Validation of the Aidlab solution for measuring Heart Rate Variability

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Aim. The purpose of this study was to validate Aidlab physiological monitor's accuracy of heart rate variability measurements during physical effort. **Methods**. 5 male and 3 female subjects performed a 15-minute stationary bike exercise protocol consisting of low, moderate, and high-demand physical loads. RR intervals were simultaneously recorded with Aidlab and Polar H7 heart rate sensor. After the removal of artefacts (data gaps accounting for 2.34% of total RR intervals), the data was synchronized and analysed. **Results and conclusion**. High correlation and agreement between the two data sets ($r > 0.99$, MPE $< 0.8\%$) was shown, proving Aidlab provides reliable HRV measurements, including for sub-max HR values during demanding physical activity. Data gaps were more frequent for high intensity exercise, thus quality control is advised in measurements involving excessive movement and sweating.

1 Introduction

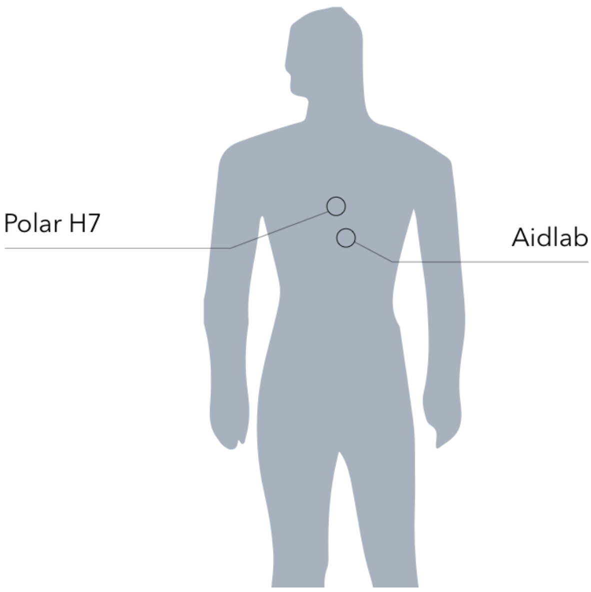
Heart rate variability, also referred to as RR variability, represents the variation of time periods between consecutive heart beats, specifically - R intervals in QRS complexes. HRV measurements, being highly correlated with autonomic nervous system activity, are proven to be useful in a wide range of life applications. Since the miniaturization and widespread availability of portable heart monitors, chronic and acute stress assessment via HRV changes observations is one of very heavily focused research topics regarding that parameter.

Many studies have proven mental stress correlation with physiological changes in the heart [1, 2]. HRV measurements are usually divided into 3 categories: long (standard length – 24h), short (5 min) or ultra-short (<5min). While it's torelable to maintain stationary position for up to 5 minutes, longer recordings are usually done outside of laboratory in partly or non-controlled conditions, being bounded with the subjects performing their daily activities. Therefore, it's worth noting that such utility requires a suitable method, one reliable despite subjects' unavoidable physical load and variable conditions.

Researchers seem to have a comparably great enthusiasm for finding HRV applications in sports. Their findings confirmed various benefits of RR variability monitoring for both individual athletes and team sports players. Considered a key to monitoring recovery, tracking training results and overtraining prevention, heart rate alternation tracking seems to have appealed to the general fitness and sports industries, resulting in heart rate monitoring devices being a fundamental gear for every runner or cyclist, many of whom go beyond heart rate and use widely available variability analysis software. Sport scientists and trainers also report positive results of introducing consistent HRV monitoring and analysis to their practice [3].

Naturally, as a recognized valuable physiological measure, HRV finds its uses in medicine. Although there are hundreds of ongoing studies, and some setbacks due to inconsistency with methodology, HRV has

Figure 1: *Aidlab and Polar H7 placement*



been identified as an indicator for risks and prognosis, mainly in some neurological, cardiological, and psychiatric conditions [4, 5, 6, 7]. Therapeutic uses of HRV biofeedback are also being explored with promissing results [8, 9].

Aidlab is a physiological monitor mounted on a chest strap, equipped with a set of sensors. It measures HRV by deriving it from collected 1-channel ECG signal. The goal of this document is to validate the quality and reliability of those measurements during periods of increased physical activity, thus proving Aidlab to be a suitable device for athlete monitoring. ECG, being a signal resulting directly from heart activity is commonly acknowledged as the most reliable method of measuring HRV, thus a validated ECG-based sports heart rate monitor - Polar H7, was chosen as a reference device. Outputs of Aidlab and Polar H7 heart rate sensor were compared and analyzed.

2 Methods

A total of 8 apparently healthy adults aged 21-30 (see 1) volunteered to take part in the study. Taking into account the fact that subjects' physical condition may differ, individual measurements were taken one subject after another as opposed to a single group session in order to achieve desirable HR ranges. Exercise of choice was stationary cycling as it allows for easy control and correction of participants' pace, thus HR range. Limited body core movements during this activity were also taken into account as an asset.

Exercises were performed during a non-disturbed 15 minute period consisting of 3 phases with increasing intensity. The experimenters monitored ongoing measurements and gave oral instructions with the end of each phase and if subjects' HR was approaching one of the current range limits. Instructions referred exclusively to HR. After initial signal quality check done prior to the start, there were no remarks or interruptions due to excessive movements or sweat overflow which could cause artefacts, in order to ensure reality-reflecting natural exercise conditions. Participants were asked to notify if at some point they felt like they could not keep up the pace, but all of them coped well with each HR range.

Table 1: *Subjects*

Num.	Sex	Age	Weight	Height	Chest CIRC
1	M	20	1.78 m	75 kg	1.15 m
2	M	21	1.85 m	77 kg	1.08 m
3	M	30	1.94 m	79 kg	1.16 m
4	M	23	1.79 m	82 kg	1.06 m
5	M	21	1.74 m	67 kg	0.97 m
6	F	29	1.63 m	54 kg	0.84 m
7	F	26	1.64 m	63 kg	1.02 m
8	F	21	1.70 m	59 kg	0.96 m

The study was carried out in compliance with the following scenario:

1. Polar H7 and Aidlab chest straps are put on the subject's chest, or below if not possible, and adjusted to fully adhere to the body and not collide with each other. (see 1)
2. Both monitors are paired with recording devices and checked for signal propriety
3. Subject does light warm up sets (non-registered)
4. Subject starts cycling with accordance to real-time instructions meant to keep him in the proper heart-beats-per-minute zones:
    - 5 minutes of light physical load (120-140 HBpm)
    - 5 minutes of moderate physical load (141-160 HBpm)
    - 5 minutes of heavy physical load (161-180 HBpm)

2.1 Data preprocessing

Despite the possibility of recording raw ECG signal on Aidlab, RR intervals were obtained directly from the device in order to examine the device's capability to indicate HRV on its own. Data from Aidlab was recorded with the use of commercially available version of Aidlab app and downloaded in form of RR interval values. Official Polar H7 commercially available apps do not allow for direct RR interval recording, so custom software was utilized. Aidlab outputs RR interval values in 1000 units per second (ms), while Polar H7 uses the format of 1024 units per second. In order to bring both sets of data to the same format (ms), values recorded by Polar H7 were divided by 1.024.

Figure 2: *Subject 6 pre-filtered data (already synchronized and brought to the same format)*

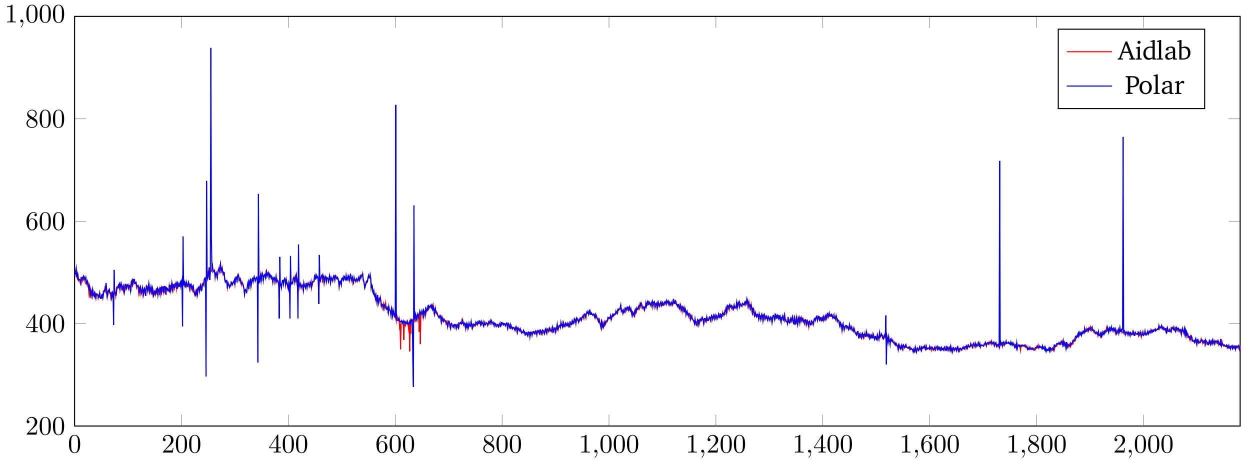


Figure 3: *Subject 6 filtered data*

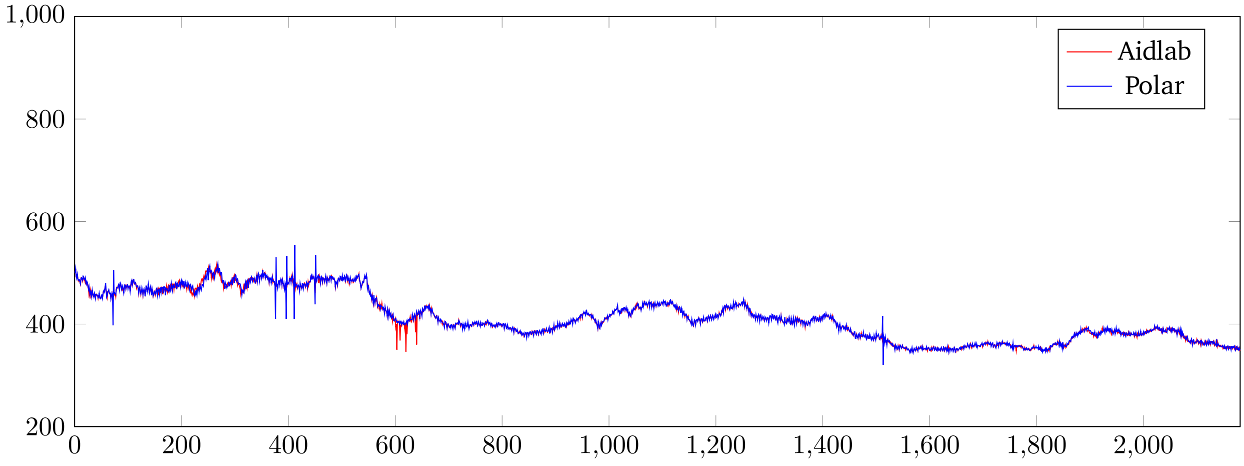


Table 2: *Missing RR intervals representation*

Subject	Total RR intervals	Rejected (PH7)	% of rejected (PH7)	Rejected (Aidlab)	% of rejected (Aidlab)
1	2268	3	0.1	7	0.3
2	2217	5	0.2	33	1.5
3	2394	167	7	11	0.5
4	2281	0	0	18	0.8
5	2224	0	0	2	0.1
6	2189	12	0.5	0	0
7	2243	0	0	76	3.4
8	2281	36	1.6	44	1.9

Note: PH7 indicates Polar H7. Two most deviating sets of intervals were caused by temporary lack of chest strap's adherence. Data gaps are a common phenomenon in non-motionless HRV measurements. The authors recognized the gap is not significant enough to disrupt the results.

The data was visually examined for major artefacts and those were excluded in order to prevent statistical data disruption (2). Corresponding proper RR intervals recorded by the other device during RR interval gap were also removed to allow synchronization of the two data sets. Removed proper RR intervals are not accounted for in 2. Following criteria for artefact identification and removal were established: an RR interval value had to exceed the mean value of proper neighbouring RR interval pairs by at least 1.5 times in order to be considered an artefact. These criteria were cross-checked with the median value of adjacent RR intervals with 100% conformity.

Such solution is justified as enormous fluctuations in subsequent values are safe to be assumed motion or sweat-induced artefacts. The likelihood of a heart defect leading to electrical signal stoppage in healthy, fit, young subjects is marginal and not statistically significant. Additionally, there was not a single portion of corrupt data correlated on both devices, further indicating signal disruption. After artefacts were removed, the data was manually synchronized based on timestamps and correlation values.

2.2 Statistical analysis

In order to check whether Aidlab is a valid HRV monitoring tool, correlation, mean differences, mean percentage error and confirmity with limits of agreement for each subject were compared in 4. Mean RR interval values, their standard devations and differences' standard deviations are displayed in 3 and 4. Bland-Altman plots and boxplots were created for distribution visualization.

3 Results and conclusion

Significant correlation in all aspects of the study was shown ($r > 0.99$, $p < 0.05$). Considering the outcome on individual participants' levels, correlations were high in each case ($0.982-0.998$) with the mean value of 0.992 ($SD = 0.005$). Mean RR interval value difference of 3.12 ($SD = 0.89$), being on average as little as 0.76% ($SD = 0.21\%$) of mean RR interval value, is practically insignificant. An average 3.92% ($SD = 1.61\%$) of measurements were outside of limits of agreement, which is satisfactory, taking conditions of the study such as movement, muscle contractions, excessive sweating into consideration. Mean and SD values shown in 2. present no significant differences. The amount of data gaps and missing intervals was evenly distributed throughout devices ($Polar - 54\%, Aidlab - 46\%$ missing intervals). Although the level 2.29% of overall missing RR intervals is statistically acceptable given a data gap filtration or manual correction is in place, 76% of those were observed in the heavy physical load phase alone, meaning 4.74% of high intensity measurements was lost. Given the above, especially for measurements taken in unfavorable physical conditions, real-time signal quality control or the use of filtration algorithms is highly advised in order to ensure data reliability. In conclusion, findings of this study prove Aidlab to be a suitable and reliable mean for HR and HRV monitoring during physically demanding tasks and exercises.

4 Bibliography

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Table 3: *Statistical analysis*

Subject	Mean PH7 RR intervals (ms)	Mean Aidlab RR intervals (ms)	SD of PH7 RR intervals (ms)	SD of Aidlab RR inervals (ms)	SD of mean difference (ms)
1	399.3	397.6	55.10	54.81	3.53
2	415.3	414.7	47.54	49.77	6.64
3	406.4	405.3	38.88	38.68	7.43
4	399.8	397.9	33.61	33.15	4.13
5	406.5	405.5	43.49	43.43	3.39
6	413.6	413.1	45.27	45.17	5.81
7	417.8	415.7	43.25	43.61	5.36
8	410.2	409.3	36.03	36.05	4.88

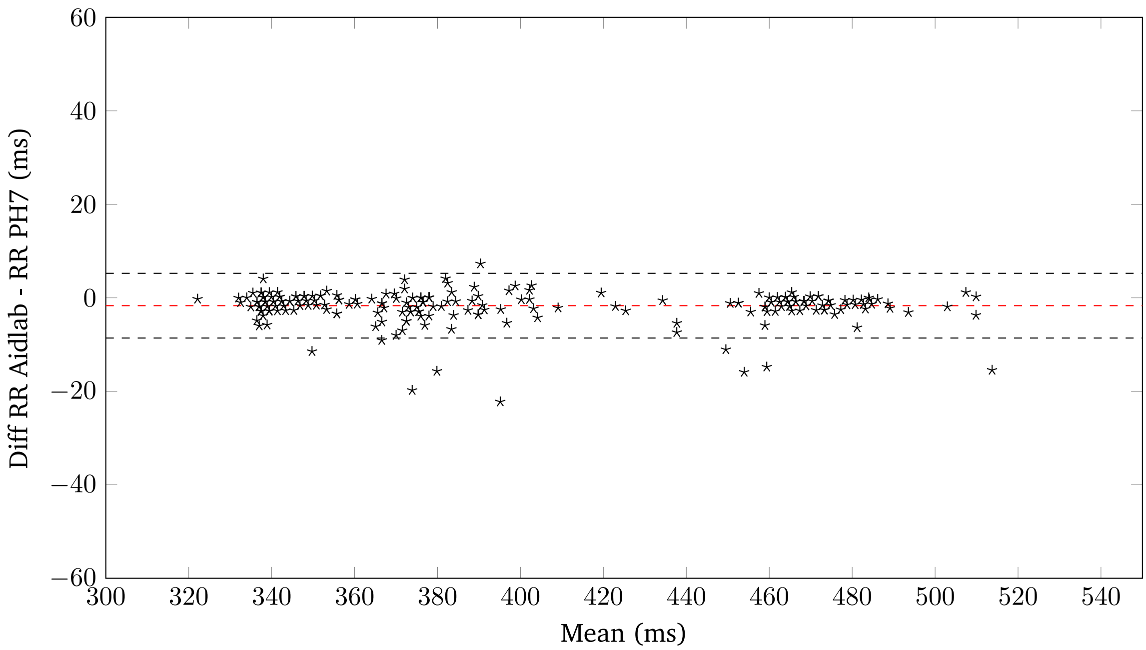
Note: PH7 - Polar H7. SD - standard deviation SD of mean difference refers to non-absolute values.

Table 4: *Statistical analysis*

Subject	Correlation	MAPD	MPE	Within LOA
1	0.9979	2.30ms	0.58%	94.15%
2	0.9917	4.82ms	1.13%	94.63%
3	0.9816	4.13ms	1.01%	98.24%
4	0.9925	3.21ms	0.80%	95.49%
5	0.9970	2.65ms	0.65%	95.36%
6	0.9918	2.61ms	0.62%	95.14%
7	0.9924	2.63ms	0.64%	97.83%
8	0.9908	2.65ms	0.64%	97.77%

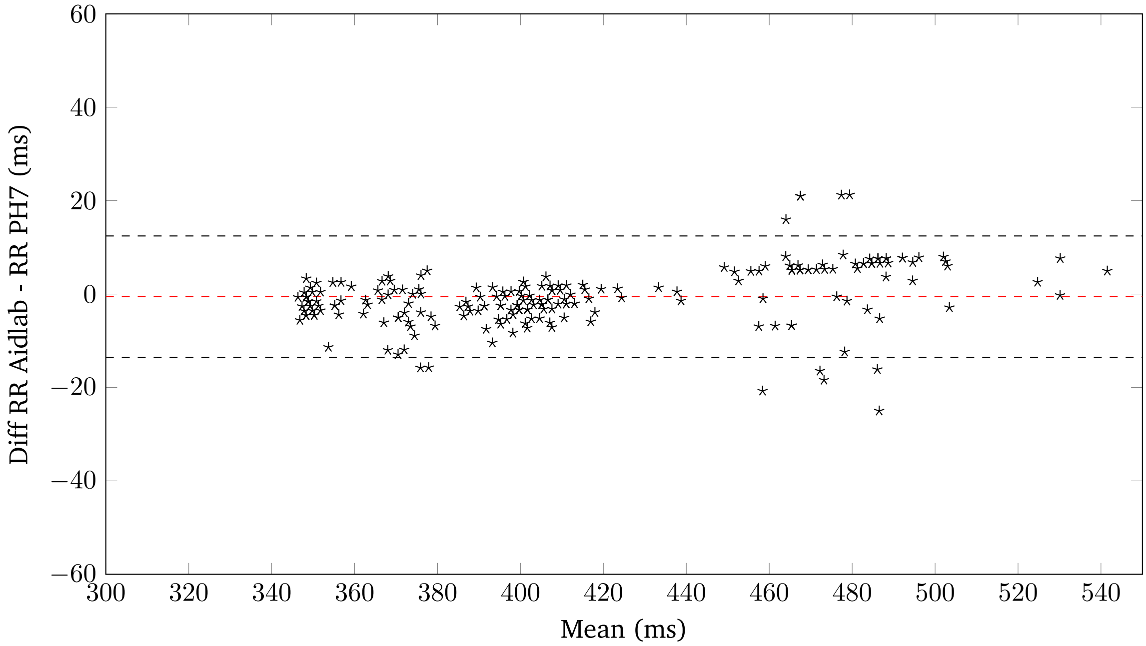
Note: MAPD indicates mean absolute pair difference, MPE - mean percentage error, LOA - limits of agreement. Within LOA refers to RR interval values within 95% limits of agreement defined as $1.96 \cdot SD$

Figure 4: *Subject 1.*



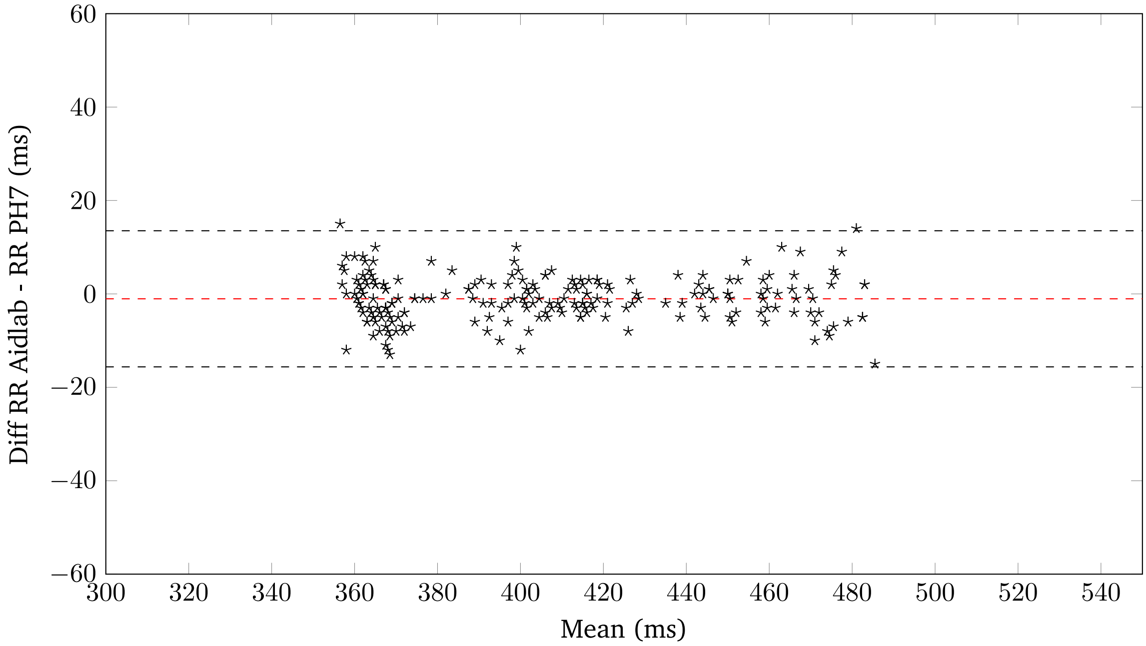
$Bias = -1.68ms, 95\%LOA = (-8.60ms; 5.24ms)$

Figure 5: *Subject 2.*



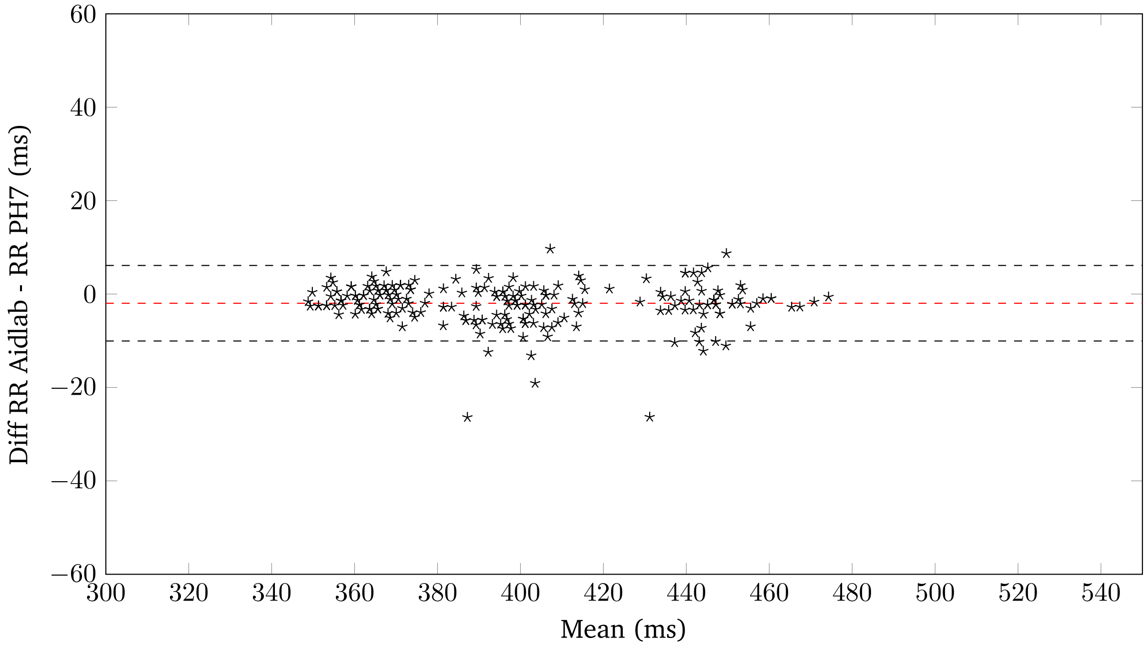
$Bias = -0.57ms, 95\%LOA = (-13.58ms; 12.44ms)$

Figure 6: *Subject 3.*



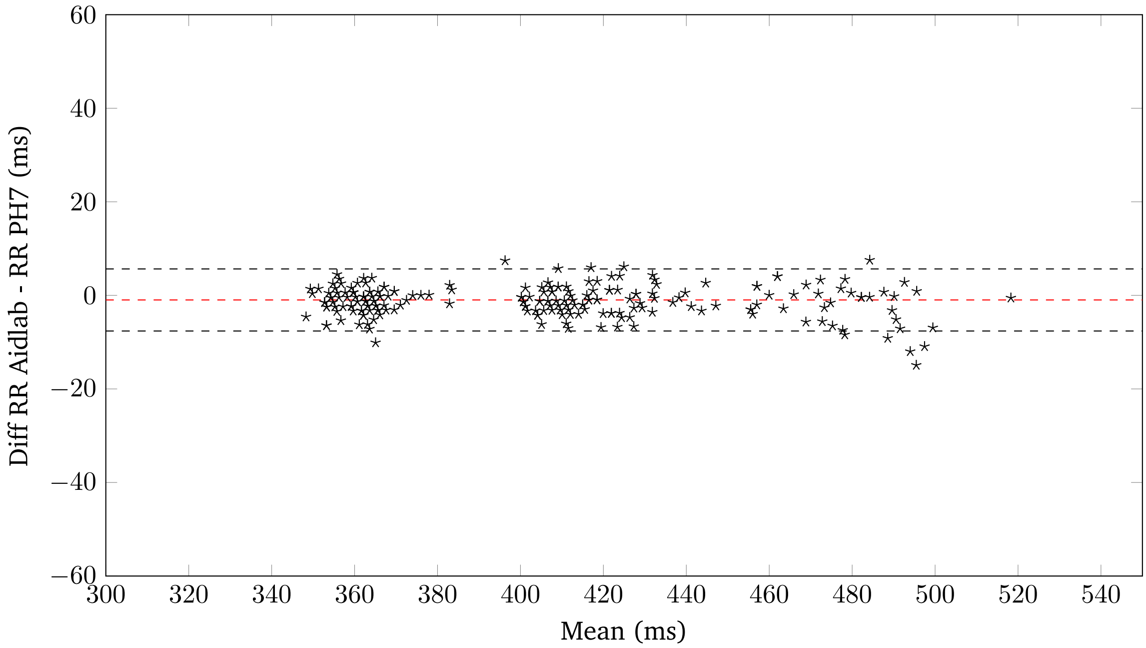
$Bias = -1.05ms, 95\%LOA = (-15.62ms; 13.52ms)$

Figure 7: *Subject 4.*



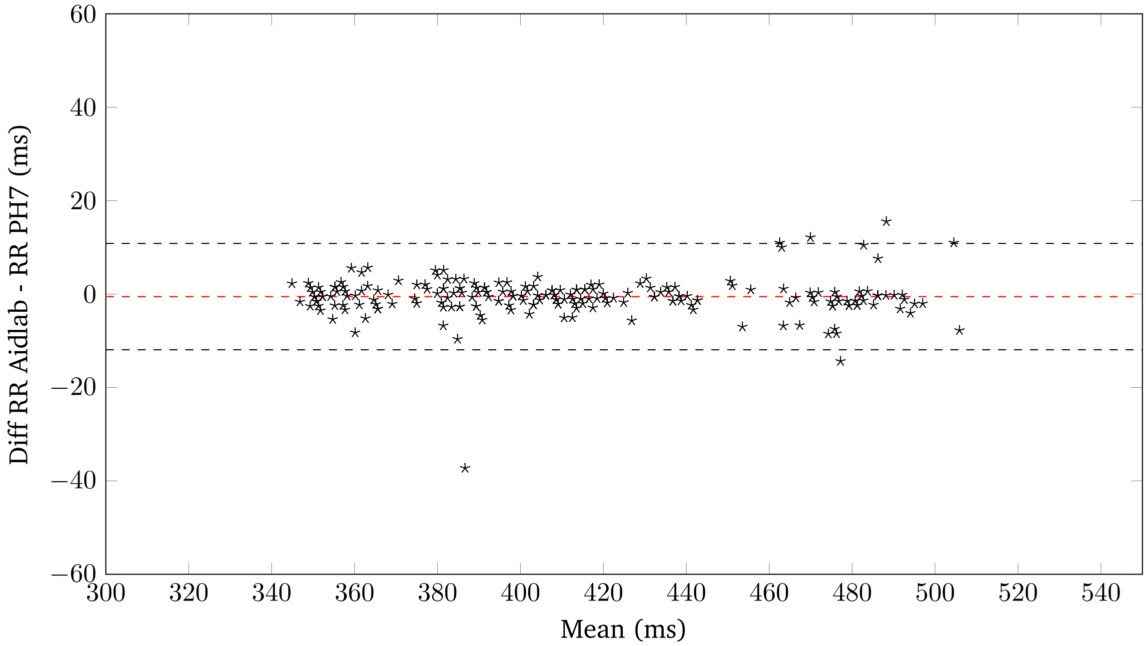
$Bias = -1.97ms, 95\%LOA = (-10.05ms; 13.52ms)$

Figure 8: *Subject 5.*



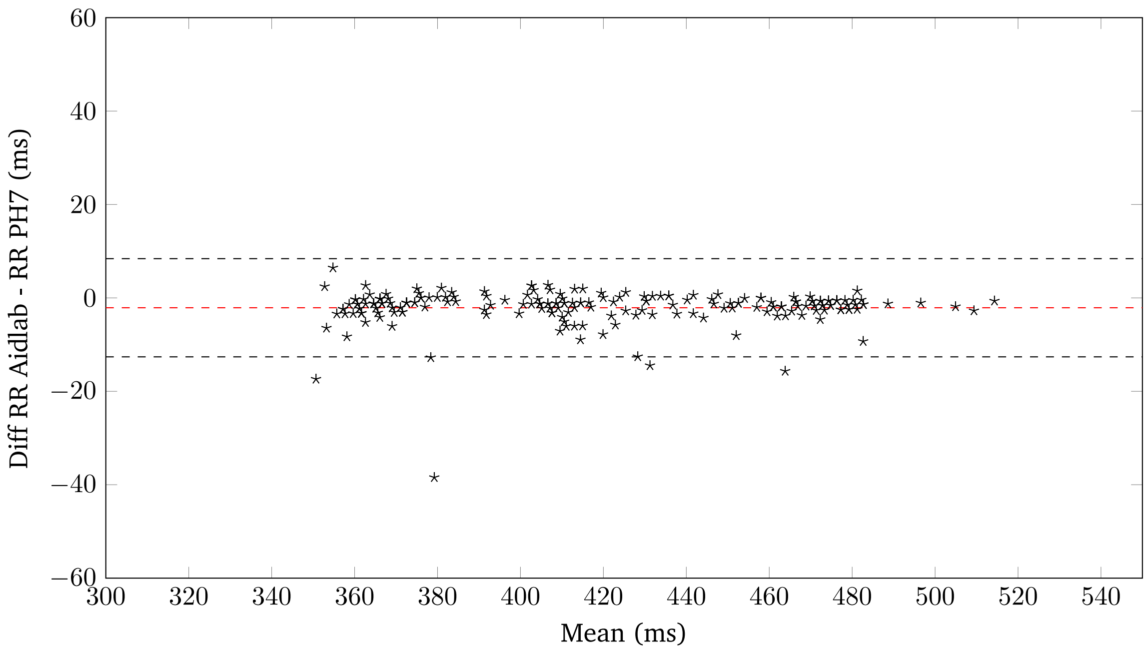
$Bias = -0.98ms, 95\%LOA = (-7.62ms; 5.65ms)$

Figure 9: *Subject 6.*



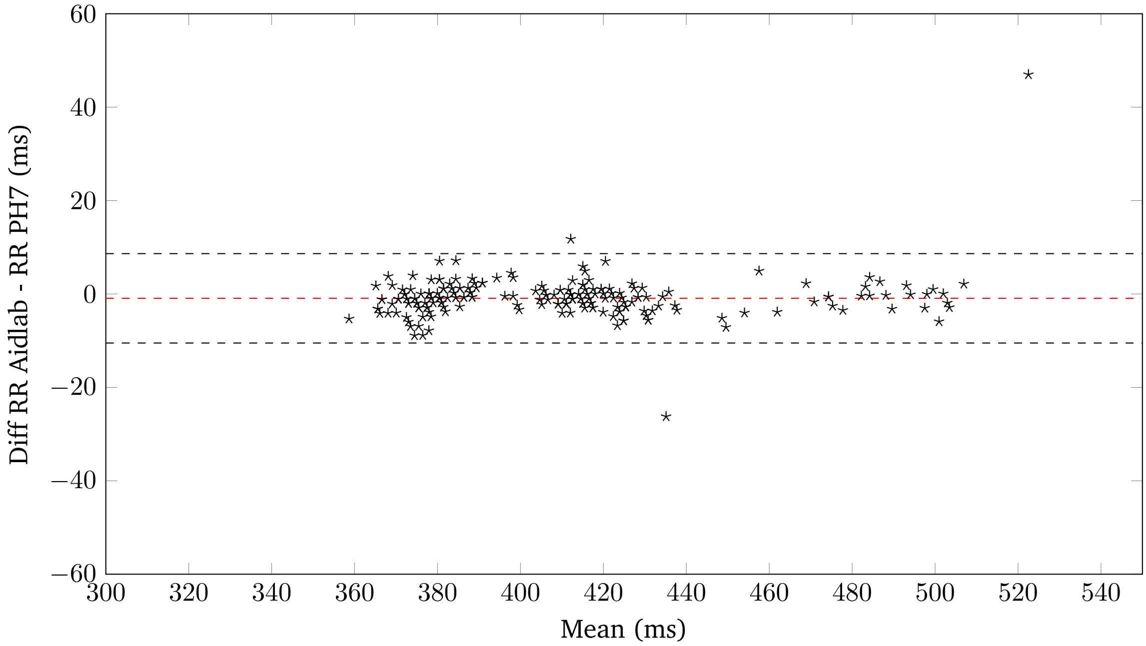
$Bias = -0.54ms, 95\%LOA = (-11.93ms; 10.84ms)$

Figure 10: *Subject 7.*



$Bias = -2.11ms, 95\%LOA = (-12.62ms; 8.40ms)$

Figure 11: *Subject 8.*



$Bias = -0.93ms, 95\%LOA = (-10.50ms; 8.64ms)$

Figure 12: *Box plots for subjects 1-4*

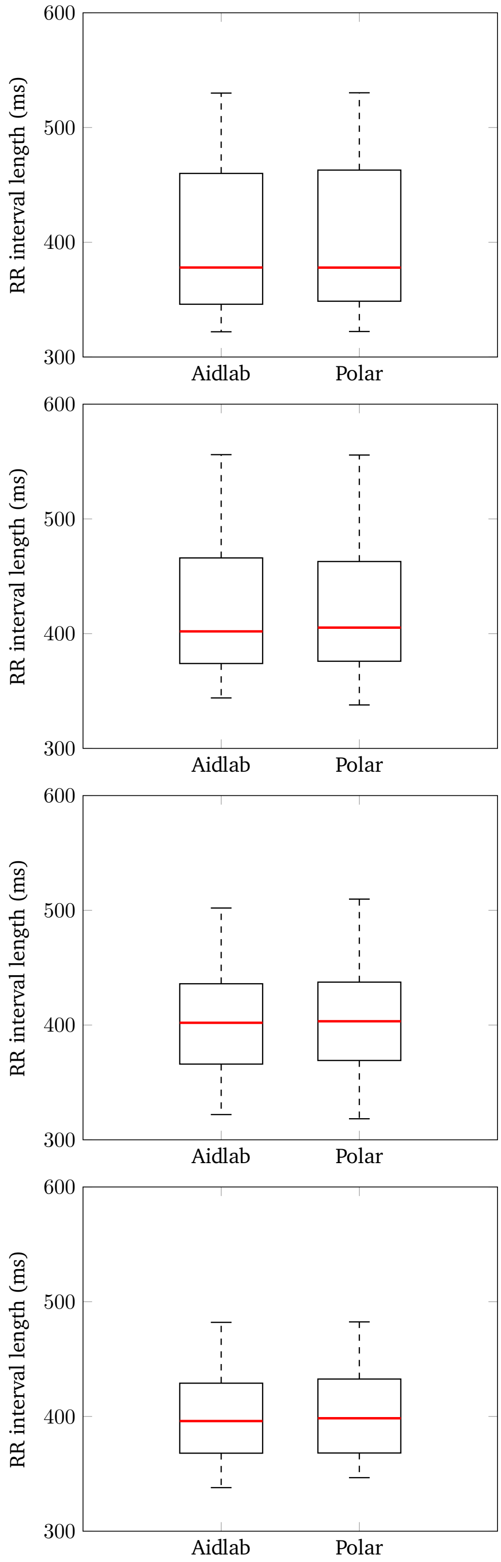


Figure 13: *Box plots for subjects 5-8*