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). HR 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 HR is 60 to 100 beats for healthy adults. Tachycardia, a high HR, is defined as above 100 bpm at rest. Bradycardia, a low HR, is defined as below 60 bpm at rest.[3]

The relationship between elevated resting HR and cardiovascular risk has been demonstrated in several large-scale epidemiological studies. Those studies provide strong confirmation that increased HR 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 HR is clear.

Binah.ai's HR algorithm uses the photoplethysmography (PPG) signal recorded from facial skin tissue (remote PPG - rPPG). The algorithm identifies the heartbeat peaks, which represent the contraction of heart ventricles.

Definitions:
Heart Rate is defined as the average number of heart beats per minute [bpm].

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

Methods

Binah.ai's HR measurements were compared to the Covidien Nellcor™ finger pulse oximeter measurements in healthy participants and participants who suffer from hypertension.

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.

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 and to avoid any movement (including talking). Each recording lasted approximately 60 seconds.

Statistical analysis:
Accuracy was calculated using the following parameters:

$$AE\ (Absolute\ Error) = \ App_i - Ref_i$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(App_i - Ref_i)^2}{N}}$$

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|App_i - Ref_i|$$

When,
N is the number of data points.
App is the measurement of the Binah.ai's application.
Ref is the measurement of the reference device.
i is the index number of the measurements.

Confidence intervals (CI) were calculated using the bootstrap method and indicate where the estimator (i.e., RMSE) would fall, with 95% confidence, for future samples.

Participants with outlier AE (defined as 3 standard deviations or more above the mean) and participants with invalid reference device values were excluded from analysis.

For this report, the Binah.ai's SDK 4.10.1 version was used.
The measurements were recorded by the mobile device models listed below.
iOS: iPhone 11 Pro, iPhone 13, iPhone 13 Pro, iPhone 13 Pro Max, iPad 6th gen.
Android: Samsung S10, Samsung S21, Samsung S21 Ultra, Pixel 6 Pro, Sony Xperia (SOV51), Huawei P30 Lite.

Results

Demographic Data:

Table 1 includes participants' demographic data for each operating system (iOS and Android).

Operating System	Number of Participants	Age Range (average)	Sex	Fitzpatrick Skin Tone *
iOS	221	18-84 (36)	F (43%), M (57%)	1 (0%), 2 (36%), 3 (54%), 4 (9%)
Android	209	18-84 (36)	F (41%), M (59%)	1 (0%), 2 (37%), 3 (54%), 4 (8%)

Table 1: Demographic data for experiments using phones with an iOS and Android operating systems.
* Fitzpatrick skin tone classifications are: 1- Pale white, 2- white, 3- Darker white, 4- Light brown, 5- Brown, 6- Dark brown or black.

Accuracy Data:

Table 2 includes accuracy data for iOS and Android (RMSE, RMSE CI 95%, MAE±SD). The AE < 1, 2, 3 bpm columns present the number (and percentage) of measurements with an absolute error, which is smaller than 1, 2, 3 bpm respectively.

Operating System	Vital Sign	Number of measurements	RMSE	RMSE CI 95%	MAE±SD	AE < 1bpm	AE < 2bpm	AE < 3bpm
iOS	**HR (bpm)**	915	0.8	[0.7, 0.9]	0.6±0.6	793 (87%)	892 (97%)	907 (99%)
Android	**HR (bpm)**	829	0.7	[0.6, 0.8]	0.4±0.6	758 (91%)	811 (98%)	821 (99%)

Table 2: RMSE, RMSE CI 95%, MAE±SD, and number of participants (and percentage) with AE < 1, 2, 3 bpm for measurements using phones with an iOS and Android operating systems, when compared to the reference device. CI were calculated using the bootstrap method. Abbreviations: RMSE - Root Mean Square Error, CI - Confidence Intervals, MAE -Mean Absolute Error, SD - Standard Deviation, AE – Absolute Error.

Pearson correlations between Binah.ai's HR estimations versus Covidien NellcorTM pulse oximeter measurements were calculated and presented in **Figure 1**. Pearson correlation coefficients (R values) were very high for both operating system (Android and iOS).
The Bland-Altman plots for comparison between measurements of the two methods (Binah's and the reference device) are presented in **Figure 2**.

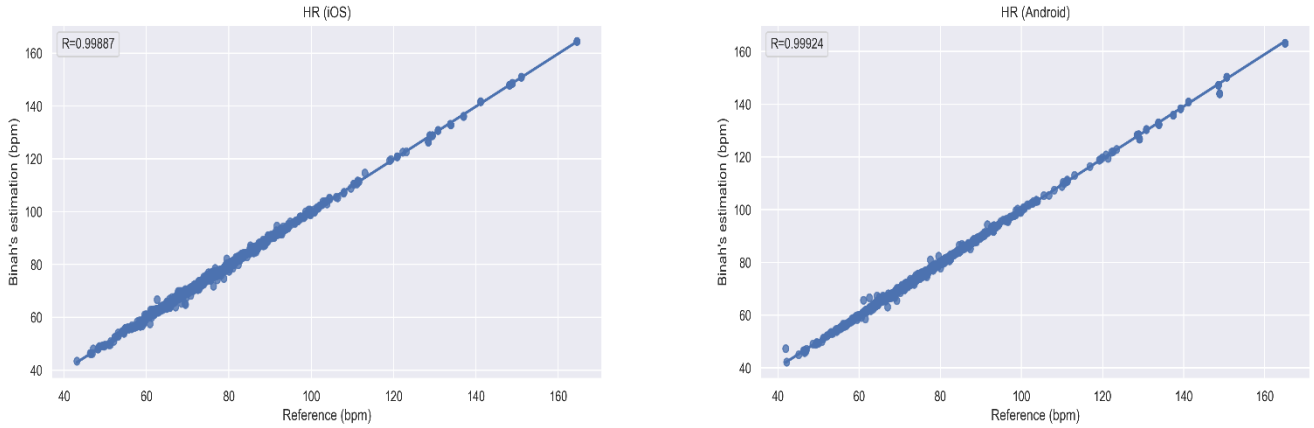

Figure 1: Binah.ai's HR estimation vs. reference device measurements. Pearson correlation was calculated and correlation coefficients are presented on each plot (R). Plots describe measurements conducted with both operating systems (iOS and Android).

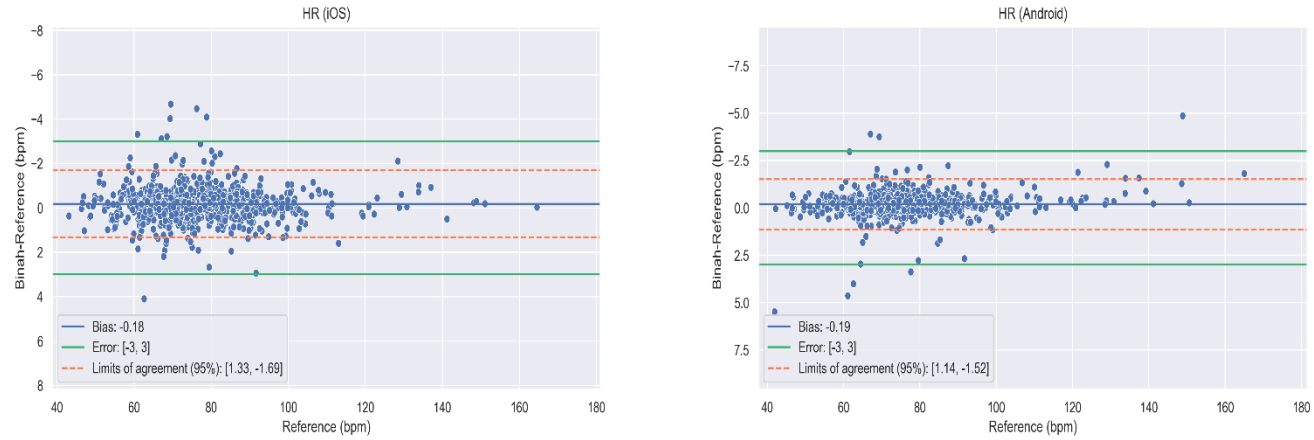

Figure 2: Bland-Altman plots for comparison between HR measurements of the two methods (Binah's and the reference device). Plots describe measurements conducted with both operating systems (iOS and Android). The "Bias" line stands for the mean difference between measurements of Binah.ai and the reference device, the "Error" lines represent the value of the accuracy criterion, the "Limits of agreement" lines mark the limit of 95% of the samples.

Conclusions

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

References

1. Betts, J. G. Heart Anatomy. in *Anatomy & physiology* 787–846 (2013).
2. Zhang, G. Q. & Zhang, W. Heart rate, lifespan, and mortality risk. *Ageing Res. Rev.* **8**, 52–60 (2009).
3. American Heart Association. All About Heart Rate (Pulse). (2017).
4. Dyer, A. R. *et al.* Heart rate as a prognostic factor for coronary heart disease and mortality: Findings in three Chicago epidemiologic studies. *Am. J. Epidemiol.* **112**, 736–749 (1980).
5. Kannel, W. B., Kannel, C., Paffenbarger, R. S. & Cupples, L. A. Heart rate and cardiovascular mortality: The Framingham study. *Am. Heart J.* **113**, 1489–1494 (1987).
6. Gillum, R. F., Makuc, D. M. & Feldman, J. J. Pulse rate, coronary heart disease, and death: The NHANES I Epidemiologic Follow-up Study. *Am. Heart J.* **121**, 172–177 (1991).
7. Diaz, A., Bourassa, M. G., Guertin, M. C. & Tardif, J. C. Long-term prognostic value of resting heart rate in patients with suspected or proven coronary artery disease. *Eur. Heart J.* **26**, 967–974 (2005).