StepUp Air:

Heart Rate & Breathing Rate Aerobic & Anaerobic Threshold Validation

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Abstract:

Background: Aerobic (**VT1**) and anaerobic threshold (**VT2**) detection requires either expensive gas analysis machines or difficult practise. A company named StepUp Air who have created a wearable Breathing Rate (**BR**) and Heart Rate (**HR**) monitor could potentially provide a cheaper solution in

Objective: The purpose of this study was to find out if it is possible to detect the aerobic (**VT1**) and anaerobic threshold (**VT2**) with use of the StepUp Air Wearable Heart Rate (**HR**)- and Breathing Rate (**BR**) sensor. As well as to determine the StepUp sensor's **HR** validity and reliability. Since StepUp Air **BR** has already been tested on validity (StepUp Solutions) it will only be tested on reliability.

Methods: 6 healthy male subjects volunteered to perform 2 tests which consisted of an incremental- and an interval cycle ergometer test. V'O2, V'CO2 uptake and **BR** were measured by a breath-by-breath analyser, while **HR** was recorded by a Polar wearable **HR** sensor alongside the StepUp Air (**BR, HR**) sensor. For reliability testing 1 participant performed a small incremental protocol with a 40 Watt increment every 3 minutes for 12 minutes for a total of 3 times.

Results: Excellent correlations were found between StepUp **HR** data and Polar in incremental testing (r=0.990-0.998) and interval testing(r=0.991-0.998). Reliability results showed excellent reliability for **HR** (ICC=0.948), yet a low reliability for **BR** (ICC=0.295). Excellent correlation (r=0.942) was found between mean V'O2 values derived from StepUp **BR** data at the point of disproportionate increase and mean V'O2 values from gas analysis machines' automated **VT2** calculations during incremental testing. Not enough results were found for **VT2** during interval testing to perform statistical analysis. No results were found for **VT1.**

Conclusion: Following this method, it can be concluded that the StepUp sensor is capable of calculating **VT2** during incremental testing and therefore providing a cheaper alternative for **VT2** determination. **HR** results showed to be valid and reliable, while **BR** results suggested values to be unreliable

Table of content:

Abstract: 2

Table of content: 3

Introduction 4

Materials and Methods: 6

- Data analysis: 9

Results 10

- Validity testing **HR**: 10
- Reliability Testing 15
- Validity testing **VT2** 15

Discussion 17

- Validity Testing **HR** 17
- Reliability testing **HR** and **BR** 17
- **VT1** 18
- **VT2** 18

Conclusion 19

Acknowledgements 19

Attachments: 20

References 47

Introduction

Aerobic (**VT1**) (Eriksson & Couzens, 2017) and Anaerobic (**VT2**) (Davis, Bassett, Hughes, & Gass, 1983) threshold values give a lot of insight into an athletes' performance and improvement in results from training. Study shows that training just below the anaerobic threshold could significantly improve stamina and therefore the physical exertion it takes before reaching the anaerobic threshold (Ghosh, 2004) (Medbø & Burgers, 1990). This is very important for a lot of endurance performing athletes like long distance runners, who need to be able to rely on their aerobic capacity so they could withstand muscle fatigue and lactic acid accumulation for a long period of time during performance, sometimes even for hours. Short endurance performing athletes such as sprinters, on the other hand, need to be able to extract a lot of energy in a short amount of time. These athletes are largely dependent on their anaerobic capacity. For an athlete or coach, being able to get insight into an athletes **VT1** and **VT2** could be incredibly beneficial. Problem remains that **VT1** and **VT2** detection requires expensive breath-by-breath analysers (Davis, Bassett, Hughes, & Gass, 1983) or difficult practise such as the D-Max method (Cheng & Kuipers, 1992) or the HRV method (Karapetian, J, & J, 2008). StepUp Air could potentially be the solution for this problem for numerous athletes.

StepUp Air is an international company based in Denmark which has focused on designing a wearable breathing- and heart rate sensor (**The StepUp sensor**). The StepUp sensor is a wearable sensor which can easily be attached to an individual's upper body with a simple chest strap, like that of a Polar® Heart Rate sensor (Windt, 2015). The StepUp sensor gives the user unique insight in their training progression by not only giving live feedback of their heart rate (**HR**), but also their breathing rate (**BR**). Being able to receive this live feedback could give the user the ability to change their training intensity and duration depending on their body's reaction to training on that day.

The StepUp Air sensor is not for sale yet and is still in a testing/improving phase, so up until now, only **BR** data from StepUp Air has been validated (r=0.998), yet the research remains unpublished (StepUp Solutions). Still, the company is eager to discover their product's capabilities. An idea had come forth to see if the product is capable of measuring the Aerobic- and Anaerobic Threshold. A 1889 study showed that, mean V'O2 values, which were calculated each minute, around the point of **VT2** determined by disproportionate increase in **BR**, showed a significant ($P<0.05$) correlation ($r=0.834$) between individual datasets (James, Adams, & Wilson, 1889). Another study, conducted in 2021, found a strong correlation ($r = 0.970$) between **VT1** and a method which uses a detrended fluctuation analysis (Tarvainen, Ranta-aho, & Karjalainen) on Heart Rate Variability

(**HRV**) (Rogers, Giles, Draper, Hoos, & Gronwald, 2021)**.** These results show to be very relevant for this research since the StepUp sensor is capable of measuring **BR** and **HRV**. The small and easily attachable/detachable sensor could make **VT** tests accessible to athletes who don't have access to expensive gas analysis machinery. Thus, the aim if this study was to answer the research question: *Is it possible to calculate **VT1** and **VT2** using the StepUp Air sensor?*

The second aim of this study was to test validity and reliability on StepUp Air's **HR** data outputs and reliability on **BR** outputs.

Materials and Methods:

Materials:

- Lode (Lode Examiner, Lode. B.V. Groningen, The Netherlands)
- Vyntus™ CPX Gas Analysis Machine
- Step Up Air: Wearable Heart Rate & Breathing Rate Sensor
- Polar H7: Wearable Heart Rate Sensor

The StepUp Air

Subjects:

Participants were recruited from The Hague University of Applied Sciences. To be eligible to participate in this study, participants had to be male between the ages of 20 and 30. All potential participants signed an informed consent next to an anamnesis form (can be found in attachments XIII), which they were obligated to fill in before testing. This was done to maintain safety since the participants were driven to exhaustion which could potentially cause safety issues such as hyperventilation or fainting. Participants also refrained from drinking alcohol and heavy exercise at least 24 hours prior to testing.

Incremental test:

The first protocol consisted of a ramp load (See **figure 1** for a visual example) on an electronically braked cycle ergometer. A Polar **HR** sensor was strapped around the participants' chest for a 2-minute rest **HR** measurement. After the Vyntus had been calibrated, the participants were asked to take place on the cycle ergometer and the mouthpiece (attached to the Vyntus CPX) and mask were attached to the participants. Depending on the participants' exercise activity (hrs/week), a starting resistance of 40 Watts (<2hrs/week) or 80 Watts (>2hrs/week) was chosen. The StepUp Air sensor was then strapped around the participants' waist alongside the Polar sensor for **HR** and **BR** recording. During the entire test, the participants were asked to maintain a pedalling frequency of 80 rounds · min^{-1}. At the start, a 3-minute warmup phase on a resistance of 40 Watts was performed. A testing phase followed, where for every 3 minutes the workload increased by 40 Watts. In the last minute of every workload, **HR** was noted, and a talk test was performed where the participants were asked to read from a form to test their speaking capabilities. These steps were repeated until the participant was either unable to maintain the pedalling frequency of 80 rounds · min^{-1} or if the participant was unable to continue due to exhaustion. When the participants volitionally gave notion of wanting to quit due to exhaustion, participants were verbally encouraged to keep going or to at least finish the 3 minutes of the workload they were on. This was done to ensure physical exhaustion and not for just quitting out of comfort reasons. This was done with care and only if it was visible the participants could go on, so no safety measures were crossed. After testing, participants were asked to keep cycling at a comfortable pace on an electrical resistance of 40W for 2/3 minutes. During these 2/3 minutes all sensors were detached from the participants and data was stored. This protocol was then repeated for all 6 participants.

Interval Test:

Although the incremental test (protocol 1) has been recognized as the way of measuring an individual's **VT1** and **VT2**, a second protocol had been added to this research which was more applicable to a real-life based exercise routine to see if any interesting outcomes would show. The second protocol consisted of an interval test (See **figure 2** for a visual representation) on an electronically braked cycle ergometer. After the Vyntus had been calibrated, the participants were asked to take place on the cycle ergometer and the mouthpiece (attached to the Vyntus CPX) and mask were attached to the participants. The StepUp Air sensor was then strapped around the participants' waist alongside the Polar sensor for **HR** and **BR** recording. During the entire test, the participants were asked to maintain a pedalling frequency of 80 rounds $\cdot$ min^{-1}. A 3-minute warmup phase on a resistance of 40 Watts started. After 3 minutes of warming up, a testing phase started where participants cycled on a starting workload of 80 Watts for a duration of 3 minutes. After 3 minutes, the workload increased to 160 Watts for another duration of 3 minutes before it was decreased to the starting workload again. This process was repeated another 2 times for a total of 3 workload increases or until the participant volitionally gave the notion that they were exhausted or if the participant was unable to maintain the pedalling frequency of 80 rounds $\cdot$ min^{-1}. After the third workload increase the workload dropped down to 80 Watts for 3 minutes before the test came to an end. This resulted in a test duration of 21 minutes (excl. warm up phase). After testing, the participants were asked to bike at a comfortable pace on an electric resistance of 40 Watts for 2/3 minutes. During this time all sensors were detached from the participants and all data was stored.

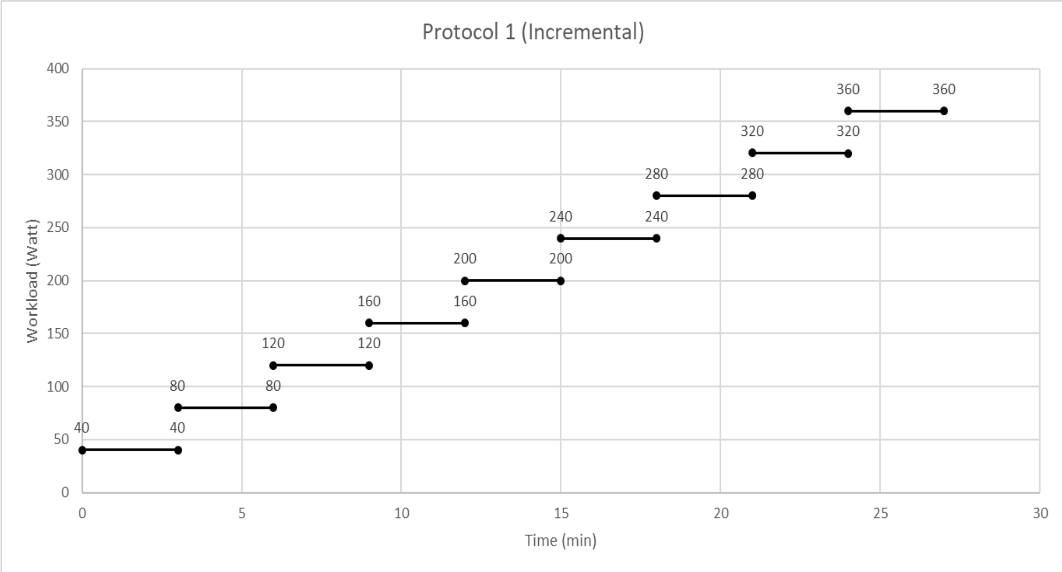


Figure 1*: Example of Protocol 1 (Starting load 40 W), Warm Up- and Cooling Down phase excluded.*

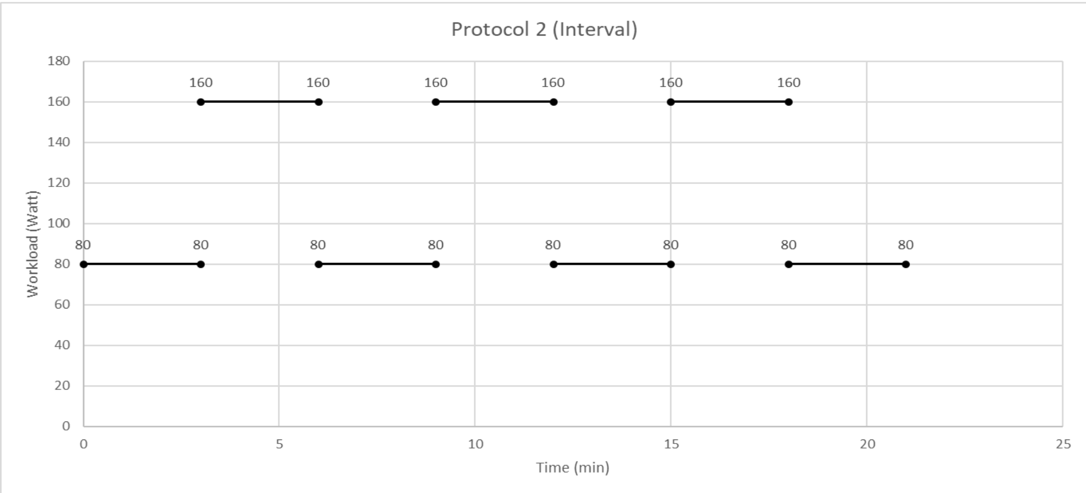


Figure 2*: Example of Protocol 2 (Starting load 80 W), Warm Up- and Cooling Down phase excluded.*

Reliability, incremental test:

The participant was wearing a StepUp **HR** and **BR** sensor and a Polar **HR** sensor. The participant cycled on a cycle ergometer for 12 minutes. With a low resistance of 40W in the first 3 minutes, a resistance of 80W from 3-6 minutes, a resistance of 120W from 6-9 minutes and a final high resistance of 160 W in the last 3 minutes. The participant was asked to maintain a pedalling frequency of 80 rounds $\cdot$ min^{-1}. This protocol was done 3 times with at least 180 minutes rest time in between tests. After this protocol, the recorded data was saved and exported to Excel.

Data analysis:

All collected StepUp Sensor, Polar and gas analyser data was exported and stored in Microsoft Excel (Microsoft Excel-spreadsheetsoftware). All unusable, corrupted, or incomplete data was overlooked, and those results were not included in the data analysis. StepUp **HR** results were validated by comparing data from the StepUp sensor to the **HR** results from a Polar H7. Since the amount of **HR** data samples (/min) from the StepUp sensor did not match that of the Polar H7, **HR** data from both sensors were down sampled and averaged per 10 seconds. The data was cut, down sampled, and analysed in Python™. For validity, Pearson correlation(r) (DeCoster) tests were executed between StepUp and Polar **HR** data. Pearson r values were interpreted as <0.29 Weak, 0.30>0.49 Low, 0.50>0.74 moderate and 0.75>1 good/excellent. Line graphs (could be found in attachments), scatter plots (used for regression analysis) and Bland Altman plots (Altman & Bland, 1999) (Bland & Altman, 1986) were made for every individual participant's **HR** dataset per test. Regression analysis had been performed in IBM® SPSS® Statistics (IBM SPSS Statistics) to calculate the linear relationship between the 2 variables, showcasing each test outcome's regression coefficient between the sensors **HR** data, the bias (%) and their corresponding R^2 value which shows how well the data fit the regression model (Hut, 2022). Bland Altman Plots that were made on **HR** data per participant calculated the limits of agreement. For reliability, Intra Class Correlation tests (**ICC**) (Bartko, 1966) were performed in IBM® SPSS® Statistics for StepUp **HR** and **BR** data to calculate the sensors' reliability. **ICC** values were interpreted as <0.5 poor reliability, 0.5>0.75 moderate reliability, 0.75>0.9 good reliability and >0.9 excellent reliability. Potential **VT1** outcomes from StepUp were compared with Vyntus' automated **VT1** calculation. For **VT2,** Individual **BR** datasets from StepUp were plotted as a line graph, where crosslines were manually drawn by following the corresponding polynomial trendline (See attachments VIII). This was done to determine the point in time (s) of disproportionate increase most accurately. V'O2 at disproportionate increase in **BR** was compared to V'O2 at Vyntus' automated **VT2** calculations. Pearson correlation tests were executed between the V'O2 values, and a Bland Altman plot was created to calculate the limits of agreement.

Results

Study Participants

All participant biometric information is presented in **table 1.** 6 healthy male participants completed the incremental test protocol, whereas out of those 6 participants, 4 also completed the interval. The mean(±SD) age of the participants was 24±1.5 with an average weight(kg) of 79.5±2.3 and height 183.2±3.6.

Table 1: Biometric information of participants:

No.	Sex	Age (Yrs.)	Height (cm)	Weight (kg)	Peak HR* (bpm)	Rest HR (bpm)	Peak VO2** (kg/ml/min)
1	M	26	185.5	83.1	194	61	38.6
2	M	23	186.0	78.7	197	64	37.3
3	M	24	183.0	81.3	196	69	57.7
4	M	23	176.1	79.8	197	76	32.9
5	M	22	182.0	78.4	198	62	42.5
6	M	26	186.7	75.8	194	102	39.5

*Peak HR calculated based on the Fox equation (220 - age = Max HR) (Shookster, Lindsey, Cortes, & Martin, 2020)

**Measured with the Vyntus CPX during peak incremental cycling test

Validity testing **HR**:

Heart Rate Data Validity Incremental test

Table 2: Pearson correlation between StepUp Air and Polar H7 during incremental tests

Participant #	1	2	3	4	5	6
r	x*	0.998	0.990	0.997	0.997	0.999

**Data was either corrupted or not collected so were not included in data analysis*

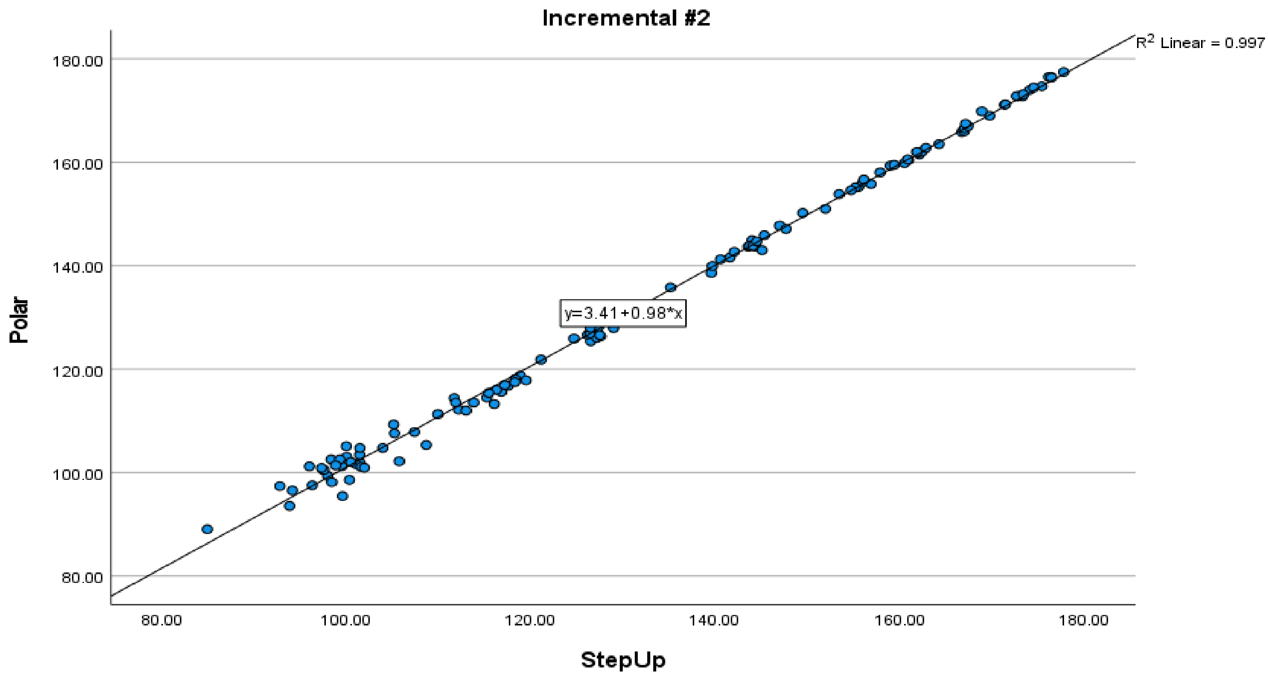


Figure 3: *Example of a scatter plot of StepUp* ***HR*** *and Polar data during incremental test (participant #3). The plot shows a regression line including corresponding the R^2 value and the plot title includes participants' number (All plots can be found in the attachments of this report).*

Table 3: Regression Analysis during incremental testing

Participant:	Bias	Bias (%)	Regression Coefficient	R^2
2	3.41	4.01	0.98	0.997
3	4.17	4.9	0.97	0.981
4	-1.89	1.87	1.02	0.994
5	1.84	1.76	0.99	0.995
6	-0.85	0.72	1	0.999

**Participant #1 data was corrupted so will not be included in data analysis, but could be found in attachments*

Pearson correlation testing for incremental tests presented in **table 2** show r values >0.9. Regression analysis shows very good regression coefficients, all of them being 1 or close to one with a bias (systemic error) of each test averagely ranging between 2.652±1.55%. Five out of 5 individual plots showcase a near perfect R^2 linear of >0.9(90%), with an average of 0.9932(99.3%).

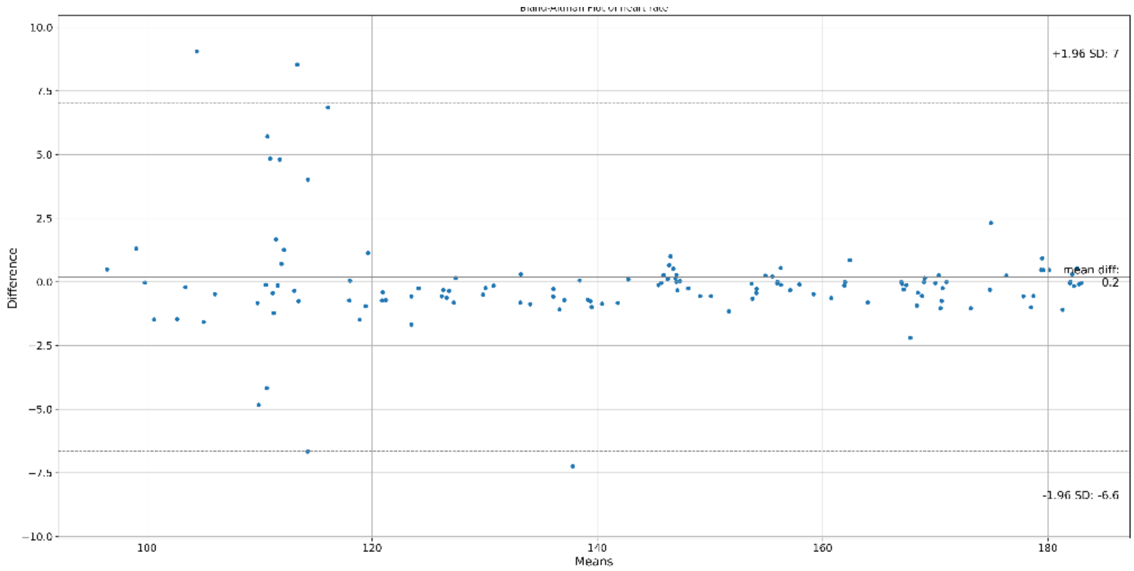


Figure 4**: Bland Altman plot incremental testing example, participant #4 (All other Bland Altman plots will be included in attachments.) All data from all the incremental testing Bland Altman plots can be found in **Table 5.

Table 4: Bland Altman Plot Results Incremental testing

Participant:	2	3	4	5	6
mean diff	0.31	0.2	0.14	0.41	-0.4
-1.96*SD	-2.8	7	5.1	-3.4	-2.2
+1.96*SD	3.4	-6.6	-4.8	4.2	1.4

Table 4 shows the mean of difference (mean diff) for every Bland Altman plot per participant and the limits of agreement. Five out of 5 tests have a mean diff 0<0.5 ranging from 0.132±0.28. Total average gives a mean(±sd) of 0.13±4.44. All Bland Altman plots (See attachments) show no noticeable pattern or slope in the estimate differences, implying there is no systemic trend in the bias. Yet, more outliers and differences were observed at low mean values, but little to no are outside the limits of agreement.

Heart Rate Data Validity Interval test

Table 5: Pearson correlation between StepUp Air and Polar H7 during interval tests

Participant #	1	2	3	4	5	6
R	x*	x*	0.994	0.991	0.998	0.991

**Data was either corrupted or not collected so will not be included in the data analysis*

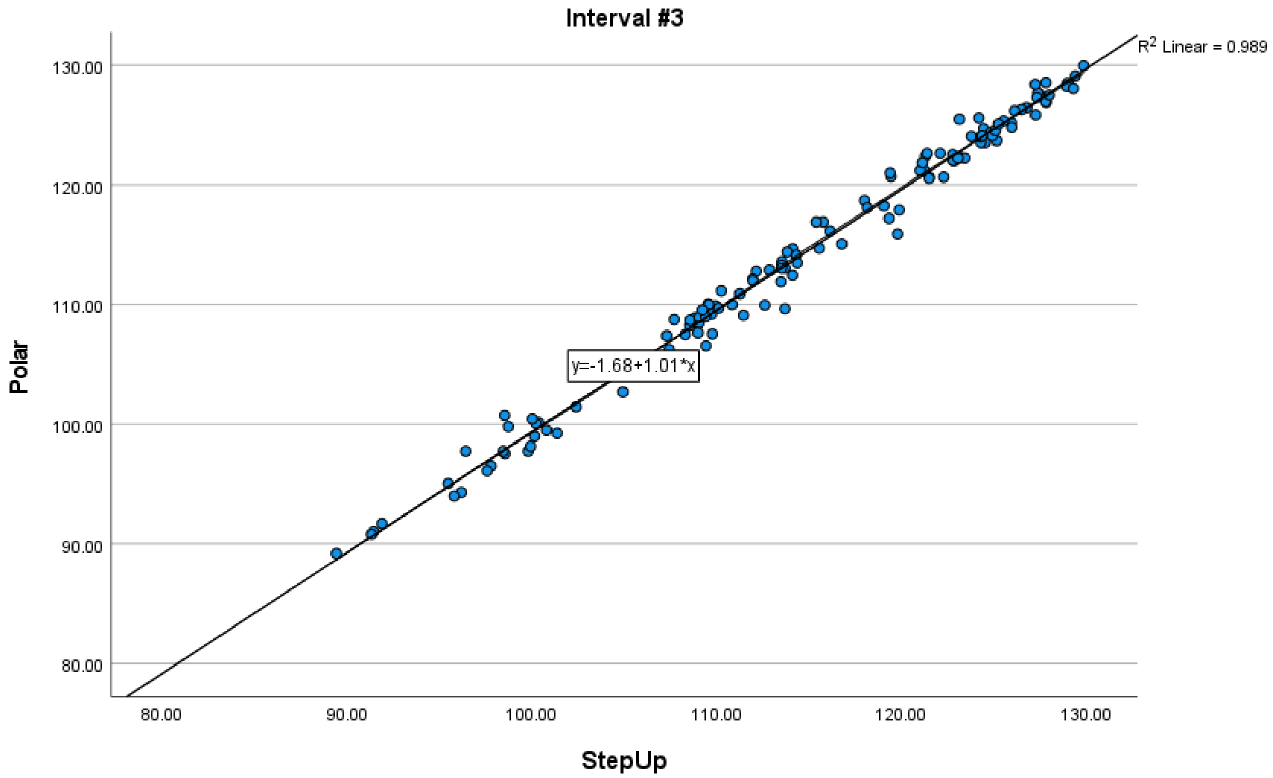


***Figure 5**: Example of a scatter plot of StepUp **HR** and Polar data during interval test (participant #3). The plot shows a regression line including corresponding the R^2 value and the plot title includes participants' number (All plots can be found in the attachments of this report).*

Table 6: Regression Analysis during interval testing

Participant:	Bias	Bias (%)	Regression Coefficient	R^2
3	-1.68	1.88	1.01	0.989
4	1.59	1.89	0.99	0.983
5	-0.11	0.13	1	0.996
6	-0.67	0.46	1	0.983

**Participant #1 and #2 not included in analysis due to missing data*

Pearson correlation test for interval testing show r values >0.9 (**Table 6**). Regression analysis on interval testing is showing very good regression coefficients being 1 or close to 1, with a bias average ranging from 1.09±0.8%. Four out of 4 individual plots showcase an R^2 linear of above 0.9(90%) with an average of 0.98775(98.8%).

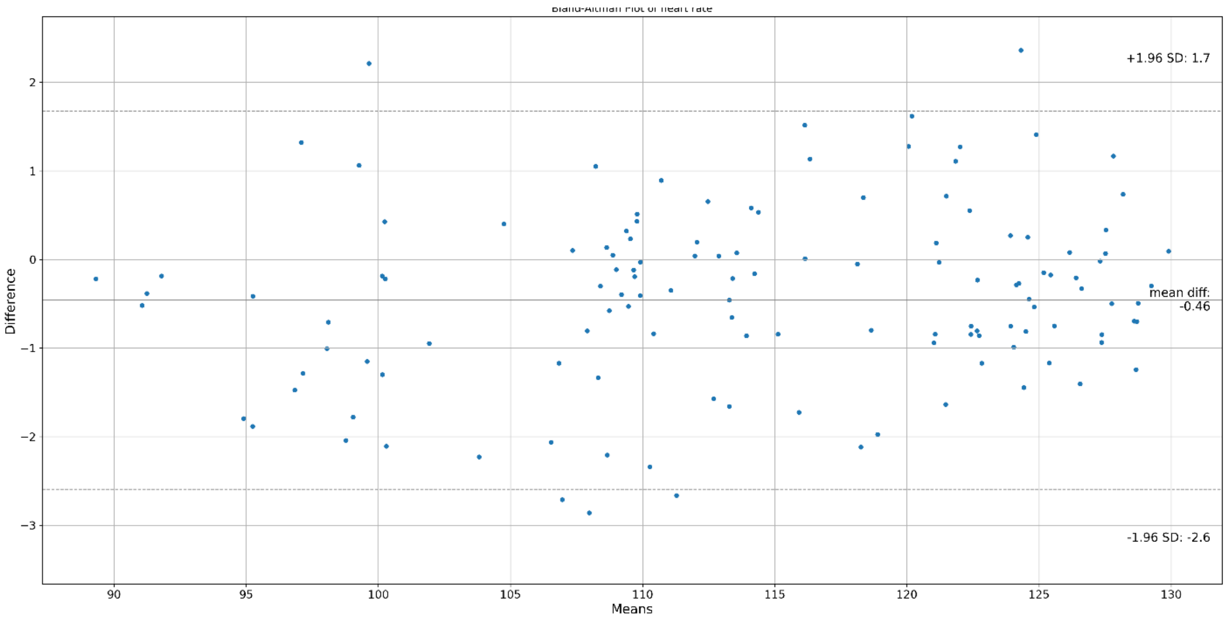


Figure 6*: Bland Altman plot interval testing, participant #3 (All other Bland Altman plots will be included in attachments). All data from all Interval testing Bland Altman can be found in* ***table 8****.*

Table 7: Bland Altman Plot Results Interval testing

Participant:	3	4	5	6
mean diff	-0.46	-0.06	-0.07	-0.21
-1.96*SD	-2.6	-6.2	-3	-2.5
+1.96*SD	1.7	6.1	2.9	2.1

Bland Altman plot results shown in **table 7** show mean differences ranging from -0.2±0.16. -1.96*SD and 1.96*SD on average lie between -0.1875±3.76, meaning on average from all 4 of the interval tests 95% of the differences will be in between this limit. Bland Altman plots for interval testing (See attachments for all plots) show no slope or pattern, suggesting there is no systemic trend in the bias. Bland Altman plots show little to no outliers outside of the limits of agreement.

Reliability Testing

Table 8: Intraclass Correlation Coefficient Heart Rate StepUp

Intraclass Correlation		95% Confidence Interval	
		Lower Bound	Upper Bound
Average Measures	.948	.724	.979

Table 9: Intraclass Correlation Coefficient Breathing Rate StepUp

Intraclass Correlation		95% Confidence Interval	
		Lower Bound	Upper Bound
Average Measures	.295	.136	.431

For **HR,** Average measures **ICC** shows a result of .948, with a 95% confidence interval showing a lower bound of 0.724 and an upper bound of 0.979 (**Table 8**).

For **BR, ICC** of average measures shows a correlation of .295 and a 95% confidence interval lower bound of 0.136 with an upper bound of 0.431 (**Table 9**).

Validity testing **VT2**

Incremental

Table 10: Mean ± SD oxygen uptake on **VT2** ($l \cdot min^{-1}$) incremental test

Participant:	1	2	3	4	5	6
StepUp:	2.13±0.28	2.17±0.1	3.41±0.12	1.91±0.07	x	2.14±0.20
Vyntus:	2.3±0.2	1.9±0.1	2.98±0.28	1.80±0.15	1.77±0.14	2.0±0.26

Table 11: Pearson Correlation **VT2** incremental testing

		Vyntus
StepUp	Pearson Correlation	0.942
	Sig. (2-tailed)	.017

Pearson correlation test between the mean V'O2 values at **VT2** from StepUp and Vyntus show a correlation of r = 0.942, which is significant ($P<0.05$) (**Table 11**). Bland Altman plot between Vyntus and StepUp incremental **VT2** values shows a very low mean of difference (0.102) and 95% confidence interval (-0.2187, 0.422695). No systemic trend in the bias was observed and no specific outliers, with all data points lying between the limits of agreement.

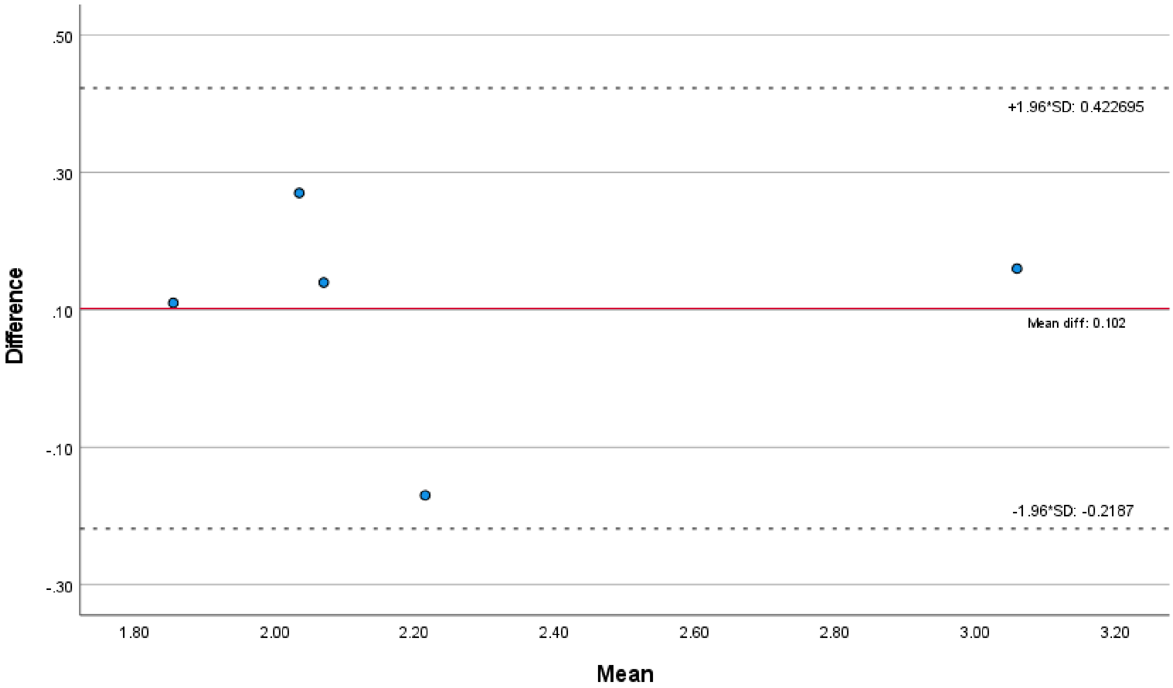


***Figure 11**: Bland Altman Plot VT2 data Vyntus and StepUp incremental*

Interval

Interval testing **BR** analysis found that no specific point of disproportionate increase could be found. **BR** data with several peaks made it unreliable to bind every point of **BR** increase with **VT2**.

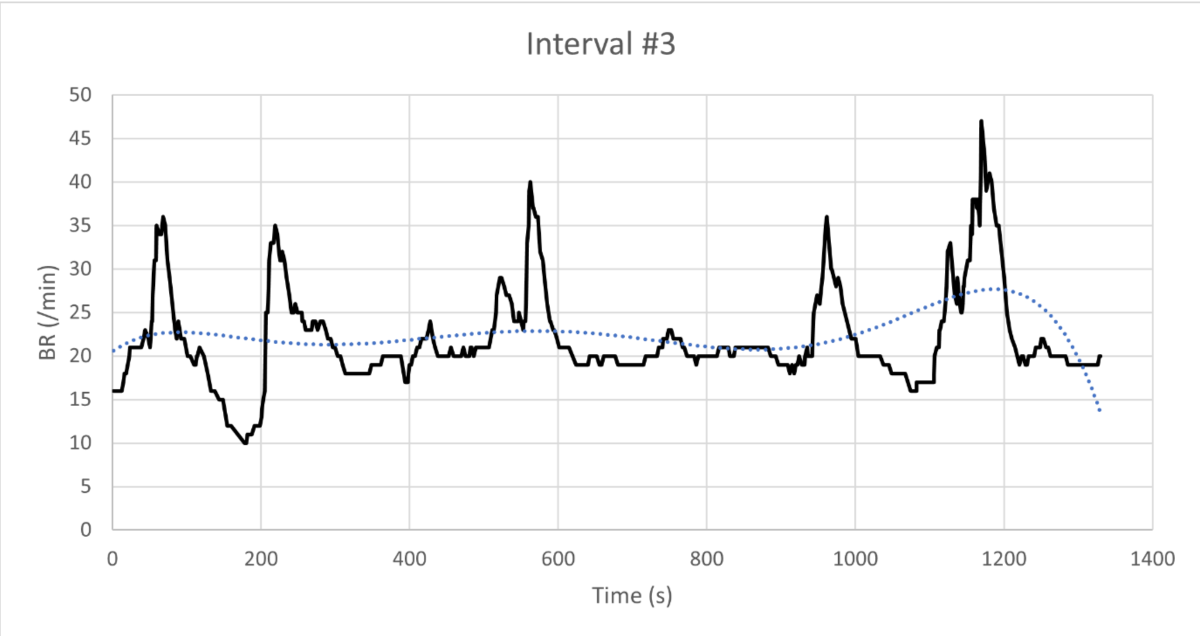


***Figure 12**: Example of interval **BR** data shows noisy **BR** values*

According to Vyntus' automated **VT** calculations, only 2 out of 4 participants would reach **VT2** during interval training. V'O2(Mean±SD) uptake around point of disproportionate increase in **BR** during interval testing of these two participants are shown in **table 14**. Not enough valuable data was collected to perform further statistical analysis.

Table 12: Mean ± SD oxygen uptake on **VT2** ($l \cdot min^{-1}$) interval test

Participant:	4	6
StepUp:	1.90±0.08	1.50±0.2
Vyntus:	1.48±0.13	2.20±0.60

Discussion

Validity Testing **HR**

It was one of this studies' intents to research the validity on the StepUp sensors' **HR** data outputs. Our results indicate the StepUp sensor to be a valid piece of equipment to use for measuring **HR** since it showed good correlation to a Polar H7 during incremental testing (r values ranging from 0.990 - 0.999). However, we observed more outliers towards the start of the incremental tests (See Attachment V). Also, Bland Altman Plots showed more difference towards the lower mean values. (Attachment III) Adjusting or repositioning the sensors for better comfort, better contact with the skin or other reasons could have caused this. This was not the case for interval testing since participants were then already familiar with the equipment and their preferable positioning for the wearable device. With that being said, more variation in differences were observed for **HR** during Interval testing compared to Incremental testing, but Interval testing showed no specific outliers (Attachment III & Attachment IV). Nonetheless, all results suggest a very strong correlation and good agreement between the StepUp sensor and the Polar H7 during incremental- or interval testing.

Reliability testing **HR** and **BR**

The **HR ICC** test outcomes showed an excellent **ICC** score of 0.984, with 95% confidence interval **ICC** values between 0.724 and 0.979. This means that 95% of all **HR** data samples would have a moderate to excellent reliability. However, **BR ICC** test results showed a low **ICC** of 0.295 which corresponds to poor reliability. 95% confidence interval **ICC** values between 0.136 and 0.431 suggest 95% of the results will show poor reliability. Poor **BR** reliability results were caused by random spikes in **BR** output values. For StepUp Air, it is known that the StepUp sensor sometimes gives out wrong (high) values, and they are busy solving it. Until that time, the sensors **BR** output remains unreliable.

VT1

No **VT1** results were found using the StepUp Sensor. But, since the StepUp Air sensor is capable of measuring **HRV** and it has been proven that **VT1** shows a strong correlation (r=0.97) with a DFA A1 method (Detrended Fluctuation Analysis of **HRV**), the StepUp sensor should be capable of calculating **VT1** using this method. Unfortunately, this method includes complex mathematical detrending methods which could not be computed for this research. Future research should be done to test StepUp Air's capability in calculating **VT1.**

VT2

Table 13: **VT2** crossed based on time

Participant:	1	2	3	4	5	6
StepUp:	719.28	823.67	1109.31	702.15	x**	1047.96
Vyntus:	739	684	946	649	551	607

Although results showed a significant ($P<0.05$) correlation ($r = 0.942$) and a good agreement on **VT2** between StepUp and Vyntus' automated calculations, it was also observed that **VT2** timestamps between StepUp and Vyntus could differ up to 400 seconds (see participant 6, **table 13**). This could have been, cause though it has been proven **VT2** can be found by the point of disproportionate increase in **BR**, not a lot of research is published to further back up this result or how to determine this point most accurately. Next to this, a study done in 2008 (Ekkekakis, Lind, Hall, & Petruzzello, 2008) tested the accuracy of several automated computer **VT** values and found that they show significant variance and thus a rather low reliability. This could have caused the automated **VT** calculations to be inaccurate, despite of the positive correlation between datasets.

For interval testing, Vyntus' gas analysis results showed only 2 out of 4 participants reached **VT2**. This could have been caused by a fixed workload protocol which was applied for every participant, while every participant might experience the workload as different in perceived exhaustion. For future interval testing, a custom workload protocol should be applied for every participant to ensure they reach **VT2**. For the participants who did reach **VT2,** results found the point of disproportionate increase in **BR** showed some uncertainties which could have been caused by the method of testing. Interval testing showed no gradual increase in **BR** since the workload did not gradually increase, which it does during incremental testing. Significant increases and decreases in workload resulted in **BR** results with several small peaks throughout the test, making it unreliable to pinpoint **VT2** using **BR** (**Figure 12**). Unfortunately, not enough usable data was found for interval testing to perform statistical analysis for **VT2**. Research on StepUp Air's capability to calculate **VT2** using **HRV** using the D-Max method (Miłosz, Adam, Jarosław, & Stanisław, 2009) or the **HRV** method (Karapetian, J, & J, 2008) could be done for future interval testing, to eliminate the issue of finding point of disproportionate increase of **BR**. A low number of participants was a limitation for this study (n = 6). Further research is necessary to further confirm the finding of this study.

Aside from purpose of this study, interesting outcomes appeared during data analysis from incremental testing **BR** values. **BR** values at the point of disproportionate increase as a percentage of the max **BR** measured that test, showed percentages to lie around 56.56±4.02%. This find could open the possibility for further research on **BR** around the point of disproportionate increase.

Table 14: **BR** at point of disproportionate increase compared to max **BR** (%)

Participant:	1	2	3	4	5	6
% of max **BR**	55%	64.1%	52%	55.7%	x	56%

Conclusion

The main purpose of this study was to answer the following research question: *Is it possible to calculate **VT1** and **VT2** using the StepUp Air sensor?* Based on this studies' results, we concluded the StepUp sensor to be capable of calculating **VT2** during incremental testing, and thus providing a cheaper solution to **VT2** determination. However, for the time being, it has not been proven if the StepUp Air sensor is capable of calculating **VT1.** We have also studied the validity and reliability of StepUp Air's **HR** and **BR** sensor. From our results we have concluded the StepUp sensor to be valid and reliable in measuring **HR,** however **BR** data appeared to be unreliable.

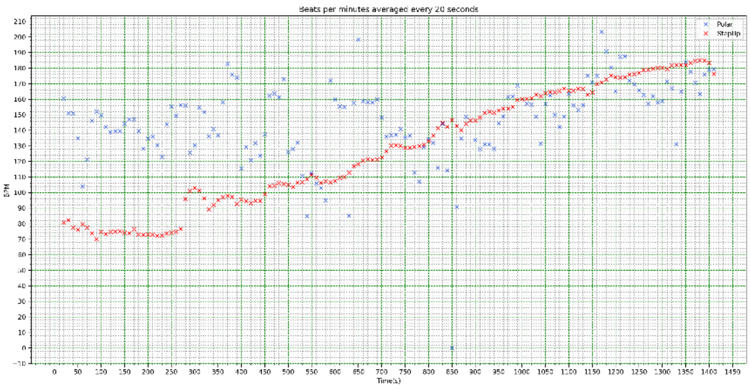
Acknowledgements

Special thanks to Charles Henri Gayot for helping with data analysis by preparing and occasionally tweaking the code in Python and helping to prepare the sensor before testing. Thanks to Rochus van der Droef for monitoring the progress of the research and occasionally helping with certain

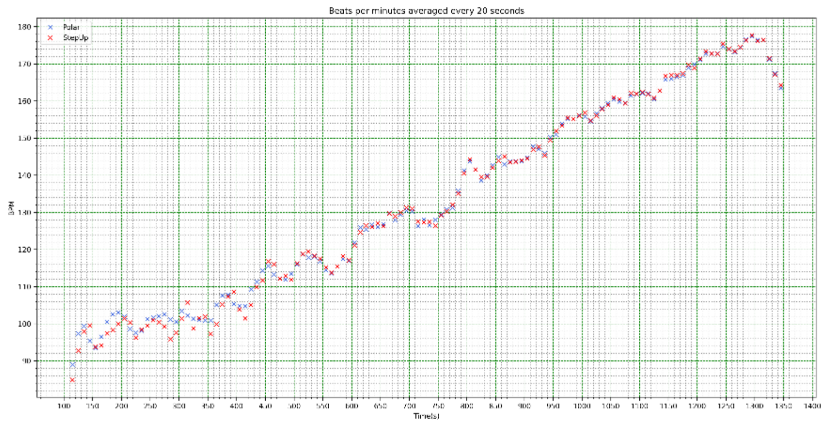
problems. Thanks to Thomas Gresty for being the contact person and being there when in need of help and checking up on the progress, as well as participating in the research. Thanks to all participants who were willing to give up their time in favour of this research.

Attachments:

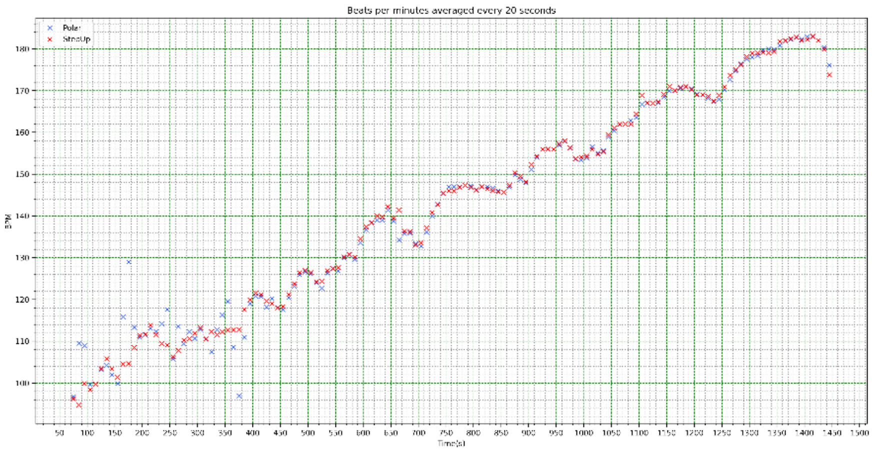
Attachment I: Data Plots down sampled 10 sec Incremental



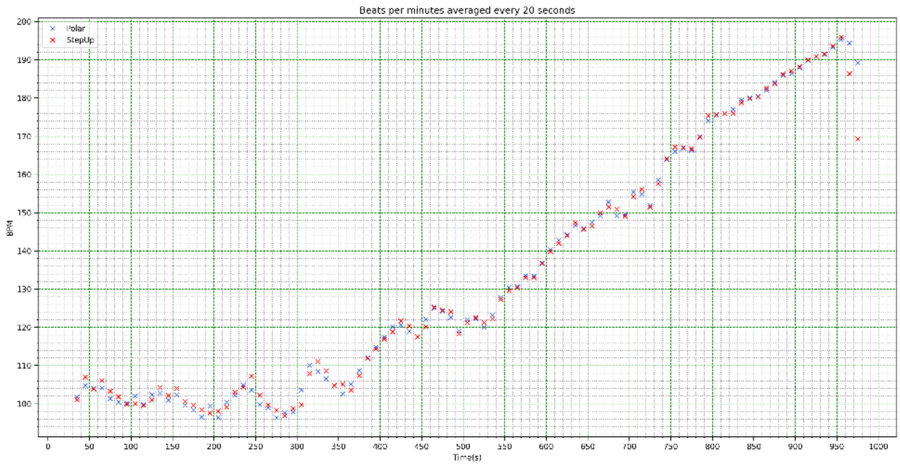
Participant #1 (Not used in data analysis)



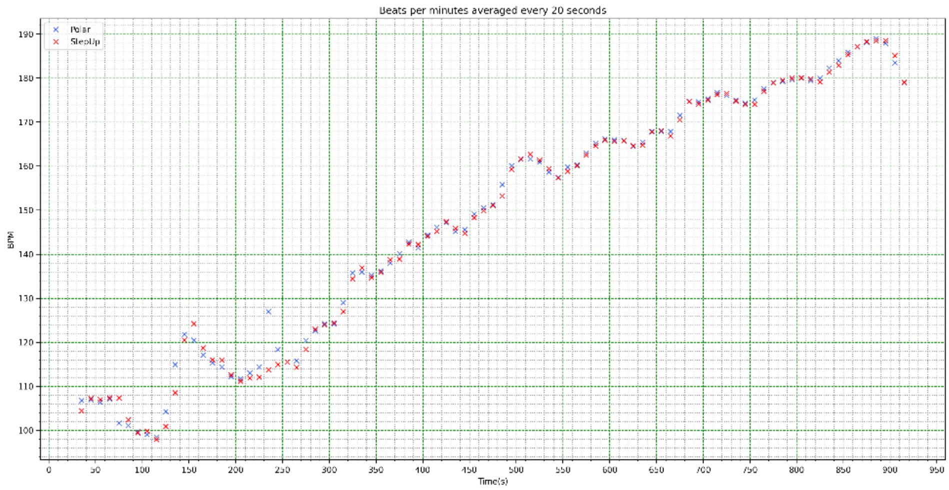
Participant #2: All titles are incorrect and should be replaced with; Beats per minute averaged every 10 seconds



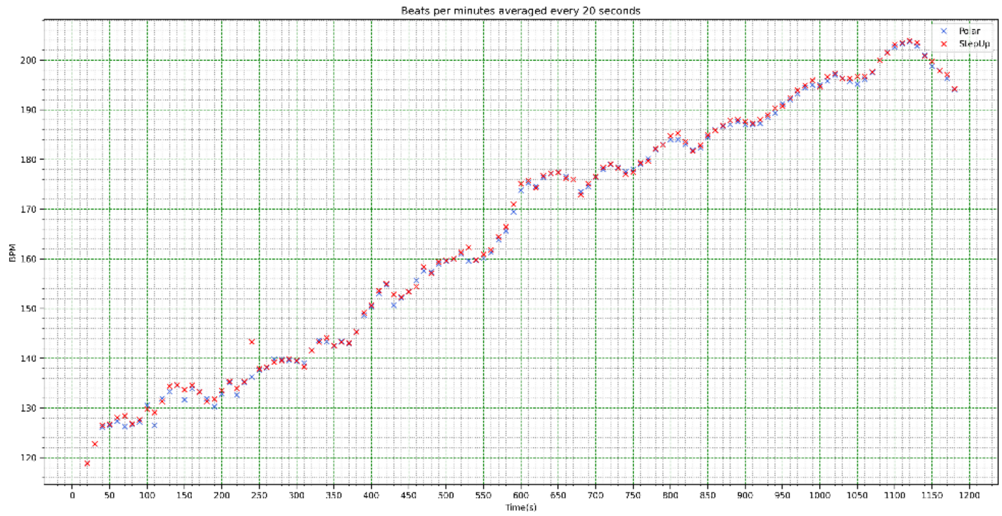
Participant #3



Participant #4

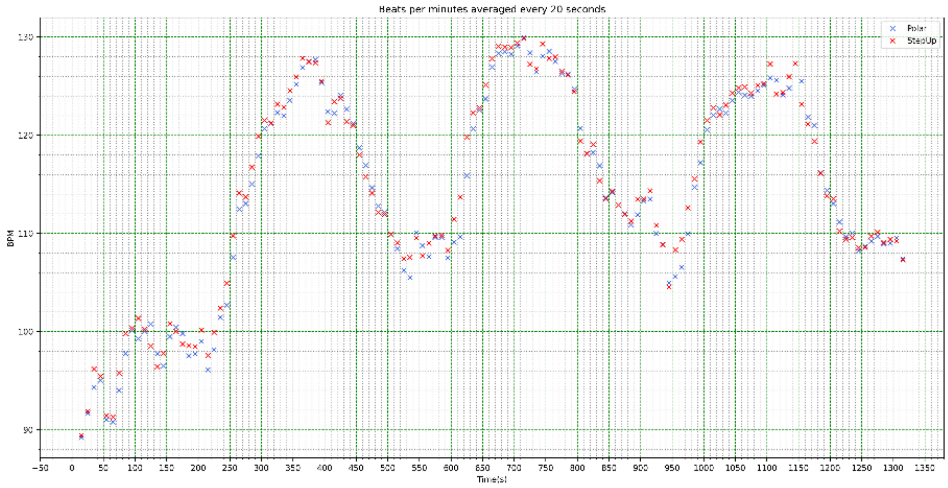


Participant #5

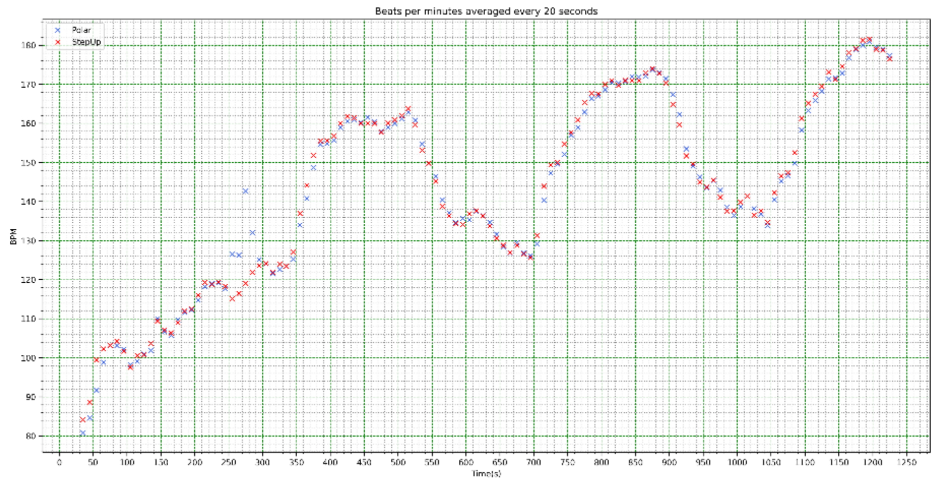


Participant #6

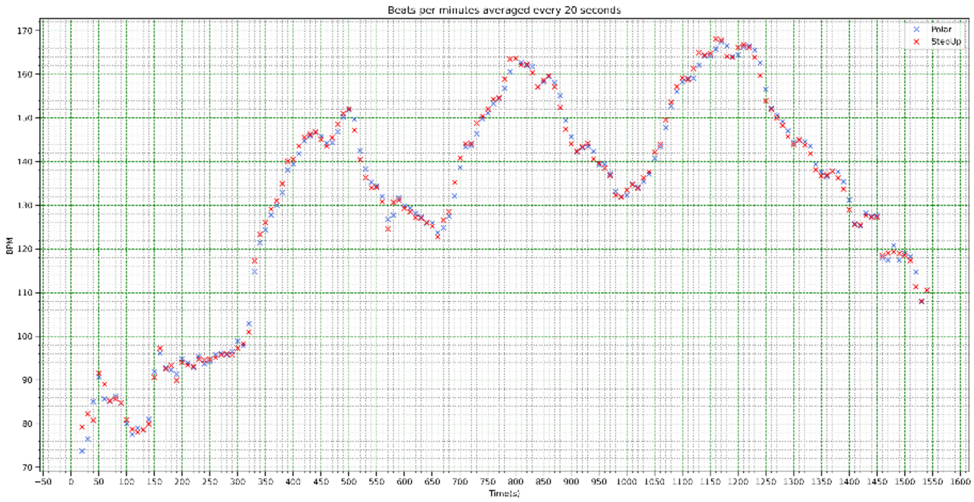
Attachment II: Data Plots down sampled 10 sec Interval



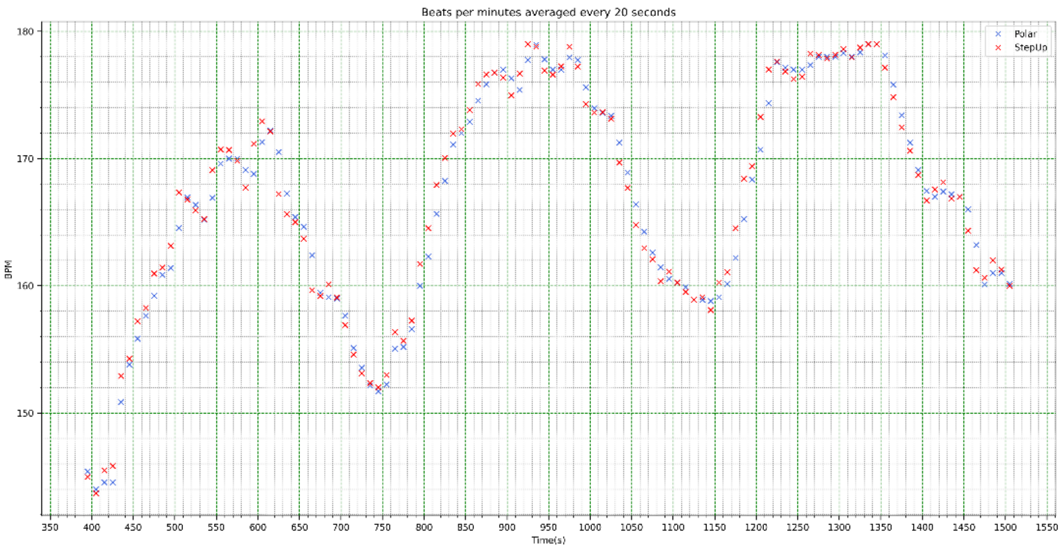
Participant #3, All titles are incorrect and should be replaced with; Beats per minute averaged every 10 seconds



Participant #4

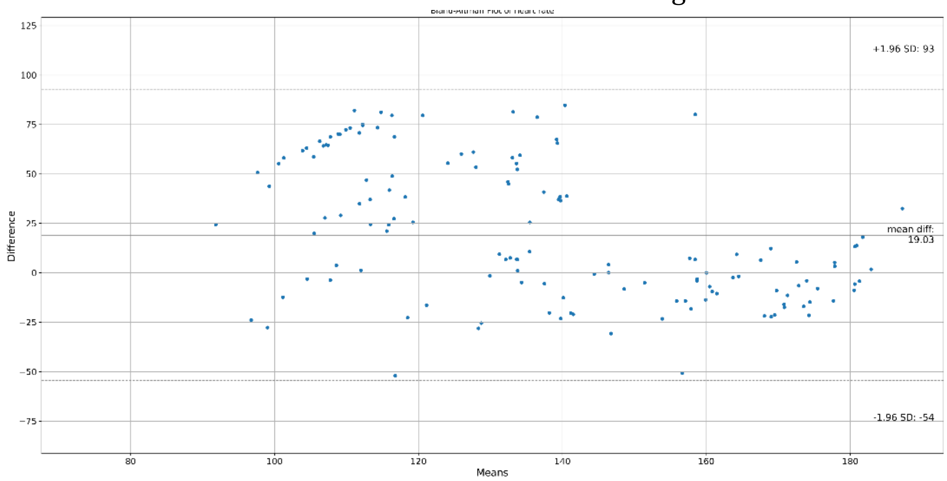


Participant #5

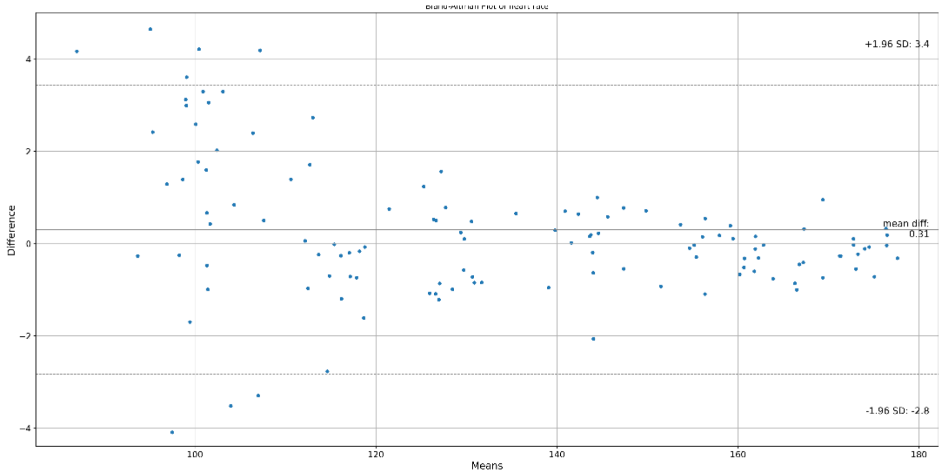


Participant #6

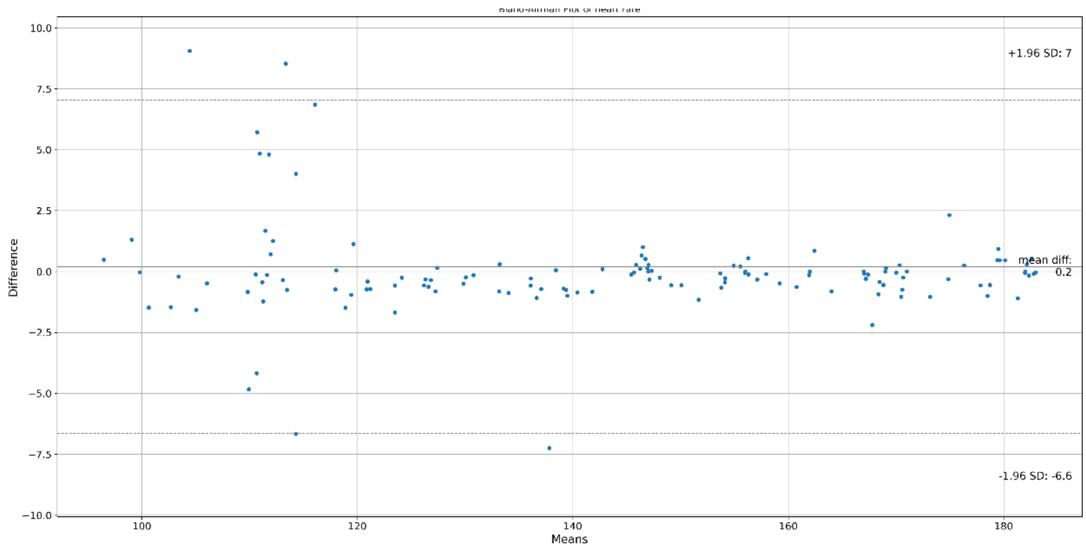
Attachment III: Bland Altman Plots Incremental testing



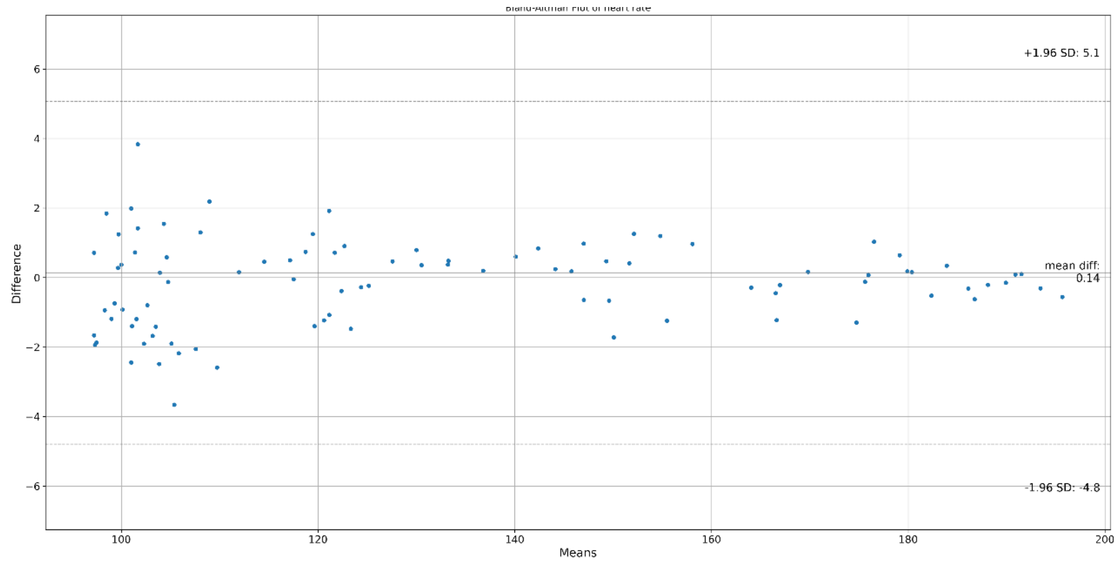
Participant #1: No used in data anlaysis



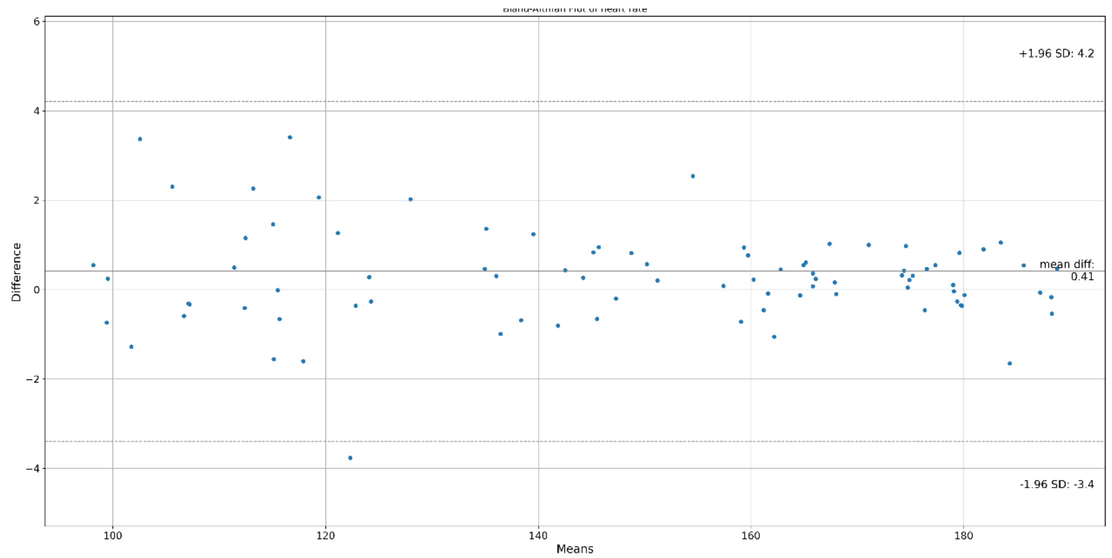
Participant #2



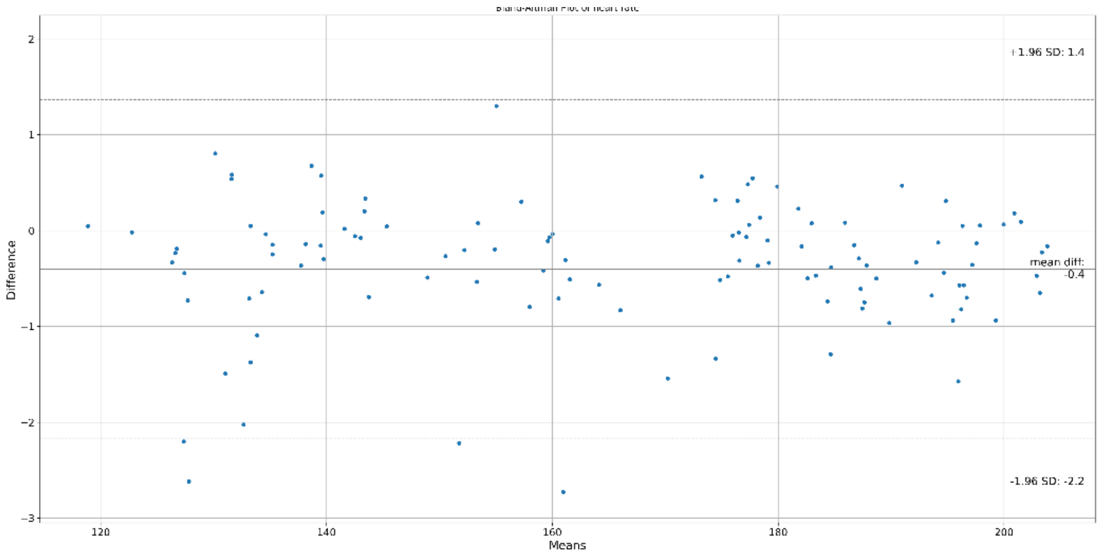
Participant #3



Participant #4

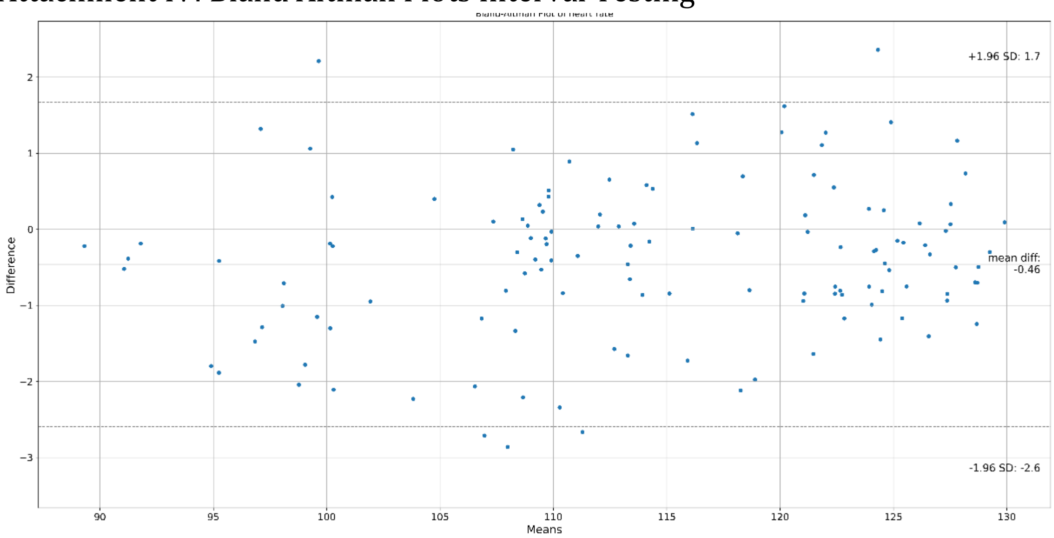


Participant #5

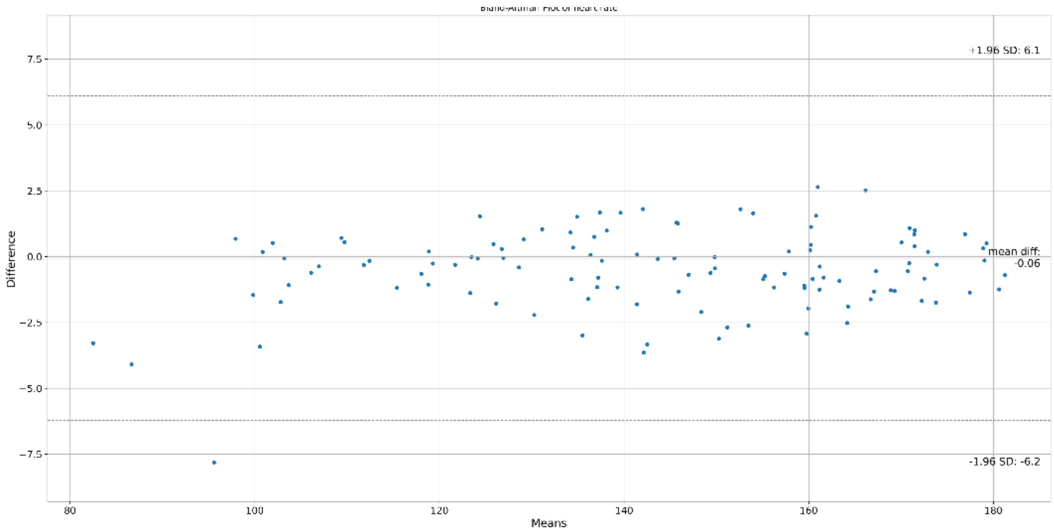


Participant #6

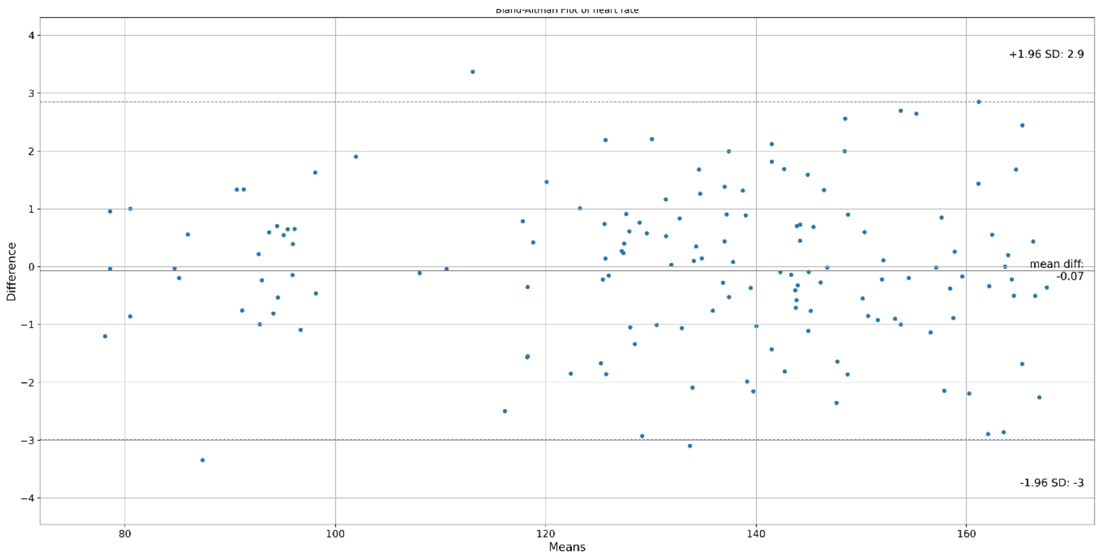
Attachment IV: Bland Altman Plots Interval Testing



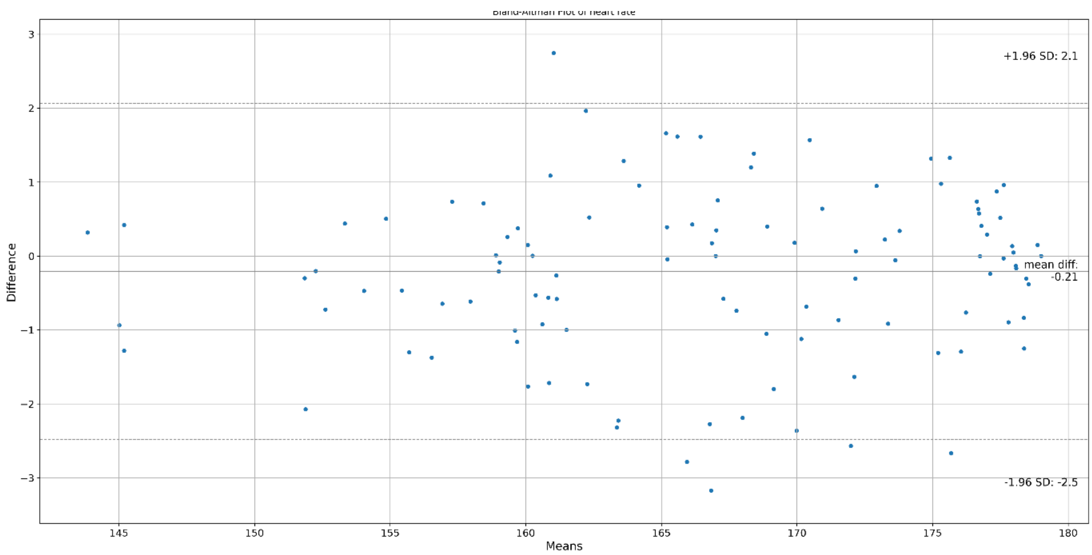
Participant #3



Participant #4

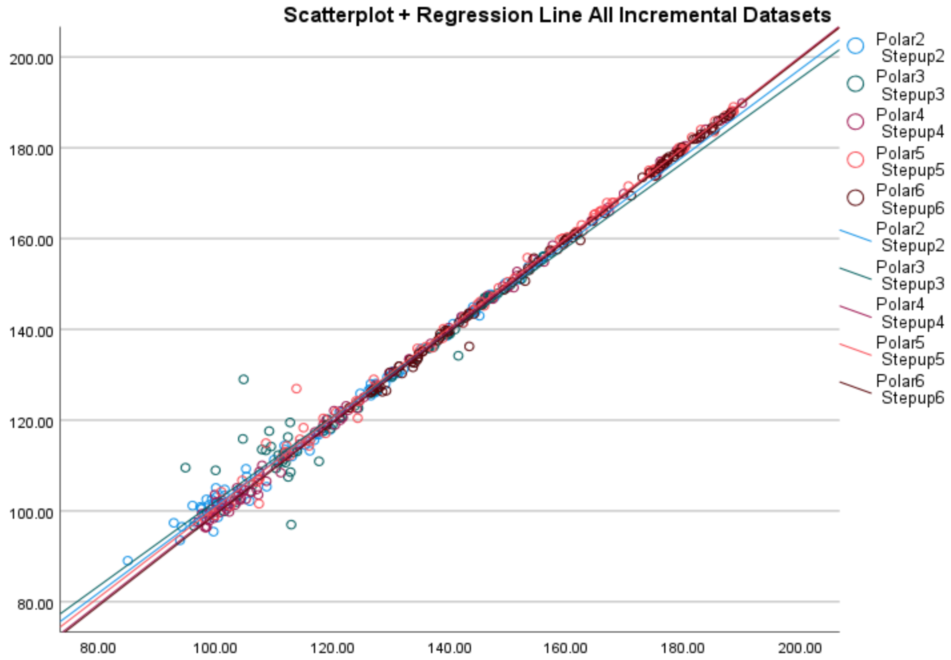


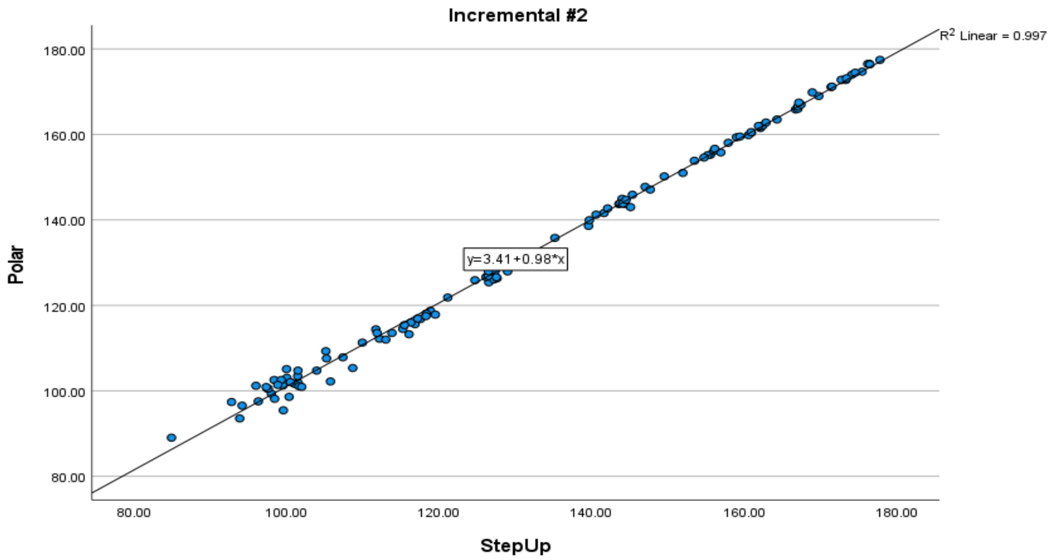
Participant #5

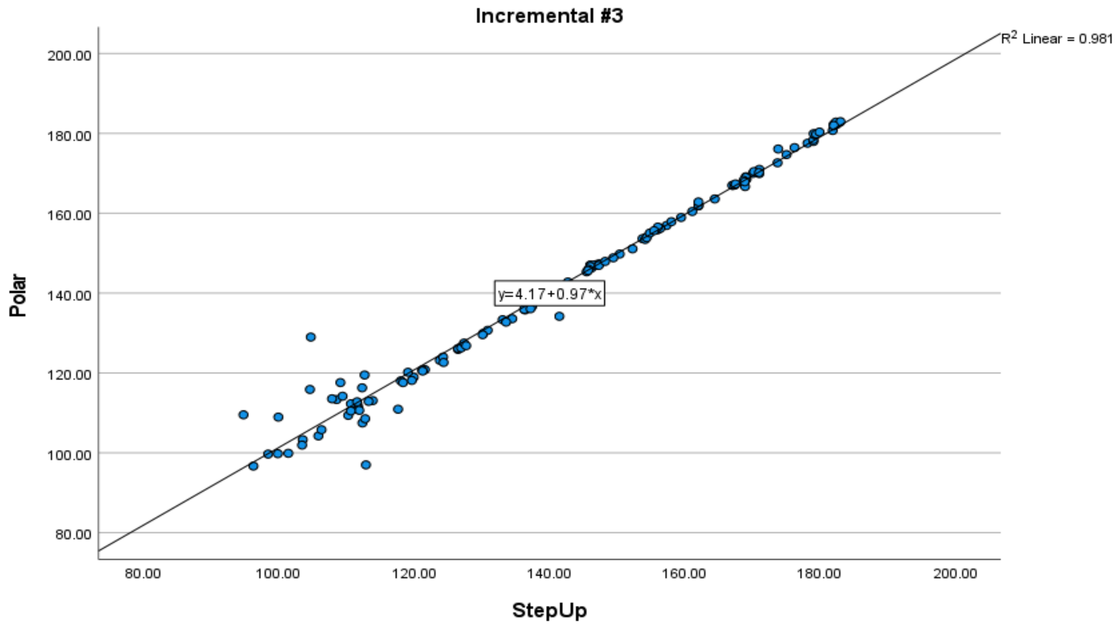


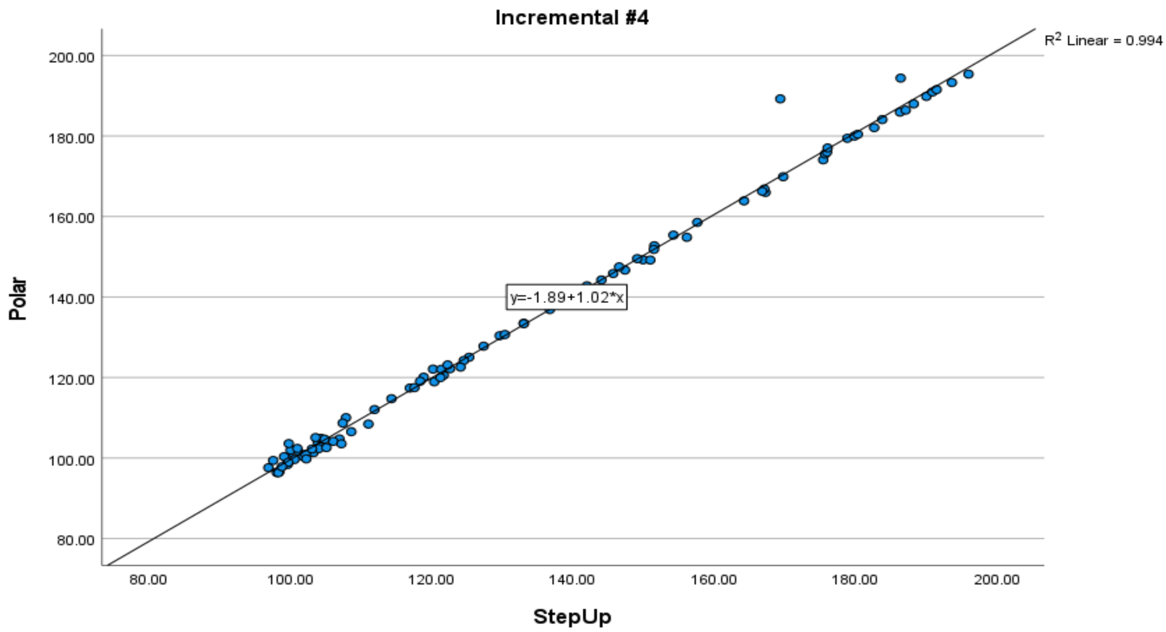
Participant #6

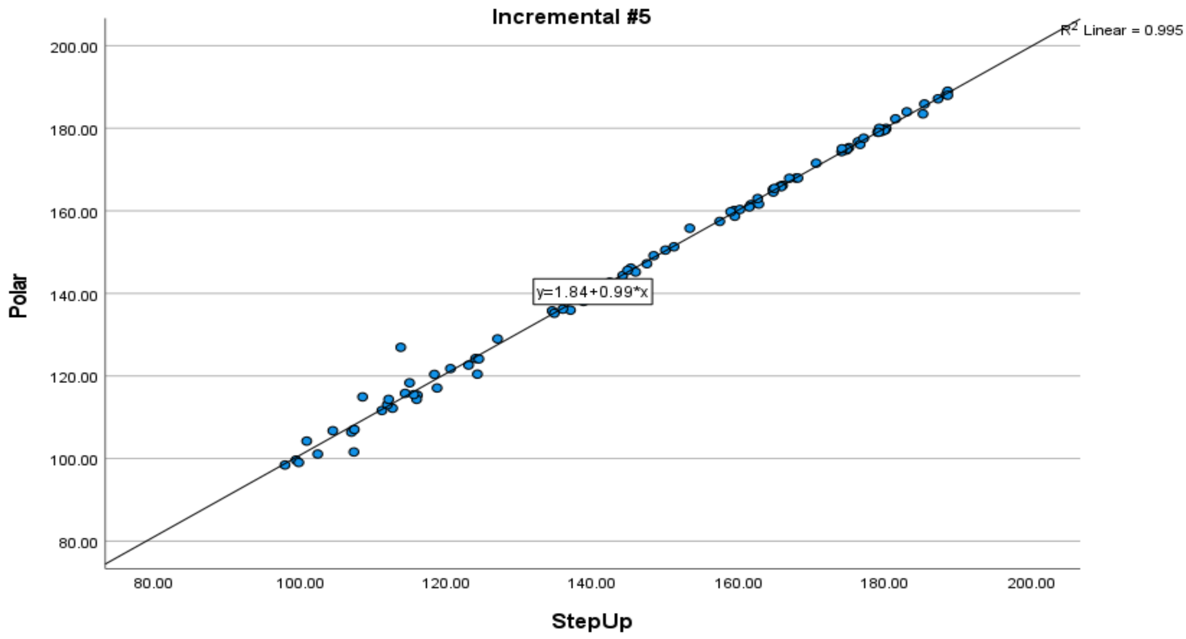
Attachment V: Scatterplots and Regression Lines Incremental Testing

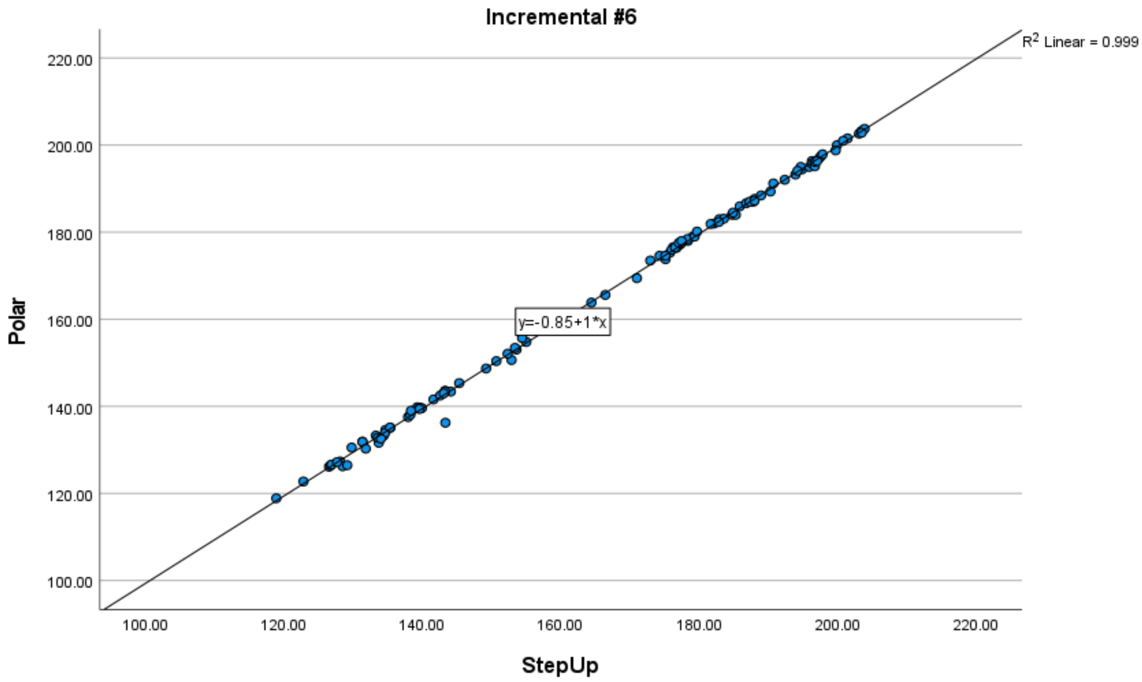




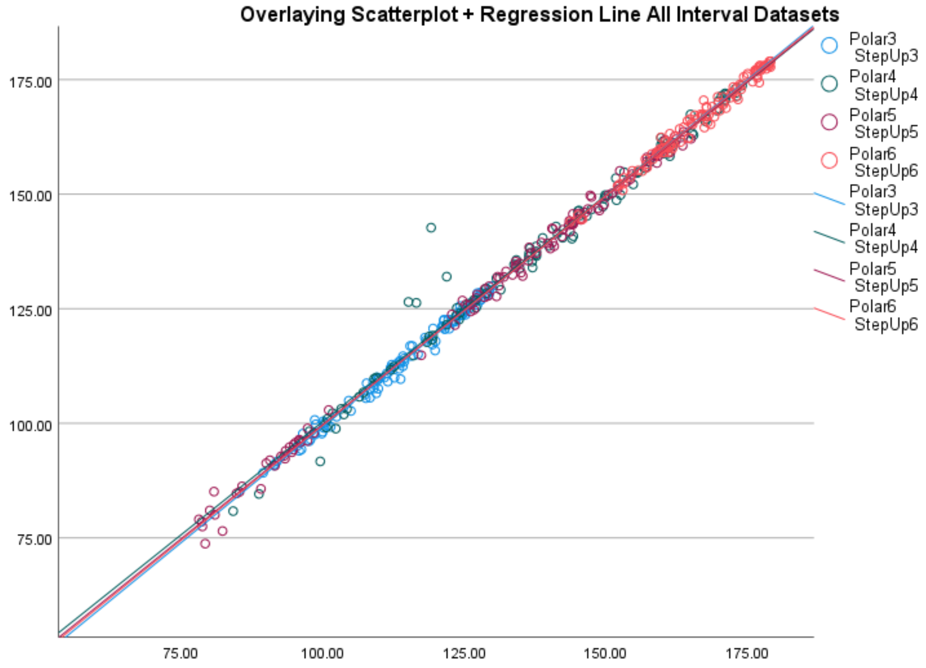

Incremental #3
R2 Linear = 0.981
y=4.17+0.97*x
Polar
StepUp
80.00
100.00
120.00
140.00
160.00
180.00
200.00

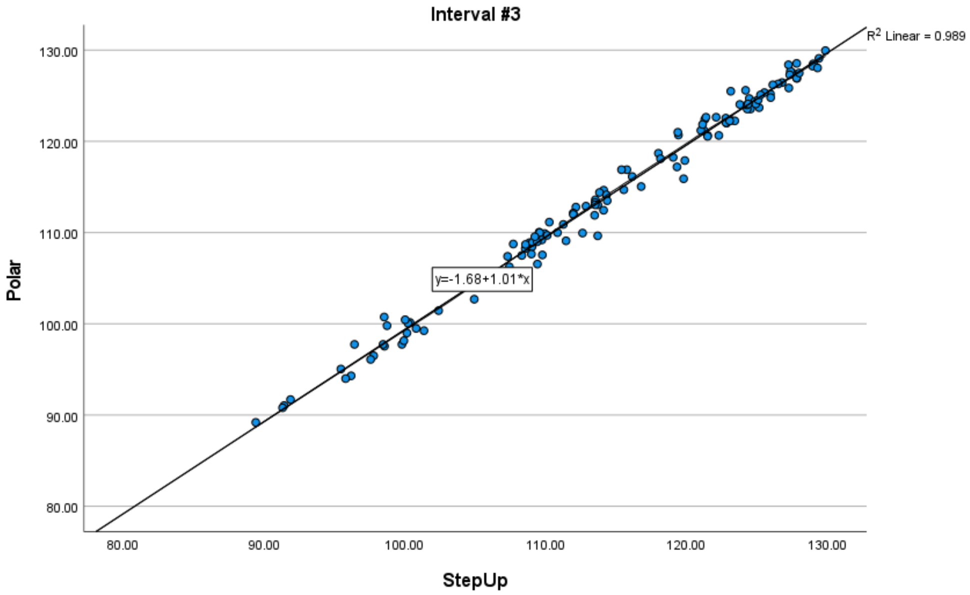

Incremental #4
R2 Linear = 0.994
y=-1.89+1.02*x
Polar
StepUp
80.00
100.00
120.00
140.00
160.00
180.00
200.00

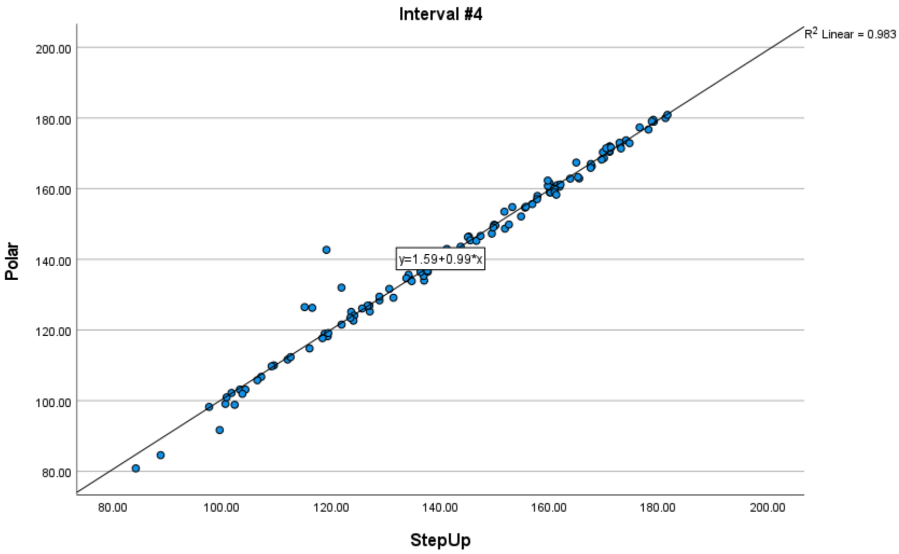

Incremental #5
R2 Linear = 0.995
y=1.84+0.99*x
Polar
StepUp
200.00
180.00
160.00
140.00
120.00
100.00
80.00
80.00
100.00
120.00
140.00
160.00
180.00
200.00

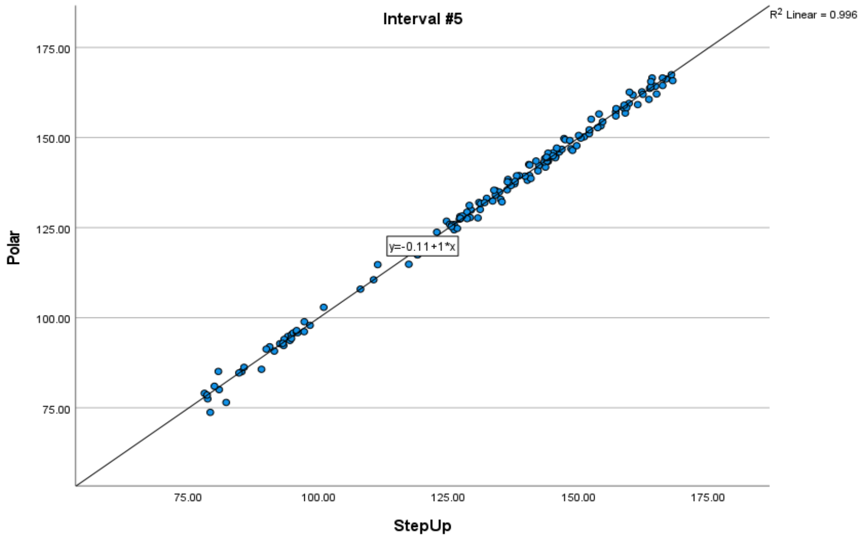

Incremental #6
R2 Linear = 0.999
y=-0.85+1*x
Polar
StepUp
220.00
200.00
180.00
160.00
140.00
120.00
100.00
100.00
120.00
140.00
160.00
180.00
200.00
220.00

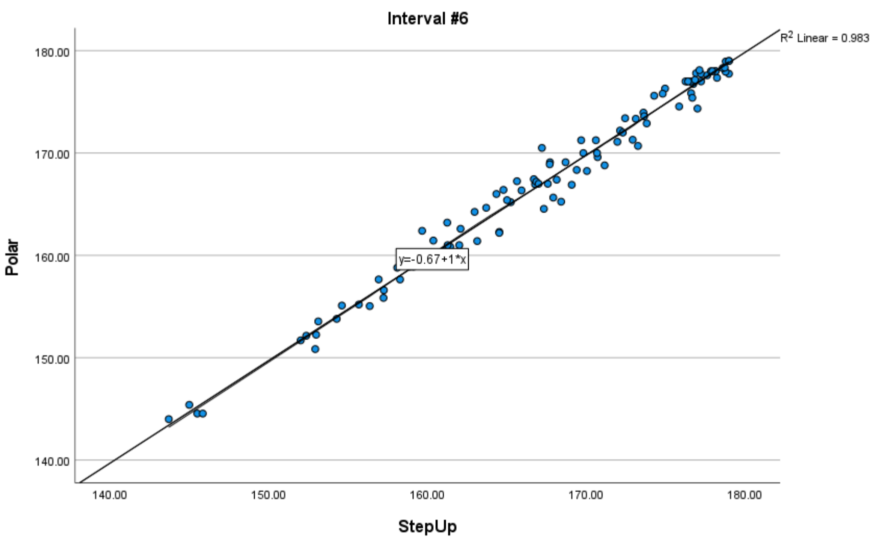
Attachment VI: Scatterplots and Regression Lines Interval Testing






Interval #4
R2 Linear = 0.983
y=1.59+0.99*x
Polar
StepUp


Interval #5
R2 Linear = 0.996
y=-0.11+1*x
Polar
StepUp


Interval #6
R2 Linear = 0.983
y=-0.67+1*x
Polar
StepUp

Attachment VII: Reliability Testing

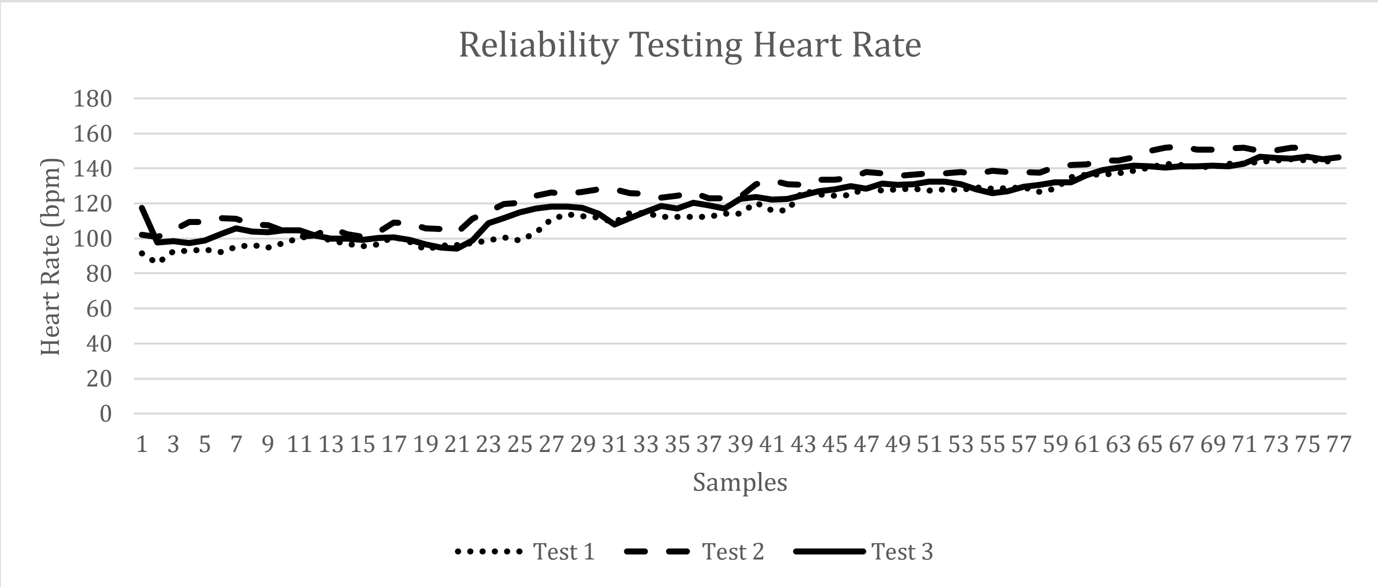


Table 8: Intraclass Correlation Coefficient Heart Rate StepUp

Intraclass Correlation		95% Confidence Interval	
		Lower Bound	Upper Bound
Average Measures	.948	.724	.979

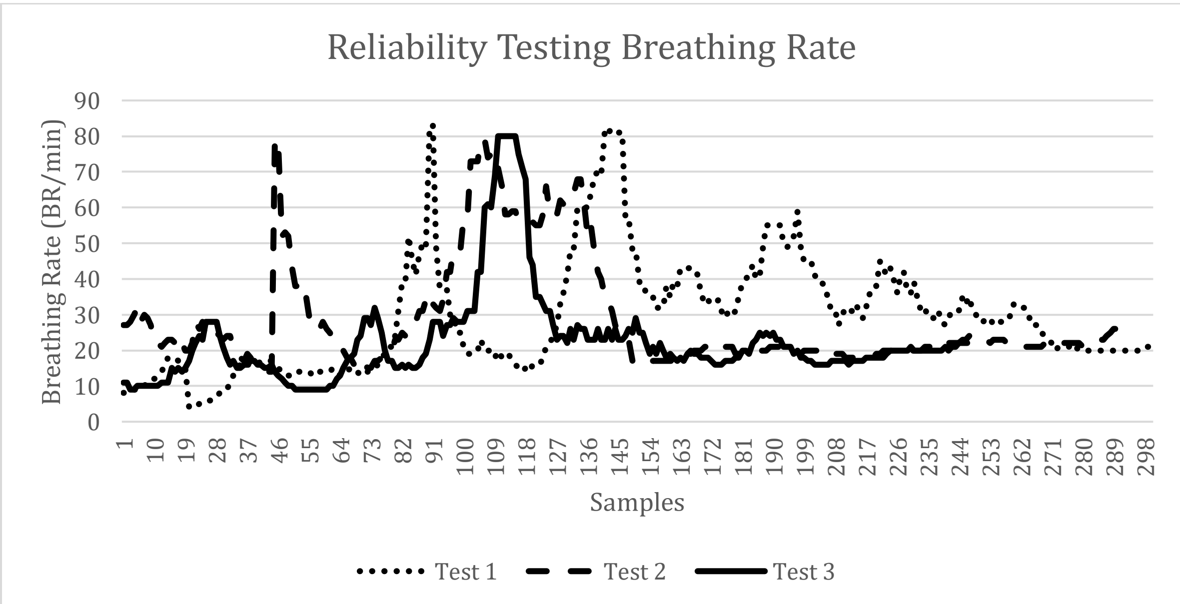
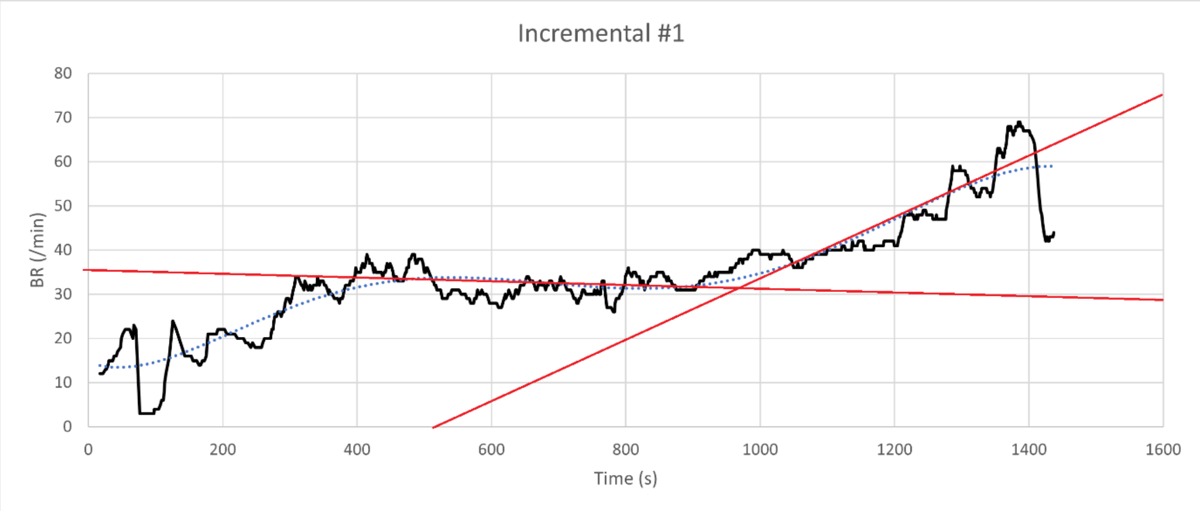
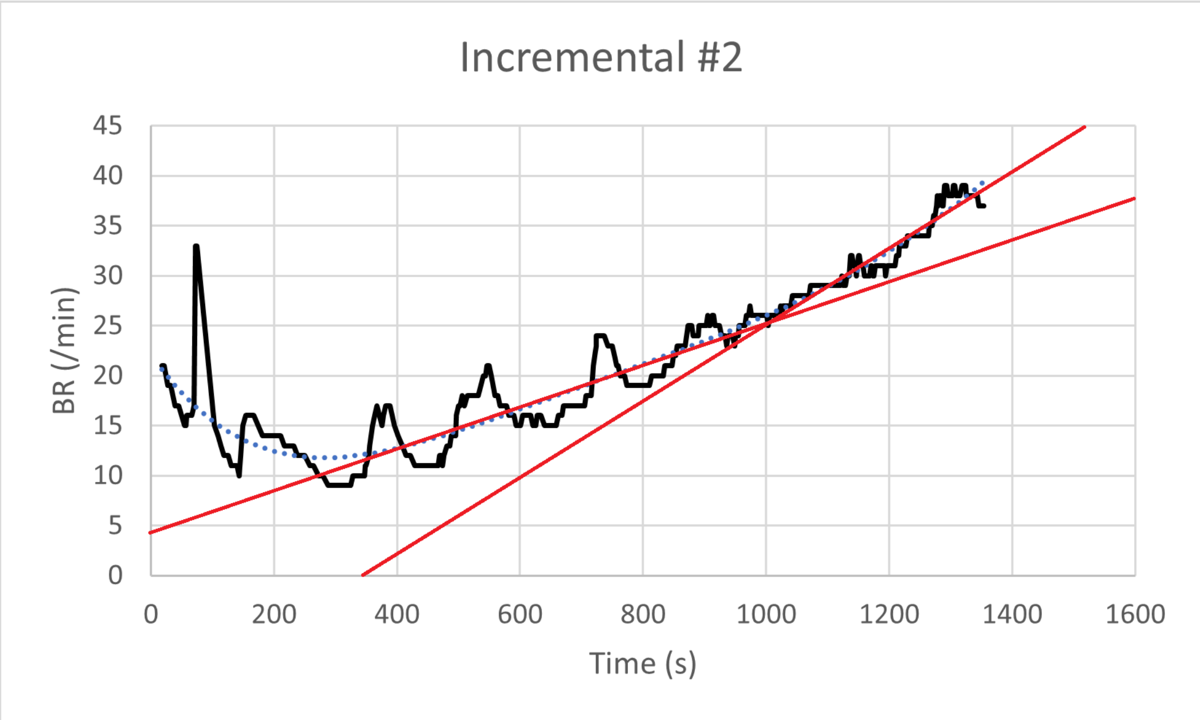


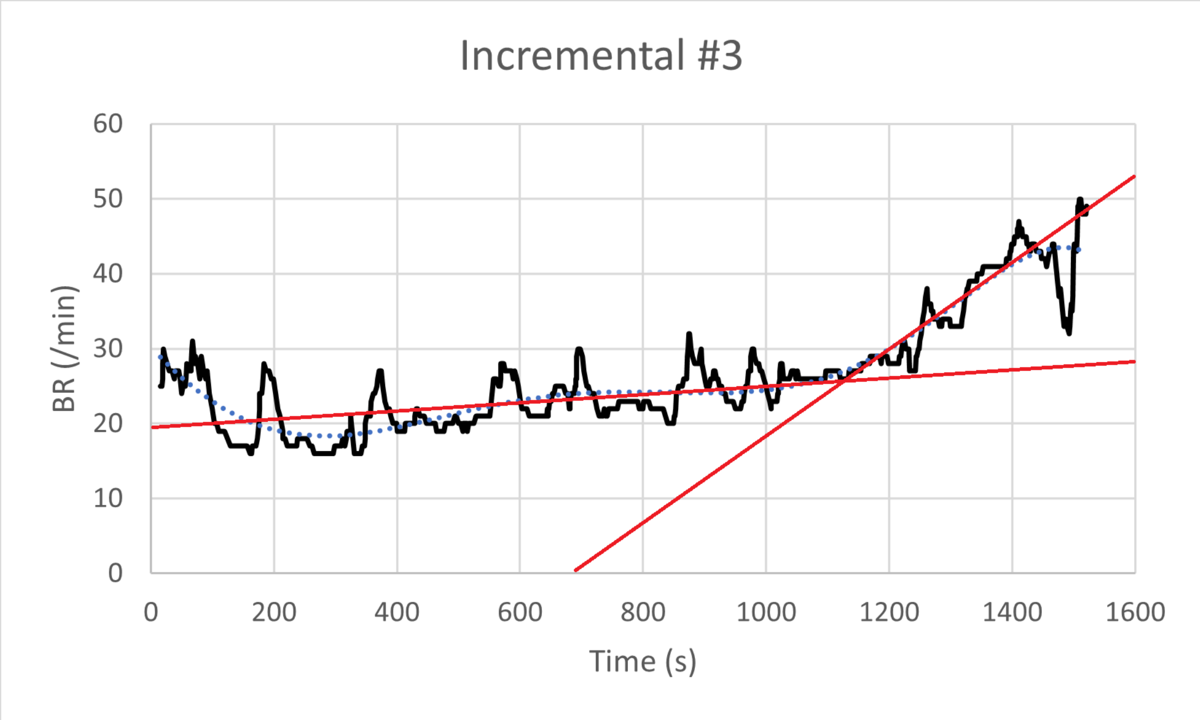
Table 9: Intraclass Correlation Coefficient Breathing Rate StepUp

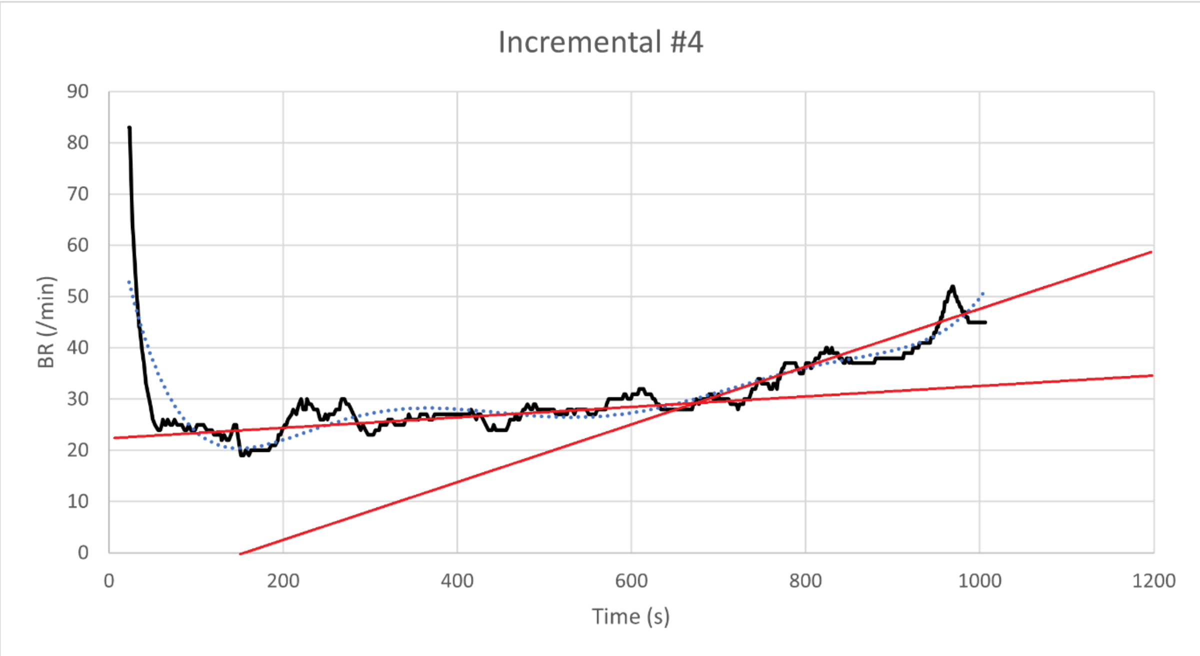
Intraclass Correlation		95% Confidence Interval	
		Lower Bound	Upper Bound
Average Measures	.295	.136	.431

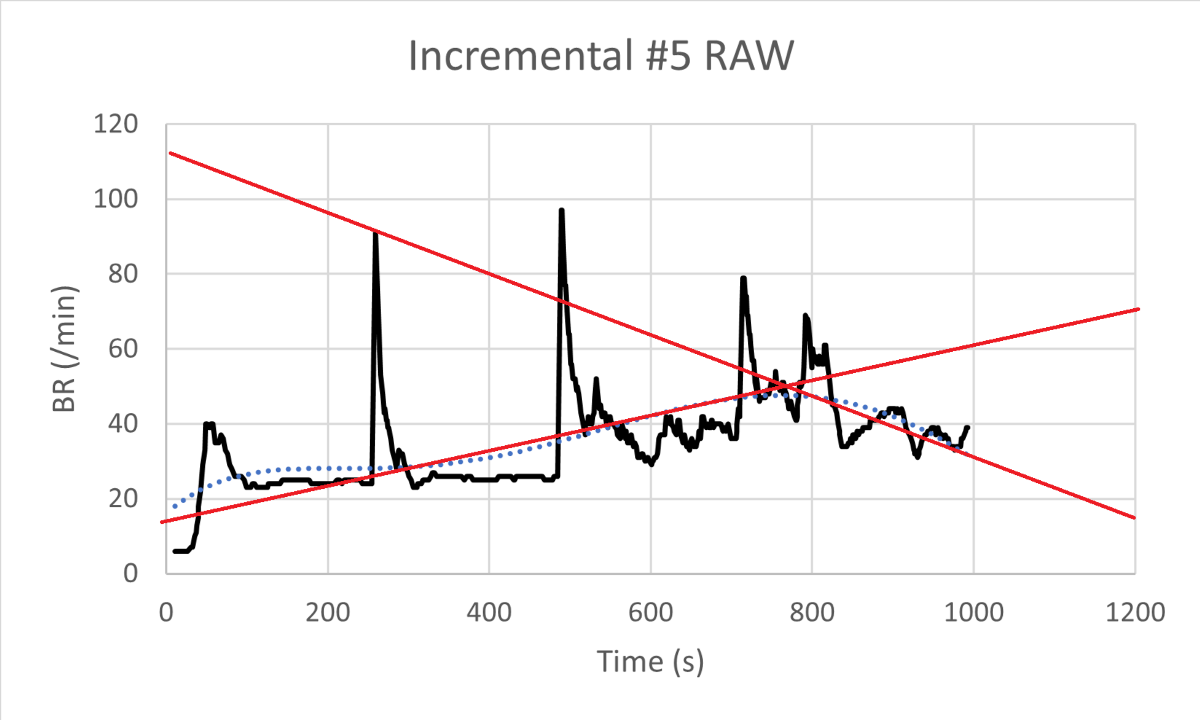
Attachment VIII: Calculating **VT1. VT2**

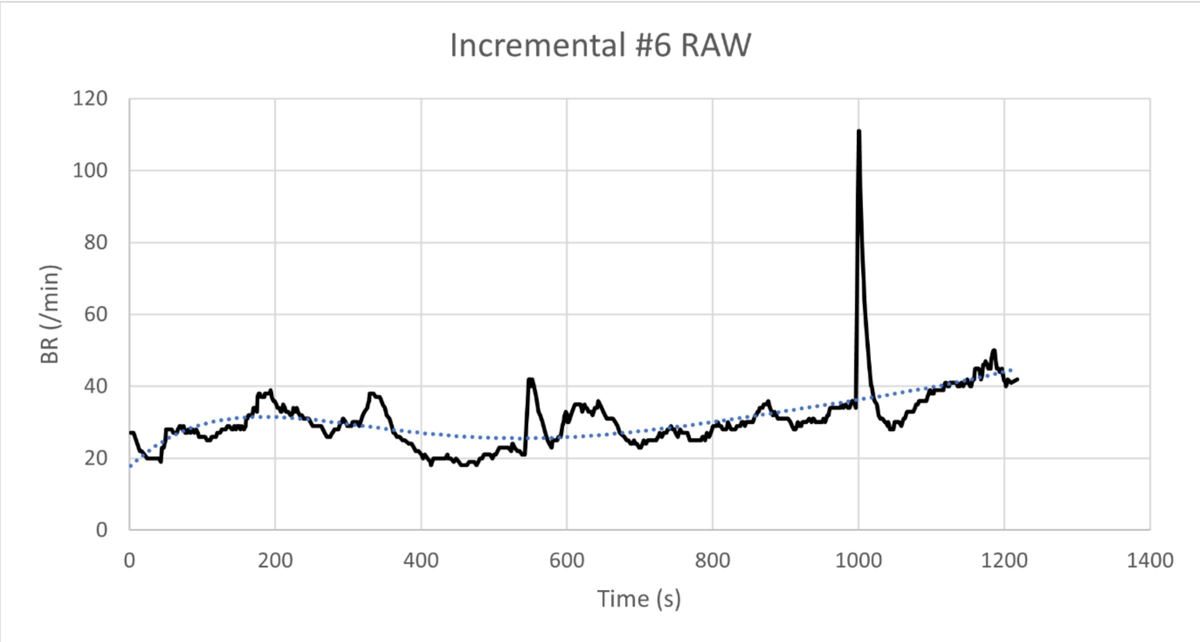




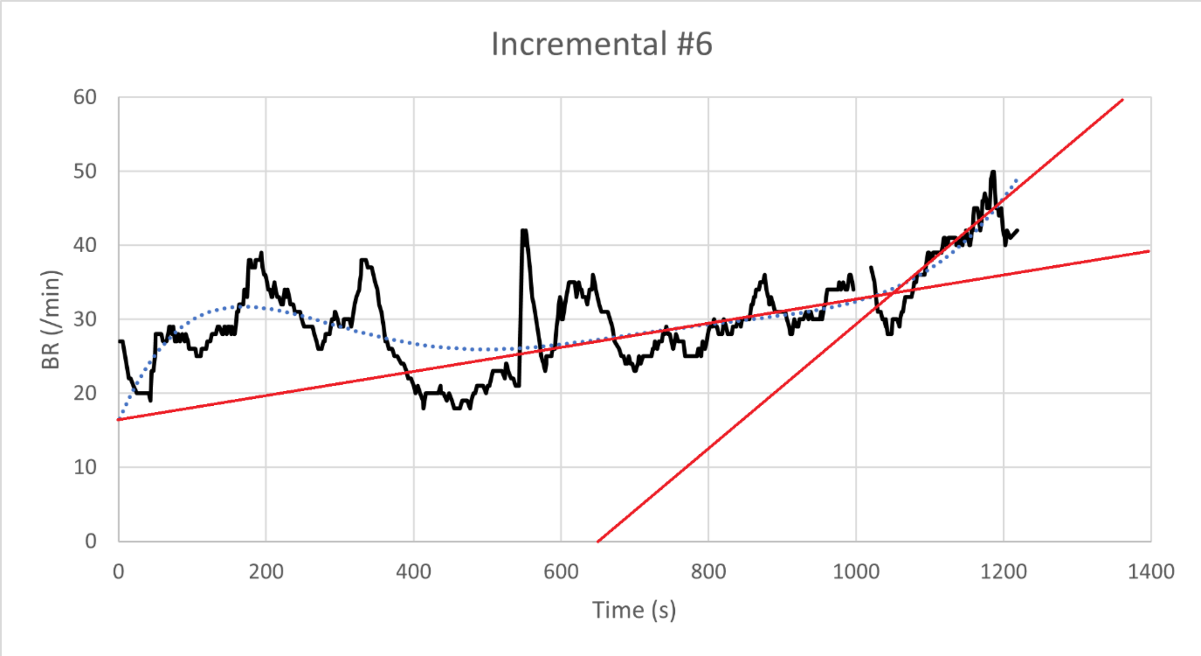

Incremental #3
BR (/min)
0
10
20
30
40
50
60
0
200
400
600
800
1000
1200
1400
1600
Time (s)

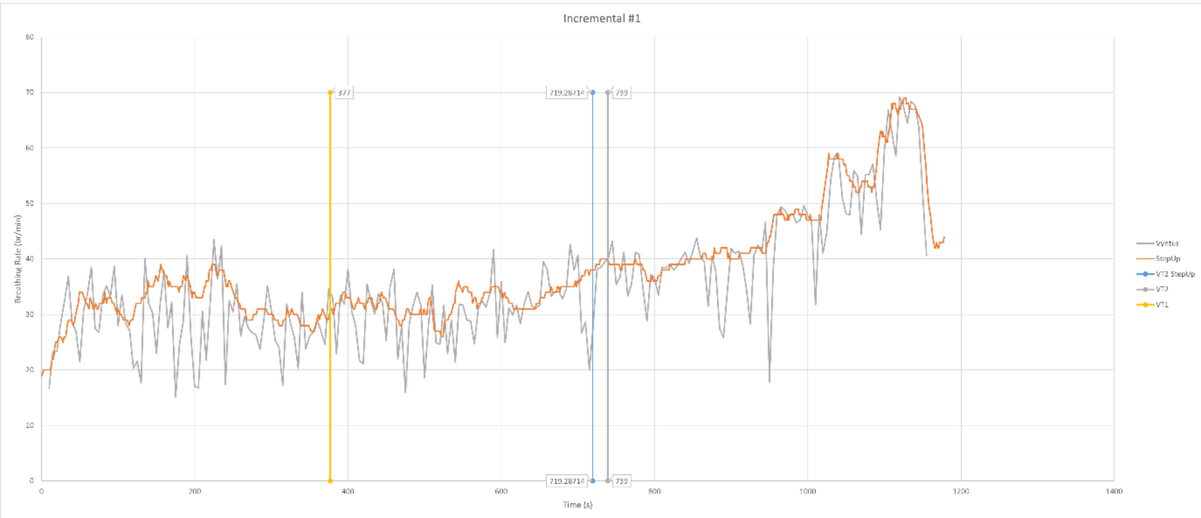

Incremental #4
BR (/min)
0
10
20
30
40
50
60
70
80
90
0
200
400
600
800
1000
1200
Time (s)

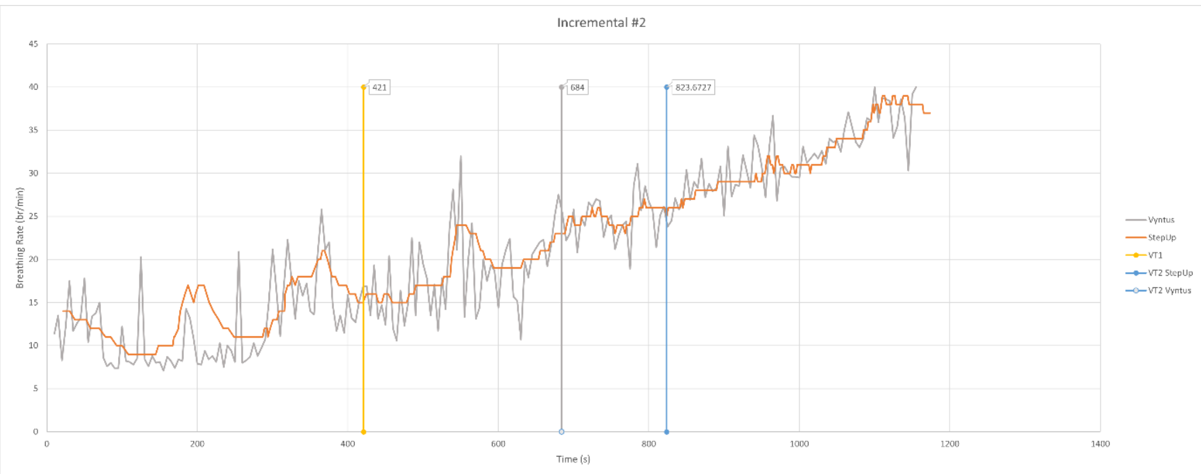


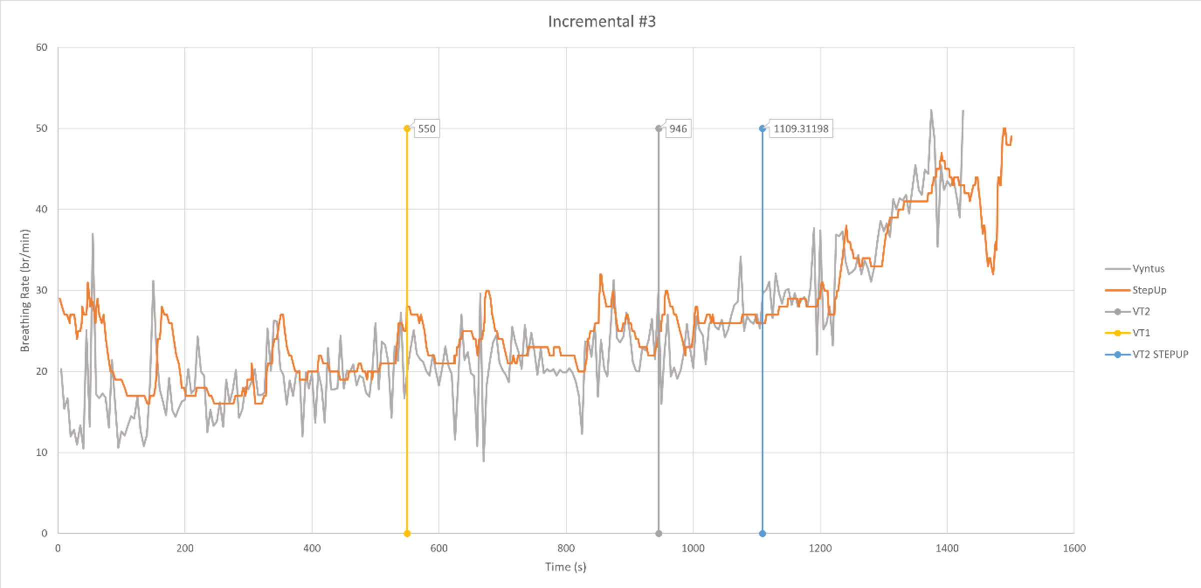


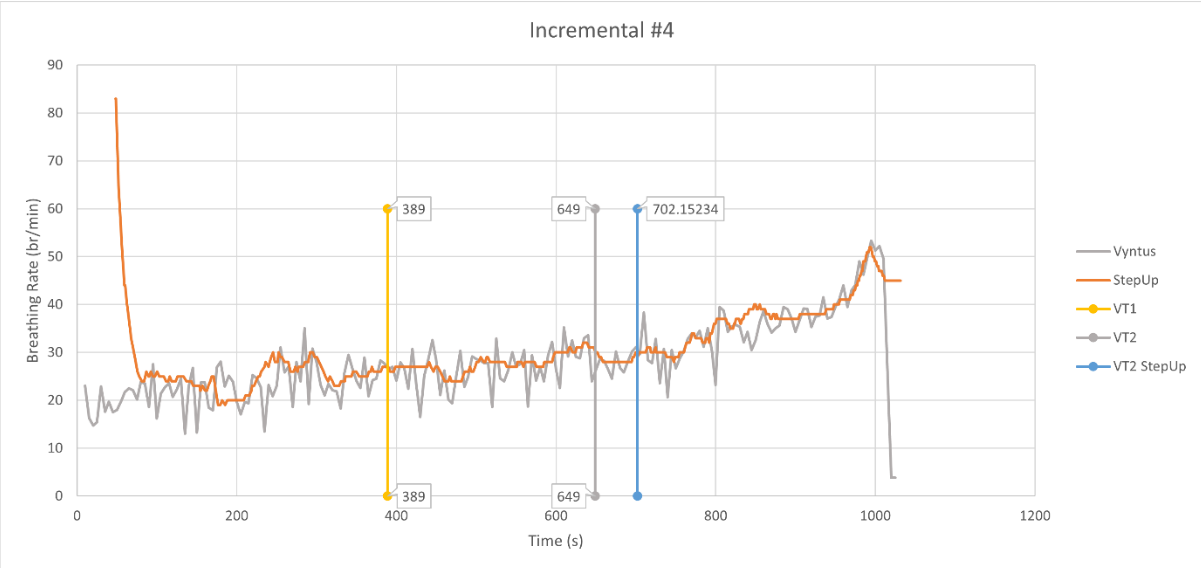
Incremental #6 Raw BR Peak at t = +-1000 was filtered due to interferance with trendline and perspective of plot

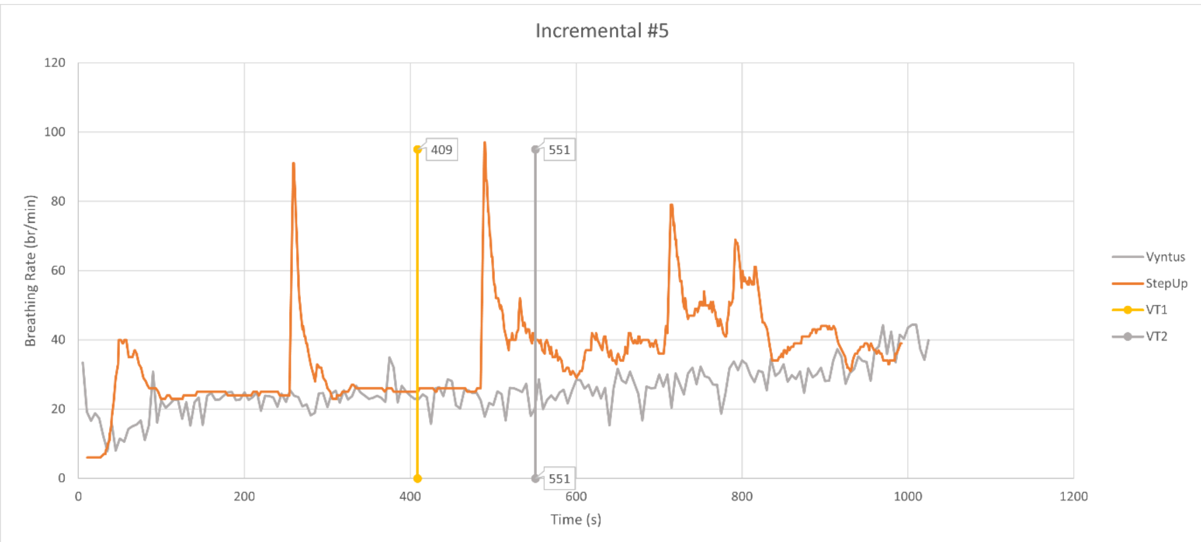

Incremental #6
BR (/min)
60
50
40
30
20
10
0
0
200
400
600
800
1000
1200
1400
Time (s)

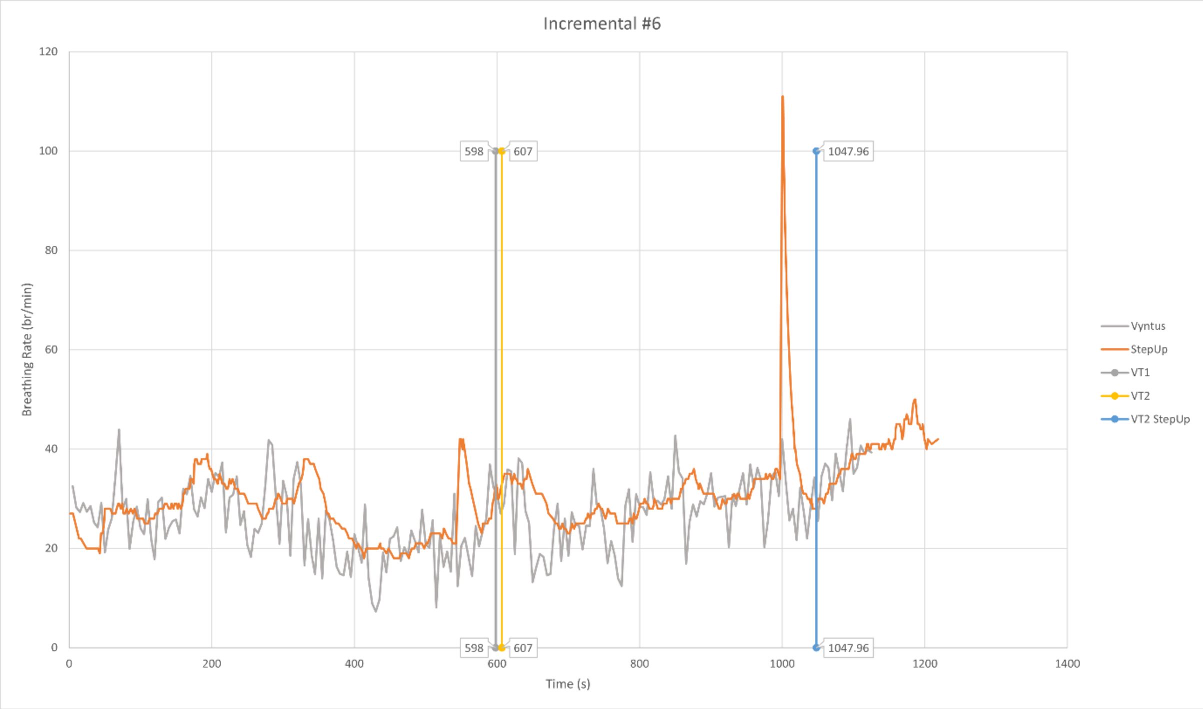

Incremental #1
Breathing Rate (br/min)
377
719.28714
739
0
200
400
600
800
1000
1200
1400
Time (s)
Vyntus
StepUp
VT2 StepUp
VT2
VT1

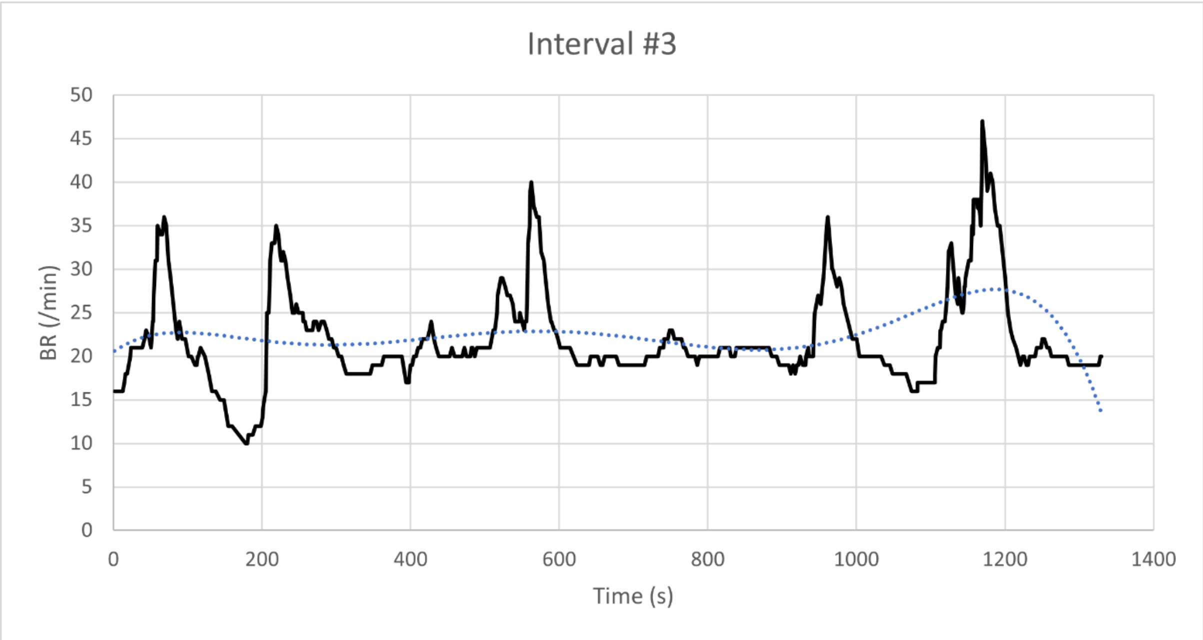

Incremental #2
Breathing Rate (br/min)
45
40
35
30
25
20
15
10
5
0
421
684
823.6727
0
200
400
600
800
1000
1200
1400
Time (s)
Vyntus
StepUp
VT1
VT2 StepUp
VT2 Vyntus

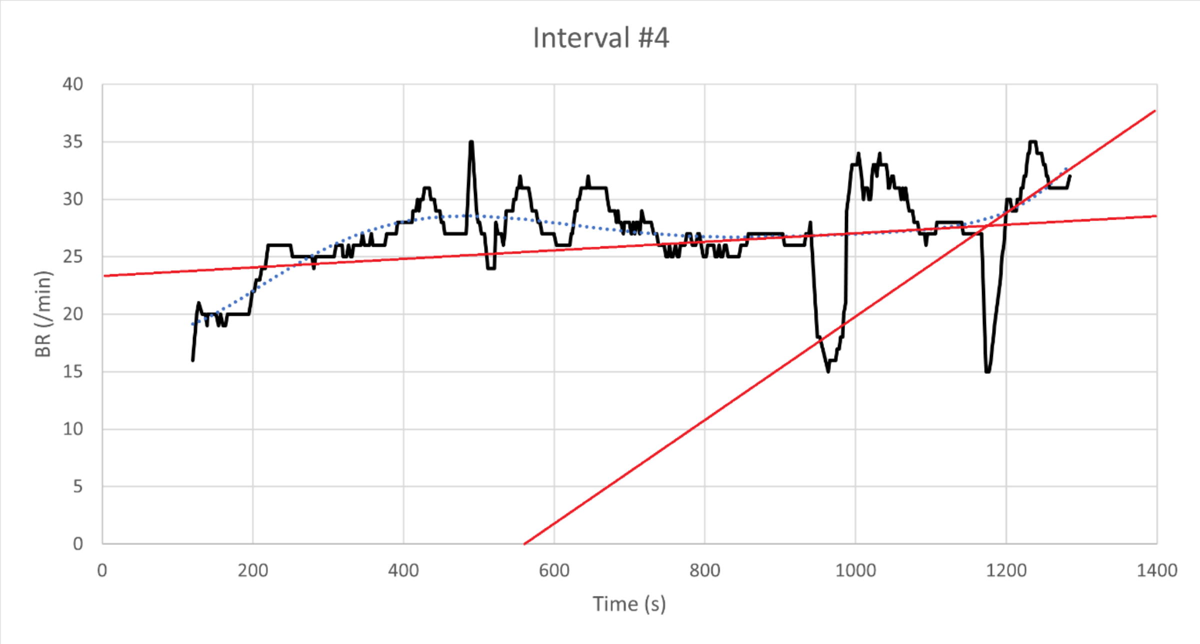

Incremental #3
Breathing Rate (br/min)
Time (s)
550
946
1109.31198
Vyntus
StepUp
VT2
VT1
VT2 STEPUP

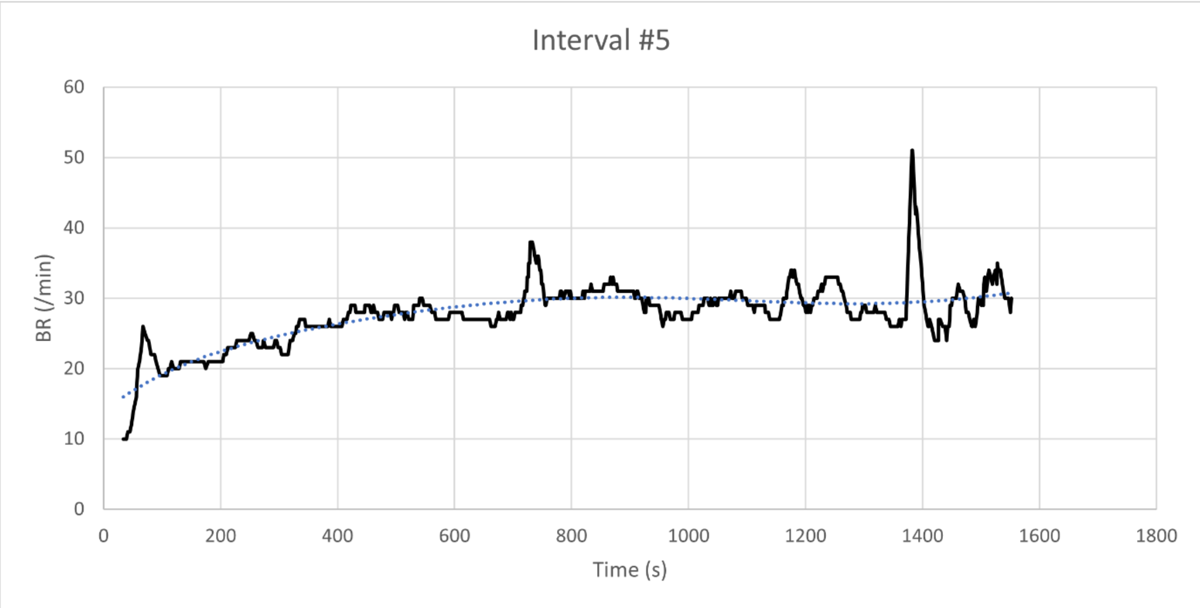

Incremental #4
Breathing Rate (br/min)
Time (s)
389
649
702.15234
Vyntus
StepUp
VT1
VT2
VT2 StepUp

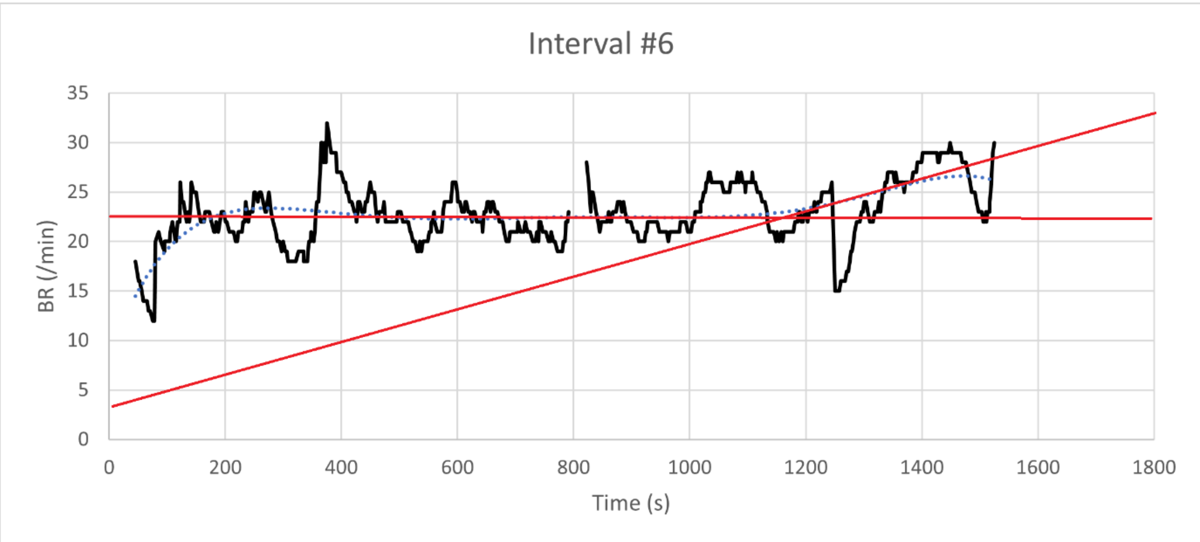

Incremental #5
Breathing Rate (br/min)
Time (s)
409
551
Vyntus
StepUp
VT1
VT2

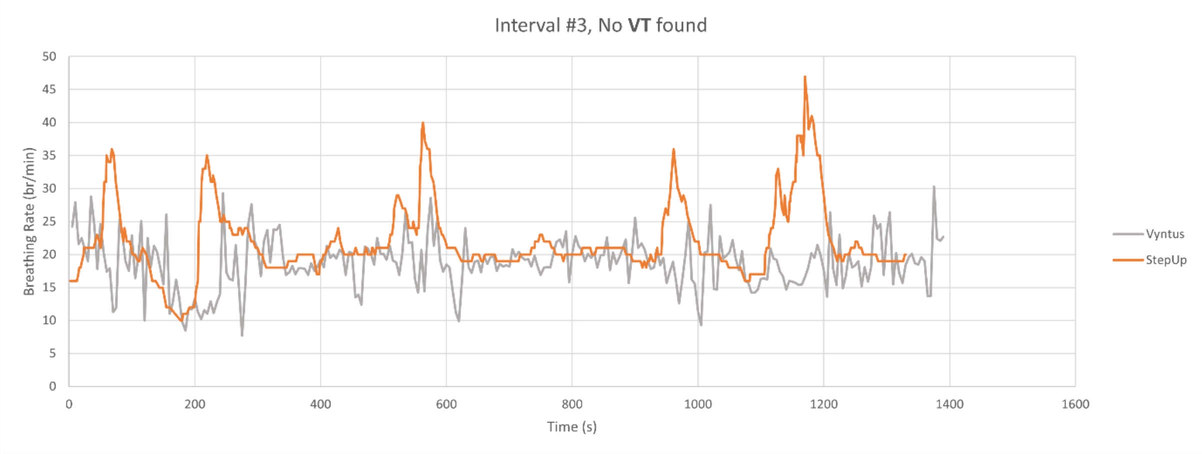

Incremental #6
Breathing Rate (br/min)
Time (s)
Vyntus
StepUp
VT1
VT2
VT2 StepUp
598
607
1047.96
0
20
40
60
80
100
120
0
200
400
600
800
1000
1200
1400


Interval #3
BR (/min)
Time (s)
0
5
10
15
20
25
30
35
40
45
50
0
200
400
600
800
1000
1200
1400

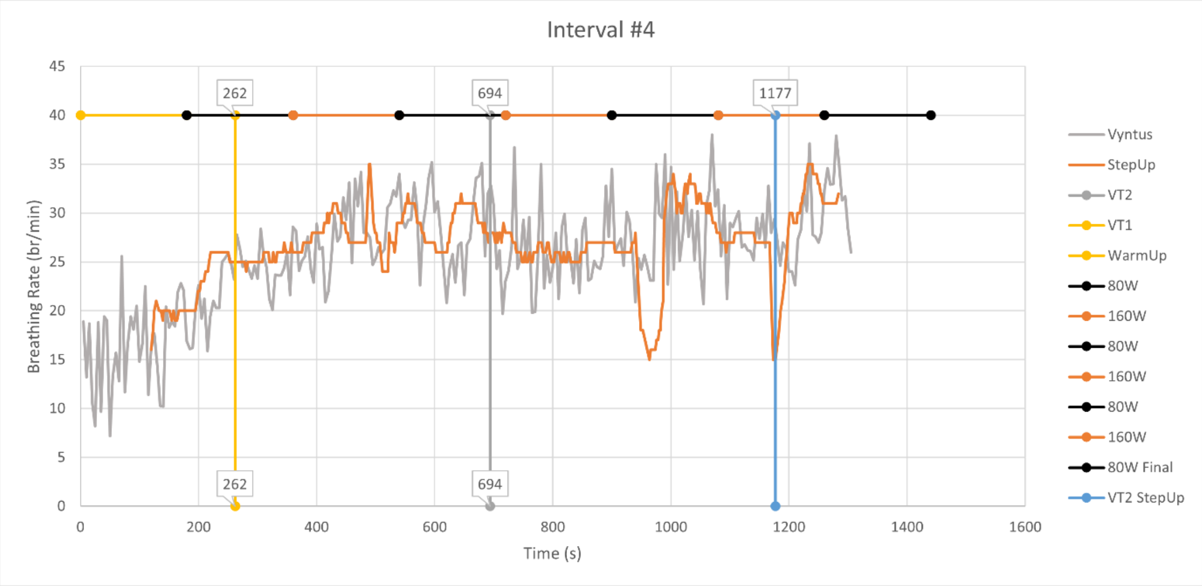

Interval #4
40
35
30
25
20
15
10
5
0
0
200
400
600
800
1000
1200
1400
BR (/min)
Time (s)


Interval #5
60
50
40
30
20
10
0
0
200
400
600
800
1000
1200
1400
1600
1800
BR (/min)
Time (s)

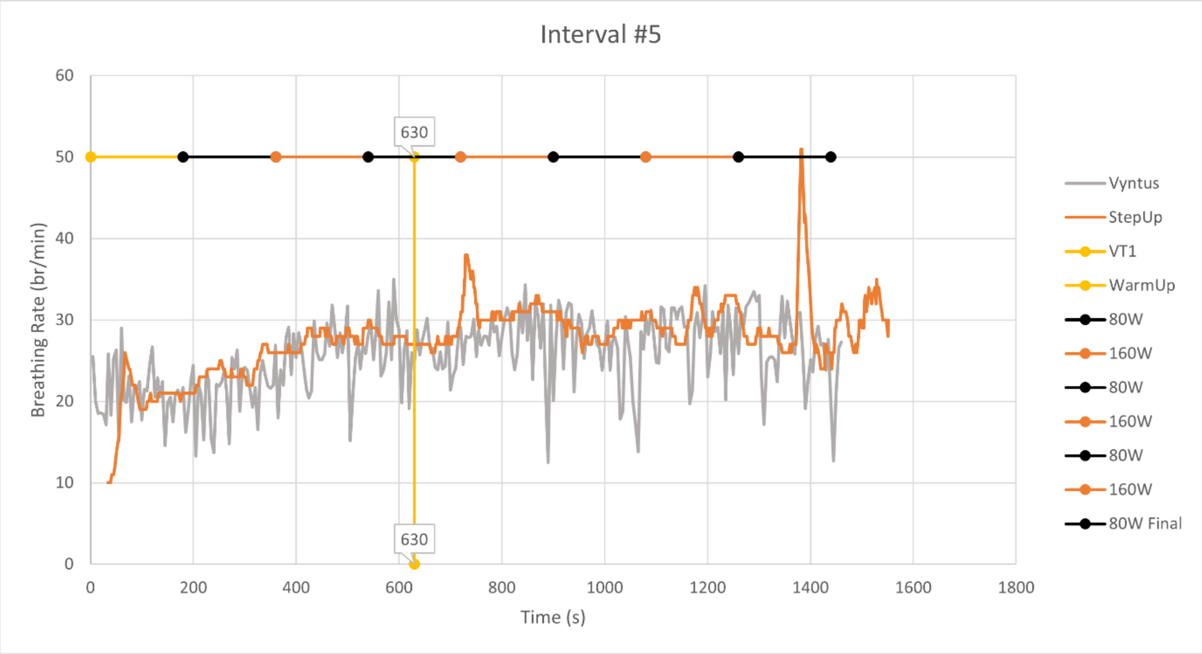

Interval #6
35
30
25
20
15
10
5
0
0
200
400
600
800
1000
1200
1400
1600
1800
BR (/min)
Time (s)



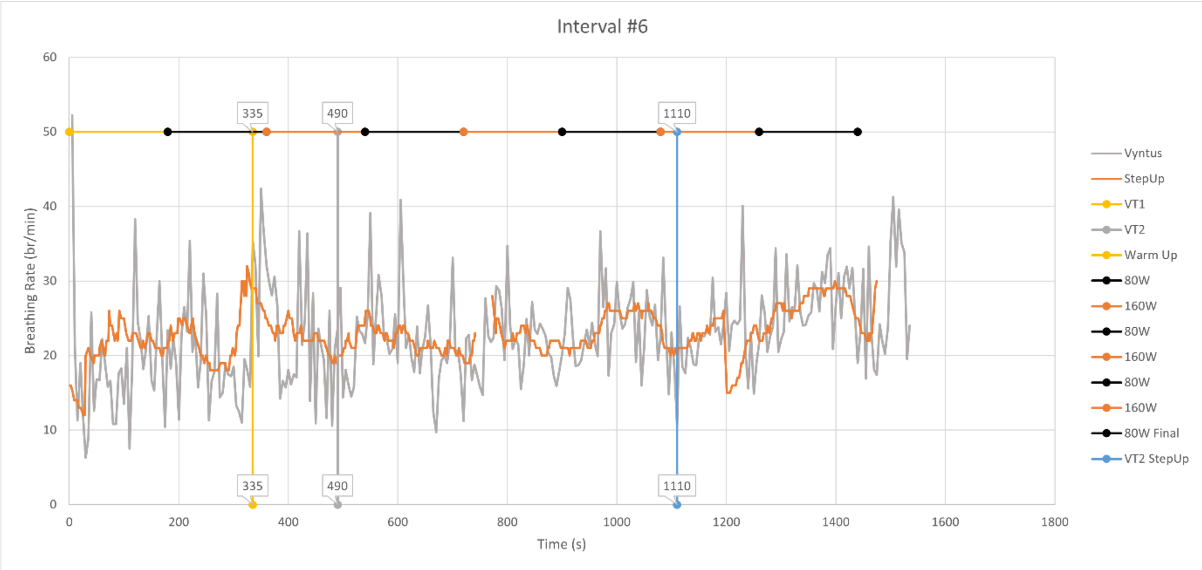
Interval #3, No **VT** found
Breathing Rate (br/min)
Time (s)
Vyntus
StepUp



Interval #4
262
694
1177
Breathing Rate (br/min)
Time (s)
Vyntus
StepUp
VT2
VT1
WarmUp
80W
160W
80W
160W
80W
160W
80W Final
VT2 StepUp



Interval #5
630
Breathing Rate (br/min)
Time (s)
Vyntus
StepUp
VT1
WarmUp
80W
160W
80W
160W
80W
160W
80W Final



Attachment IX: Talk Test

- Ongoing research confirms that the Talk Test is a valuable tool for monitoring (and controlling) exercise intensity.
- Studies in a variety of populations, including healthy individuals, cardiac patients, and athletes, have demonstrated that the Talk Test is a very good marker of VT1.
- At an intensity level above VT1, but below VT2, an exerciser will still be able to speak, but not comfortably.
- VT2 represents the point at which high-intensity exercise can no longer be sustained due to the accumulation of lactic acid.
- The Talk Test can be administered in a variety of ways, including reciting something familiar such as the Pledge of Allegiance, or reading from a text. After the recitation, if they can answer “yes” to the question, “Can you speak comfortably?”, then their intensity level is below VT1.
- If the client hesitates or answers equivocally to this question, their intensity is probably right at VT1.
- If the client answers no, they are probably close to or above VT2.
- Compared to %VO2max or %MHR, the Talk Test has several advantages as a method of programming and monitoring exercise because it is based off an individual’s unique metabolic or ventilatory responses.
- Additionally, training at or near VT1 increases the likelihood of a better exercise experience and enhances long-term adherence.

Attachment X: The StepUp Sensor

Attachment XI: Additional info

- *What is the Aerobic Threshold (**VT1**)?*

During rest and a low intensity of exercise your body uses aerobic respiration to create energy. When exercise intensity is increased and your body requires more oxygen to compensate for the loss of oxygen in aerobic respiration, you start breathing faster. The point where the amount of oxygen your body uses is in equilibrium with the amount of oxygen you breathe in is known as the Aerobic Threshold or Ventilatory Threshold I (**VT1**) (Eriksson & Couzens, 2017). When **VT1** is crossed and there is a shortage of oxygen for aerobic respiration, anaerobic respiration will take place in your body instead. As a by-product of anaerobic respiration, lactic acid is formed which then gets transported into your blood.

- *What is the Anaerobic Threshold (**VT2**)?*

During lactic acid formation, your blood is also busy removing the lactic acid, so that lactic acid does not accumulate in your blood (di Prampero & Ferretti, 1999). When exercise intensity is increased even more, a point will be reached where lactic acid accumulation and removal are in equilibrium (Heck, et al., 1985). This point is known as the Anaerobic Threshold (**VT2**). When the Anaerobic Threshold is exceeded, lactic acid levels in the blood start accumulating rapidly. As a result, the pH value of your blood drops and there is a significant increase in muscle fatigue. (Rusdiawan, Sholikhah, & Prihatiningsih, 2020). Lactic Acid is also responsible for the burning sensation in your muscles during exercise.

Participation Code: ....

Attachment XII: Anamnesis form

Full Name:
Weight(kg):
Length (m):
BMI (kg/m² = weight / length²):
Sex (M/F):
Date of birth:
Birthplace:
City:
General Practitioner:

Check the answer which applies:

	RISK FACTORS	YES	NO	?
1	Is the BMI higher than 30?			
2	Have male relatives (father, son, brother) before age 55 or female relatives (mother, sister, or daughter) before age 65 had a myocardial infarction or sudden death or undergone bypass surgery?			
3	Are you a smoker or have you stopped smoking recently (within the past 6 months)?			
4	Do you have high blood pressure (upper pressure > 140, lower pressure > 90) and/or are you taking medication for high blood pressure?			
5	Do you have high cholesterol (above 5.2) and/or are you taking medication for high cholesterol? (if unknown, then probably OK, fill in: NO)			
6	Do you have diabetes?			
7	Do you regularly practice one or more active sports? If not, do you engage in moderate physical activity for 30 minutes a day on most days of the week?			
	SYMPTOMS	**YES**	**NO**	**?**
9	Do you ever experience pain in your chest?			
10	Do you ever feel short of breath at rest or on light exertion?			
11	Do you often suffer from dizziness?			
12	Do you ever faint?			
13	Do you ever have obviously swollen ankles?			
14	Do you experience frequent heart palpitations?			
15	Does your heart sometimes go very fast at rest (Above 100 per minute)?			
16	Do you ever experience severe pain in your legs while walking?			
17	Do you have a heart defect (e.g., murmur)?			
18	Are you ever abnormally tired during normal activities?			
19	Do you have asthma, bronchitis or any other lung conditions?			
20	Do you have a thyroid disorder?			

21	Do you suffer from a liver illness?			
22	Do you regularly use medications? If Yes, please indicate on the back of this form which ones.			
23	Have you ever been rejected for health reasons?			
24	Do you feel healthy at this moment in time?			

Any comments on one or more answers on the back of this form

Date: 21-11-2022. Autograph participant: .... *Autograph Researcher: ....*

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