S3Bike: An Electrically Assisted Cycle Monitored in Heart Beat to Help People with Heart Problem

Tests and Choice of the Best Heart Rate Sensor

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Abstract: Many older people give up all physical activities because of their feeling of insecurity outdoors. In parallel, the number of Electrically Assisted Cycles (EAC) in the cities increases significantly. Purpose: The aim of the current study is to know if it's possible to monitor their heart rate via an EAC to give a secure access to locomotion of people under medical advice. Methods: It is two-fold: For all the experiments, our reference is the Polar H7 chest strap. First, we compared different sensor's positions during a 30 seconds' effort test indoors on a healthy subject. Then, we studied the repeatability and the reproducibility of the PulseSensor placed on the cyclist's earlobe during rest and test efforts on two samples of 12 health subjects. Results: The PulseSensor placed on the earlobe is reliable indoors. Conclusion: The PulseSensor can be a good sensor to monitor an EAC in heart rate. But we need to design a system to integrate all the electronic directly on the cyclist and his helmet and to protect it from the outdoors interactions like the exposure to the sun, the humidity or the cyclist's perspiration.

1 INTRODUCTION

1.1 Heart Disease Concerns for the Mobility

Cardiovascular and heart diseases are the secondary causes of death in France just after tumours (Ministère des Solidarités et de la Santé, 2016). This remains true among frailty elderly. Even if the main factors are linked to tobacco and drug-taking, the lake of physical activity is also considered as an aggravating factor. World Health Organization recommends at least 150 minutes of moderate-intensity physical activity throughout the week to fight against sedentary lifestyle. For those with poor mobility, they should perform physical activity to enhance balance and prevent falls, 3 or more days per week. Among the recommended sports, we noticed swimming, cycling and walking. We decided to focus on cycling to associate physical activity with an ecological mobility solution. In particular, Electrically Assisted Cycling (EAC) has the advantage that they can assist the rider when the effort becomes too much important.

Heart rate is one of the main physiological indicator of the physical exertion, and monitoring this parameter can be value to assess Electrically Assisted Cycles. Of course, we could use the ways existing today to measure heart rate. But our main goal was to make the sensor the fuller acceptance we can for elderly people. That is why, we decided to integrate it in the cyclist's helmet, supposing that the helmet should be always worn.

1.2 Experimental Setups

The reference of all the next data is the reliable sensor connected to the Polar H7 chest strap device (International journal of sport physiology and Performance, 2017). For a starting base, we tested an Arduino compatible heart rate sensor and performed preliminary validity study on healthy volunteer's subjects. First, we selected the better place to put the sensor thank to our preliminary study. Then we proved the sensor's validity during rest and test

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efforts indoors. Finally, the last experiment showed us the impact of outdoor elements, and so, let us other research fields to protect the sensor.

1.3 LED Pulse Sensor Functioning

The sensor that we tested is a non-invasive heart rate monitoring sensor. The signal that is emitted is an analogue fluctuation in voltage with a periodic wave shape from a green LED. The pulse sensor amped responds to relative changes in light intensity. This latter is proportionally transformed into a certain value. So, the light reflected back to the sensors characterizes the pulse. When the system finds the moment when the signal is high, it measures the time between all the pulses and sends the Inter Beat Interval. Finally, the processor totals and posts the heart rate in beats per minute.

2 PRELIMANARY STUDY: BEST SENSOR POSITION

2.1 Methodology

We used a sample of one healthy volunteer subject to make a first hypothesis on the best sensor position. The reference of our data is still the reliable sensor connected to the Polar H7 chest strap devices. We connected a PulseSensor on an Arduino Uno. With an USB port and a cable, we could see the 50Hz direct data on our computer. A specific program in Python is needed to log the data in a file. The Polar captor registered one data point per second and we used it to compare the two signals when the test was over. Our signal had to be reliable for the high and low heart rate, so we designed an effort test which would show these extremums. After having connected the two sensors on the body of the cyclist, we started programs and devices. During the 30 first seconds, the subject didn't move on the indoor cycling: It's the rest time. When this time was over, the subject began his exercise and pedalled as fast as possible with a high-power yield for 30 more seconds. Finally, the cyclist stopped his efforts and return to a rest state for 30 seconds. Also, the test duration was 90 seconds. The event which allowed us to have time aligned between the two sensors was the sudden heart rate increase after the 30 seconds of rest. So, it was a manual calibration. We made this experiment on three different parts of the body. First, we fixed the sensor on the forehead temple behind the helmet. Then we tested the sensor on the index finger. Finally, we clipped the sensor on the cyclist's earlobe.

2.2 Results

We compared the results obtained by the two kinds of sensors on a graph. The following graphs represents the Heart rate in Beats per minute over the time in seconds. There are 3 graphs for the 3 positions tested. The blue function is the heart rate obtained with the pulse sensor connected to Arduino and the orange with the Polar chest strap.

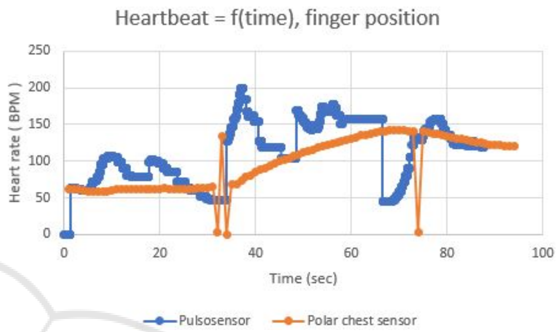

Figure 1: Graph of heart rate function over time for the finger sensor's position.

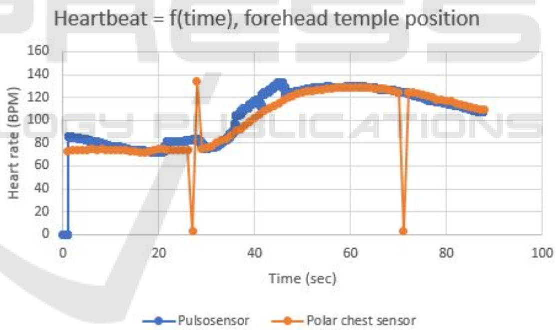

Figure 2: Graph of heart rate function over time for the forehead temple sensor's position.

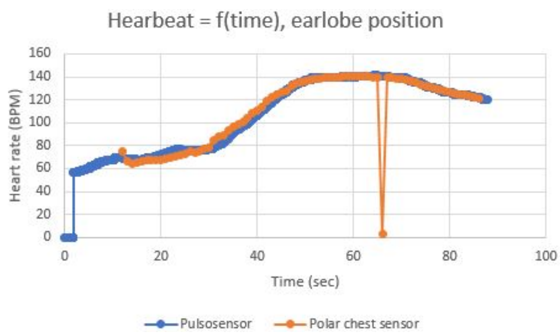

Figure 3: Graph of heart rate function over time for the earlobe sensor's position.

We decided to accept the pulse sensor's values with a 2% margin of error in comparison to the Polar thoracic chest strap. On the 3 graphs, the orange curve follows a logical curve.

2.2.1 Finger Position

We can easily say that the finger is not the best place to put our pulse sensor. Indeed, they are a lot of false values in the blue graph and there is no trend. There are only 17 values in the margin of error by 88, in other words, the blue curve has 18.1% of correct measurements.

2.2.2 Forehead Temple Position

When we placed the pulse sensor on the cyclist's temple, the blue curve was more reliable but not perfect. There were still some false values, and the trend when cyclist was at rest is imprecise. If we consider the entire function, 67% of values are within the margin of error.

2.2.3 Earlobe Position

The pulse sensor is in the optimal position when it is placed on the cyclist's earlobe. As a matter of fact, when we analysed the values, there are 76 measures by 88 which are included in the margin of error. So, it represents more than 80% of the entire function. We didn't obtain the precision that we were looking for but there are some ways to do this.

2.3 Conclusion

Regarding the results, we chose to place the sensor on the earlobe for the next experiment. Indeed, it's the best location to have the same results as our reference, the Polar thoracic chest strap. To perform this sensor and make its values under our margin of error, we will have to imagine a simple procedure of preliminary sensor calibration. We could also filter illogical values with a filtering step. Moreover, this position is an advantage for our future project because we are going to make our system on-board and place the Arduino microprocessor on the cycling helmet, not far from the earlobe.

3 EXPERIMENT: REPRODUCIBILITY AND REPEATABILITY

The aim of this experiment was to prove that the measurements obtained with the pulse sensor on the earlobe are reproducible and repeatable with a 10% confident limit.

3.1 Materials and Methods

To show that, we designed two experiments with two different samples. The test took place indoors. For both, the sensor tested was the pulse sensor connected to an Arduino Microprocessor and the reference still was the Polar sensor on the thoracic chest strap. Then, the test was the same as the first experiment. We started the programs and devices and at the same time, the healthy subject stayed calm, without pedalling for 30 seconds. Then he began the test effort and pedalled as fast as possible for 30 seconds. Finally, he stopped the test and as during the first 30 seconds, didn't move on the bike. We disconnected the sensors after 30 seconds. So, the experiment for one subject has a duration of 90 seconds. To prove that the results are reproducible, we repeated the previous experiment with a sample of 11 healthy subjects, between 20 and 25 years old (N=11). We compared the error rate between the pulse sensor's measurements and those from the Polar thoracic chest strap. The repeatability was tested with a sample of 3 healthy subjects (N=3). Each of them repeated the experiment 5 times in the same physical conditions. We also compared the approval limit got with the Bland-Altman method and our confident limit of 90%.

3.2 Results

3.2.1 Reproducibility

Thanks to the Bland-Altman method, we could say that our measures were similar with a confident interval of 90% and even 95%. Indeed, we got the correlation plot and the Bland-Altman plot's figures below.

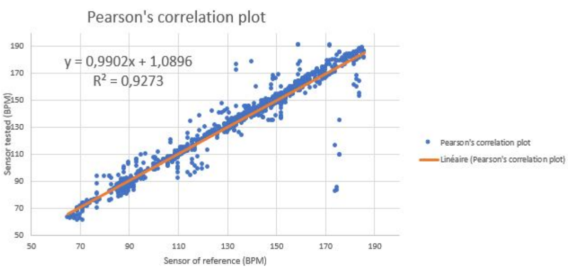

Figure 4 : Pearson's correlation plot for the reproducibility test.

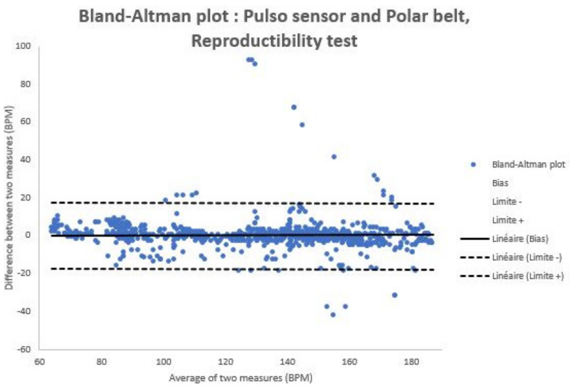

Figure 5: Bland-Altman plot to compare PulseSensor to the Polar chest strap for the reproducibility test.

We measured approval limits and we got an approval interval of [-17.3; +17.6]. Yet, when we analyzed our results, there are only 3.96% of measures which are out of the approval interval. So, the confident interval is included in the approval interval. We can conclude that the measures got with the PulseSensor are reproducible.

3.2.2 Repeatability

The test of repeatability showed that, in our conditions, it was difficult to reproduce the same test 5 times. Indeed, we had some sensor's position gap between different experiment on the same subject. Despite of this, the results were in the 90% confident interval. We should be able to reduce our confident limit with a preliminary calibration of the sensor's placement. Our results for this test are listed in the table below.

Tableau 1: Bland-Altman results for repeatability test of PulseSensor.

subject	test	approval limit	percentage of measures out of approval limit	<10%
1	1	[-41,8 ; 56,4]	9,40%	yes
	2	[-3,4 ; 3,8]	7%	yes
	3	[-7,9 ; 5,9]	5,90%	yes
	4	[-1,5 ; 1,8]	3,50%	yes
	5	[-2,5 ; 2,7]	4,70%	yes
2	1	[-22,5 ; 33,2]	5,80%	yes
	2	[-4,5 ; 3,8]	1,20%	yes
	3	[-34,6 ; 22,3]	9,40%	yes
	4	[-25 ; 18,4]	7%	yes
	5	[-6,3 ; 5,5]	2,40%	yes
3	1	[-12,6 ; 13,9]	3,50%	yes
	2	[-38,5 ; 48]	7,10%	yes
	3	[-4,5 ; 5,1]	3,50%	yes
	4	[-7 ; 9,2]	5,70%	yes
	5	[-12 ; 16,4]	5,50%	yes

3.3 Discussion

Thanks to this study, we can determine the advantages and the drawbacks of the pulse sensor for our specific use. First, the earlobe is a good and easy position for elderly people to place the sensor whatever their clothes or their flexibility. Then, its integration in the compulsory helmet make it unforgettable to have. We also don't need to design an adapted hanging system for each cyclist because the exact position of the sensor on the earlobe doesn't impact the results. But our experiments present some limits, and should be considered as a preliminary study. First, we used a sample of only one subject to determine the better place where putting the PulseSensor. Then, it could have measurement's errors due to a wrong contact between the sensor and the earlobe. So, we need to design a mechanical fix system and make a preliminary calibration of its placement to reproduce the test in the same conditions. Moreover, we made all tests indoors even though in the future, it will be a system for cyclists outdoors. So, our results are significant for an indoor use, but first outdoors test shown that environmental variables (humidity, cyclist's vibrations, light…) have a significant effect on measurement accuracy. That's why our next work will be to design a better system to protect our sensor from the extern light ray and to fix it on the user's earlobe.

4 CONCLUSIONS

The PulseSensor is a reliable sensor when it's placed on the earlobe and tested indoors. After designing systems to make it on-board, we will be able to test it in real conditions: On a biking trip. Then, the final step will be to monitor an EAC with the PulseSensor.

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