HEART RATE MONITOR ACCURACY

27.03.2015

EPSON
Introduction

Epson approached Progressive Sports Technologies Ltd. (an independent research and design consultancy) to conduct an investigation into the accuracy of optical heart rate sensors, with respect to an electrocardiogram (ECG) and chest strap heart rate monitor (HRM).

An ECG is a recording of the electrical activity of the heart, detected via electrodes that are placed on the skin surface. It is considered one of the most accurate and practical ways of monitoring heart activity. A chest strap HRM also utilises a system of electrodes, positioned inferior to the wearer’s pectoralis major muscles. HRMs vary in their accuracy of recording heart rates, but are the most common method of measuring heart rate during sport. Recently, there has been an increase in the integration of optical heart rate sensors into sports wristwatches. Optical heart rate sensors measure heart rate through a system of LEDs and an electro-optical cell to detect the pulsing volume of blood flow under the skin. The aim of the test was to compare the accuracy of an Epson SF-810 optical HR sensor against an ECG, a Chest strap ANT heart rate belt and a competitor optical HRM device.

Methodology

The accuracy of the heart rate monitors was tested using a 30-minute treadmill exercise protocol comprising of five distinct physical intensities (supine, standing, low-intensity walking, medium-intensity walking, and high-intensity walking) as shown in Table 1; referred to as Phase 1. The test period for the supine condition was longer in duration than the other physical conditions in order to obtain a true representation of the participant’s basal heart rate. Following this exercise period, eight of the test participants completed an additional 10-minute protocol that included two exercises (low-intensity running and high-intensity running), as shown in Table 2; referred to as Phase 2. Due to the volatile nature of the ECG output, data was only collected from the Chest strap, SF-810 and competitor devices during this period.

Accuracy was determined over the 30-minute period (Phase 1 for all participants), then again for the 10-minute running period (Phase 2) including transitions. To understand accuracy during different types of exercises; data from the last three minutes of each test period was extracted from the recording and compared separately.

Table 1: Outline of the Phase 1 exercise protocol, stating the time for each physical condition and corresponding analysis period. n.b. Measurement of all walking gaits was conducted at a constant velocity of 6 kph and the different intensity levels were achieved by means of altering the incline of the treadmill (0%, 7.5% and 15% for low-, medium- and high-, respectively).

<table>
<thead>
<tr>
<th>Physical Intensity Condition</th>
<th>Test Period (minutes)</th>
<th>Analysis Period (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supine</td>
<td>10</td>
<td>7 – 10</td>
</tr>
<tr>
<td>Standing</td>
<td>5</td>
<td>2 - 5</td>
</tr>
<tr>
<td>Low-intensity walking</td>
<td>5</td>
<td>2 - 5</td>
</tr>
<tr>
<td>Medium-intensity walking</td>
<td>5</td>
<td>2 - 5</td>
</tr>
<tr>
<td>High-intensity walking</td>
<td>5</td>
<td>2 - 5</td>
</tr>
</tbody>
</table>

Table 2: Outline of the phase 2 exercise protocol (undertaken by 8 participants), stating the time for each physical condition and the corresponding analysis period.

<table>
<thead>
<tr>
<th>Physical Intensity Condition</th>
<th>Test Period (minutes)</th>
<th>Analysis Period (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-intensity running</td>
<td>4</td>
<td>1 – 4</td>
</tr>
<tr>
<td>High-intensity running</td>
<td>4</td>
<td>1 – 4</td>
</tr>
</tbody>
</table>
Fifteen subjects, 11 males (age 25 yrs ± 3; weight 83 kg ± 16) and four females (age 26 yrs ± 2; weight 64 kg ± 8), completed the study. Each subject’s skin was first prepared for the application of the ECG electrodes by shaving the area, if required, before exfoliating the region and cleaning with an alcohol swab. Ten electrodes were placed on the participant’s torso at the locations indicated in Figure 1.

![Figure 1: Exercise ECG electrode locations diagram (left) and (right) application of the electrodes on the test subject.](image)

Following the application of the ECG electrodes, the participants donned the wrist-based optical heart rate monitors as well as the chest belt. One device was worn on each wrist (SF-810 on the left, and the competitor on the right), above the ulnar styloid process and fitted closely to ensure good contact between the optical sensor and the skin surface (Figure 2). Once all of the devices had been set to record, the exercise protocol was commenced. All walking and running exercises were performed on a pre-programmed treadmill. Cadence for the walking trials was noted and participants were instructed to maintain this pace throughout Phase 1 of the test, assisted by a metronome.

![Figure 2: Placement of the wrist-based HRMs above the ulnar styloid process of the left (SF-810) and right (Competitor) arms of the subject.](image)
Statistical Analysis

The optical heart rate sensor devices were compared to ECG during Phase 1 and the Chest strap during Phase 2. A Heart Rate Accuracy Index (as adopted by the SEC group) centred on the formula detailed below, calculates the concordance rate against the true heart rate of the mentioned devices.

\[
(\text{Index}) = \sum_{i=0}^{N} \left\{ \frac{1}{N} \right\} \quad N: \text{Num of measured heart rate}
\]

\[A_i: \text{ True Heart Rate} \]
\[B_i: \text{ Measured Heart Rate} \]

For Phase 1, the accuracy index for each device is calculated every 15 seconds, which is the output frequency of the ECG – this value is based on the average of the previous 15 seconds, and as such this process was mirrored for each of the devices tested. For Phase 2, the accuracy index for each device is calculated every second, which was the recording frequency of the Chest strap.

Results

Heart Rate Accuracy Index

The heart rate accuracy index summates the error in the number of heart beats per minute recorded by each device. The average error is then taken away from 100%, where 100% is the heart rate recorded by the ECG device in Phase 1, and the Chest strap in Phase 2.

Table 3: The mean (± one standard deviation) heart rate accuracy index for each device during Phase 1 and 2 (including transition periods), where ECG is considered to be 100% accurate.

<table>
<thead>
<tr>
<th></th>
<th>ECG</th>
<th>Chest strap</th>
<th>SF-810</th>
<th>Competitor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phase 1 (30-min exercise)</strong></td>
<td>100.0% (0)</td>
<td>95.3% (3.8)</td>
<td>95.0% (2.3)</td>
<td>93.3% (3.2)</td>
</tr>
<tr>
<td><strong>Phase 2 (10-min running)</strong></td>
<td>-</td>
<td>100.0%</td>
<td>99.3% (0.5)</td>
<td>98.3% (2.6)</td>
</tr>
</tbody>
</table>

Conclusion

In the above study, 15 participants walked and ran in both the Epson SF-810 and a competitor device, whilst also instrumented with 12-lead ECG and Chest strap heart rate devices. The aim of the study was to compare the readings recorded by the devices in each of the set activities. A heart rate accuracy index was derived as discussed. This heart rate accuracy index indicated that all devices were at least 90% comparable to ECG.

**Phase 1**: The Epson SF-810 recorded 95% heart rate monitoring accuracy, during which, the accuracy of both wrist worn products was benchmarked against an ECG which was taken to be 100% accurate.

**Phase 2**: The Epson SF-810 recorded 99.3% heart rate monitoring accuracy, during which, the accuracy of both wrist worn products was benchmarked against a chest strap which was the best way of monitoring heart rate during this level of activity.

During this study, in both phases the Epson SF-810 displayed greater heart rate monitoring accuracy on average than the competitor.
Appendix A

The heart rate in beats per minute (bpm) over time for every participant as recorded by each of the monitoring devices for the entirety of the test period.

Participant 1
Participant 2

Heart Rate (bpm)

Time (mm:ss)

ECG
Chest strap
SF-810
Competitor

0:00 0:30 1:00 1:30 2:00 2:30 3:00 3:30 4:00 4:30 5:00 5:30 6:00 6:30 7:00 7:30 8:00 8:30 9:00 9:30 10:00 10:30 11:00 11:30 12:00 12:30 13:00 13:30 14:00 14:30 15:00 15:30 16:00 16:30 17:00 17:30 18:00 18:30 19:00 19:30 20:00 20:30 21:00 21:30 22:00 22:30 23:00 23:30 24:00 24:30
Participant 3

Heart Rate (bpm) vs Time (mm:ss)

- ECG
- Chest strap
- SF-810
- Competitor
Participant 4

Heart Rate (bpm) vs Time (mm:ss)

- ECG
- Chest strap
- SF-810
- Competitor
Participant 5

Heart Rate (bpm) vs. Time (mm:ss)

- ECG
- Chest strap
- SF-810
- Competitor
Participant 7

Heart Rate (bpm) vs Time (mm:ss)

- ECG
- Chest strap
- SF-810
- Competitor
Participant 10

- ECG
- Chest strap
- SF-810
- Competitor
Participant 11

Heart Rate (bpm) vs. Time (mm:ss)

- ECG
- Chest strap
- SF-810
- Competitor
Participant 12
Participant 13
Participant 15

Heart Rate (bpm) vs Time (mm:ss)

- ECG
- Chest strap
- SF-810
- Competitor