January 2020

Comparative Study between Wearable Sensor and Cuff Arm Blood Pressure Meter in Measuring Blood Pressure and Heart Rate Monitor Using Statistical Approach

E Cheng

E Lim

W H. Tan

W Mustafa

S Syed Idrus

See next page for additional authors

PAPER • **OPEN ACCESS**

Comparative Study between Wearable Sensor and Cuff Arm Blood Pressure Meter in Measuring Blood Pressure and Heart Rate Monitor Using Statistical Approach

To cite this article: E M Cheng *et al* 2020 *J. Phys.: Conf. Ser.* **1529** 022082

Comparative Study between Wearable Sensor and Cuff Arm Blood Pressure Meter in Measuring Blood Pressure and Heart Rate Monitor Using Statistical Approach

E M Cheng[1], E A Lim[2], W H Tan[1], W A Mustafa[3], S Z Syed Idrus[4], N F Mohd Nasir[1], M Abdulmalek[5], H G Beh[6], Y S Lee[3], and S N A Mou Yusop[1]

[1]School of Mechatronic Engineering, Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis, Malaysia.
[2]Institute of Engineering Mathematics, Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis, Malaysia.
[3]Department of Electrical Engineering Technology, Faculty of Engineering Technology, Sg. Chuchuh Campus, Universiti Malaysia Perlis, 02100 Padang Besar, Perlis, Malaysia.
[3]Sport Engineering Research Center, Campus Pauh Putra, Universiti Malaysia Perlis, 02100 Padang Besar, Perlis, Malaysia.
[4]Center of Excellence Geopolymer and Green Technology, Universiti Malaysia Perlis, 01000 Kangar, Perlis, Malaysia.
[5]University of Wollongong in Dubai, Faculty of Engineering and Information Sciences, Block 15, Dubai Knowledge Park, PO Box 20183, Dubai, United Arab Emirates.
[6]Faculty of Science and IT, Department of Fundamental and Applied Sciences, Universiti Teknologi PETRONAS, 32601, Seri Iskandar, Perak Darul Ridzuan, Malaysia.

emcheng@unimap.edu.my

Abstract. Heart rate and blood pressure monitoring during physical activity and exercise allow early diagnosis of cardiovascular disease (CVD) and obesity. Plethysmography(PPG) has become popular worldwide for personal health monitoring systems. However, the accuracy of this technology in monitoring heart rate and blood pressure during activity is poorer than at rest. It limits their application. In this study, the performance of the wearable sensor and arm cuff blood pressure meter in measuring heart rate and blood pressure on the left arm is compared. Five healthy volunteers conducted the same exercise protocols, i.e., at rest, jump rope, treadmill walking, running (long run) and sprinting (short-run). The wearable sensor shows a mean absolute percentage error in 6.08% and Pearson coefficient in 0.61. Besides, the lowest range of 95% limit of agreement for diastolic blood pressure during treadmill run was found at 30.50.

1. Introduction

Implementation of a healthy lifestyle is always a challenge in these days due to increasing rates of urbanization and a diet filled with processed foods have led us to a sedentary lifestyle [1]. A systematic analysis concludes that the proportions of adults having over body-mass index or obesity were rising and causing 3.4 million deaths worldwide [2]. On top of that, the Global Burden of Disease estimated that cardiovascular disease (CVD) is the main death factor with 15 million deaths worldwide in 2010 and annual increment was expected.

In this day and age, many people aware that the vital sign monitor, is essential to ensure the healthiness of an individual for longevity. Great attention arose among people on the importance of physical fitness have developed an interest to monitor their vital signs regularly. Medical checkup might be the best approach for vital sign monitoring. However, it is time-consuming, especially for those who have a busy working schedule. Although the current electronic blood pressure meter is cordless and convenient, this blood pressure is bulky in size and unhandy. Therefore, the advent of wearable devices receive great attention due to their facile interaction with the human body for vital sign, e.g. monitoring heart rate, blood pressure, number of burned calories, steps and distance count and etc. [3] Nevertheless, the accuracy of this wearable sensor in monitoring blood pressure and heart rate is questionable. Many users of this wearable device discontinue the usage within 6 months after purchase due to its inaccuracies [6]. The inaccuracies might be attributed to spot measurement, contact measurement and motion artifacts corruption during the usage of photoplethysmography (PPG) in measuring heart rate and blood pressure [4]. In addition, literature [5] reported that PPG can measure systolic blood pressure more accurate diastolic blood pressure estimation [5]. It causes arguments among users and manufacturers. In this work, the wearable sensor was compared with conventional and electronic arm cuff blood pressure meter to verify the performance wearable sensor statistically through different kind of exercises.

2. Methodology

2.1 Procedures

Five adult participants with normal body mass index and no ill medical history were recruited from Universiti Malaysia Perlis. These recruited participants conducted each activity for 5 times and each time blood pressure and heart rate were measured on the left arm. All participants were given an overview of procedures, potential risks. Withal, they need to answer the National Academy of Sports Medicine PAR Questionnaire and consent letter. All participants must be free from any exhaustive activity 24 hours before the training day. They were also advised to have a light meal before any activity started.

2.2 Monitor devices

2.2.1 Plethysmography(PPG) in a wearable device

A real-time dynamic wrist fitness tracker that applies the photoplethysmography principle through an optical sensor located at the backside of the tracker. Participants need to wear it tightly in 2cm below the ulna joint to ensure the full contact between the optical sensor user's skin. This fitness tracker is connected to a mobile phone through a mobile application where all data can be acquired.

2.2.2 Fully Automatic Arm Style Electronic Blood Pressure Monitor (arm cuff)

An oscillometry blood pressure meter that works by wrapping the cuff to the upper arm for blood pressure and heart rate measurement. Participants need to wrap the cuff 2-3cm from the brachial artery and lay the hand with the same level of the heart.

2.3 Data Analysis

Mean and Standard Deviation (SD) of heart rate and blood pressure were calculated from the measured blood pressure and heart rate after each activities using wearable sensor and arm cuff blood pressure meter as listed in Table 1. These collected data were compared and evaluated evaluated through Bland-Altman plot, Mean Absolute Percentage Error (MAPE) and Pearson Correlation, r by using Statistical Package for Social Science (SPSS) software [6]. Bland-Altman plot shows the agreement of measurement between two data collected from wearable sensor and blood pressure meter where the differences between the collected data from the wearable sensor and blood pressure meter [7]. Range of 95% confident interval of upper and lower limits of agreement is used to analyze the consistency of collected data visually in the Bland-Altman plot. Pearson product-moment correlation or r is a numerical measure used in determining the strength among measurement [8]. The mean absolute percentage error (MAPE) is calculated to provide a gauge of general measurement error of the monitors [9].

2.4 Training Plan

Participants conducted the planned activities for mileage and track run at Stadium UniMAP. Each participant conducted all planned activities in turn. Five different activities are assigned, i.e., rest, jump rope, treadmill, long and short run to collect heart, systolic and diastolic blood pressure for comparison. Hence, the accuracy of the wearable sensor and blood pressure meter in measuring heart rate and blood pressure could be compared. During measurement, participants were advised to remain silent or not to make any unnecessary movement to avoid any motion artifact from a physical movement which might cause the ill effect to the measured results. Participants blood pressure and heart rate were measured in the sitting position after each activity using a wearable sensor and blood pressure meter.

Blood pressure and heart rate measurement at rest condition was taken 3 minutes after registration. Then, the participants start each planned activities individually without assistance. Blood pressure and heart rate measurement were conducted immediately after each activity was finish. The sequence of conducted activities is jump rope (1 minute), long run (2.4 km), short run (100 m) and treadmill run (10 minutes). Next, the participant proceeds to activity scheduled for the week whether it is (long run) jogging, (short run) sprinting or treadmill walking.

3 Result and Discussion

In Table 1, heart rate for long run shows the largest standard deviation (SD) while the SD is the smallest at rest. Treadmill running lists the smallest SD in systolic blood pressure measurement and short run shows the smallest SD for diastolic blood pressure. Short run and at rest shows the biggest deviation in systolic and diastolic blood pressure measurement respectively. These observations indicate that the wearable sensor has poorer consistency in measuring heart rate and blood pressure measurement when compared with arm cuff blood pressure meter. It might due to loose contact between optical sensor at the wearable device and skin of participant, or presence of impurities that cause a blockage (e.g. sweat, dust and etc) to the optical signal.

Table 1: Bland-Altman Analysis for all activities

Parameter	Activity	Absolute Mean Error	SD	Bland-Altman Plots 95% Limit of Agreement		
				+1.96 SD	-1.96 SD	Range
Heart Rate	Rest	3.60	8.87	13.79	-20.99	34.77
	Jump Rope	12.70	19.99	26.48	-51.88	78.36
	Treadmill	3.52	14.57	25.04	-32.08	57.11
	Long Run	3.36	34.60	64.46	-71.18	135.63
	Short Run	6.80	16.44	39.02	-25.42	64.44
Systolic Blood Pressure	Rest	2.40	12.8	22.69	-27.49	50.18
	Jump Rope	6.84	13.27	32.85	-19.17	52.02
	Treadmill	1.72	8.06	17.52	-14.08	31.60
	Long Run	4.76	10.35	25.05	-15.53	40.57
	Short Run	18.84	13.37	7.37	-45.05	52.41
Diastolic Blood Pressure	Rest	4.92	25.06	54.04	-44.20	98.24
	Jump Rope	3.96	7.80	11.33	-19.25	30.58
	Treadmill	1.84	7.78	13.41	-17.09	30.50
	Long Run	5.64	9.58	13.14	-24.42	37.55
	Short Run	6.44	7.26	7.79	-20.67	28.46

In Table 2, measured heart rate through long run shows insignificant correlation (r = 0.03) compared with other activities. Likewise, the measured systolic blood pressure shows the insignificant correlation of short run with 0.06 of r value. Meanwhile, measured diastolic blood pressure at rest shows poor correlation at rest condition with 0.122.

The accuracy of the wearable device in measuring heart rate and blood pressure is different for each activity modality. The measured heart rate during jump rope shows the largest MAPE with 21%. It might be due to the motion artifact caused by arm swinging during activity. Literature [10,11] reported that removal or attenuation of motion artifact in the PPG of the wearable sensor is very challenging because the PPG sensor detects dynamic changes on one spot measurement. Previous studies [13,14] also reported that measured data from heart rate in high-speed activity using wearable monitor is more accurate than low-speed activity [11,12]. High-speed exercises increase heart rate as the number of cardiac cycles per time frame is increasing to supply oxygen demand. Oxygenated blood is pumped throughout the body in high pressure and high velocity from the heart via arteries. Since narrow openings of arterioles impeding the exit of blood from arteries caused by ventricular contraction when blood is pumped to all parts of the body, the pulse in the radial artery is stronger than rest condition [13]. MAPE of measured heart rate for short run is higher than long run about 1.24%. This is because, wearable sensor applies a PPG based method to measure changes in blood volume in capillaries under the skin and as oxygenated blood deliverable is increasing, the optical sensor is unable to detect variations in blood volume associated with the pulse of blood caused by each cardiac contraction during short run [4,14].

PPG is not suitable to measure blood pressure because blood pressure is the pressure within the vessels when blood flows to all parts of the body. Implementation of pulse transit time to calculate blood pressure from the blood volume in capillaries is unreliable because the blood pressure and velocity in capillaries decrease over time as the blood flow from the artery to a vein. It can be seen that the measured systolic and diastolic blood pressure for long run shows the smallest MAPE with 6.08% and 9.52%, respective when compared with rest and short run.

Table 2: Pearson Correlation and MAPE

Parameter	Activity	Pearson Correlation, r	Mean Absolute Percentage Error, MAPE, (%)
Heart Rate	Rest	0.61	9.94
	Jump Rope	0.55	21.00
	Treadmill	0.44	20.50
	Long Run	0.03	14.72
	Short Run	0.34	15.96
Systolic Blood Pressure	Rest	0.33	9.00
	Jump Rope	0.17	7.13
	Treadmill	0.57	7.57
	Long Run	0.16	6.08
	Short Run	0.06	8.35
Diastolic Blood Pressure	Rest	0.12	18.50
	Jump Rope	0.31	17.51
	Treadmill	0.56	10.51
	Long Run	0.56	9.52
	Short Run	0.42	11.07

4 Conclusion

Five volunteers have been recruited to conduct jump rope, treadmill, long and short run. Their heart rate, systolic and diastolic blood pressure was measured using a wearable device with PPG based sensor and arm cuff electronic blood pressure meter. Statistical analysis was conducted on the collected data from participants to find a range of 95% limit of the agreement, Pearson coefficient, and mean absolute percentage error. Measured heart rate at rest exhibit highest Pearson coefficient, i.e. 0.61 for heart rate at rest. Meanwhile, MAPE of heart rate and blood pressure measured by the wearable sensor are different. They exhibit the lowest MAPE at different activity. Heart rate and blood pressure during jump rope, at rest and short run show high MAPE compared to other activities. Besides, the wearable device indicates that blood pressure has an insignificant correlation with heart rate as reading from each activity shows significant difference among Pearson coefficient and a range of 95% limit of agreement for heart rate and blood pressure measurement. Suffice to say, PPG-based wearable device exhibit inconsistent results. There is still improvement are required for better accuracy. The reading from the wearable device can be referenced, instead of an indicator of the vital sign.

Acknowledgment

The authors gratefully acknowledge the support from Universiti Malaysia Perlis for providing facilities for this research work.

References

[1] Thomas S S, Nathan V, Zong C, Soundarapandian K and Member S 2016 BioWatch : A Noninvasive Wrist-Based Blood Techniques for Posture and Subject Variability **20** 1291–300

[2] Ng M, Fleming T, Robinson M, Thomson B, Graetz N, Margono C, Mullany E C, Biryukov S, Abbafati C, Abera S F, Abraham J P, Abu-Rmeileh N M E, Achoki T, AlBuhairan F S, Alemu Z A, Alfonso R, Ali M K, Ali R, Guzman N A, Ammar W, Anwari P, Banerjee A, Barquera S, Basu S, Bennett D A, Bhutta Z, Blore J, Cabral N, Nonato I C, Chang J-C, Chowdhury R, Courville K J, Criqui M H, Cundiff D K, Dabhadkar K C, Dandona L, Davis A, Dayama A, Dharmaratne S D, Ding E L, Durrani A M, Esteghamati A, Farzadfar F, Fay D F J, Feigin V L, Flaxman A, Forouzanfar M H, Goto A, Green M A, Gupta R, Hafezi-Nejad N, Hankey G J, Harewood H C, Havmoeller R, Hay S, Hernandez L, Husseini A, Idrisov B T, Ikeda N, Islami F, Jahangir E, Jassal S K, Jee S H, Jeffreys M, Jonas J B, Kabagambe E K, Khalifa S E A H, Kengne A P, Khader Y S, Khang Y-H, Kim D, Kimokoti R W, Kinge J M, Kokubo Y, Kosen S, Kwan G, Lai T, Leinsalu M, Li Y, Liang X, Liu S, Logroscino G, Lotufo P A, Lu Y, Ma J, Mainoo N K, Mensah G A, Merriman T R, Mokdad A H, Moschandreas J, Naghavi M, Naheed A, Nand D, Narayan K M V, Nelson E L, Neuhouser M L, Nisar M I, Ohkubo T, et al 2014 Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: a systematic analysis for the Global Burden of Disease Study 2013 *Lancet* **384** 766–81

[3] An B W, Shin J H, Kim S-Y, Kim J, Ji S, Park J, Lee Y, Jang J, Park Y-G, Cho E, Jo S and Park J-U 2017 Smart Sensor Systems for Wearable Electronic Devices *Polymers (Basel).* **9** 303

[4] Sun Y and Thakor N 2016 Photoplethysmography Revisited: From Contact to Noncontact, from Point to Imaging *IEEE Trans. Biomed. Eng.* 1–16

[5] Soltan Zadi A, Alex R, Zhang R, Watenpaugh D E and Behbehani K 2018 Arterial blood pressure feature estimation using photoplethysmography *Comput. Biol. Med.* **102** 104–11

[6] Cleophas T J and Zwinderman A H 2010 *SPSS for Starters*

[7] Vesna I 2009 Understanding Bland Altman Analysis *Biochem. Medica* **19** 10–6

[8] Akolgu H 2018 User's Guide to Correlation Coefficient *Turkish J. Emerg. Med.* **8** 91–3

[9] de Myttenaere A, Golden B, Le Grand B and Rossi F 2016 Mean Absolute Percentage Error for regression models *Neurocomputing* **192** 38–48

[10] Chen M De, Kuo C C, Pellegrini C A and Hsu M J 2016 Accuracy of Wristband Activity

Monitors during Ambulation and Activities *Med. Sci. Sports Exerc.*

[11] Gillinov S, Etiwy M, Wang R, Blackburn G, Phelan D, Gillinov A M, Houghtaling P, Javadikasgari H and Desai M Y 2017 Variable accuracy of wearable heart rate monitors during aerobic exercise *Med. Sci. Sports Exerc.* **1** 1697–703

[12] Wallen M P, Gomersall S R, Keating S E, Wisløff U and Coombes J S 2016 Accuracy of heart rate watches: Implications for weight management *PLoS One* 1–11

[13] Campbell N A, Reece J B, Urry L A, Cain M L, Wasserman S A, Minorsky P V. and Jackson R B 2014 *Biology, A Global Approach* (Pearson Education Ltd.)

[14] Alian A A and Shelley K H 2014 Photoplethysmography *Best Pract. Res. Clin. Anaesthesiol.* **28** 395–406