FINAL MASTER'S THESIS

Assessment of the accuracy and reliability of heart rate and blood oxygen saturation measurement in wearable devices

Autor: Antoni López Giménez

Director: Juan José Ramos Castro

Index

1.Introduction

1 Introduction

- Heart rate (HR) and blood oxygen saturation (SpO2) are two vital signs that reflect cardiovascular and respiratory health.
- Wearable devices that can measure HR and SpO2 non-invasively and continuously are becoming increasingly popular for both fitness and medical purposes.
- However, measuring HR and SpO2 in wearable devices is challenging due to various factors such as device design, sensor technology, signal processing, user behavior, and environmental conditions.

Source: https://es.getwellue.com/productos/ox%C3%ADmetro-de-pulso-de-dedo-oxysmart-%E2%84%A2

1.1 Purpose

For all the previous arguments, the main objetives of this thesis are:

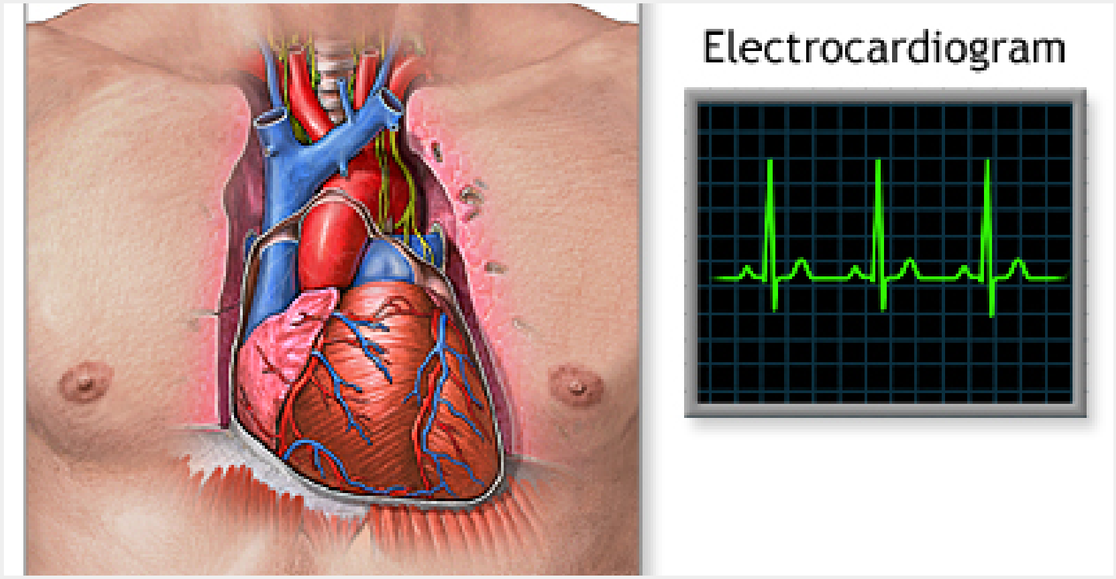
- How good LifeVit Vital measures Heart Rate (HR) and blood oxygen saturation (SpO2).
- Compare LifeVit Vital results with gold-standard methods.

Motivation:

- Add LifeVit Vital to ReHub Dycare telerehabilitation platform

To fulfil the previous objetives:

- The Bland-Altman method was used the method consistency.
- The challenges and limitations of using PPG-based sensors devices.
- Possible improvements and future directions for research in this field.



Source: https://medlineplus.gov/ency/imagepages/8772.htm

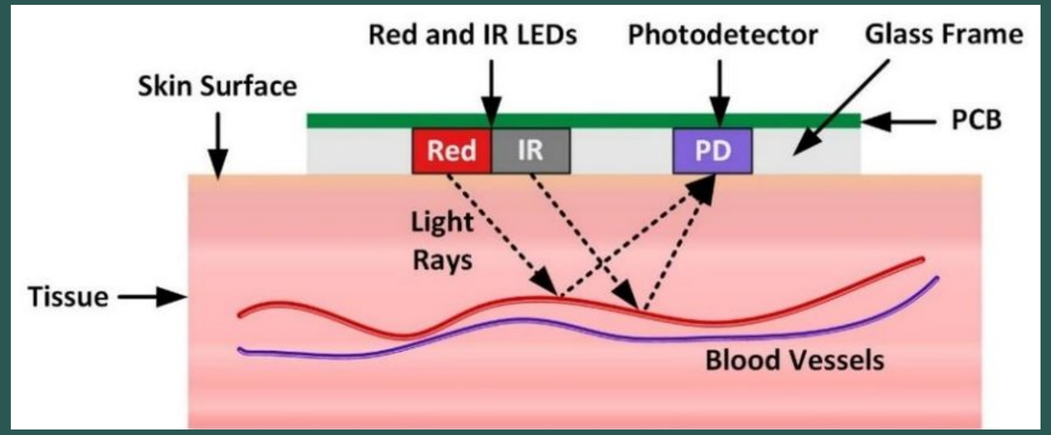
Source: https://unsplash.com/es/fotos/-msTEzGwKJs

1.2 State of the Art

- The gold-standard for measuring heart rate (HR) is electrocardiography (ECG), which records the electrical activity of the heart using electrodes attached to the skin.
- The gold-standard for oxygen saturation is a blood test. SpO2 is an indirect method accepted as a reference with a pulse oximeter.
- Pulse oximetry is a widely used and accepted method for measuring SpO2 because it is non-invasive, convenient, and provides continuous monitoring.

1.2 State Of the Art (II) : Photoplethysmography

Most wearable devices use optical sensors based on photoplethysmography (PPG) to measure HR and SpO2.



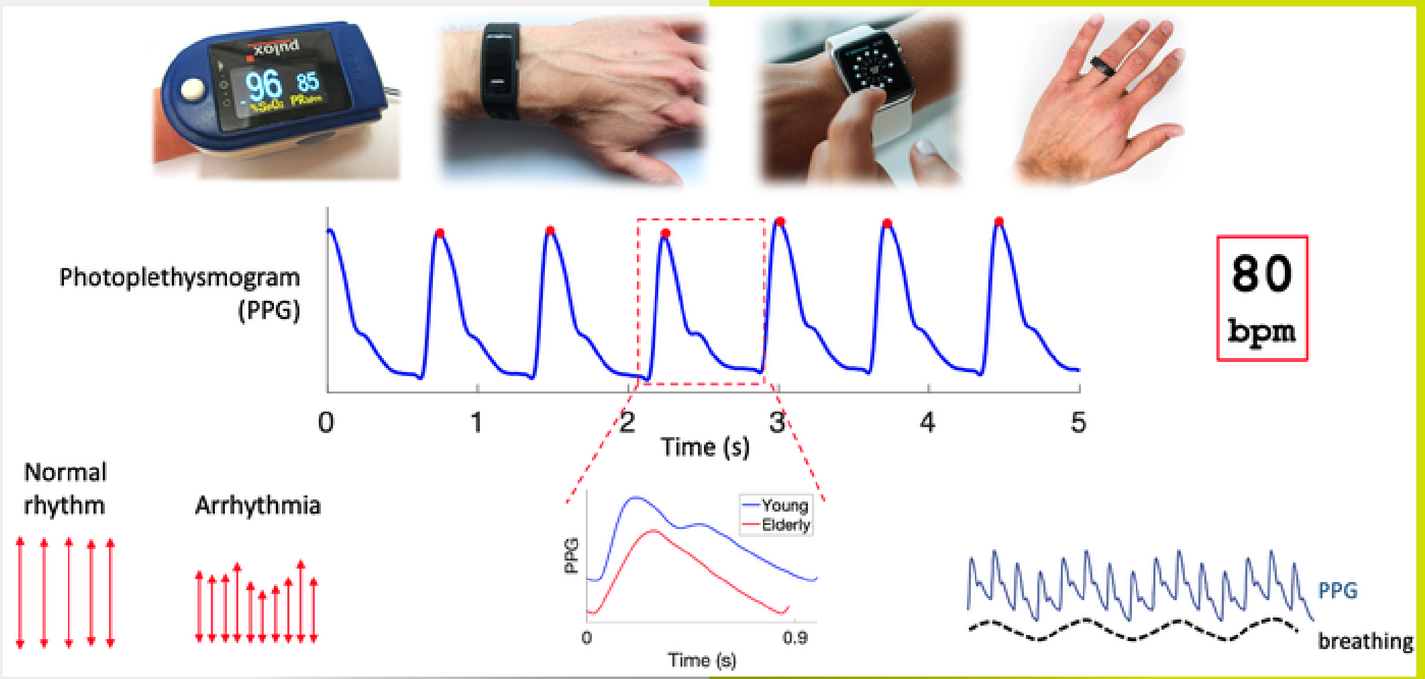
PPG is a technique that uses light-emitting diodes (LEDs) to illuminate the skin and photodetectors to measure the changes in light absorption caused by blood volume pulsations.

PPG can be obtained from different body locations, such as the finger, earlobe, wrist, or forehead. However, wrist-worn devices are more convenient and comfortable for users than other locations.

And it can be classified into two types: transmissive and reflective. Transmissive PPG uses LEDs and photodetectors on opposite sides of the tissue, while reflective PPG uses LEDs and photodetectors on the same side of the tissue.

1.2 State of the Art (III)

- To measure HR, PPG use algorithms to detect the difference between peaks of the signal.
- To measure SpO2 PPG use algorithms to estimate the ratio of oxygenated to deoxygenated hemoglobin.
- PPG signals can be affected by noise and artifacts from various factors, impacting the reliability of HR and SpO2 measurements in wearable devices.



Source: https://peterhcharlton.github.io/project/understanding-ppg/

2. Methodology

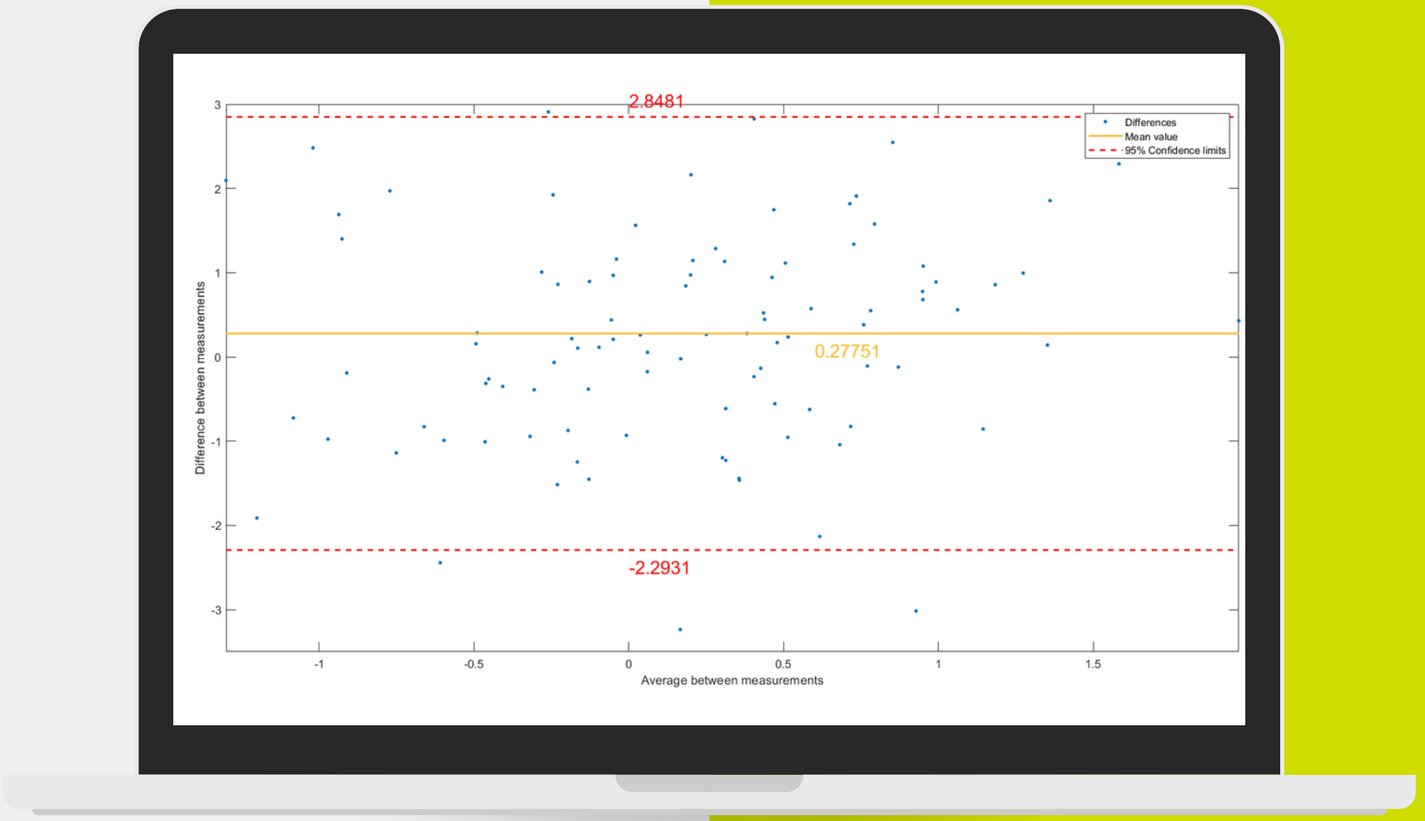
2. Methodology

The methodology includes a review of, the statistical method used, the specific protocol followed during the experiment, the code and the data processing.

Custom code was developed to analyze the data collected during the experiment and obtain final heart rate and SpO2 data for each device and position of the volunteer.

2.1 Bland-Altman Method

- The Bland–Altman method is a statistical approach used to compare two different methods of measuring a quantity.
- It was developed by D.G. Altman and J.M Bland in September 1983.
- The method involves plotting the differences between the two methods against their averages.
- The mean difference represents the estimated bias between the methods, while the outer dotted lines represent the 95% confidence limits of the differences.



Source: own image

2.2 Protocol

The protocol for this study involved measuring heart rate and blood oxygen saturation using the LifeVit Vital smartwatch and comparing it to gold-standard methods such as electrocardiography (ECG) and oximetry.

Measure	Value
Volunteers sex	14 men, 8 women
Height (cm)	177.9 ± 6.3
Weight (kg)	72.4 ± 8.4
BMI (kg/m^2)	22.9 ± 2.6
Average number of smokers	4
Proportion of smokers	18.2%
Frequency of physical activity (times per week)	3.5 +- 1.6
Most common types of physical activity	Gym (13 volunteers) Running (9 volunteers) Basketball/Soccer (4 volunteers each)
Volunteers with respiratory problems	0% (0)
Volunteers with heart problems	4.5% (1)
Volunteers with other previous pathologies	9.1% (2)

The protocol was adjusted to harmonize with a PhD student's work, involving blindfolding and white noise isolation for all experiments except the moderate activity experiment. The experiment was carried out on volunteers in different positions:

1. Lie down
2. Sit down
3. Stand up
4. Moderate Activity

The population size for the assessment was agreed to be 15–20 volunteers, with 22 ultimately participating, and it was found that very dark skin could affect results, but no sensitive groups were affected by the technology.

2.3 Code

Three scripts were developed to analyze the data collected during the experiment and the LifeVit SDK was modified in order to obtain the data from the device.

Analysis_Script.m

The MATLAB script was coded to load data from .mat and .txt files, apply filtering and peak detection techniques to obtain heart rate and respiration signals from ECG and Biopac data, adjust for possible delays, remove non-interesting values, interpolate signals, and create new tables with final heart rate and SpO2 data.

BA_Method_Script.m

This MATLAB script was created to perform the Bland-Altman method with the aim to be able to compare all the methods of interest with a graphic way.

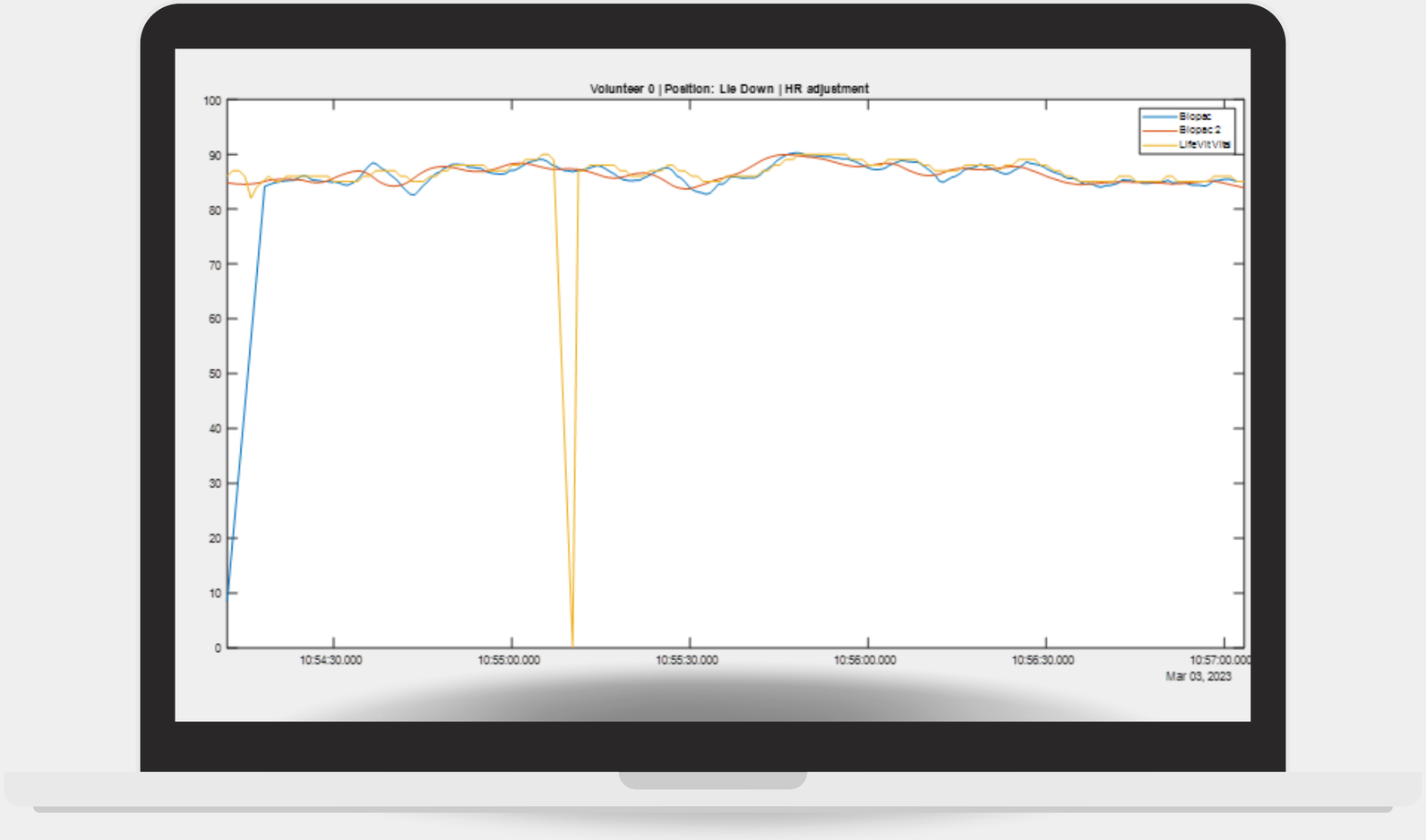
BraceletVitalActivity.java

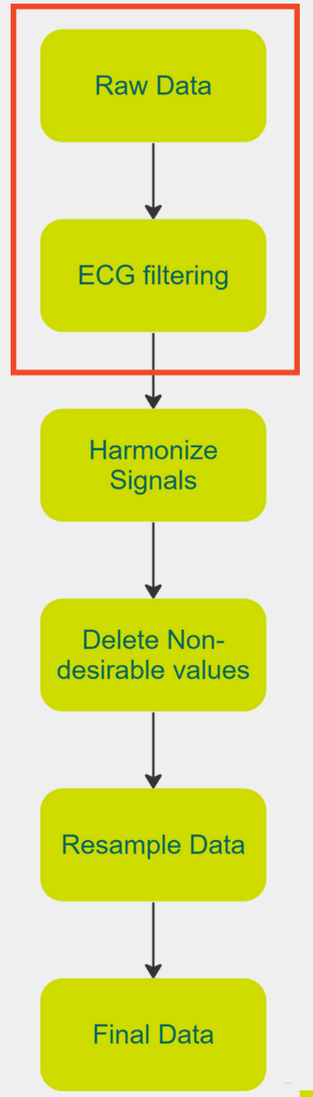
The class was modified to manage only the options of interest, create new variables and functions to save measurements, and schedule specific operations at regular intervals.

SpO2_Wellue_reference.m

This MATLAB script was developed to obtain measurements from the Wellue oximeter, parse the bytes sent by the device using a BLE characteristic, and add the parsed data to a timetable.

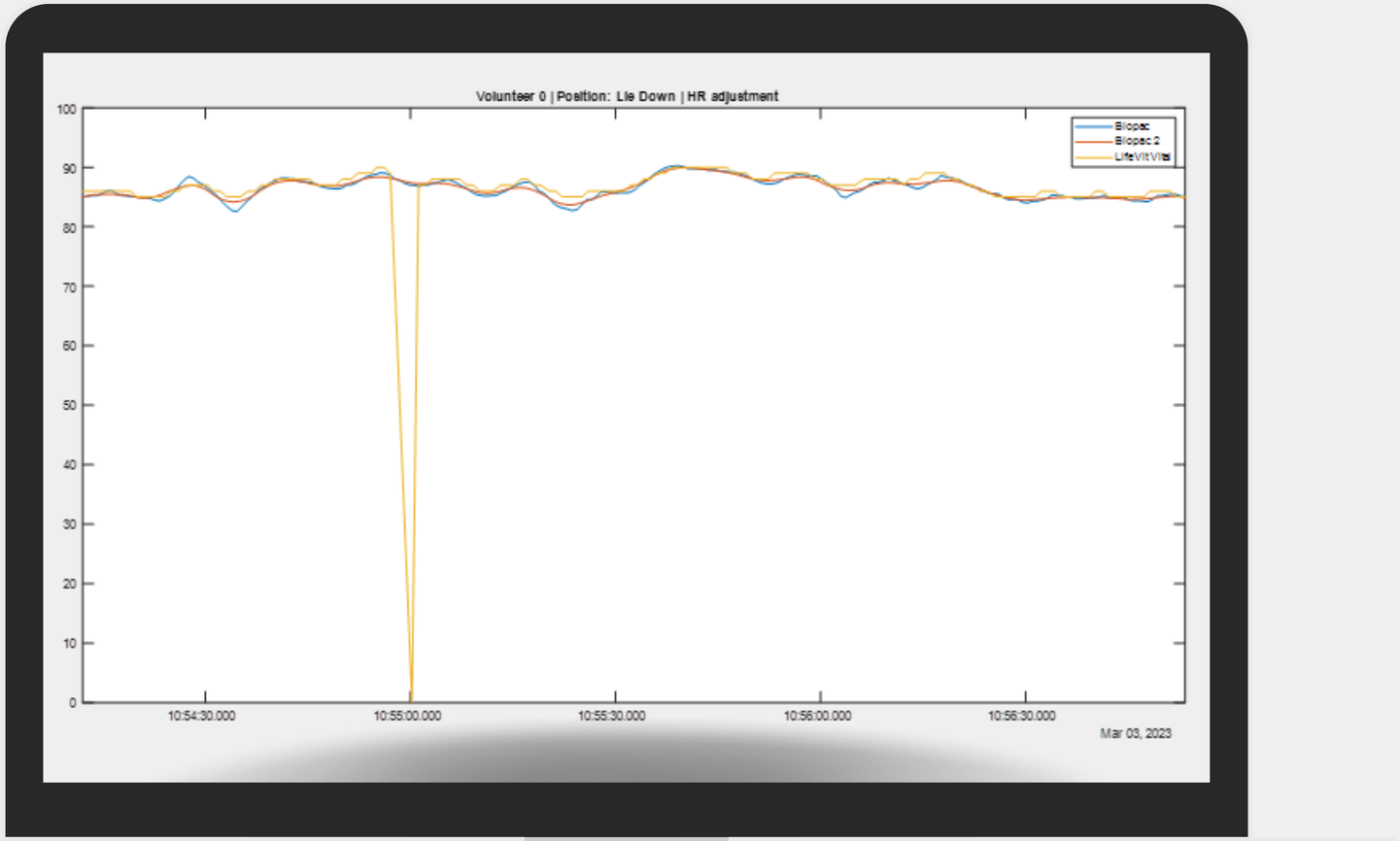
2.4 Data Processing

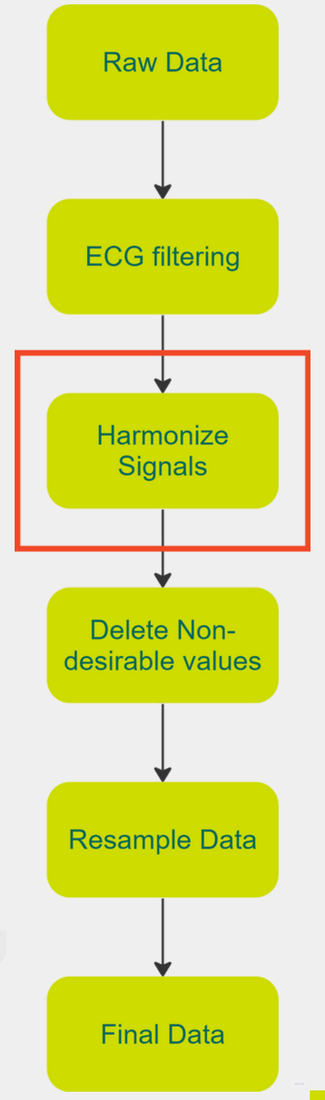




Data filtered once the delay has been corrected.

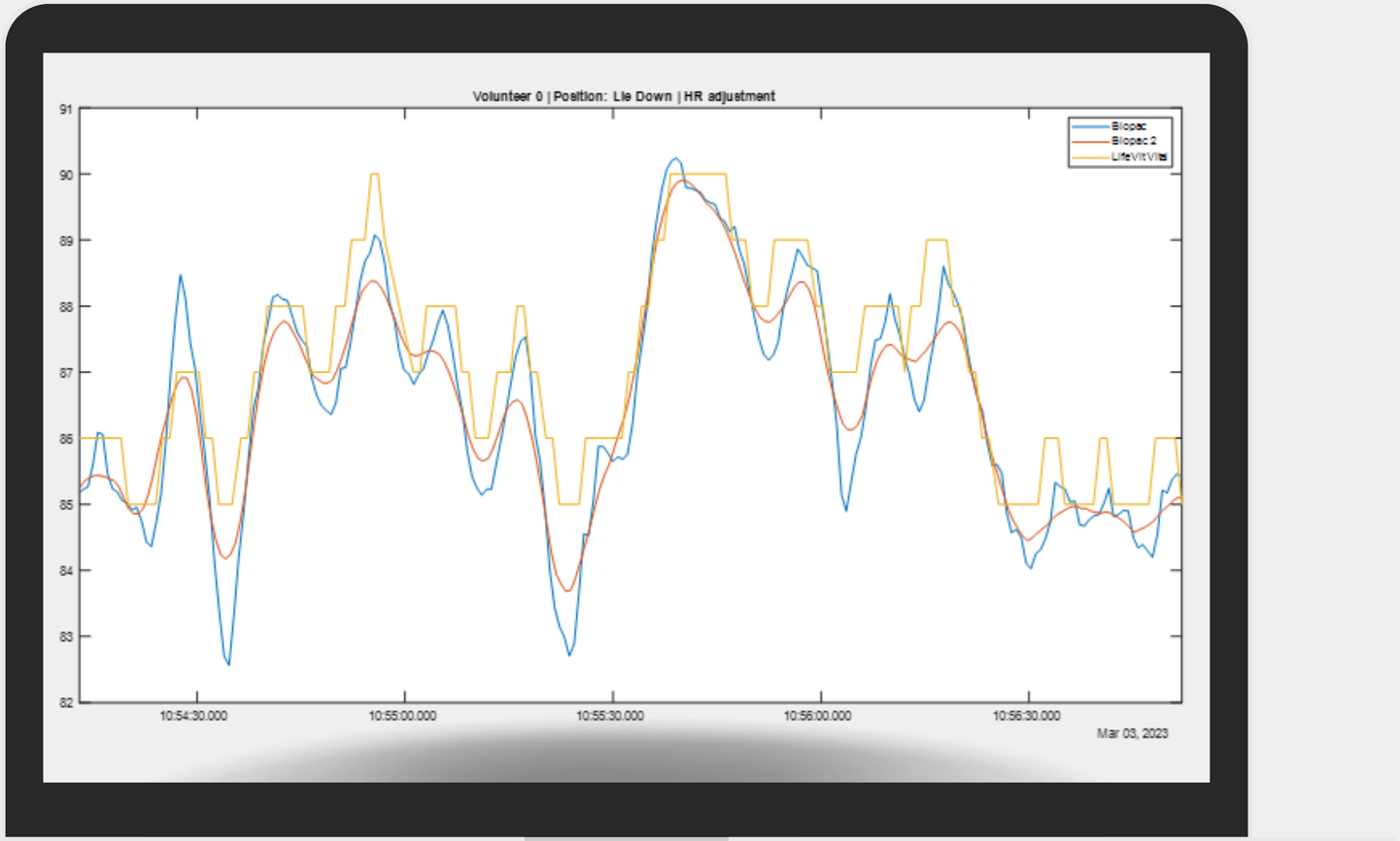
2.4 Data Processing (II)

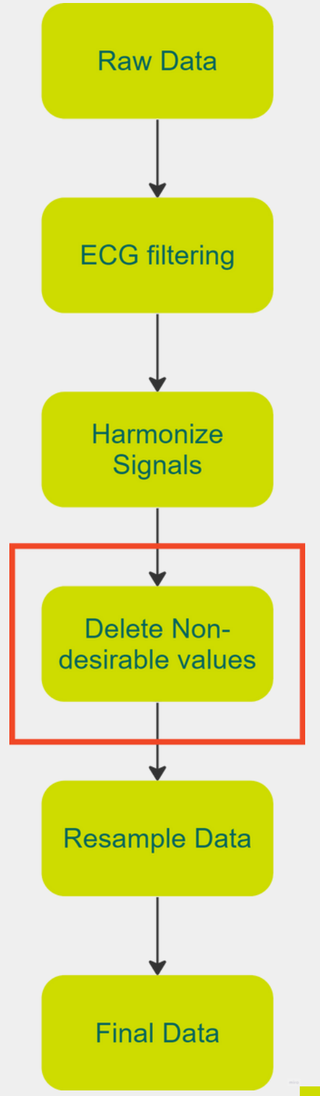




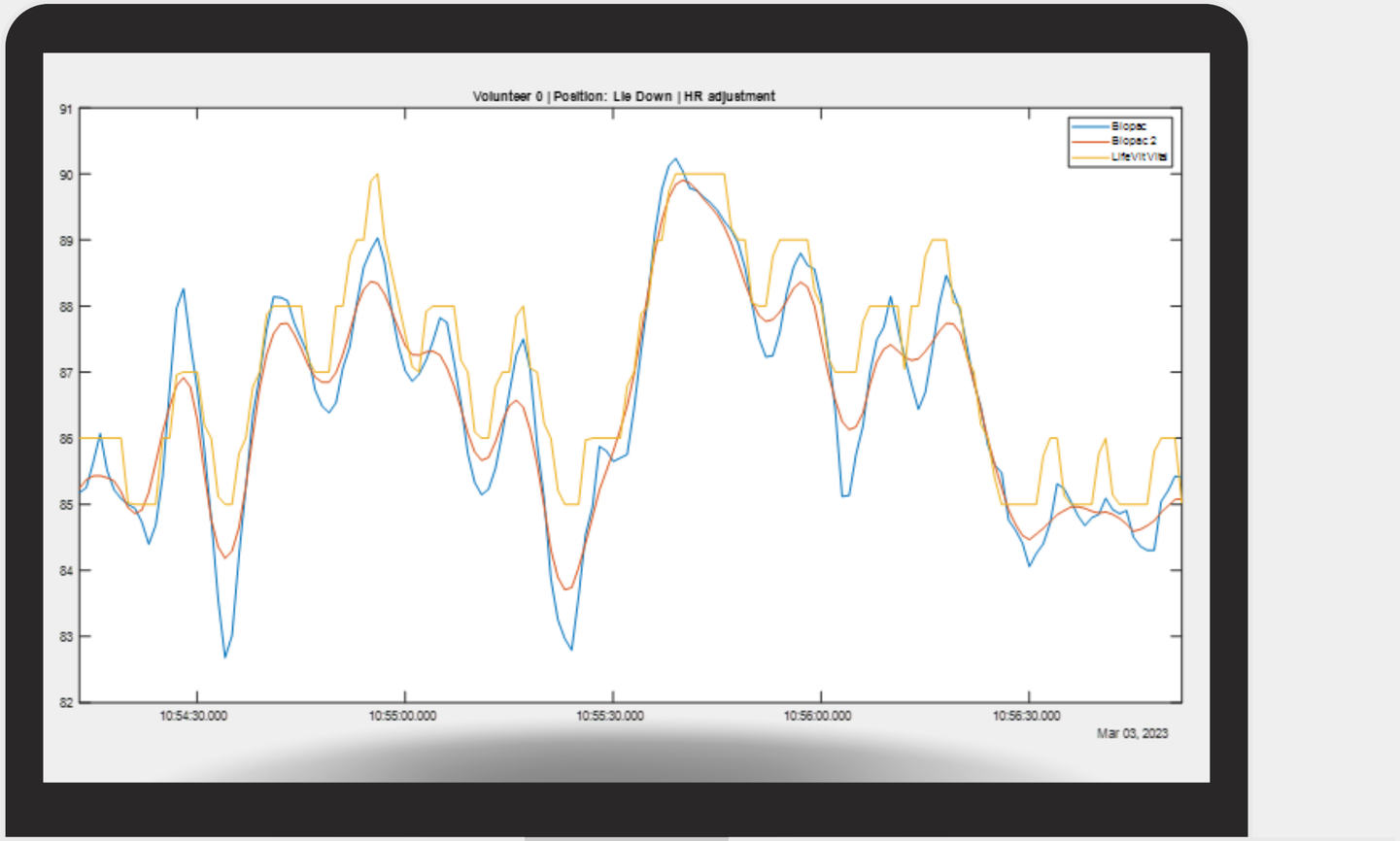
Data filtered once the delay has been corrected.

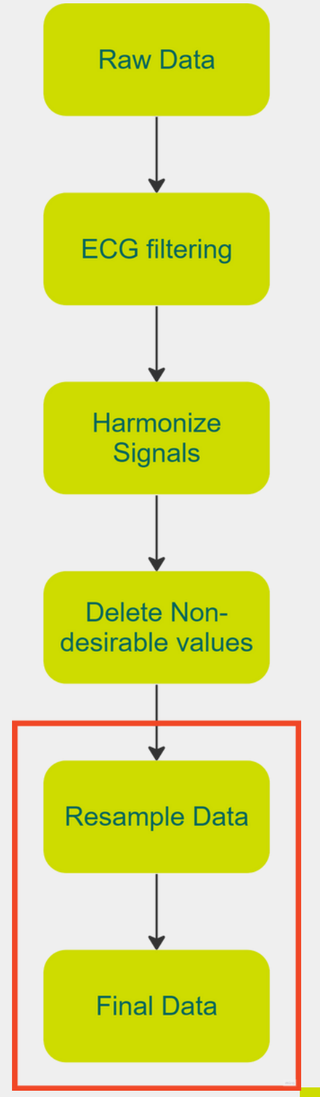
2.4 Data Processing (III)





2.4 Data Processing (IV)





Final Data Resampled

3. Results

3. Results Overview

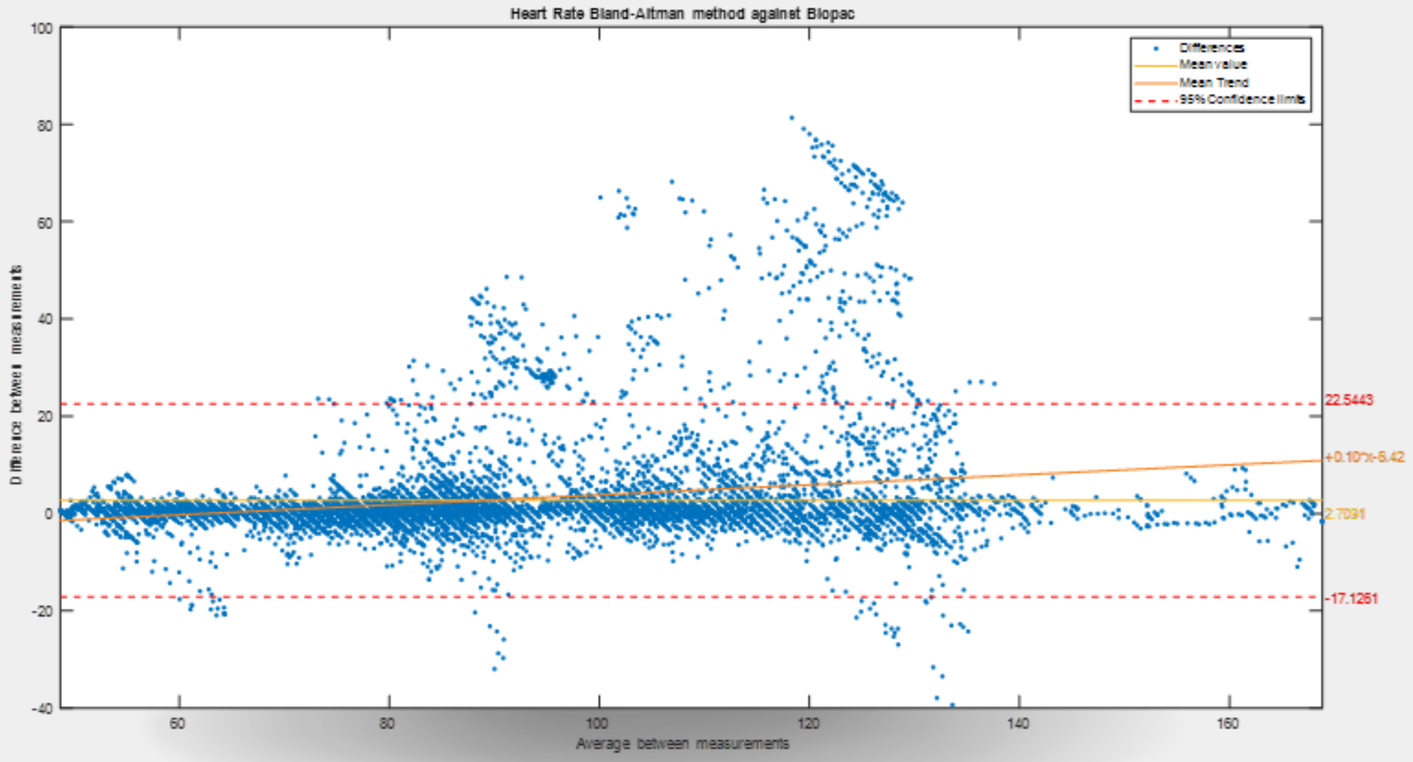
To understand properly the results obtained we will show the results following this structure for both measurements:

- General Results with and without moderate activity
- Lie Down
- Sit Down
- Stand Up
- Moderate Activity

3.1 Heart Rate Results

3.1.1 Overall Results

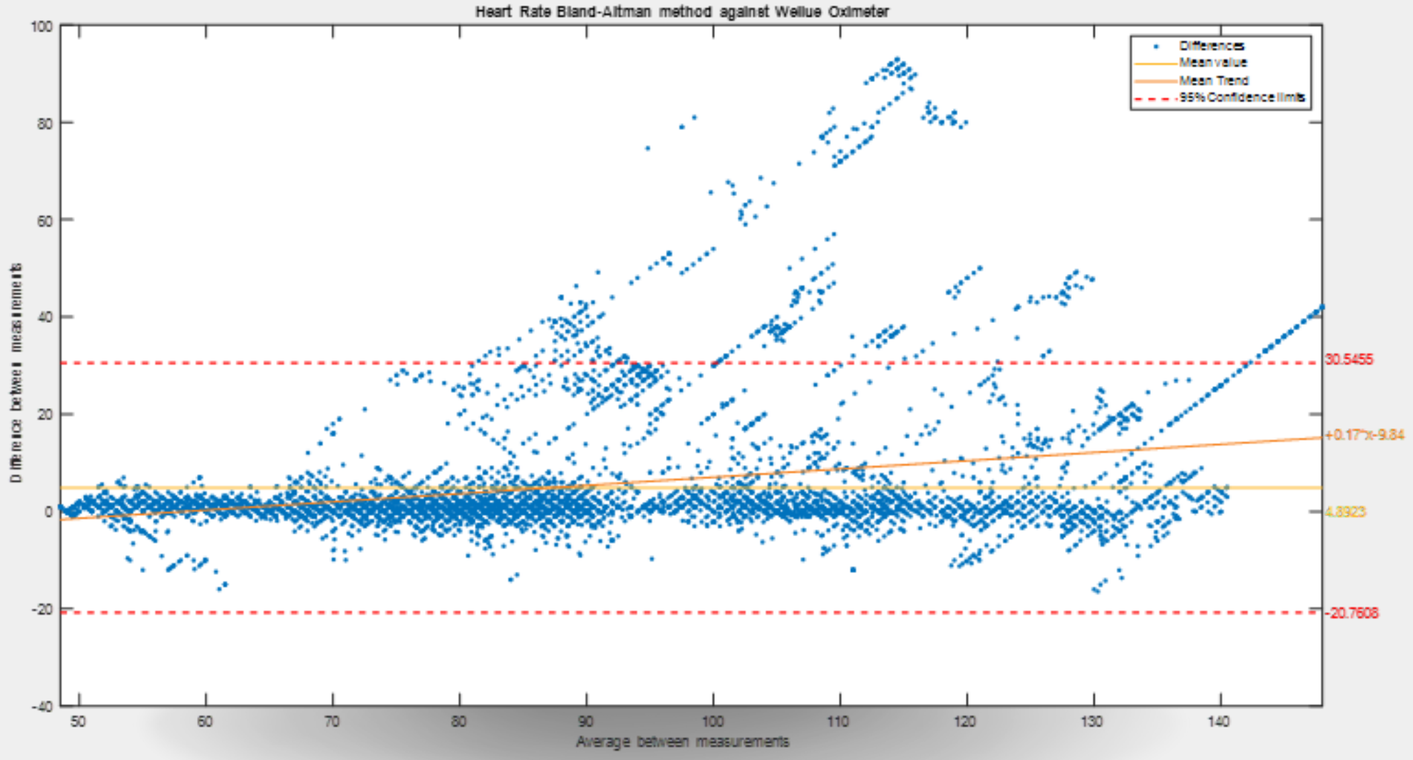
LifeVit vs Biopac



HR LifeVit measurements against Biopac

3.1.1 Overall Results

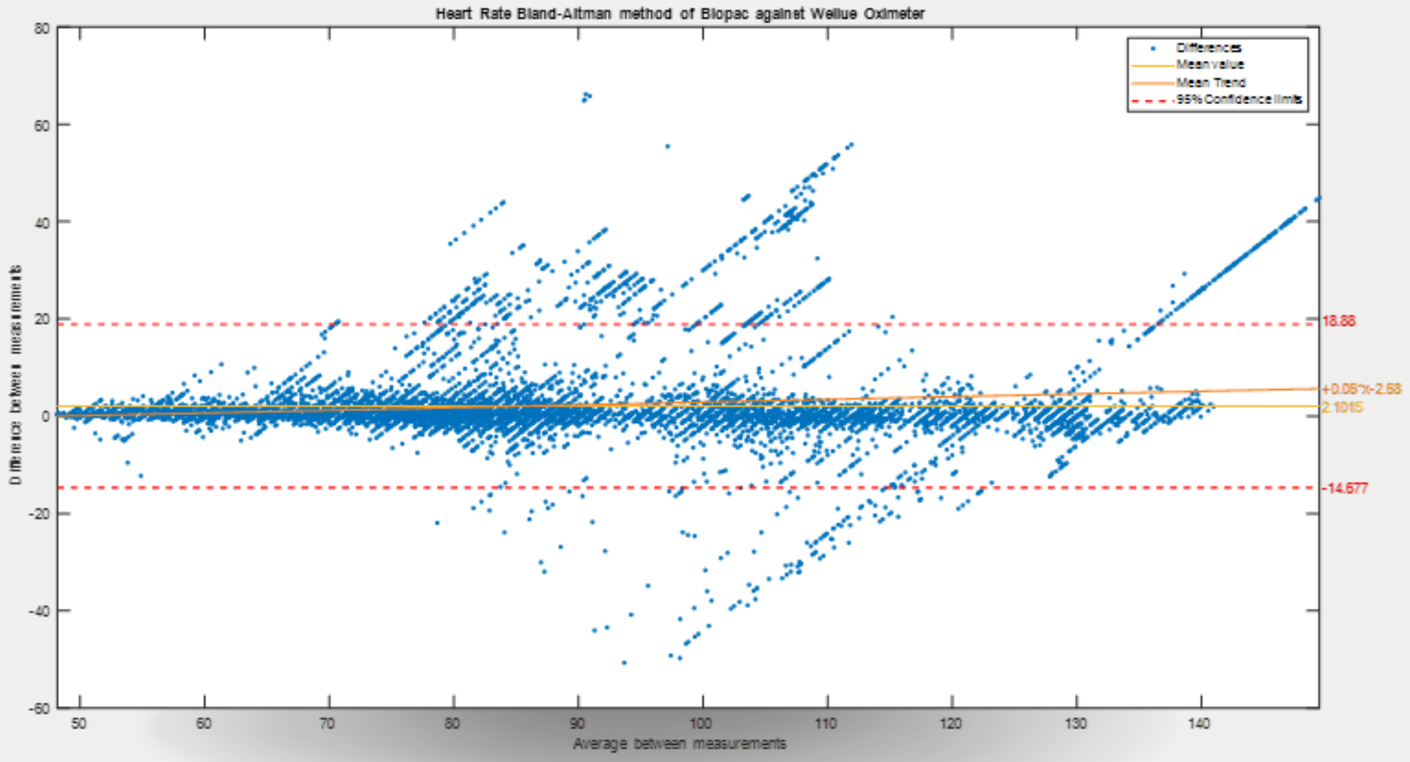
LifeVit vs Wellue



HR LifeVit measurements against Wellue oximeter

3.1.1 Overall Results

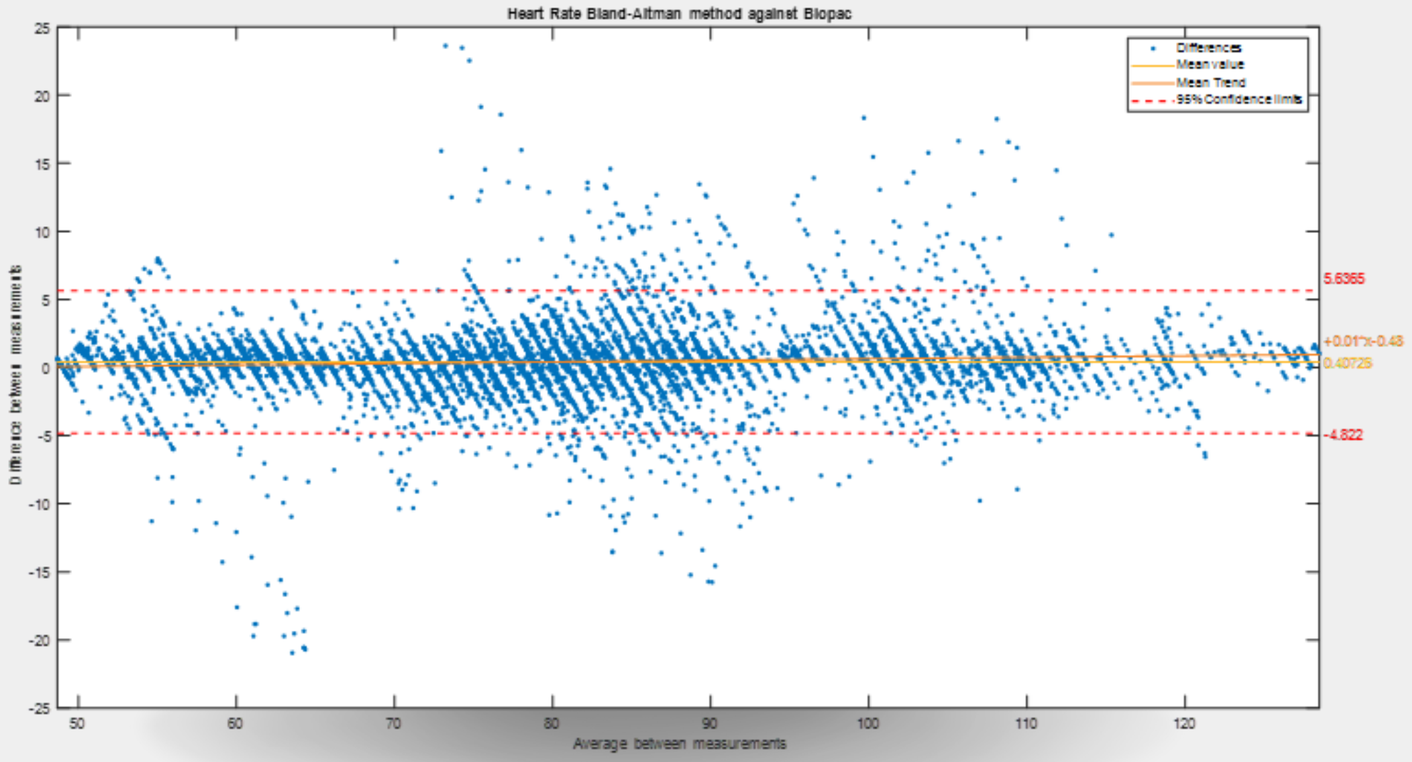
Biopac vs Wellue



HR Biopac measurements against Wellue oximeter

3.1.1 Overall Results without MA

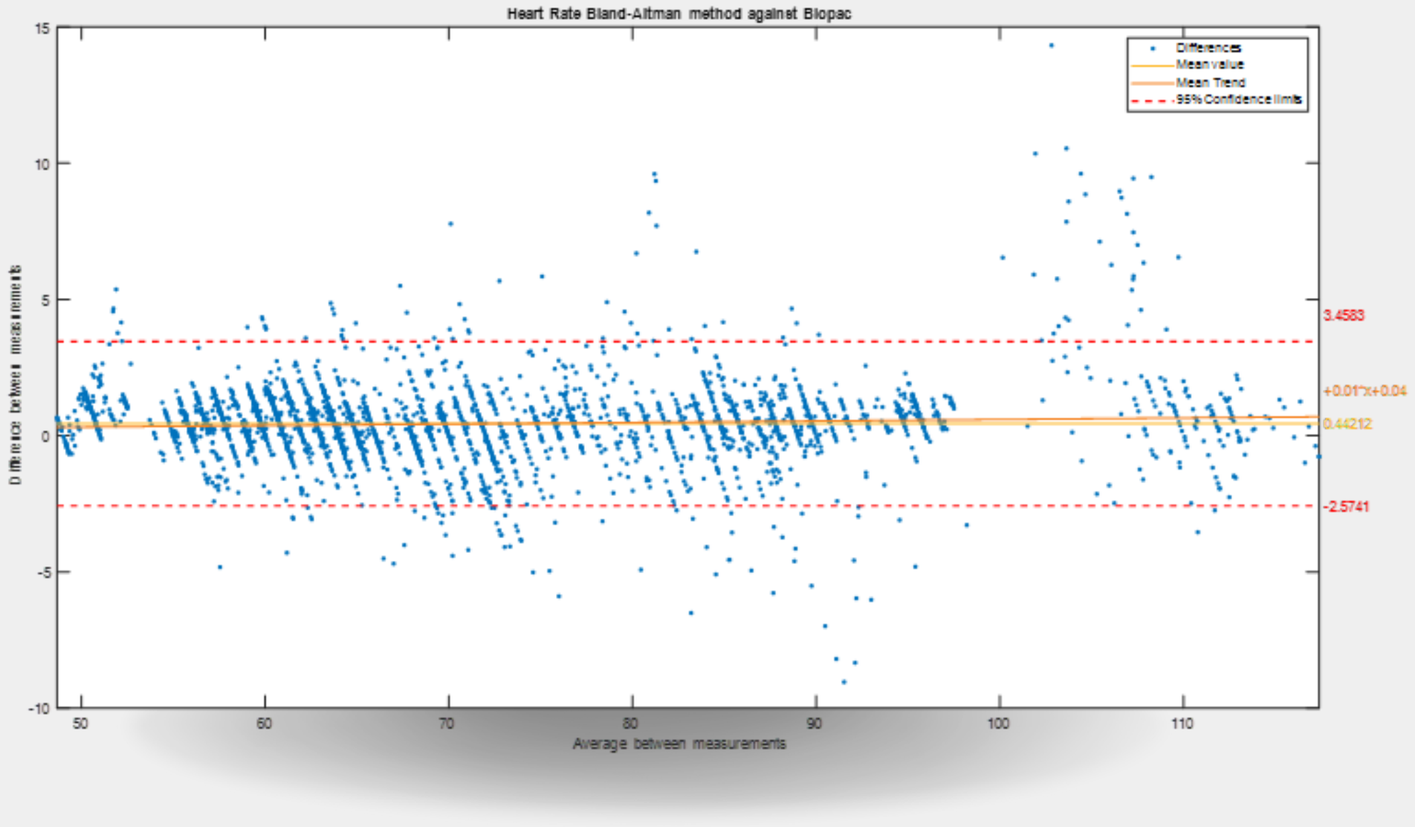
LifeVit vs Biopac



HR LifeVit measurements against Biopac without sport

3.1.2 Lie Down Results

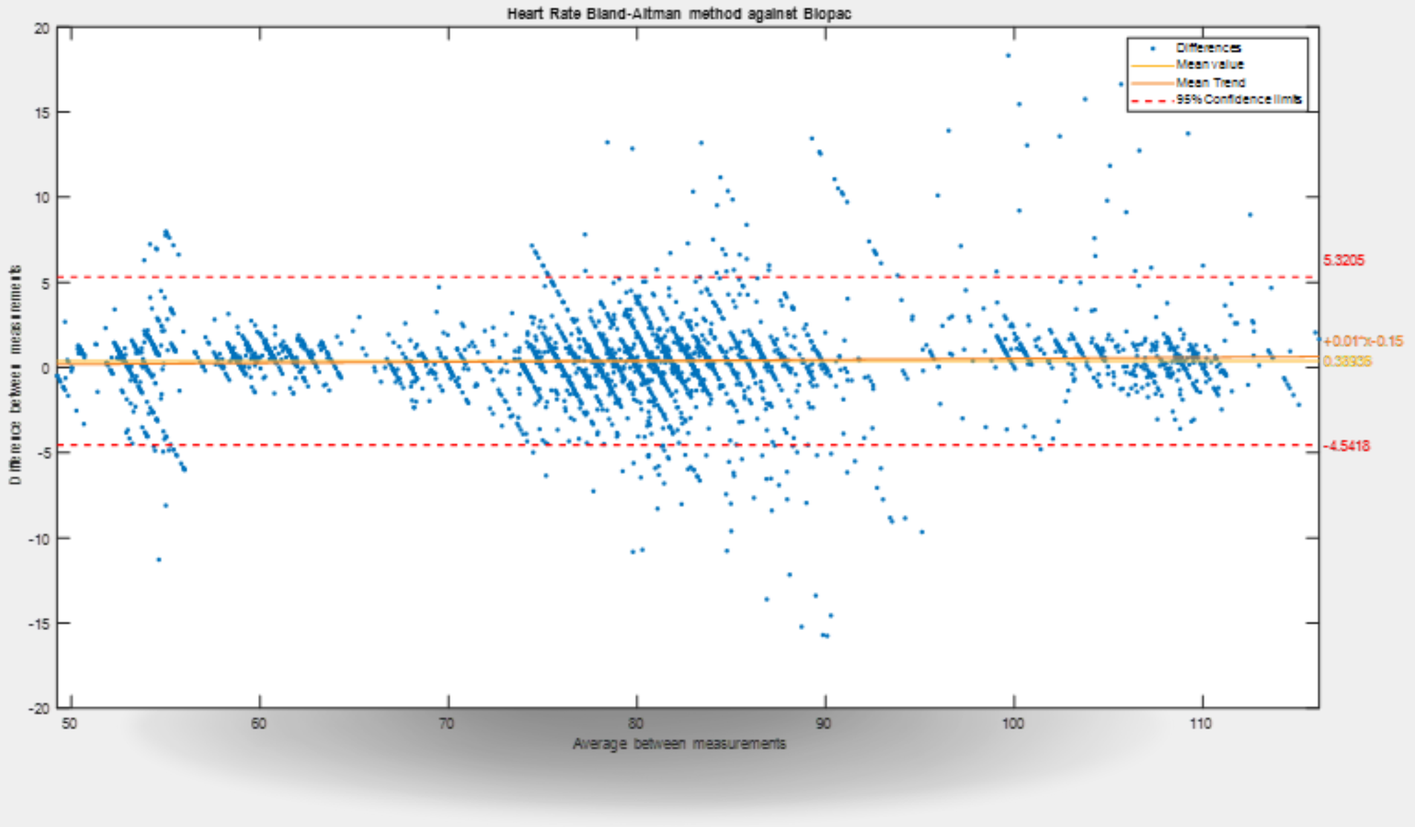
LifeVit vs Biopac



HR LifeVit measurements against Biopac (Lie Down Position)

3.1.3 Sit Down Results

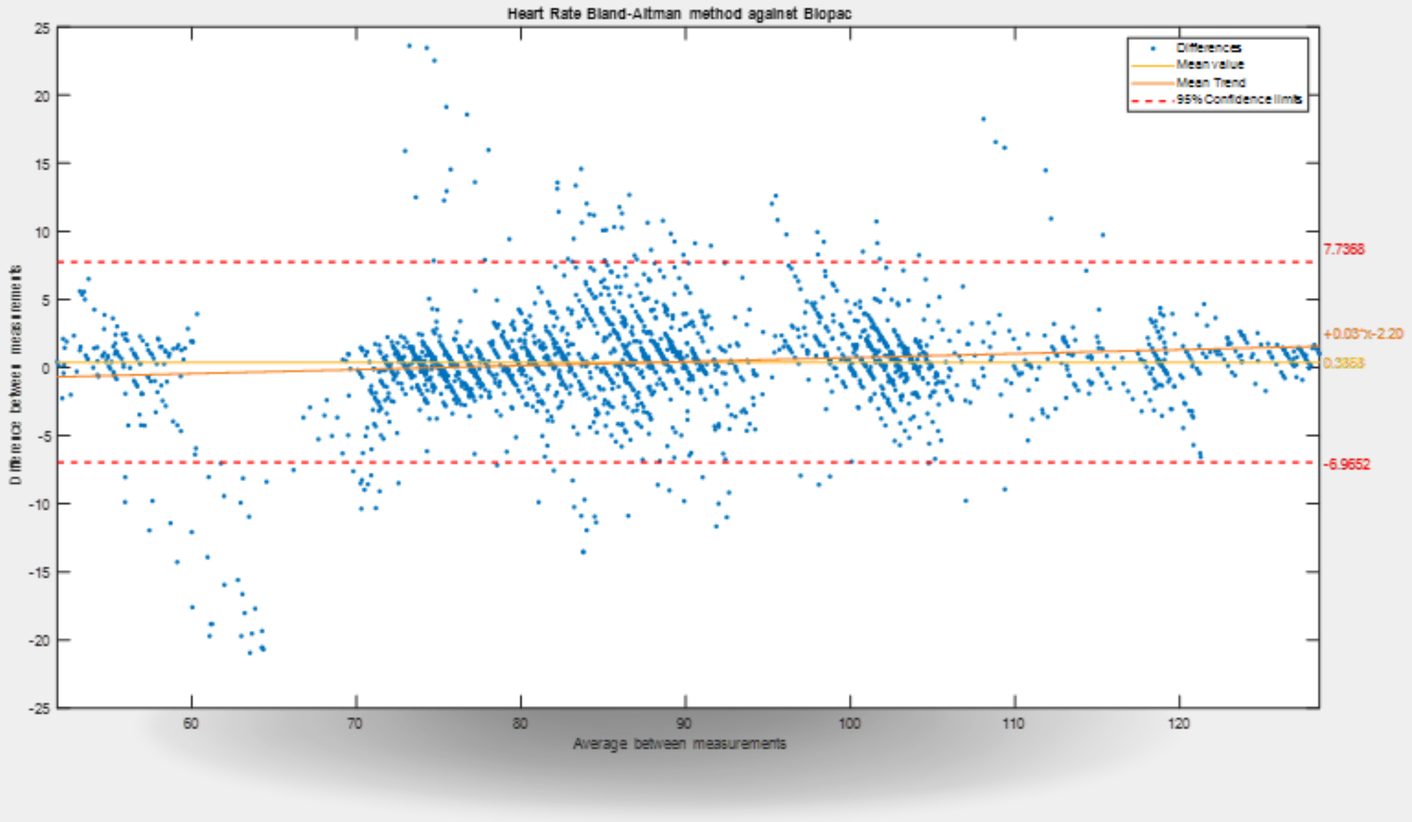
LifeVit vs Biopac



HR LifeVit measurements against Biopac (Sit Down Position)

3.1.3 Stand Up Results

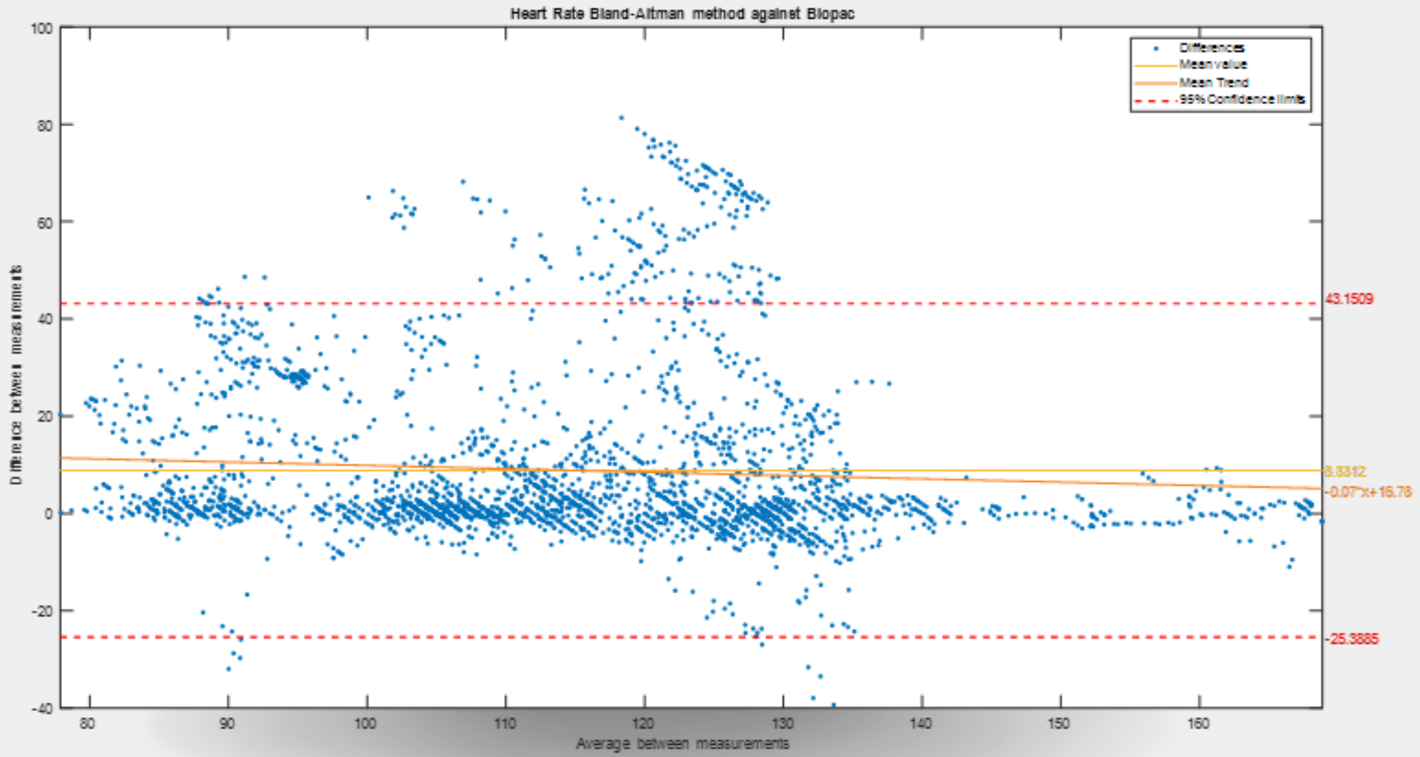
LifeVit vs Biopac



HR LifeVit measurements against Biopac (Stand Up Position)

3.1.4 Moderate Activity Results

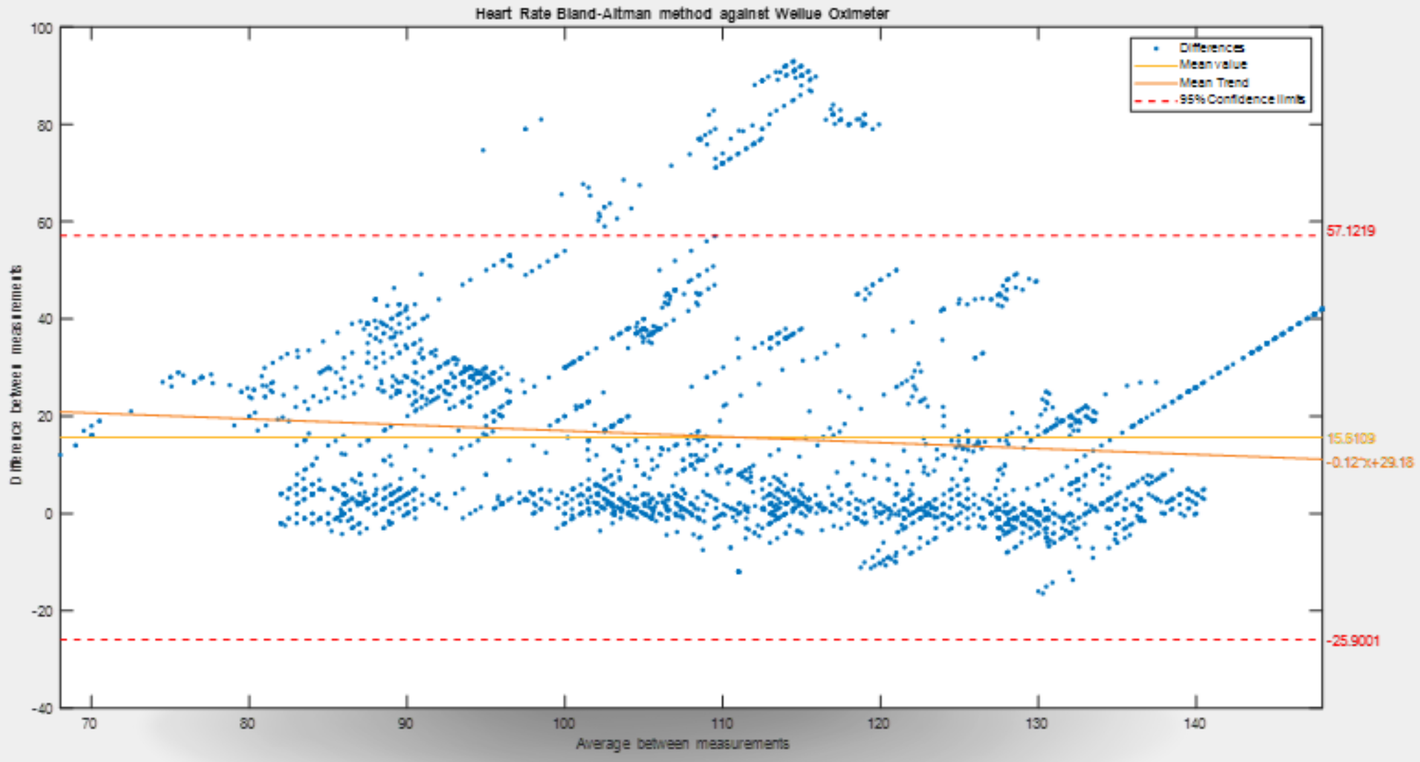
LifeVit vs Biopac



HR LifeVit measurements against Biopac (Sports Position)

3.1.4 Moderate Activity Results (II)

LifeVit vs Wellue

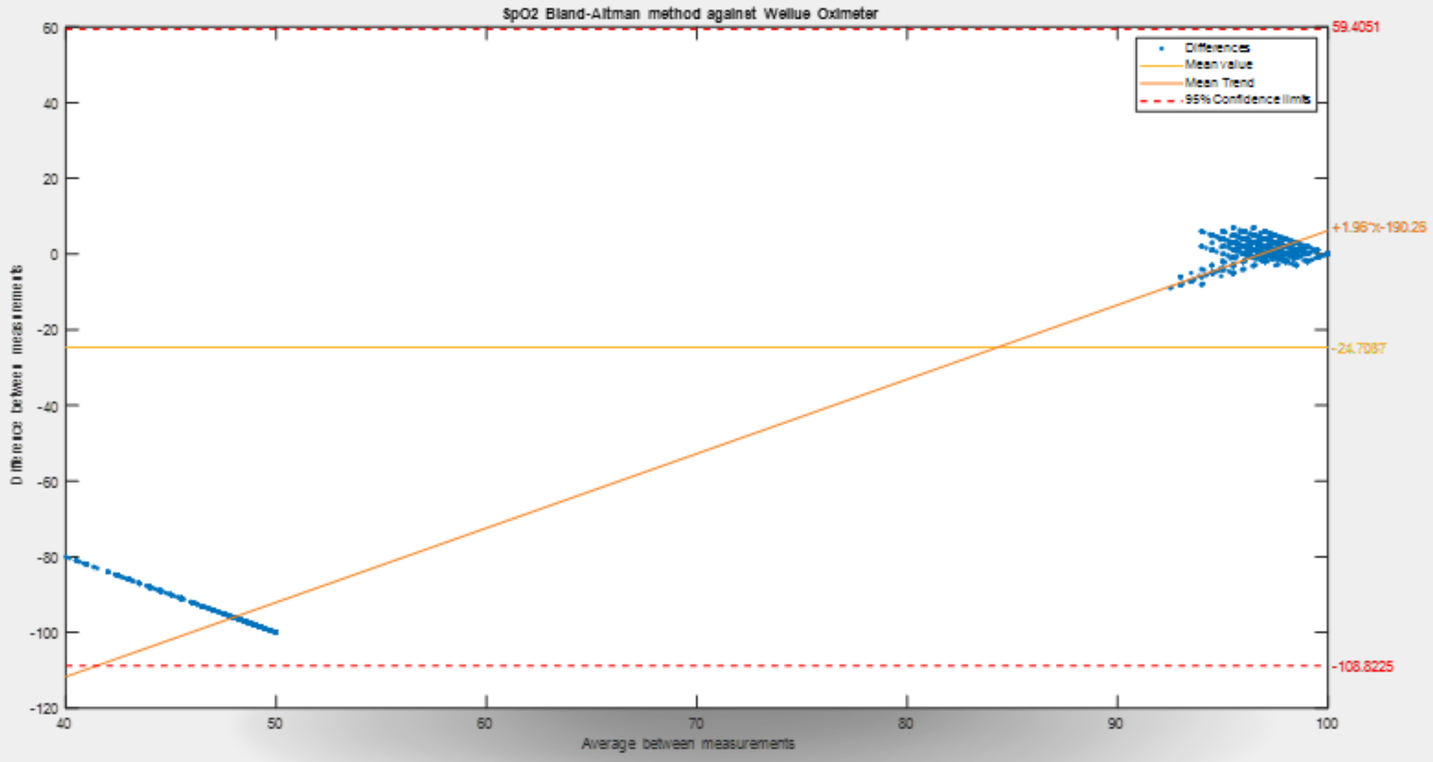


HR LifeVit measurements against Wellue oximeter (Sports Position)

3.2 Blood Oxygen Saturation (SpO2) Results

3.2.1 Overall Results

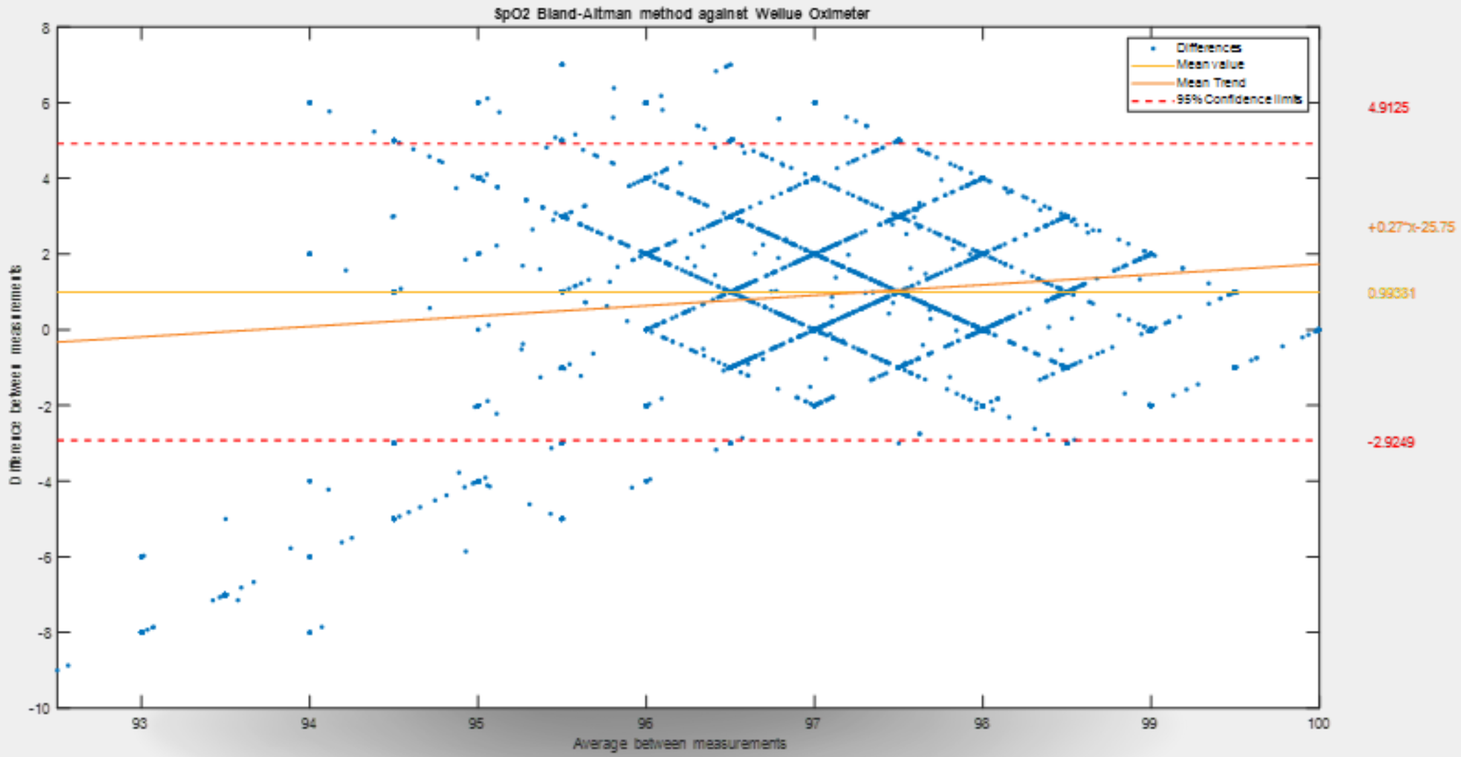
LifeVit vs Wellue



SpO2 LifeVit measurements against Wellue Oximeter

3.2.1 Overall Results without MA

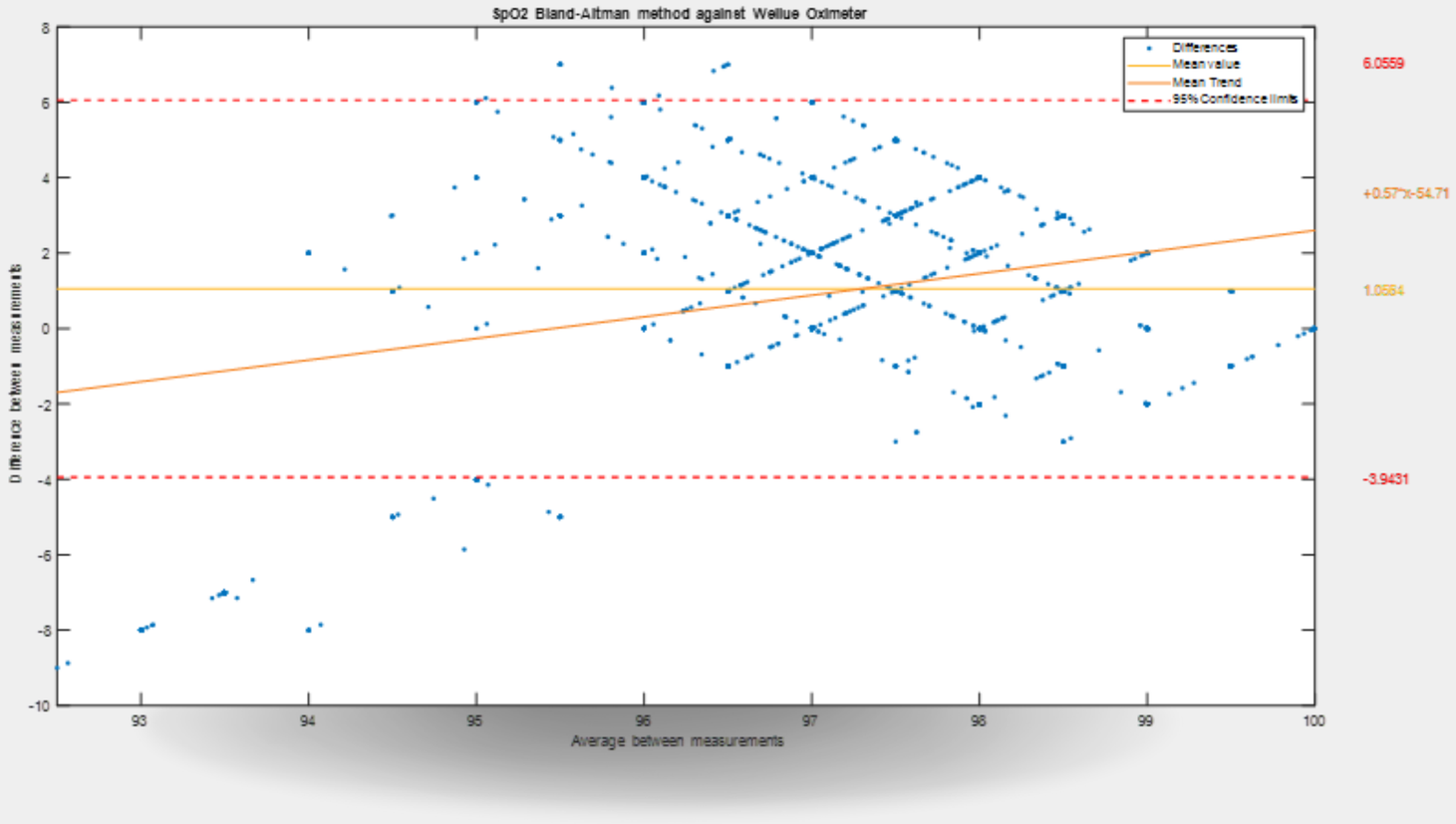
LifeVit vs Wellue



SpO2 LifeVit measurements against Wellue Oximeter without sport

3.2.2 Lie Down Results

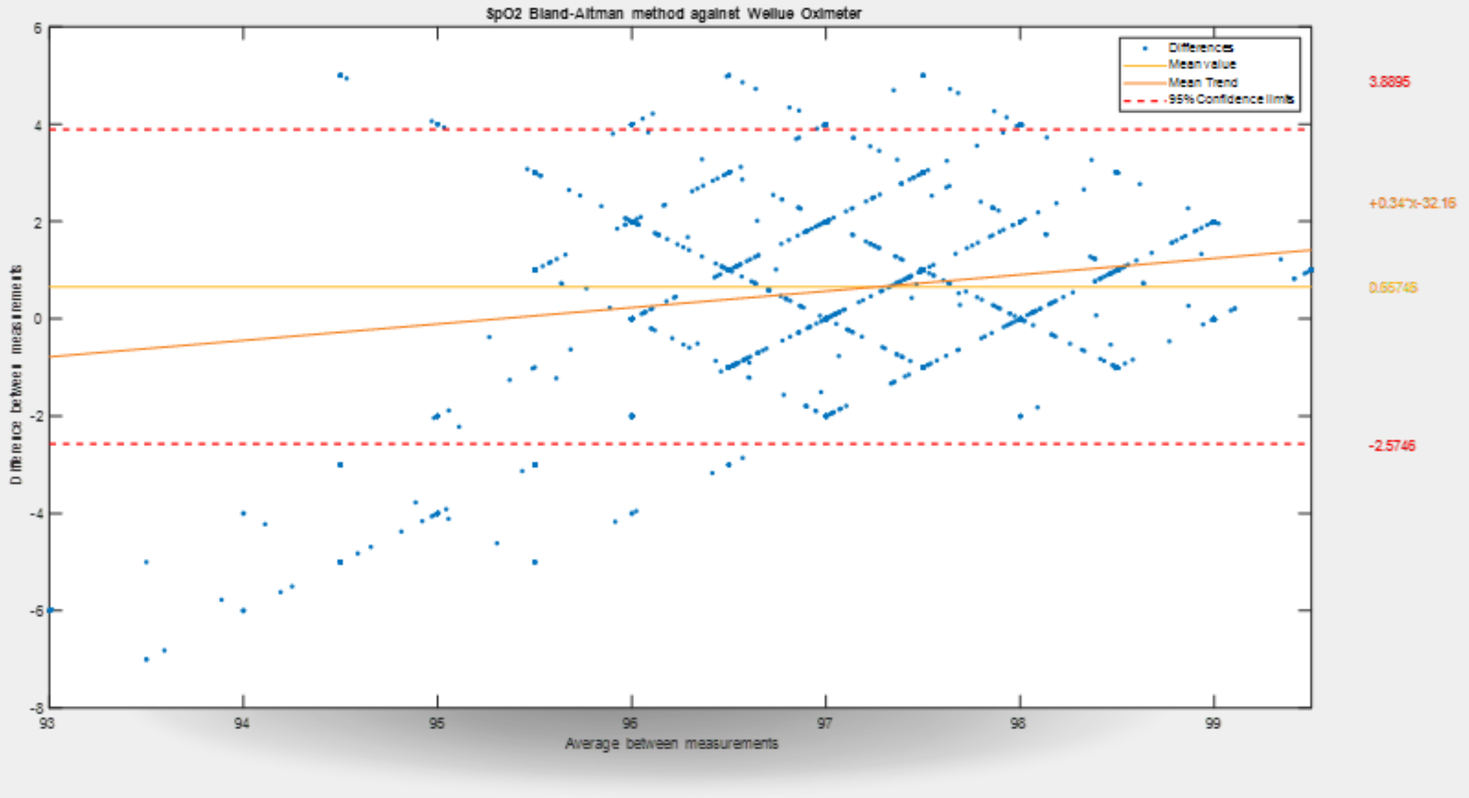
LifeVit vs Wellue



SpO2 LifeVit measurements against Wellue oximeter (Lie Down Position)

3.2.3 Sit Down Results

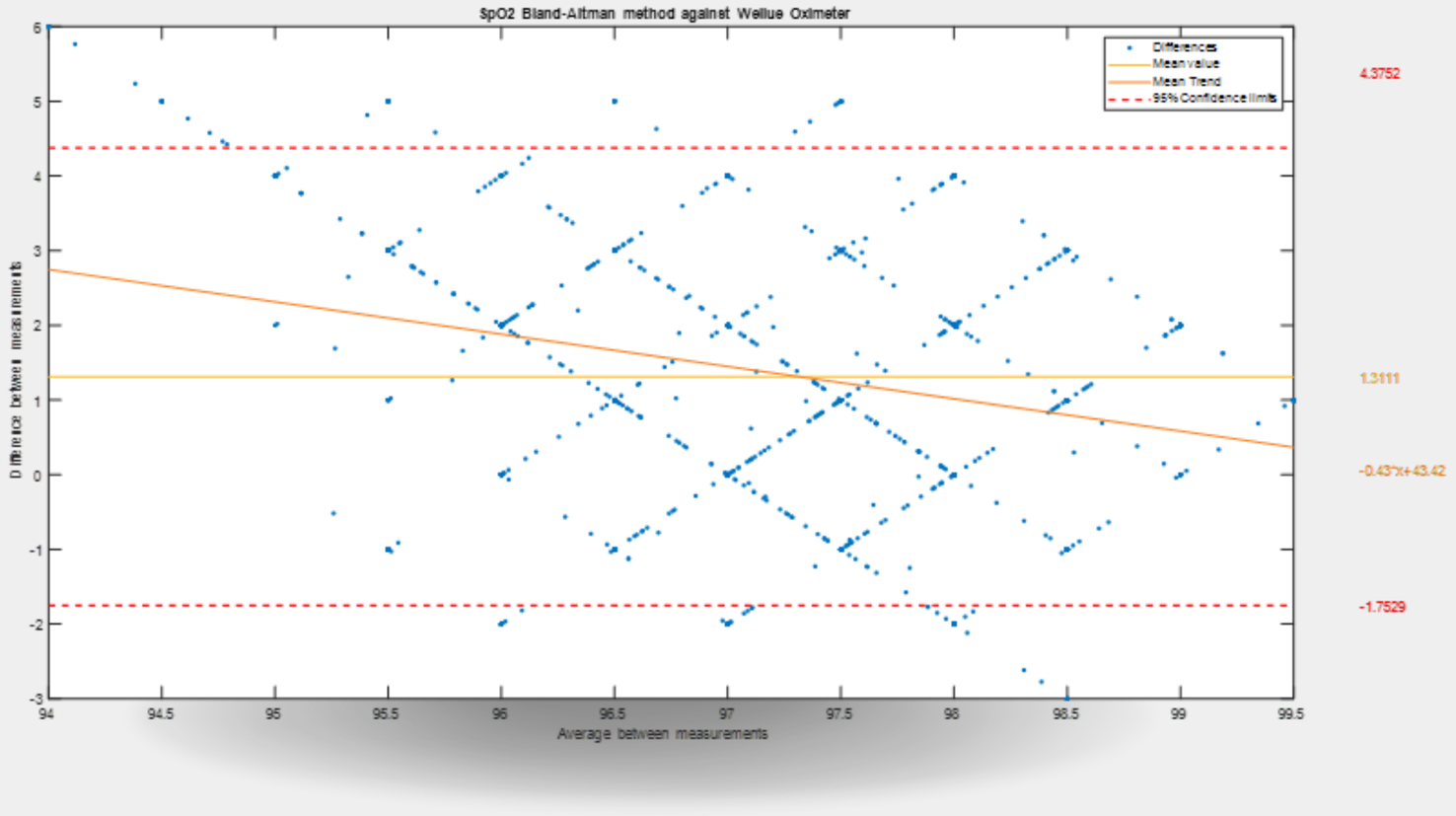
LifeVit vs Wellue



SpO2 LifeVit measurements against Wellue oximeter (Sit Down Position)

3.1.3 Stand Up Results

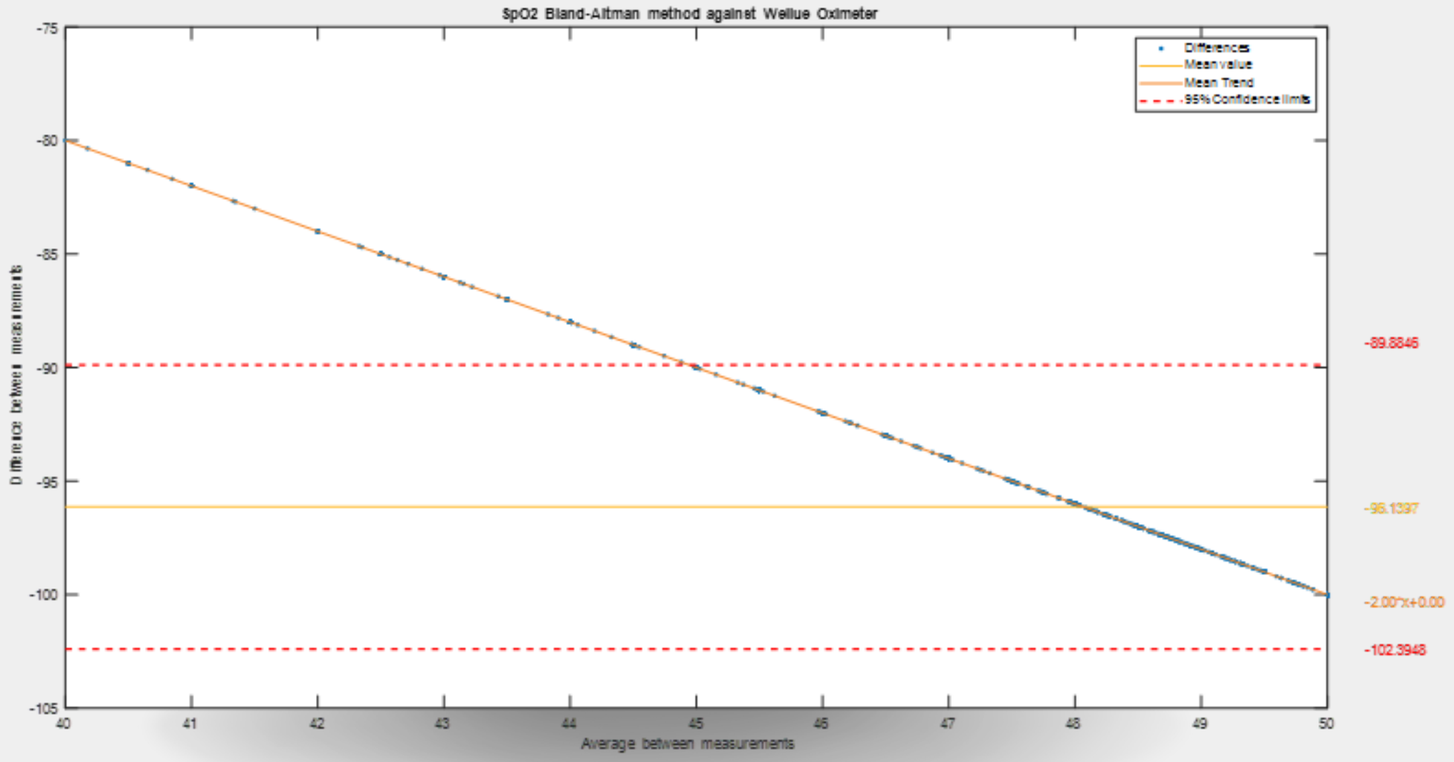
LifeVit vs Wellue



SpO2 LifeVit measurements against Wellue oximeter (Stand Up Position)

3.1.4 Moderate Activity Results

LifeVit vs Wellue



SpO2 LifeVit measurements against Wellue oximeter (Sports Position)

Position	Device	HR (bpm) mean	HR (bpm) LoA	SpO2 (%) mean	SpO2 (%) LoA
Lie Down	Biopac	0.44	-2.57 to 3.45	-	-
	Biopac 2	0.44	-2.24 to 3.13	-	-
	Wellue	0.87	-1.99 to 3.74	1.05	-3.94 to 6.05
Sit Down	Biopac	0.38	-4.54 to 5.32	-	-
	Biopac 2	0.38	-4.02 to 4.79	-	-
	Wellue	0.80	-3.20 to 4.82	0.65	-2.57 to 3.88
Stand up	Biopac	0.38	-6.96 to 7.73	-	-
	Biopac 2	0.38	-6.30 to 7.07	-	-
	Wellue	0.63	-4.71 to 5.99	1.31	-1.75 to 4.37
Sport	Biopac	8.88	-25.38 to 43.15	-	-
	Biopac 2	8.87	-25.01 to 42.76	-	-
	Wellue	15.61	-25.90 to 57.12	-96.13	-102.39 to -89.88

3.3 Results Summary Table

4. Discussion, Conclussions and Suggestions

4.1 Conclusions

Some conclusions extracted from the experiments were:

- The wearable device is safe to use but must be properly adjusted.
- Wear the device 1-2 fingers above the pisiform bone.
- Dark skin may affect measurement accuracy.
- Allow a few minutes for the device to display heart rate measurements immediately.
- Movement can produce non-realistic values.
- SpO2 readings take a few seconds to obtain normal measurements and are affected by movement.

4.2 Discussion

- The accuracy of the wearable device depends on the biological signal being measured.
- The device provides reasonable heart rate measurements in most situations.
- The best results were obtained in the lie-down position.
- The difference between confidence interval limits was smaller in the lie-down position than in other positions.
- Volunteers #0 and #11 obtained the best results.

4.3 Suggestions

Some suggestions could be:

- The device can be integrated into the ReHub telerehabilitation platform with confidence in heart rate measurements.
- SpO2 values may not be accurate and patients should be informed of this.
- The device is not a medical device but can help professionals monitor patients' health during exercises.
- Future firmware updates or algorithms may improve the accuracy of the device's measurements.

5. Dedication

5. Dedication

As all my previous professional and academic achievements, I want to dedicate this thesis to my mum because, alone since my father is not with us, in the worst moments of my life she always reminds me that always it is necessary to keep calm, keep your head up and face this new challenge that life has set to you.

Thanks mum.

6. Bibliography

1. EUR-Lex - 32017R0745 - EN - EUR-Lex. (n.d.-b). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32017R0745

2. Bayoumy, K., Gaber, M. A., Elshafeey, A., Mhaimeed, O., Hill, E., Marvel, F. A., Martin, S. S., Muse, E. D., Turakhia, M. P., Tarakji, K. G., & Elshazly, M. B. (2021). Smart wearable devices in cardiovascular care: where we are and how to move forward. Nature Reviews Cardiology, 18(8), 581–599. https://doi.org/10.1038/s41569-021-00522-7

3. Accurate Detection of Heart Rate and Blood Oxygen Saturation in Reflective Photoplethysmography. (2020, December 9). IEEE Conference Publication | IEEE Xplore. https://ieeexplore.ieee.org/document/9408845

4.Dias, D., & Cunha, J. P. (2018). Wearable Health Devices—Vital Sign Monitoring, Systems and Technologies. Sensors, 18(8), 2414. https://doi.org/10.3390/s18082414

5.Alfonso, C., Garcia-Gonzalez, M. A., Parrado, E., Gil-Rojas, J., Ramos-Castro, J., & Capdevila, L. (2022). Agreement between two photoplethysmography-based wearable devices for monitoring heart rate during different physical activity situations: a new analysis methodology. Scientific Reports, 12(1). https://doi.org/10.1038/s41598-022-18356-9

6.Altman, D. G., & Bland, J. M. (1983). Measurement in Medicine: The Analysis of Method Comparison Studies. Journal of the Royal Statistical Society. Series D (The Statistician), 32(3), 307–317. https://doi.org/10.2307/2987937

7.Gerke, O. (2020). Nonparametric Limits of Agreement in Method Comparison Studies: A Simulation Study on Extreme Quantile Estimation. International Journal of Environmental Research and Public Health, 17(22), 8330. https://doi.org/10.3390/ijerph17228330

8. A Real-Time QRS Detection Algorithm. (1985, March 1). IEEE Journals & Magazine | IEEE Xplore. 8.A Real-Time QRS Detection Algorithm. (1985, March 1). IEEE Journals & Magazine | IEEE Xplore.

9.1-D digital filter - MATLAB filter. (n.d.). https://www.mathworks.com/help/matlab/ref/filter.html?s_tid=doc_ta

10.Zero-phase digital filtering - MATLAB filtfilt. (n.d.). https://www.mathworks.com/help/signal/ref/filtfilt.html

11.. Spaccarotella, C., Polimeni, A., Mancuso, C., Pelaia, G., Esposito, G., & Indolfi, C. (2022). Assessment of Non-Invasive Measurements of Oxygen Saturation and Heart Rate with an Apple Smartwatch: Comparison with a Standard Pulse Oximeter. Journal of Clinical Medicine, 11(6), 1467. https://doi.org/10.3390/jcm11061467

Thanks!

Questions?