1. Background

As one of the research projects of CERT, a hydraulic bed sensor was developed to estimate heart rate (HR) based on ballistocardiography (BCG) as an unobtrusive measurement principle [1, 2]. BCG reflects the mechanical vibrations of the body caused by the heartbeat [3].

Heart rate variability (HRV) is the variation of the beat-to-beat time in milliseconds usually measured with electrocardiography (ECG). HRV reflects the status of the autonomic nervous system and is an accepted risk indicator especially for cardiovascular events like myocardial infarction or stroke, but also for general health. Short-term HRV is usually calculated with a five minutes ECG recording [4].

Blood pressure (BP) is the pressure exerted by circulating blood upon the walls of the blood vessels. It is expressed in terms of systolic pressure over diastolic pressure in millimeters of mercury (mm HG). Conventionally BP can be measured using a sphygmomanometer, which is a device composed of an inflatable rubber cuff wrapped around the arm. A measuring device indicates the cuff's pressure. A bulb inflates the cuff and a valve releases pressure. As the heart beats, blood forced through the arteries cause a rise in pressure, called systolic pressure, followed by a decrease in pressure as the heart's ventricles prepare for another beat. This low pressure is called the diastolic pressure. BP can be also estimated by combining information captured by the BCG and ECG [5] or BCG and Photopletismography (PPG) [6].

PPG is a technique that measures the change in skin blood volume using a small light probe that is placed on the surface of the skin. Different sites for measuring PPG include the ear, forehead, ankle and finger.

2. Objectives

The study will investigate:

The agreement of the short-term HRV indices extracted from the ECG and the BCG registered simultaneously over five minutes to evaluate the potential use of BCG as an unobtrusive replacement of ECG for short-term HRV analysis.
i. A non-invasive monitoring of blood pressure using BCG and PPG.

ii. The relation of bed posture and changes BCG waveforms.

3. Experiments

Participation in the study will involve one visit. This visit will last about 45 minutes and include the following activities:

The participant will be asked to:

**Heart Rate Variability study**

**Experiment 1:** Lie still on your back for ten minutes.

**Bed Postures study**

**Experiment 2:** Lie on your back for one minute.
**Experiment 3:** Lie on your left side for one minute.
**Experiment 4:** Lie on your right side for one minute.
**Experiment 5:** Lie on your stomach for one minute.

**Blood Pressure study (optional)**

**Experiment 6:** Lie down on your back and breathe normally until three BP measurements are taken using a commercial digital arm-BP monitor (with a BP cuff).
**Experiment 7:** Pedal a stationary upright bicycle at a low pace and lowest level of resistance for two minutes. Increase your pace until you feel that your level of exertion has reached 11-14 in the Borg Rating of Perceived Exertion (RPE) scale (see next page).
**Experiment 8:** Return to the bed and lie down on your back until the BP measurements show steady values (three to five minutes).

During all the experiments, ECG will be recorded using three leads and BCG will be recorded using a hydraulic bed sensor placed unobtrusively under the bed mattress. In addition, pulse (with two finger sensors) and respiration (with a respiratory belt transducer wrapped around your abdomen) will be recorded to refine the heart rate estimation algorithms. If the participant agrees to participate in the Blood Pressure study, blood pressure will be measured using a commercial digital arm-BP monitor.
Blood Pressure study (optional)-Borg Rating of Perceived Exertion (RPE) scale

<table>
<thead>
<tr>
<th>BORG RPE</th>
<th>BREATHING</th>
<th>TRAINING ZONE</th>
<th>% of MHR*</th>
<th>EXERCISE TYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>No exertion at all</td>
<td>No Exertion</td>
<td>1</td>
<td>50%-60% Warm up</td>
</tr>
<tr>
<td>7</td>
<td>Very light</td>
<td>Very Light</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
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<td>9</td>
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<tr>
<td>10</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>11</td>
<td>Fairly light</td>
<td>Deeper but comfortable breathing. Able to hold a conversation.</td>
<td>2</td>
<td>60%-70% Recovery</td>
</tr>
<tr>
<td>12</td>
<td>Somewhat hard</td>
<td>Aware that breathing is harder; able to talk but difficult to hold conversation</td>
<td>3</td>
<td>70%-80% Aerobic</td>
</tr>
<tr>
<td>13</td>
<td>Hard</td>
<td>Starting to breathe hard and getting uncomfortable</td>
<td>4</td>
<td>80%-90% Anaerobic</td>
</tr>
<tr>
<td>14</td>
<td>Very hard</td>
<td>Deep and forceful breathing. Uncomfortable and not wanting to talk</td>
<td>5</td>
<td>90-100% VO2 Max</td>
</tr>
<tr>
<td>15</td>
<td>Extremely hard</td>
<td>Extremely hard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Maximal</td>
<td>Maximum exertion</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* % of maximum heart rate

4. Data Acquisition

Heart Rate Variability Experiment
The ECG will be recorded using three leads and the BCG will be recorded using a hydraulic bed sensor placed unobtrusively under the bed mattress. In addition, pulse and respiration will be recorded to refine the heart rate estimation algorithms.

Four types of signals will be collected simultaneously from each volunteer:

1) Electrical heartbeat signal captured by a three lead ECG,
2) Mechanical heartbeat signal captured by a hydraulic bed sensor,
3) Pulse signal captured by a piezo-electric finger sensor and an infrared photoelectric sensor PPG (IR-Plethysmograph), and
4) Respiratory chest movement captured by a chest belt.

1) Electrical Heartbeat Data Collection
The electrical heartbeat will be recorded with ECG using hardware from ADInstruments [7].

The equipment consists of:

- PowerLab (PL3516/P): High-performance data acquisition hardware
• BioAmplifier (FE132): Biological amplifiers optimized for the measurement of biological signals such as ECG
• ECG Flat Electrodes: A set of 3 gold plated, hat-shaped, disk recording electrodes
• Disposable ECG Electrodes
• LabChart: Data acquisition and HRV analysis software

2) **Mechanical Heartbeat Data Collection**
The mechanical heartbeat will be recorded using a BCG hydraulic bed sensor placed unobtrusively under the bed mattress [1].

The hydraulic bed sensor will be connected to:

- PowerLab (PL3516/P): High-performance data acquisition hardware (same acquisition hardware that is collecting the ECG recording)

3) **Pulse Data Collection**
The pulse recording will be recorded using a piezo-electric sensor from ADInstruments [7].

The equipment consists of:

- Pulse Transducer (DIN) TN1012/ST: Connects directly to the PowerLab (PL3516/P) Pod input
- Infrared photoelectric sensor PPG (IR-Plethysmograph - velcro strap MLT1020PPG): Connects directly to the PowerLab (PL3516/P) Pod input

4) **Respiration Data Collection**
The respiratory chest movement will be recorded using a piezo-electric chest belt from ADInstruments [7].

The equipment consists of:

- Respiratory Belt Transducer (BNC) MLT1132: Connects directly to the BNC Input on PowerLab (PL3516/P)

5) **Blood Pressure Experiment**
BP will be measured for each volunteer using a commercial digital arm-BP monitor at the beginning and the end of each exercise (six measurements in total) along with all the measurements collected in the HRV experiment.
5. References


