare

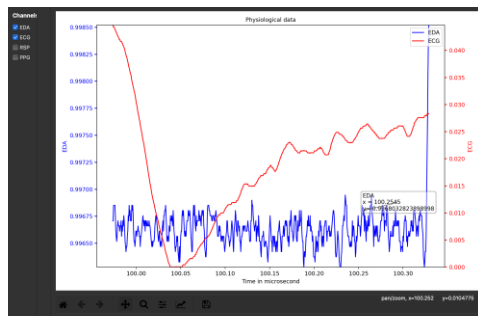

Figure 9. The different data only shares the x-axis. This makes it easier to visually compare

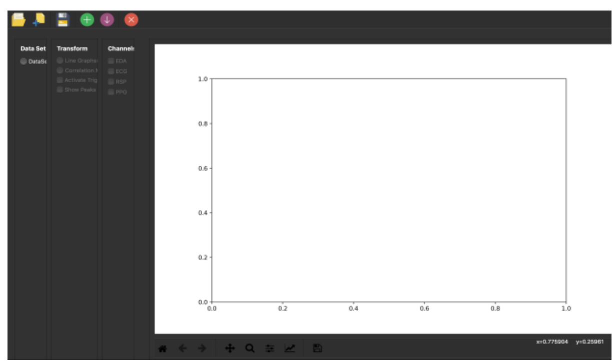

Figure 10.To be able to plot line graphs a data set must be selected(clicked), application shows this visually.

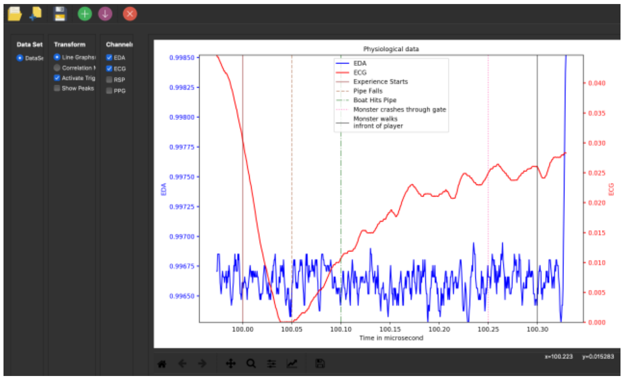

Figure 11. Triggers in the virtual environment are visually depicted

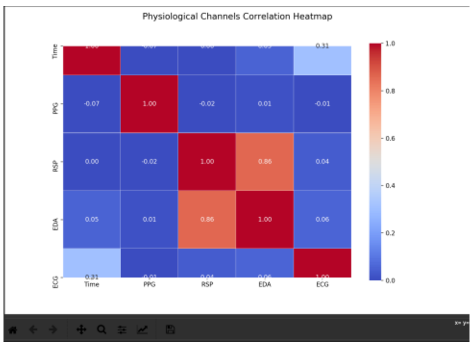

Figure 12. The correlation Heatmap

3.2.2.5 Iteration 5

We then implemented the suggestions from iteration 4. User can add annotations/comments on the plot area by double clicking the right mouse button. This functionality will allow users to mark something of interest and keep track of it, and this type of functionality is widely used in many visualization systems [7]. Users will be able to notice peaks and troughs on the line graph with the help of visual aids, a green arrow, facing upwards, is used to represent a peak and a red arrow, facing downwards, is used to represent a trough. User can also download the plot area as an image and also save the state of the application.

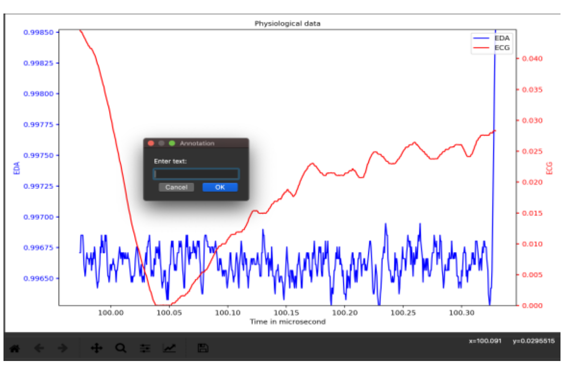

Figure 13. Users can enter annotations

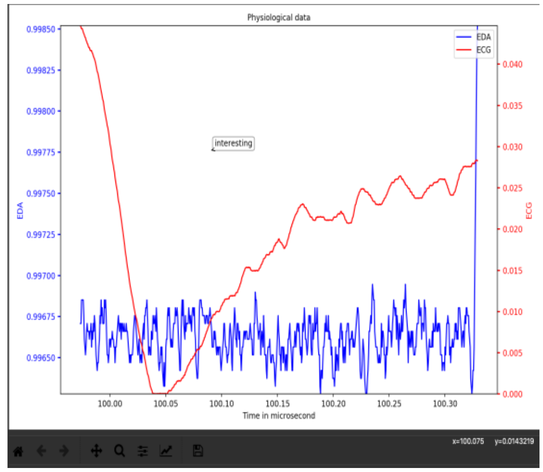

Figure 14. User annotation

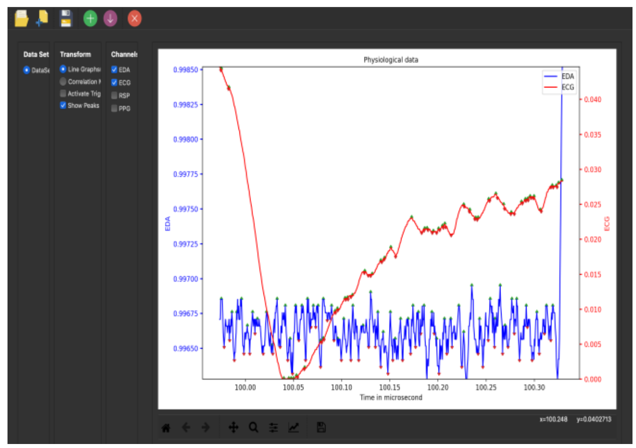

Figure 15. The peaks and troughs are highlighted

3.2.3 Implementation

Various tools were used to make the application and the paper prototype. The paper prototype was made on www.proto.io. The site allows user to make interactive prototypes, it provides useful templates and icons. The graphical user interface of the desktop application was developed using the Python PyQT framework. PyQT is python binding of the popular cross platform GUI toolkit QT. PyQT was used because it enables the application to be cross platform. Matplotlib, a python graphing library, was used to render the line graphs. Also, it was used to provide zooming capabilities, panning, undo, redo and downloading capabilities. NumPy, a python data science library, was used to normalize the data and used to find peaks and troughs. Seaborn, a python visualization library, was used to create the correlation heatmap and used to read excel data.

4 Results

After iteration 5 we decided to freeze development due to time constraints. After the five iterations each feature of the application was evaluated, but the application as a whole was not evaluated. Also, some clients did not evaluate some features after the five iterations and the evaluations during the iterations were informal and unsatisfying, the client(s) available simply used the application, suggested fixes and gave requirements. To formally evaluate the state of our application as a whole we decided to do a heuristic evaluation. We used a heuristic evaluation because it is a valuable way to evaluate visualization tools [19]. A heuristic evaluation is a qualitative approach that uses a set of heuristics to analyse the usability and the user interface of an application [20]. Evaluators use the heuristic to find potential usability problems in the user interface and assign a severity level to the problem [20]. The main outcome of the heuristic evaluation is a list of categorized potential usability problems intended to support the development team in allocating resources to the most needed fixes [20]. Heuristic evaluations are low-cost and easy to use, but heuristic evaluations often find problems that to specific and have a low-priority [16].

For our heuristic evaluation, evaluators were asked to find at least six problems with the application using Nielsen's ten usability heuristics for user interface design [15] as they were using the application. Refer to Appendix C for a list of the heuristics. Evaluators had to describe the problem, say which heuristic was violated, give recommends for fixing the problem and assign a severity level to the problem. The severity levels: low, medium, high and critical. Then after they had identified the problems, they had to rate the usability of the application using a 5-level Likert-like scale (1- very poor to 5 - very good, 3- reasonably usable). The evaluators were the clients.

Evaluator	**Usability Rating (using a 5-level Likert-like scale)**
James Gain	4
Timothy Gwynn	3
Siphumelele Sigwebela	3
Average rating: 3.33	

Critical problems identified by the evaluators and recommended solutions	
Problem description	Recommended solution
Annotations/user comments cannot be saved at the moment.	Fix save and load cycle for annotations.
Triggers introduce too many different line styles (which can be overwhelming)	Add number labels to the trigger lines and add these to the legend.
When you initial activate the correlation heatmap, only a small portion of it is visible.	Start zoomed out
Some numbers displayed out of plot area (in correlation matrix)	Fix that.
Lines of graphs are confusing when all of them are enabled. Has very low visibility	Adjust line width depending on how zoomed in the display is. Also consider other line display styles.
Tooltip not visible when all data lines are enabled	Consider displaying this to one side and not in the graph area
Using the application, you cannot compare participants with each other, you can only evaluate one participant at a time.	Be able to visualize more than one participant data set.
Toggling checkboxes in correlation graph mode breaks view when moving it.	Make checkboxes non-interactable while in correlation graph mode.
Crashes on invalid file selection when loading data	Warn user of incorrect file selection.

Problems identified by more than one evaluator	**Number of times identified**
Annotations/user comments cannot be saved at the moment.	3
Problems with the scaling of the graphs	2
When you initial activate the correlation heatmap, only a small portion of it is visible.	3
Icons on bottom row too dark	2
No help or documentation	2
No form of error prevention	3
Using the application, you cannot compare participants with each other, you can only evaluate one participant at a time.	2
Graph scales are hard to read when all data types are selected	2

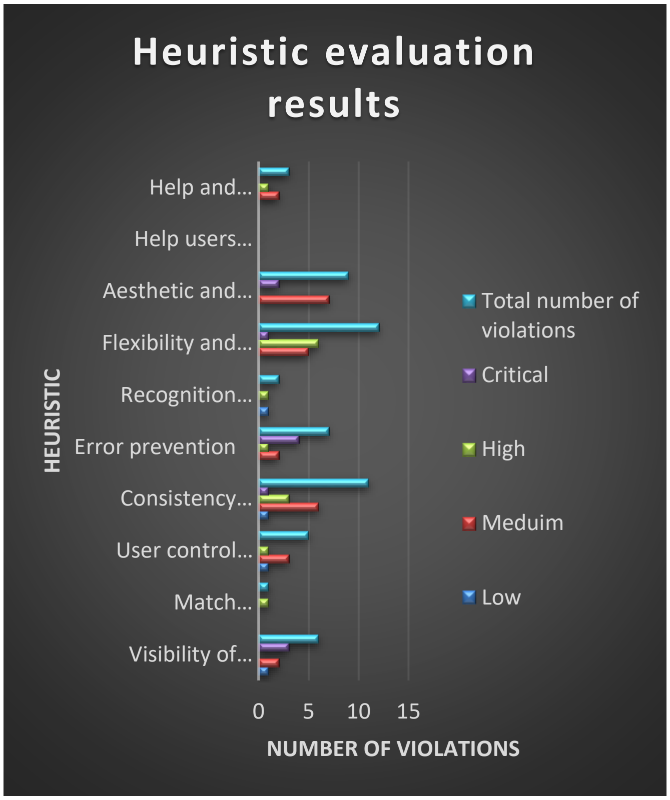

Figure 16. The combined heuristic evaluation results from the evaluators

5 Discussion

The results from the heuristic evaluations were very insightful. The application was deemed reasonably usable by the evaluators, it had an average usability rating of **3.33**. Before the heuristic evaluation, the application only had one form of error prevention, undo and redo. But it could not handle other errors, for example it crashed if the file uploaded had the wrong file format. Evaluators were not satisfied with the error prevention of the application, the heuristic with the most critical problems was error prevention. A very common problem identified by the evaluators was that the correlation heatmap matrix was too big for the plot area (some parts of the correlation matrix were not visible), a user has to use the panning function to see the different sections of the heatmap. We knew that this would be a problem but before this heuristic evaluation we couldn't solve the problem. Also, another common problem was that user comments/annotations could not be saved and used at a later stage, time constraints prevented us from implementing this. After the heuristic evaluation we fixed all of the critical problems describe in table 2, we did not fix other problems because of time constraints and these other problems were not critical problems.

We used Nielsen's heuristic because we have utilized them before, but it might have been a good idea to use heuristics made specifically for visualization systems. Nielsen's heuristics are for use interface design. The number of people needed for a heuristic evaluation concerned us. How many people needed for a heuristic evaluation is an open question, there is no consensus [16]. But some researchers have attempted to answer this question. Nielsen at el. [17] reported that five evaluators found about 2/3 of usability problems using heuristic evaluation and Virzi et al. [18] (1992) reported that only 3-5 evaluators are needed to identify 80% of usability problems. Based on this, the number of evaluators in our project might be enough to spot most of the usability problems.

For this project there was no research question(s) or specific requirements. We were tasked with building an alternative visualization system, this was not driven by a need but by curiosity if we could build a usable alternative visualization system. This made requirement gathering challenging. The initial requirements of the project were vague because the clients were uncertain on what they wanted. We had to design and make an initial prototype using ideas from the visualization literature and our own ideas. And after this the clients provided the requirements using our initial design/prototype as a base, but the uncertainty remained. The informal manner of the evaluations done during the iterations probably hindered our development. A heuristic evaluation should have been done after each iteration involving every client, this would have reduced the problems and improved the usability rating.

6 Conclusion

From this project a reasonably usable desktop application that visualizes physiological data was produced. This desktop application does not have the drawbacks that plague AcqKnowledge and Excel. The desktop application is free, easily distributed, simple and specifically made for visualizing physiological data frequently used the psychology department. The is room for improvement, the application has numerous small and large the problems that prevent it from having a usability rating of 5. These problems have to be solved before the application can be used widely. Future developments will be to fix these problems (from the heuristic evaluation) and conduct larger usability tests.

APPENDIX

Appendix A

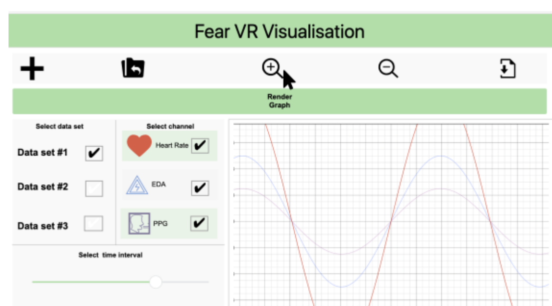

Figure 17. Paper prototype interface design

Appendix B

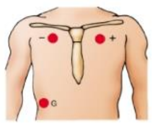

Figure 18. Placement of the electrodes on the body

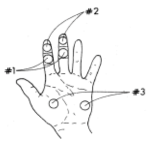

Figure 19. Placement of the electrodes on the hand

Appendix C

Nielsen's heuristics- Ten Usability Heuristics for User Interface Design [15]:
1)Visibility of system status
2)Match between system and the real world
3)User control and freedom
4)Consistency and standards
5)Error prevention
6)Recognition rather than recall
7)Flexibility and efficiency of use
8)Aesthetic and minimalist design
9)Help users recognize, diagnose, and recover from errors; N10-
10) Help and documentation.

ACKNOWLEDGMENTS

We would like to thank our clients for evaluating our applications, providing the requirements and guiding us. We would especially like to thank Siphumelele Sigwebela for helping with the experiment, teaching us about physiological signals and just supporting us in general.

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