Heart Rate validation

Introduction

The human heart consists of four chambers, the left atrium, the left ventricle, the right atrium, and the right ventricle. Each of the upper chambers (atriums) acts as a receiving chamber and contracts to push blood into the lower chambers (ventricles). The ventricles serve as a pump, transport oxygenated blood to the body's tissues and return deoxygenated blood and carbon dioxide to the heart. Heartbeats are composed of phases of heart muscle contraction and relaxation[1].

Heart rate (HR) is a term used to describe the number of times the heart beats per minute (the frequency of the cardiac cycle). Heart rate also serves as an indicator of autonomic nervous system activity and metabolic rate. Various factors can affect HR, including physical fitness, psychological status, diet, drugs, and the interaction of genetics and the environment.[2] The normal resting heart rate is 60 to 100 beats for healthy adults. Tachycardia, a high heart rate, is defined as above 100 bpm at rest. Bradycardia, a low heart rate, is defined as below 60 bpm at rest.[3]

The relationship between elevated resting heart rate and cardiovascular risk has been demonstrated in several large-scale epidemiological studies. Those studies provide strong confirmation that increased
heart rate is an independent risk factor for all-cause and cardiovascular mortalities.[4–7]
Thus, the need for an easy-to-use and accessible method to measure and monitor heart rate is clear.

Binah.ai's Heart Rate algorithm uses the photoplethysmography (PPG) signal recorded from facial skin tissue (remote PPG - rPPG) or, if light conditions are challenging, from a fingertip placed on the camera's lens (PPG). The algorithm identifies the heartbeat peaks, which represent the contraction of heart ventricles (R peaks of the QRS complex of the ECG wave).

Definitions:
RR intervals (RRi) are defined as the difference between successive R peaks.
RR intervals are calculated as:
$RR(n) = R(n) - R(n-1)$, where n is the beat index number.
Heart Rate [in beats per minute] is calculated as:
60/average RR(n)

This report describes the results of a validation experiment, that compares Binah.ai's Heart Rate measurements with the measurements of medically accurate reference device.

Methods

In validation experiments, heart rate was measured in healthy participants and patients, who suffer from hypertension. Binah.ai's Heart Rate measurements were compared to the Covidien Nellcor™ finger pulse oximeter measurements.

Measurement set-up:

Each participant was instructed to sit as stably as possible. A Covidien Nellcor™ pulse oximeter was placed on each participant's finger. Recordings were conducted in a testing room located in Binah.ai's offices, with controlled and fixed artificial ambient light.

For rPPG measurements, a mobile device was placed on a stand in front of the participant. The participant's face filled over 20% of the frame's area (distance of 30-40 cm) and was positioned in the center of the frame. The camera was set at the level of the forehead and positioned perpendicular to the face. Participants were instructed to look at the screen during the whole recording.
For PPG measurements, a mobile device was placed on the participant's hand, with the participant's finger covering the entire area of the camera lens (in iOS devices, the finger covered the torch, while in Android devices, the finger did not cover the torch). The participant's hand rested comfortably on a soft pillow at heart level, with the wrist aligned with the forearm.
rPPG and PPG experiments were conducted simultaneously so that participants were looking at the mobile device positioned in front of them, while an additional mobile device was on their hand, recording the PPG signal on their finger.
Participants were instructed to avoid any movement (including talking) and to avoid changing finger pressure on the lens during the recordings. Each recording lasted approximately 60 seconds.

For this report, the Binah.ai's SDK 4.4.2 version was used.
The measurements were recorded by the mobile device models listed below.
Models used for rPPG measurements -

iOS: iPad 6th gen, iPhone 11 Pro, iPhone 13, iPhone 13 Pro Max

Android: Samsung s10, Samsung S21, Samsung S21 Ultra, Sony Xperia, Huawei P30 Lite
Models used for PPG measurements -

iOS: iPhone 8, iPhone 11 Pro, iPhone 13 Pro, iPhone 13 Pro Max

Android: Samsung Note 9, Samsung s10, Samsung S21, Samsung S21 Ultra, Huawei P30

Results

Tables 1-4 include demographic data for each operating system (iOS and Android) and for each mode (PPG and rPPG).

iOS:

Vital Signs	Number of Participants	Age Range (average)	Sex	Fitzpatrick Skin Tone *
Heart Rate (bpm)	222	18-84 (36)	F (43%), M (57%)	2 (37%), 3 (53%), 4 (10%)

Table 1: Demographic data for rPPG experiments using phones with an iOS operating system.

Vital Signs	Number of Participants	Age Range (average)	Sex	Fitzpatrick Skin Tone *
Heart Rate (bpm)	222	18-82 (36)	F (43%), M (57%)	2 (38%), 3 (52%), 4 (10%)

Table 2: Demographic data for PPG experiments using phones with an iOS operating system.

Android:

Vital Signs	Number of Participants	Age Range (average)	Sex	Fitzpatrick Skin Tone *
Heart Rate (bpm)	216	18-84 (36)	F (41%), M (59%)	2 (39%), 3 (53%), 4 (8%)

Table 3: Demographic data for rPPG experiments using phones with an Android operating system.

Vital Signs	Number of Participants	Age Range (average)	Sex	Fitzpatrick Skin Tone *
Heart Rate (bpm)	219	18-84 (37)	F (41%), M (59%)	2 (39%), 3 (52%), 4 (9%)

Table 4: Demographic data for PPG experiments using phones with an Android operating system.

* Fitzpatrick skin tones are: 1- Pale white, 2- white, 3- Darker white, 4- Light brown, 5- Brown, 6- Dark brown or black.

Accuracy and persistency:
Tables 5-8 include statistical information (RMSE, MAE, MAE SD, 95% CI) for each operating system (Android and iOS) and for each mode (PPG and rPPG).

iOS:

Vital Signs	Number of measurements	RMSE	MAE	MAE SD	CI 95%
Heart Rate (bpm)	1047	0.77	0.59	0.69	[0.55, 0.63]

Table 5: RMSE, MAE, MAE SD, and 95% CI for rPPG experiments using phones with an iOS operating system. Abbreviations: RMSE - Root Mean Square Error, MAE -Mean Absolute Error, MAE SD -Mean Absolute Error Standard Deviation, CI - Confidence Intervals.

Vital Signs	Number of measurements	RMSE	MAE	MAE SD	CI 95%
Heart Rate (bpm)	940	0.63	0.4	0.65	[0.35, 0.43]

Table 6: RMSE, MAE, MAE SD, and 95% CI for PPG experiments using phones with an iOS operating system. Abbreviations: RMSE - Root Mean Square Error, MAE -Mean Absolute Error, MAE SD -Mean Absolute Error Standard Deviation, CI - Confidence Intervals.

Android:

Vital Signs	Number of measurements	RMSE	MAE	MAE SD	CI 95%
Heart Rate (bpm)	846	0.7	0.49	0.98	[0.42, 0.56]

Table 7: RMSE, MAE, MAE SD, and 95% CI for rPPG experiments using phones with an Android operating system. Abbreviations: RMSE - Root Mean Square Error, MAE -Mean Absolute Error, MAE SD -Mean Absolute Error Standard Deviation, CI - Confidence Intervals.

Vital Signs	Number of measurements	RMSE	MAE	MAE SD	CI 95%
Heart Rate (bpm)	776	0.72	0.52	1.14	[0.44, 0.6]

Table 8: RMSE, MAE, MAE SD, and 95% CI for PPG experiments using phones with an Android operating system. Abbreviations: RMSE - Root Mean Square Error, MAE -Mean Absolute Error, MAE SD -Mean Absolute Error Standard Deviation, CI - Confidence Intervals.

Pearson correlations between Binah.ai's Heart Rate estimations versus Covidien Nellcor™ pulse oximeter measurements were calculated (Figure 1). Pearson correlation coefficients (R values) were very high for both operating system (Android and iOS) and both modes (rPPG and PPG).

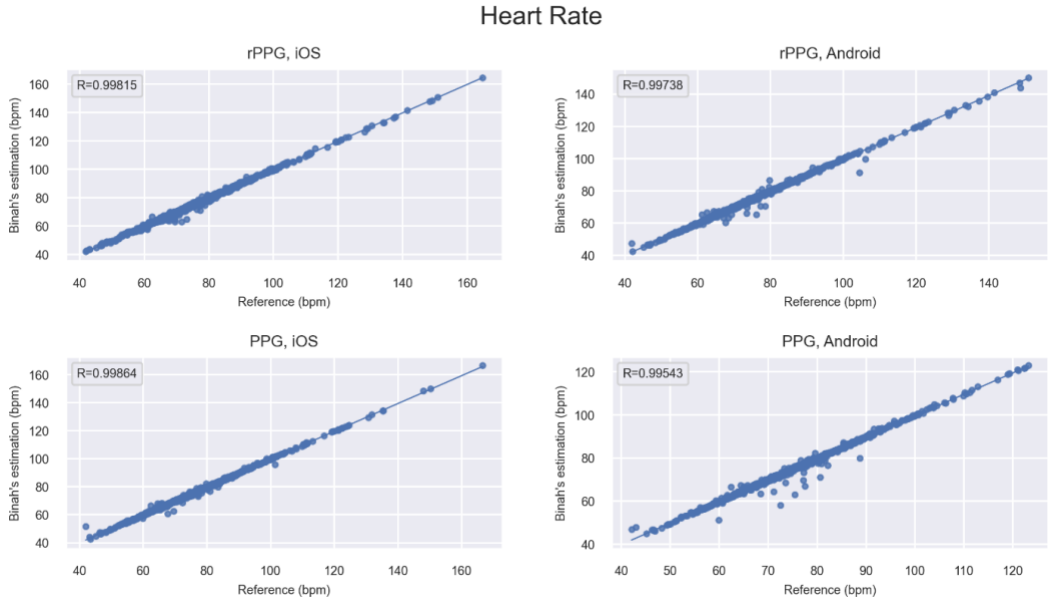

Figure 1: Binah.ai's Heart Rate estimation vs. reference device measurements. Pearson correlation was calculated and correlation coefficients are presented on each plot (R). Plots describe

measurements conducted in both modes (rPPG and PPG) and both operating systems (iOS and Android).

Conclusions

This report summarizes the results of validation experiments in which Binah.ai's Heart Rate measurements were found to be highly correlated with the measurements of the reference device.

References

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