Temporal Changes of Fiducial Seismocardiogram Points Due to Different Sensor Placements on the Chest

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Abstract

This research focused on morphology changes due to sensor placement of the seismocardiogram (SCG). Data was recorded from seven male subjects, in supine position, accelerometers were placed in both vertical (V) and horizontal (HL) positions leading from the xiphoid process. The subjects were asked to perform a Valsalva maneuver and signals were analyzed before and after. Features of aortic valve closing (AC), aortic valve opening (AO) and the mitral valve closing (MC), were annotated. The features were performed for five cardiac cycles for every participant. The average of absolute percentage changes over the seven subjects was calculated for both V and HL cases. The correlation coefficients between all signals were also calculated to quantify the linear relationships. Moving ¼ of the length of the sternum changes MC point an average of 3.2%, AO annotation 2.6% but AC did not change. At the suprasternal notch annotations change significantly. HL array placement near apex showed negative correlation and inversion of peaks. It was found that the signal morphology does depend on the placement upon the sternum, however, placement differences might not induce significant changes in the timing fiducial points of SCG.

1. Introduction

Cardiovascular diseases (CVD) are the leading causes of death worldwide [1]. In the United States, one person dies every 37 seconds from CVD [2], resulting in an estimated cost of $351.2 billion in 2014-2015 [3]. Early detection and diagnosis of CVD depends a variety of clinical modalities, including electrocardiogram (ECG), echocardiography, cardiac catheterization, computerized tomography, and magnetic resonance imaging scans [4]. ECG plays an important role in the initial diagnosis and monitoring of CVD. ECG measures the cardiac electrical activity that can diagnose diseases such as myocardial ischemia or arrhythmias. However, it does not provide information about the mechanical activity of the heart, which can aid in diagnosis of cardiac contractility dysfunction. Echocardiography is one of the most accepted methods for diagnosing heart diseases by providing a picture of the heart in real time with high fidelity [5, 6]. However, the echocardiography exam has high operational cost and require specialists.

SCG has emerged as a promising technique for the assessment of cardio-mechanical function. SCG measures local vibrations due to the heartbeat against the chest [7, 8]. Such information might be used in complement with other methods (such as ECG, and echocardiography) for clinical diagnoses of heart diseases.

Past investigations have looked at the efficiency and applicability of SCG in monitoring cardiac events. It was shown that it is possible to detect cardiac events observed in echocardiography using SCG [9, 10]. During SCG recording, these events include mitral valve closure (MC), aortic valve opening (AO), isovolumic moment (IM) during the systole, and aortic valve closure (AC) during diastole [11] (Figure 1). Detection of these features depends on SCG morphology, which is influenced by many factors such as: body posture, sensors placement, and inter-subject variability [12]. Thus, the goal of this work is to investigate changes in the morphology of SCG when the sensors are placed along the sternum or to the left of the chest.

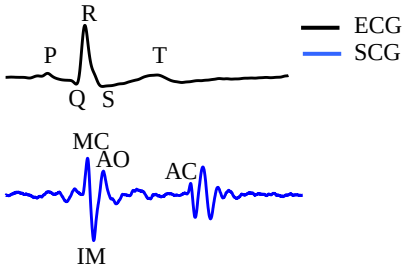

Figure 1: ECG and SCG waveforms showing cardiac events.

2. Methodology

Simultaneous ECG (lead III, Biopac MP160), and five SCG (Accelerometer Z axis, Analog Devices Inc., 1-Channel Amplifier Class AB SC-70-5, Maxim Integrated) signals were collected from seven male subjects (age: 30.28 ± 6.6 years, height: 166.57 ± 13.98 cm, and weight: 75.14 ± 10.2 Kg). There were two experiments, first vertical (V) SCG sensors were placed vertically along the sternum. Second Horizontal (HL), sensors were placed horizontally between the xiphoid process and the heart apex. Data was recorded from each subject in a supine position for 5 minutes with a sampling frequency of 2 kHz. In the first minute, subjects were asked to inhale and exhale for 10 seconds each, while in the fourth minute they performed a Valsalva maneuver for 20 to 25 seconds. The second, third, and fifth minute are baseline. The experimental set up of data recording for V and HL configurations is depicted in Figure 2.

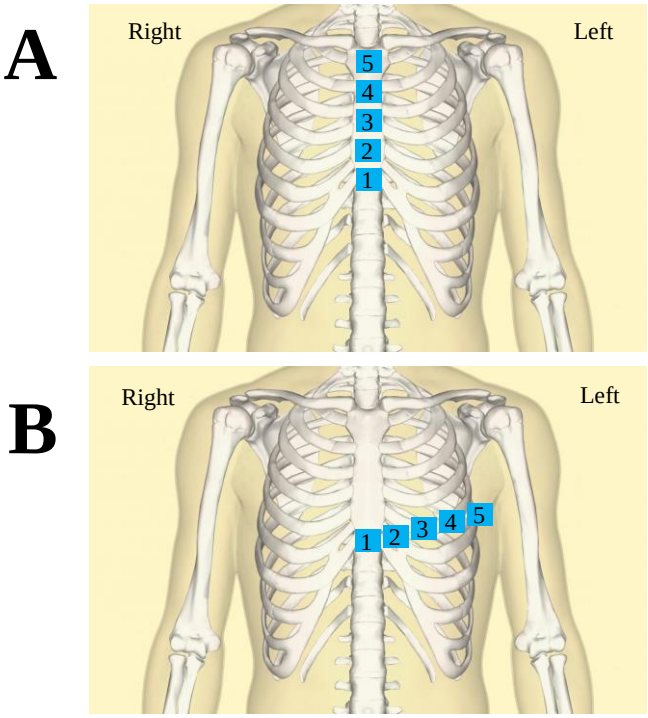

Figure 2. **A** Vertical and **B** Horizontal sensor arrays

The data acquisition was performed using BIOPC systems and two researchers did the signals annotation manually in order to avoid any errors that might affect the output of this study. All data were recorded at Biomedical Engineering Research Laboratory at the University of North Dakota, United States. The study was conducted under an ethics approval from the University of North Dakota and all participants signed informed consent forms prior to the experiment.

3. Results

Visualization of the SCG plots for one subject can be shown in Figure 3. These plots give a representation of five cardiac cycles of SCG signals collected in vertical (A) and horizontal (B) positions across the chest as described earlier. On the vertical orientation of the sensor array, moving up to ¼ of the length of the sternum changes the mitral valve closure point on an average of 3.2%, aortic valve opening annotation 2.6% and aortic valve closing did not change at all. Shifting the sensor to the top position upon the suprasternal notch significantly changed the annotations (Figure 3, A). The results were almost the same for cycles happening immediately after the Valsalva maneuver. On the horizontal sensor array across the chest there was a negative shift in correlation as the sensors moved towards the apex position of the chest. Represented visually the peaks started to invert relating to the negative correlation of SCG1 and SCG5 (Figure 3, B). The correlation coefficients vertical and horizontal are recorded in table 1 and table 2, respectively.

	SCG1	SCG2	SCG3	SCG4	SCG5
SCG1	1	0.77	0.57	0.28	0.05
SCG2	0.77	1	0.76	0.46	0.12
SCG3	0.57	0.76	1	0.68	0.28
SCG4	0.28	0.46	0.68	1	0.53
SCG5	0.05	0.12	0.28	0.53	1

Table 1: Correlation coefficients as a relationship between each SCG sensor in the array. The first two sensors above the xiphoid process (SCG 2 & SCG3) show a closer relationship in morphology to the typical SCG compared to the fourth and fifth SCG sensors (SCG4 & SCG5).

	SCG1	SCG2	SCG3	SCG4	SCG5
SCG1	1	0.66	0.42	0.08	-0.12
SCG2	0.66	1	0.74	0.33	-0.05
SCG3	0.42	0.74	1	0.65	0.14
SCG4	0.08	0.33	0.65	1	0.40
SCG5	-0.12	-0.05	0.14	0.40	1

Table 2: Correlation coefficients as a relationship between each SCG sensor in the horizontal array. As the sensors moved across the chest towards apex there is a negative correlation and inversion of peaks.

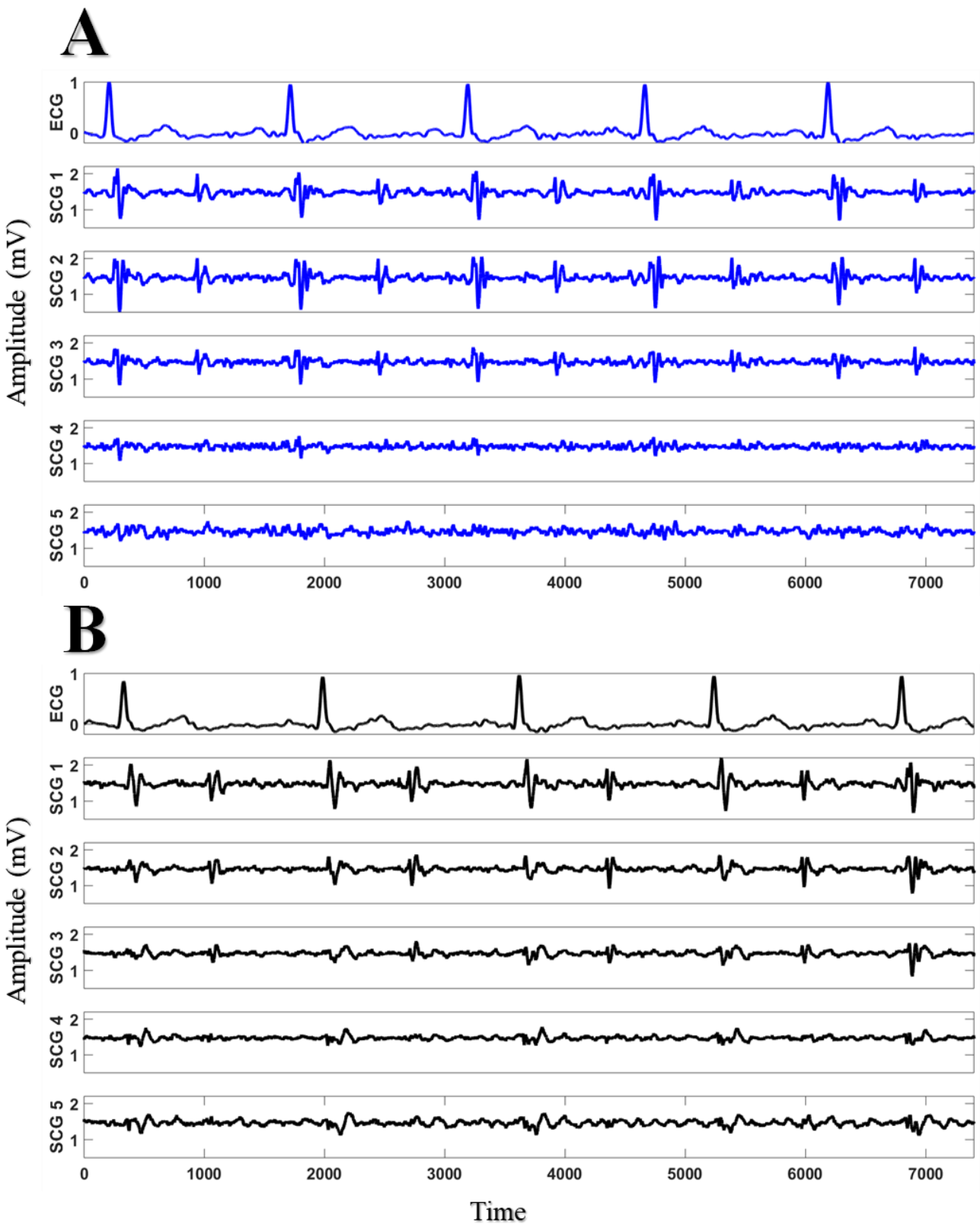

Figure 3: Both plots, top waveform is ECG and the second waveform are typical SCG placement on xiphoid process on sternum with x-axis time (ms). **A** represents the vertical sensor array waveform morphologies change based on sensor position. Third through fifth waveform are sensors leading up the chest, respectively. **B** represents the horizontal sensor array waveform morphologies change based on sensor position across the chest. The third through fifth waveform are sensors leading across the chest to apex, respectively.

4. Discussion

In this study the placement of SCG sensor arrays was conducted to investigate the signal morphology changes due to sensors placement. The traditional placement of SCG sensor is at the xiphoid process. In the work presented, vertical and horizontal placement of a five SCG sensor array was conducted to look not just at the morphology change but also to search the hypothesis of a better placement position closer to the heart. The correlation coefficients had shown that in the vertical sensor case (A) the SCG1 being on the xiphoid process had highest strength of signal and correlated to SCG2 and SCG3. Beyond SCG3 as the sensor array continued up the sternum the signal morphology had shown loss of peaks and information leading to lower correlation. In the case representation of the horizontal array (B) from the sensor array lead from xiphoid process SCG1 again having the highest strength of signal but the morphology of the signals leading to the apex of the heart, SCG2 to SCG 4, had retained the general shape of the SCG. However, in leading to SCG placement five, the horizontal array style of SCG placement yields an observation that correlated with the placement hypothesis. In correlation there is a negative value leading to the representation that the signals are inverting. This can be seen also in the signals leading closer to the apex location of the heart. As a corollary, as the sensors are moved closer to the heart there may be potential to still yield SCG morphologies. This in tandem with other techniques of cardiomechanical vibrations (e.g., apexcardiography) could provide higher fidelity cardiovascular monitoring without the need for multiple sensor placements of each technique.

4. Conclusions

This study comprised an investigation into analyzing mechanical vibration of the heart through SCG. The morphologies of this signal show information about how the heart is acting mechanically. How the morphologies change due to this sensor placement shows the sensitivity of this signal to vibration attenuation. Early detection and diagnosis of cardiovascular diseases rely on the clinical modalities of ECG, echocardiography, cardiac catheterization, computerized tomography, and magnetic resonance imaging scans. These techniques lack in the ability to provide critical information about the mechanical activity of the heart, which proves to be useful for diagnosis of cardiac contractility dysfunction and valvular diseases. Future works leading to better placement of the SCG can allow for bundled instrumentation including different techniques in tandem with SCG.

References

[1] Mc Namara, Kevin, Hamzah Alzubaidi, and John Keith Jackson. "Cardiovascular disease as a leading cause of death: how are pharmacists getting involved?." *Integrated pharmacy research & practice* 8 (2019): 1.

[2] Heron, Melanie P. "Deaths: leading causes for 2017." (2019).

[3] Benjamin, Emelia J., Paul Muntner, Alvaro Alonso, Marcio S. Bittencourt, Clifton W. Callaway, April P. Carson, Alanna M. Chamberlain et al. "Heart disease and stroke Statistics-2019 update a report from the American Heart Association." *Circulation* (2019).

[4] Lin, Wen-Yen, Wen-Cheng Chou, Po-Cheng Chang, Chung-Chuan Chou, Ming-Shien Wen, Ming-Yun Ho, Wen-Chen Lee et al. "Identification of location specific feature points in a cardiac cycle using a novel seismocardiogram spectrum system." *IEEE journal of biomedical and health informatics* 22, no. 2 (2016): 442-449.

[5] O. T. Inan *et al.*, "Ballistocardiography and seismocardiography: a review of recent advances," *IEEE Journal of Biomedical and Health Informatics*, vol. 19, no. 4, pp. 1414–1427, Jul. 2015, doi: 10.1109/JBHI.2014.2361732.

[6] M. Etemadi and O. T. Inan, "Wearable ballistocardiogram and seismocardiogram systems for health and performance," *Journal of Applied Physiology*, vol. 124, no. 2, pp. 452–461, Aug. 2017, doi: 10.1152/japplphysiol.00298.2017.

[7] B. S. Bozhenko, "Seismocardiography—a new method in the study of functional conditions of the heart," Ter Arkh, vol. 33, pp. 55–64, 1961.

[8] D. M. Salerno and J. Zanetti, "Seismocardiography for monitoring changes in left ventricular function during ischemia," Chest J., vol. 100, pp. 991–993, 1991.

[9]. Zanetti, J. "Seismocardiography: A new technique for recording cardiac vibrations concept, method, and initial observations." J. Cardiovasc. Technol. 1990, 9, 111–118.

[10] Crow, R.S.; Hannan, P.; Jacobs, D.; Hedquist, L.; Salerno, D.M. "Relationship between seismocardiogram and echocardiogram for events in the cardiac cycle." Am. J. Noninvasive Cardiol. 1994, 8, 39–46.

[11] Laurin, A., Khosrow-Khavar, F., Blaber, A. P., & Tavakolian, K. (2016). "Accurate and consistent automatic seismocardiogram annotation without concurrent ECG." *Physiological measurement*, *37*(9), 1588.

[12] Dürichen, R., Verma, K. D., Yee, S. Y., Rocznik, T., Schmidt, P., Bödecker, J., & Peters, C. (2018, October). "Prediction of electrocardiography features points using seismocardiography data: a machine learning approach." In *Proceedings of the 2018 ACM International Symposium on Wearable Computers* (pp. 96-99).

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