Evaluating the Effects of Respiration, Body Orientation and Heart Rate on Body Surface Potentials in Healthy Subjects

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Abstract

In this study we investigated the influence of inspiratory and expiratory hold, reclined body position (45˚) and exercise-increased heart rate (HR) on the 67-electrode body surface potential maps (BSPM) of healthy subjects. We computed difference maps between these conditions and resting supine position of R, S, T amplitudes. Within these difference maps we determined the value from leads with the maximal (positive and negative) differences. The location (lead) and occurrence of these maximal differences were visualized on a generic 3D torso model. Ten healthy individuals were included (Five male), with a median age of 28 yrs and showing a median HR increase of 28 bpm post exercise. From the results, inspiratory hold and increased HR had the greatest effect on the body surface potentials, specifically on the left sided leads. These findings will help to differentiate normal variations from pathological changes in signals obtained with the 67-electrode BSPM system.

1. Introduction

Body Surface Potential Mapping (BSPM) provides information about the spatial, temporal, and magnitude aspects of cardiac electrical activity [2]. Unlike conventional electrocardiograms (ECGs), BSPM employs multiple electrodes placed across the chest and back to facilitate sophisticated examination [1]. The accuracy and evaluation of BSPM are influenced by a variety of physiological factors, such as body orientation, respiration, and heart rate. Previous studies have illustrated the substantial influence of body position and respiration on 12-lead ECG readings [3] [5]. There are no exclusive resources describing the impacts of above-mentioned confounding factors on 67-lead BSPM. So, in this study we investigate the impact of these factors on our 67-electrode BSPM study, focusing on identifying the largest amount of change and its specific location.

2. Methods

2.1. Study Population and data acquisition

Participants were included in this study if they had a regular sinus rhythm and did not have cardiac related complaints (chest pain, shortness of breath, palpitations etc.). 67-lead BSPM was continuously recorded (Figure 1) using a Biosemi acquisition set-up under resting supine position for 50 seconds, followed by 10-second inspiratory and expiratory holds both in supine position, then another 50 seconds of recording with the upper body reclined at a 45-degree angle. Following this, the participants were instructed to perform 30 squats to elevate their HR, then a post-exercise BSPM was recorded for 5 minutes while they were in a supine position. For each condition, the first 10 seconds after noise and artifacts subsided were analyzed.

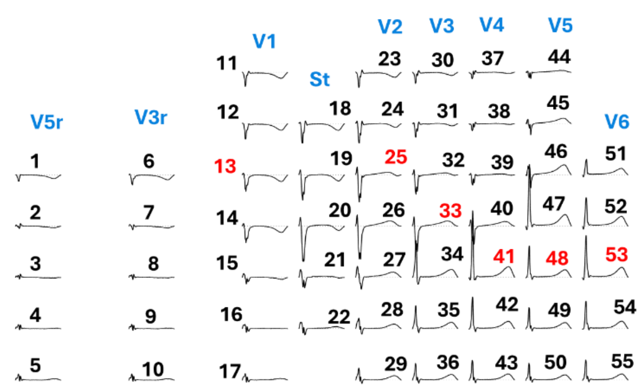

Figure 1. BSPM recording with lead numbers (back leads excluded), where the position of each column is indicated in blue, and 12 lead electrodes are highlighted (St = Sternum).

2.2. Data processing

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The entire data processing and analysis were done using MATLAB (R2016B). We utilized the original sampling rate of 2048 Hz and applied a high-pass filter at 0.25 Hz to correct for baseline shift in the BSPM signal and a customized notch filter [4] to suppress powerline noise (50 Hz). We computed the median beats for each condition based on 10 second BSPM data. The QRS onset, QRS end, and T-end were manually annotated on the Root Mean Square (RMS) signal of the median beat from resting supine position. We used this as a reference to annotate the corresponding fiducials in the other conditions (respiration, body orientation, and increased HR) for each subject, thereby streamlining the extraction of median beats. Finally, a baseline correction from QRS-onset to T-end was applied.

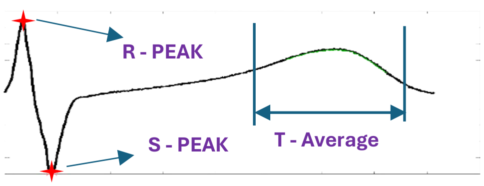

Figure 2. An example of R, S, T peaks extracted from a median beat.

From the computed median beats, we extracted R, S, T amplitudes. R and S waves and their minimum amplitude/duration were defined according to Annex FF of the standard "Particular requirements for the basic safety and essential performance of electrocardiographs" (IEC 60601-2-25:2011) [6].

First, we used a moving average (MA) filter on the resting median beats to reduce the effect of noise and cancel small narrow waves and we identified the peaks. Then we used the sample index of the found peaks to search in the original non-MA filtered median beat for the original amplitude as the amplitude of the median MA filtered beat was attenuated by the filtering.

In some subjects and for some leads, the T-wave morphology changed sign or became biphasic between different conditions. Therefore, we measured the T-wave amplitude as the average of a fixed (± 50 ms) window around the T-peak.

These methods (see also Figure 2) allowed us to effectively differentiate between actual R, S, T amplitude changes, noise and shifting morphology. We measured the heart rates for the post-exercise HR evaluation using all successive R-peaks in the measurement window.

2.3. Data Analysis

For a visual comparison, we computed R, S and T difference maps between resting supine condition and the following conditions: inspiratory and expiratory hold, reclined body position (45˚) and exercise-increased heart rate (HR). We also used a 3D generic torso model to visualize the location where the maximal amplitude changes (positive and negative) occurred and the frequency of their occurrence. This was visualized on a group level for the R, S and T amplitudes separately.

For the detected R, S, T peaks, we also identified the maximum positive and maximum negative difference between resting supine condition and the other conditions over all leads for each subject. Then we computed the median of these across all subjects along with the interquartile range (IQR), for each condition. These values were plotted on a box plot and the changes among conditions were evaluated.

3. Results

The effects of inspiratory and expiratory hold, reclined body position exercise-increased HR on 67-BSPM were evaluated in ten healthy volunteers, 5 males, 5 females, with a median age of 28 years. The change in wave morphology and the difference maps for R and S amplitude changes between resting supine condition and inspiratory hold of a single subject are displayed in figure 3 as a representative example. The S becomes deeper in lead 20 (a) while the R-wave increases in lead 35 and decreases in lead 52 (c). The general torso model is depicted in figures 3.1-3.4 for each condition, showing the location and frequency of occurrence of the maximum positive and negative amplitude changes across the ten subjects. The latter is represented by the color of the dots (red for a positive difference, blue for a negative difference. The frequency is represented by the size of the dot, with the smallest dot representing one subject). The back electrodes appear shaded, but very few maximal values were found on the back electrodes. Finally, the median and IQR among subjects of the maximal changes per condition are depicted in Figure 4 as box plots.

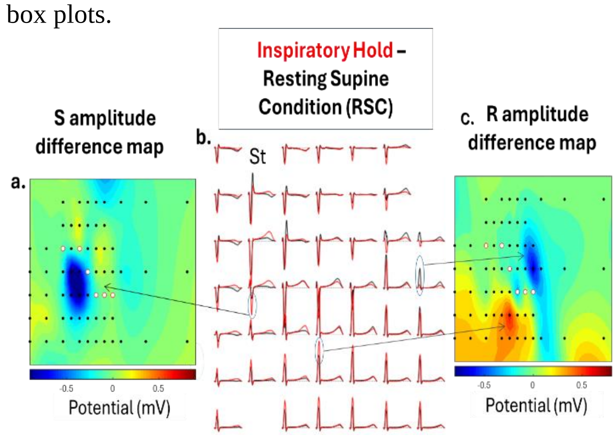

Figure 3. An example of a visual observation of the median beats between resting supine condition (black) and inspiratory hold (red). The corresponding isopotential maps color code the positive (red) and

negative (blue) differences for R amplitude **(c.)** and S amplitude **(a.).** The 12-lead frontal electrodes are highlighted by red circles**.**

3.1. Inspiratory hold, supine position

During inspiratory hold, the median largest positive differences for R, S, and T are 0.31 mV, 0.17 mV, and 0.17 mV, respectively. They occurred at lower leads 35 and 36 (V3-column) for R. For S on lead 25 around the V2-position and for T on and left of the sternum at leads 19, 20, 27, 34 (V2-V4 position). Conversely, the median largest negative differences for R, S, and T are -0.68 mV, -0.64 mV, and -0.15 mV, respectively. They occurred at left sided lead 52 for R, for S on sternum at lead 20 (between V1-V2) and for T at lead 47 on the left side, slightly above V5.

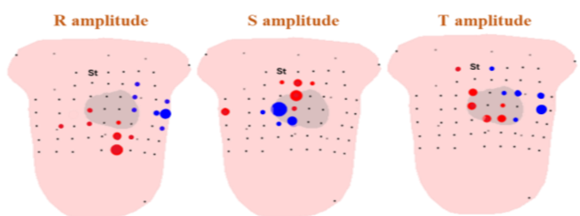

Figure 3.1. Inspiratory hold maximal changes. Red = positive, blue = negative. Smallest dots (n = 1), largest dots (n = 6).

3.2. Expiratory hold, supine position

We observed the median largest positive differences for R, S, T as 0.30 mV, 0.20 mV, 0.05 mV, respectively. These occurred at lead 46 (upper left) for R, at lead 26 (right of V3) for S, at lead 25 (V2) for T amplitude, although with large variations. The largest negative differences for R, S, T are -0.23 mV, -0.12 mV, 0.06 mV, respectively, for R at lead 41 (lower mid-clavicular line), for S at lead 25 (V2) and for T at lead 34 (below V3).

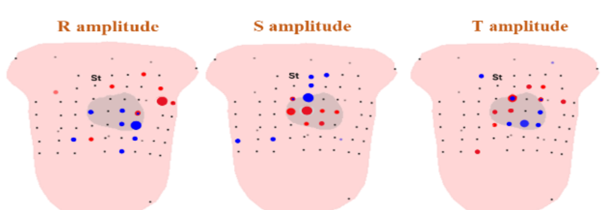

Figure 3.2. Expiratory hold maximal changes. Red = positive, blue = negative. Smallest dots (n = 1), largest dots (n = 3).

3.3. Exercise-increased HR, supine

The median largest positive differences for R, S, and T are 0.19mV, 0.22mV, and 0.14 mV, respectively. They occurred for R at leads 34 and 41 (around V4), for S on and left of the sternum at leads 18, 23 and 25 (V1, V2 level and up). For T at leads 20, 26 located on and left of the sternum (at V3-level). The median largest negative difference for R, S, T are -0.63mV, -0.50mV, -0.15mV, respectively. They occurred on the extreme left at lead 52 (above V6) for R, for S at lead 20 on the lower sternum and for T at lead 46 on the upper left side.

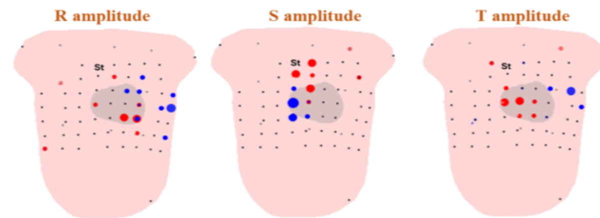

Figure 3.3. Increased HR maximal changes. Red = positive, blue = negative. Smallest dots (n = 1), largest dots (n = 4).

3.4. Reclined body position

The reclined body position showed smaller effects compared to the other conditions. We observed the median largest positive differences for R, S, T as 0.17 mV, 0.13 mV, 0.07 mV, respectively. The largest negative differences for R, S, T are -0.14 mV, -0.13 mV, -0.03 mV. Lead location was quite spread-out over-all subjects, there was no clear clustering at any lead.

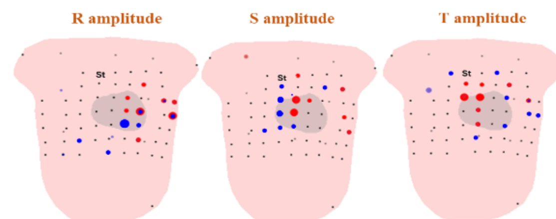

Figure 3.4. Reclined body maximal changes. Red = positive, blue = negative. Smallest dots (n = 1), largest dots (n = 2).

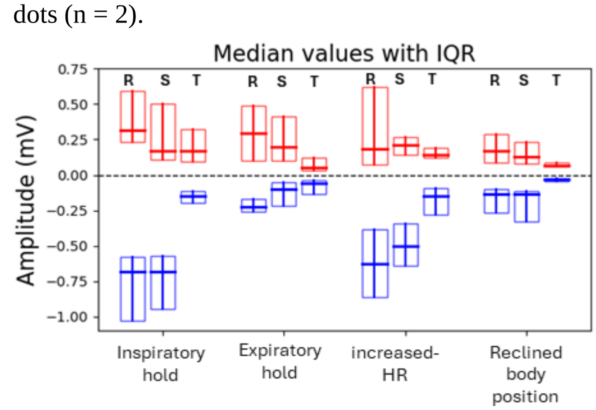

Figure 4. Positive and negative maximum changes for all subjects. The central mark indicates the median and box edges indicate the 25th and 75th percentile.

4. Discussion

The effects of inspiratory/expiratory hold, reclined body position and increased HR were investigated on the body surface potentials in healthy subjects. The difference maps for the parameters R, S and T between resting and other experimental conditions were examined and the value and location of the maximal change was established for all subjects. The inspiratory hold and increased HR had the greatest effect while the reclined position had the smallest effect. As can be seen in Figure 4, the maximum decrease in R peak was bigger than its maximum increase. Likewise, the maximum S peak increase (reflected by negative numbers in Figure 4, being opposite in direction, becoming more negative) was bigger than its decrease. The maximum decrease in R is about the same as the maximum increase in S and vice versa in all conditions, indicating that the magnitude of the whole ECG vector does not change but it only changes in direction caused by the different conditions. Although there is considerable intersubject variation, in general the depolarization vector shifts downward and to the right with inspiration and, to a smaller extent, in opposite direction during expiration. The effect of respiration on repolarization reflects the depolarization effect.

The increased heart rate condition has a surprisingly large effect on the ECG vector, both for depolarization and repolarization, almost matching that of deep inspiration, both in size and in general direction, although with considerable subject variation. The data does not provide a clear explanation, but a deeper respiration pattern after the exercise could certainly play a role. The repolarization amplitude effect is consistent with the depolarization effect, even though T-waves become shorter reflecting the well-known faster ventricular repolarization at higher heart rates.

The change in body position caused only small differences and their location / direction are not very distinct, possibly because the recline angle was only 45 degrees.

Overall, the left sided leads 36 (low on the chest, V3-column), 52, 47 (above V6 and V5) and the leads on and around sternum 23, 18, 25, 20, 26, 21 (from top to bottom) were mostly affected in most of the subjects among all conditions. In many cases the leads with the largest differences are not covered by the 12-lead ECG, highlighting the importance of the BSPM.

5. Conclusion

In our study, we examined the impacts of inspiratory and expiratory hold, exercise-increased HR and reclined body position on 67-lead BSPM in healthy subjects. We observed that inspiratory hold and increased HR had the highest influence on the R, S, T amplitudes and were similar, and consistent with an ECG vector shift downward and to the right, without clear magnitude change, while expiration had an opposite but smaller effect. 45 degree reclined sitting position has little effect on the BSPM. The occurrence of maximum differences observed mostly on the left sided frontal leads among subjects, rarely on right sided or back leads. These findings may aid in differentiating the normal variations from changing pathological conditions in patient follow-up.

Acknowledgements

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