

# Validity of A Portable EKG Device to Monitor Heart Rate and Rhythm in College-aged Male Athletes

*Original Research*

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## Abstract

**Introduction:** Sudden cardiac death (SCD) is the leading medical cause of death for male athletes, especially in anaerobic-based sports. Standard 12-lead electrocardiograms (STD-EKG) have received recent attention for their diagnostic utility, but lack the practicality for mass screenings. The purpose of this investigation was to assess the validity of a compact HD-EKG unit during various testing environments: rest, aerobic activity, and immediate recovery of anaerobic activity in college-age, male athletes.

**Methods:** Twelve college-aged ( $19.9 \pm 1.1$  years old), male athletes volunteered. Test procedures included two ECG devices, a STD-EKG and a high-definition (HD-) EKG, simultaneously recording heart rate (HR) and rhythms during rest, a single-stage walking test, and during recovery of the Wingate Anaerobic Power test.

**Results:** Paired t-tests did not detect differences between measures of HR and rhythm ( $t(47) = -0.71, p > 0.05$  and  $t(4) = 0.82, p > 0.05$ , respectively). The two measures of HR were very strongly related ( $r = 0.98, p < 0.001$ ). However, the absolute difference between the STD-EKG and HD-EKG averaged  $3.47 \pm 4.44$  bpm, which is significantly different than the acceptable variance of  $\pm 2$  bpm.

**Conclusions:** Wearable technology, such as a portable HD-EKG device worn during vigorous anaerobic activity, such as the Wingate Anaerobic Power test, may identify athletes most at risk for SCD.

**Key Words:** sudden cardiac death, electrocardiogram, wearable technology

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## Introduction

There are approximately 100-150 deaths during sports activities in the United States annually.<sup>1</sup> While the most common causes of sudden death in athletes are nonmedical or traumatic cases, sudden cardiac death (SCD) is the leading medical cause of death,<sup>2</sup> with an estimated rate of 1:50,000 collegiate athletes per year.<sup>3</sup> Researchers have established that there is a transient, increased risk of arrhythmia-based sudden death associated with vigorous exertion.<sup>3</sup> In an effort to reduce SCD incidence in sport, the American Heart Association (AHA) developed a competitive athlete pre-screening tool to follow during the annual preparticipation physical exam

(PPE).<sup>4</sup> If an abnormality is noted during the PPE, the examiner may recommend that the athlete receive an electrocardiogram (ECG), echocardiogram, stress test, or other follow-up diagnostic testing.<sup>4</sup>

Although recommendations for the pre-screening of athletes are in place, from 2003-2013, SCD accounted for 79 of the 514 total student athlete deaths (1:53,705), with male athletes accounting for 81% of SCDs.<sup>5</sup> Further breakdown of factors impacting SCD revealed 72 of the 79 deaths occurred with exertion, and the majority of SCD occurred in basketball, football, and men's soccer, respectively.<sup>5</sup> To date, there is no consensus on the most effective and efficient screening tool to identify underlying cardiovascular conditions in young athletes.

A few investigators have attempted to identify heart rate variability (HRV) as an indicator of abnormal cardiac function.<sup>6,7</sup> However, there have been limited studies using wearable technology and HRV to evaluate cardiac function in athletes.<sup>6-8</sup> In a comparison of amateur athletes and sedentary subjects, a portable monitor (BioHarness 3.0) enabled comparisons of ECG tracings, heart rate (HR) and HRV during rest, aerobic exercise, and recovery.<sup>8</sup> However, the response of the athletic heart to anaerobic exercise, simulating a sudden burst of vigorous exertion, has not been evaluated.

In the current study, a portable, compact, 2-lead high-definition electrocardiogram device (HD-EKG) was tested on athletes to wirelessly monitor the electrical activity of the heart in real time. Evaluation of HR, short-term HRV, and rhythm in aerobic and anaerobic conditions may provide more insight in identifying cardiovascular conditions in athletes. Therefore, the purpose of this investigation is to assess the validity of a HD-EKG unit during various testing environments: rest, aerobic activity, and immediate recovery of anaerobic activity in college-age, male athletes. The researchers hypothesize that there will be no difference between the HD-EKG and STD-ECG for HR and rhythm recordings.

## **Methods**

### *Participants*

Thirteen college-aged male athletes from a small university in Wisconsin volunteered to participate in this study during their off-season. Participants completed a pre-participation medical history questionnaire. Researchers excluded participants if they had any known cardiovascular, respiratory, metabolic, or musculoskeletal conditions that may affect physiological responses to exercise testing. All participants completed an Institutional Review Board approved written liability waiver and informed consent, indicating their voluntary participation in the study.

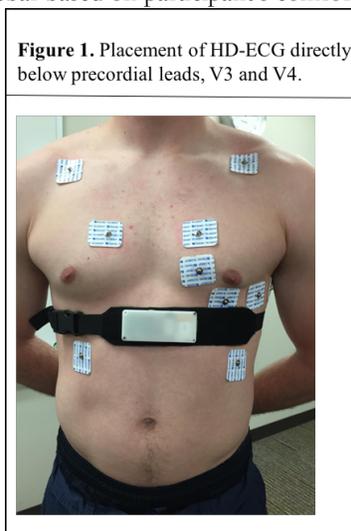
### *Protocol*

Five days prior to the first scheduled testing session, participants attended an orientation session where they received instruction on completing questionnaires to document their physical activity, dietary intake, and sleep quality during the 72-hours before testing. Participants received verbal and written pre-test instructions related to exercise clothing, as well as avoiding exertion the day of testing.<sup>9</sup> Instructions also included refraining from ingesting food or drink containing caffeine, alcohol, or other stimulants that may affect HR, blood pressure, or heart rhythm at least 3 hours prior to scheduled testing.<sup>9</sup>

All testing was performed in an environmentally-controlled university exercise physiology laboratory and followed the American College of Sports Medicine procedures for fitness testing.<sup>9</sup> Researchers collected baseline resting HR and blood pressure measurements after 5-minutes of seated rest, in accordance with AHA guidelines.<sup>10</sup> The researchers also collected anthropometric data, including height (m) and weight (kg) using a Health o meter® (McCook, IL) balance beam scale with

stadiometer. The researchers assessed body composition following standardized procedures for waist circumference using a Gulick (Creative Health Products, Ann Arbor, MI) tape measure, and percent body fat using the skinfold technique with Lange (Beta Technology, Santa Cruz, CA) calipers and the Jackson-Pollock 3-site formula for men.<sup>11,12</sup>

Prior to exercise testing, each participant completed a resting ECG, using both the STD-ECG and HD-EKG. To reduce variability in trace quality due to differences in skin preparation, as well as electrode placement technique and methodology, the same researcher performed all resting ECGs. The ECGs were recorded in the supine position during the last 30-seconds of the 5-minute rest period. For the STD-ECG, standard skin preparation included the researcher removing any excess body hair as needed, cleansing with an alcohol swab, drying, and lightly abrading the skin at the electrode placement sites with 3M™ Red Dot Trace Prep (St. Paul, MN).<sup>13</sup> The STD-ECG was recorded using the Cardiac Science CareCenter MD wireless ECG monitoring device (Bothell, WA) with disposable, diagnostic ECG skin electrodes and the modified Mason-Likar 12-lead electrode placement.<sup>14</sup> Following the set-up of the STD-ECG, the HD-EKG electrode sensors were dampened, and the device was secured to the participant using a chest strap placed directly below the precordial leads, V3 and V4, as displayed in Figure 1. The 2-lead HD-EKG signals, which correspond to lead I and V3 of a STD-ECG,<sup>13</sup> was synced with the Applied Advanced Technologies (Milwaukee, WI) application. After the resting ECGs were acquired and HR was recorded, the participant stood up and walked a short distance so the researchers could determine if any electrodes needed to be adjusted and then applied a stretchable net stress vest. Researchers explained that test procedures would include performing a Ebbeling single-stage treadmill walking test (SSWT) as a warm-up for the Wingate anaerobic power test (WAP).<sup>15</sup> Measurements of HR, blood pressure, oxygen saturation and rate of perceived exercise would be obtained at the end of each phase of testing, and symptoms of abnormal responses to exercise would be continuously monitored.<sup>9</sup> Set-up concluded with a researcher escorting the participant to the Monark Ergonomic 894 E Peak cycle ergometer (Vansbro, Sweden) to adjust seat height to accommodate stature, such that the participant's knee would be slightly flexed (approximately 25 degrees) at maximal leg extension, and to adjust the handlebar based on participant's comfort.<sup>9</sup>



Next, the participant was guided to the Woodway Desmo treadmill (Waukesha, WI) to complete the SSWT as a submaximal warm-up. The researchers followed the Ebbeling SSWT procedures, adjusting the treadmill speed within the first minute to allow the participant to achieve an exercise HR equivalent to approximately 60% HR<sub>max</sub> at the conclusion of the test.<sup>15</sup> Although HR and rhythm were continuously

monitored, only during the last 30 seconds of this phase did the two ECG devices record tracings. During the 4-minute exercise stage, the treadmill speed remained constant, and the grade was increased to 5%.<sup>15</sup> To ensure a steady state HR during the last two minutes of the exercise stage, researchers collected HR at each minute with the STD-ECG.<sup>15</sup> Similar to the warm-up phase, STD-ECG and HD-EKG tracings were recorded during the last 30 seconds.

Upon completion of the SSWT, the participant was immediately transferred to the previously set up cycle ergometer to complete the WAP. Participants completed a 1-minute warm-up, pedaling at a self-selected moderate-to-vigorous pace against no resistance. Researchers then instructed the participants to pedal at full speed with the cycle ergometer unloaded. Once full pedal speed was achieved (5-8s), the researchers immediately counted down to the start of the test, applying the calculated workload (0.075 kg per kg of body weight) for 30 seconds.<sup>16</sup> Throughout the WAP, researchers verbally encouraged the participant. Immediately upon test completion, the participant started active recovery pedaling at a self-selected light pace with no resistance, while the researchers collected 6-second rhythm strips with the STD-ECG and HD-EKG at 30-seconds and 60-seconds post WAP. The researchers terminated recovery when the participant's HR returned to pre-exercise values or below 100 bpm.

#### Statistical Analysis

Data from participants (n=12) who completed all testing components were analyzed. To assess the validity of the HD-EKG, the researchers conducted a paired samples t-test between STD-ECG and HD-EKG HR and rhythm recordings and conducted a Pearson correlation for each of the conditions (rest, SSWT, immediately post-WAP, and recovery). To reflect clinical practice in measuring, the researchers set the acceptable absolute difference between measures to two bpm. The researchers calculated an absolute difference score to determine the range of variability between measures and conducted a one-sample t-test with the criterion value of two. Bland-Altman<sup>17</sup> and line of best fit plots presented graphical of data. The researchers assessed data using SPSS 25.0 (IBM, Chicago, IL) with statistical significance set to  $p < 0.05$  *a priori*.

#### Results

Table 1 presents participants demographic and anthropometric data. Table 2 depicts the mean, standard deviation, and 95% confidence interval for both HR measures during the four conditions. The two measures were not significantly different for HR ( $t(47) = -0.71, p > 0.05$ ) or frequency of abnormal heart rhythms (Table 3;  $t(4) = 0.82, p > 0.05$ ). Absolute differences ( $3.47 \pm 4.44$ bpm) were significantly different compared to the standard acceptable difference score of 2 bpm ( $t(59) = 0.255, p = 0.01$ ). However, 12% of recordings had a difference score of 0 (7/60), while 60% had a difference score of  $\leq 2$  bpm (36/60). The two measures of HR were very strongly related ( $r = 0.98, p < 0.001$ ) specifically during rest, immediate post-WAP, and recovery ( $r = 0.89, p < 0.001$ ;  $r = 0.75, p = 0.005$ ;  $r = 0.67, p = 0.02$ ; respectively), as supported by the line of best fit and Bland-Altman plots (Figure 2). The two measures of HR were not related for the SSWT ( $r = 0.02, p > 0.05$ ).

**Table 1.** Participant (n = 12) baseline and anthropometric data

| Variables                            | Mean  | SD  |
|--------------------------------------|-------|-----|
| Age (y)                              | 19.9  | 1.1 |
| Height (m)                           | 1.7   | 0.5 |
| Weight (kg)                          | 79.7  | 8.8 |
| Body mass index (kg/m <sup>2</sup> ) | 26.5  | 2.8 |
| Percent body fat                     | 10.5  | 3.5 |
| Resting HR (bpm)                     | 66.5  | 5.3 |
| Resting Systolic BP                  | 121.8 | 7.8 |
| Resting Diastolic BP                 | 69.3  | 6.6 |

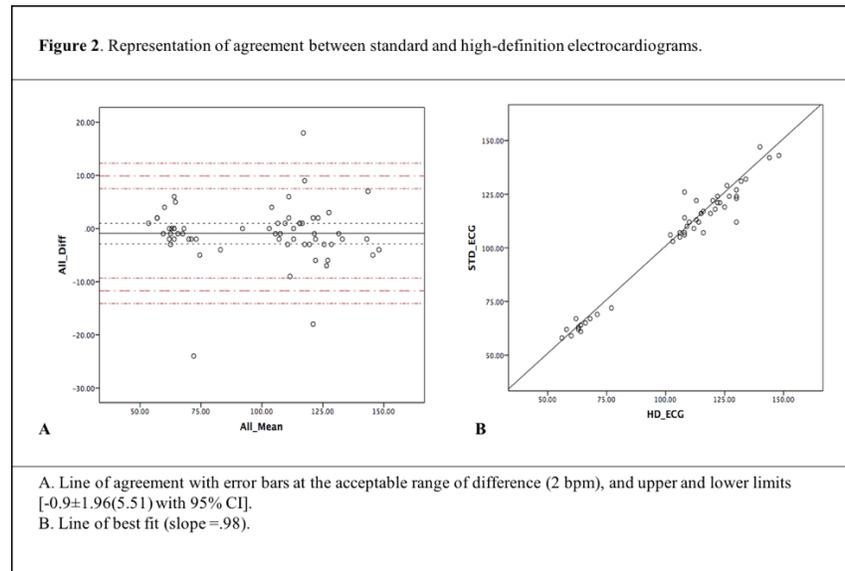
**Table 2.** Heart rate values as assessed by a standard and high-definition electrocardiograms.

|                               | Standard |        |                  | High-definition |         |                  |
|-------------------------------|----------|--------|------------------|-----------------|---------|------------------|
|                               | Mean     | (SD)   | [95% CI]         | Mean            | (SD)    | [95% CI]         |
| <b>Rest</b>                   | 64.08    | (4.12) | [ 62.11, 66.97]  | 64.33           | (5.71)  | [ 62.37, 69.21]  |
| <b>Single stage walk test</b> | 117.83   | (3.24) | [115.77, 119.89] | 118.92          | (5.92)  | [115.16, 122.68] |
| <b>Immediate post-WAP</b>     | 131.00   | (8.41) | [125.66, 136.34] | 130.92          | (10.46) | [124.27, 131.24] |
| <b>Recovery</b>               | 108.08   | (3.11) | [106.10, 110.06] | 108.92          | (4.32)  | [106.17, 111.66] |

CI – confidence interval; WAP = Wingate anaerobic power test

**Table 3.** Rhythm analysis between standard and high-definition electrocardiograms

|                            | Standard | High-definition |
|----------------------------|----------|-----------------|
| <b>Normal sinus rhythm</b> | 1        | 1               |
| <b>Sinus bradycardia</b>   | 3        | 4               |
| <b>LVH</b>                 | 7        | 0               |
| <b>LAE</b>                 | 8        | 8               |
| <b>PVC</b>                 | 10       | 10              |



## Discussion

The purpose of the current investigation was to evaluate the validity of a portable, compact HD-EKG unit compared to a STD-EKG in evaluating HR, short-term HRV, and heart rhythms under various testing environments: rest, aerobic activity, and immediate recovery of anaerobic activity in college-age, male athletes. To our knowledge this is the first study to evaluate wearable technology compared to a STD-EKG under anaerobic testing conditions to simulate a sudden burst of vigorous physical activity associated with anaerobic sports, such as basketball, which have a higher incidence of SCD.<sup>5</sup> In the present study, the measured HR values and rhythms obtained from the tracings between the HD-EKG and STD-EKG were not different.

Our primary findings for the HD-EKG are consistent with previous studies reporting a strong correlation between the EKG and more recent HR monitors, using chest electrodes, in assessing the RR interval to determine HR.<sup>18–20</sup> As a practitioner, an acceptable range for accuracy in manually measuring resting HR using radial

pulses is  $\pm 2$  bpm.<sup>21</sup> Our results fall within this range 60% of the time. If the acceptable difference was broadened to  $\pm 3$  bpm as demonstrated in recording radial pulses of using different time durations from 6 to 30 seconds,<sup>21</sup> 72% of our measures would fall within that range. Furthermore, our data were collected during moderate-to-vigorous physical activities, which increases the HR variance due to errors associated with increased artifact (noise) with increasing exercise intensity.

In addition to detecting the RR interval for HR measurement, the HD-EKG also has the capacity to monitor heart rhythms to potentially detect arrhythmias. The focus of the Applied Advanced Technologies application was the detection of atrial fibrillation (Afib), which is a common arrhythmia in athletes.<sup>22</sup> Due to the association between left atrial enlargement and Afib,<sup>23</sup> left atrial enlargement was evaluated as well as other common arrhythmic conditions found in individuals who regularly participate in exercise due to physiological, functional or structural adaptations of the heart, commonly known as "Athlete's Heart".<sup>24</sup> With the exception of left ventricular hypertrophy (LVH), there was no difference between the two devices in detecting the frequency of abnormal heart rhythms (Table 4). One explanation for the inability of the HD-EKG to capture LVH is that this arrhythmia is most evident in leads V1, V2, V5 and V6;<sup>25</sup> whereas, the HD-EKG device monitored leads I and V3.

Limitations of this study include a small sample size, and the results can only be applied to apparently healthy, active males. Due to missing data for HRV, the utility of the HD-EKG as a valid tool for determining HRV could not be evaluated. In addition, the HD-EKG did not detect LVH, which may have resulted from electrode placement. While LVH is a physiological adaptation to training, it is not always a protective adaptation.<sup>6</sup> Future studies on chest strap placement are warranted. Furthermore, the participants in this study did not present with any uncommon, non-training related ECG changes that would require further medical evaluation.

Based on the results of this investigation, the HD-EKG is a valid tool for the detection of RR intervals for HR measurement as well as the identification of common abnormal heart rhythms under rest, aerobic activity, and immediate recovery of anaerobic activity in college-age, male athletes. Compared to other portable devices, a standard HR monitor cannot provide the depth of information as the HD-EKG, and the STD-ECG is not practical in a field setting due to lead wires that could fall off, damage to the device, or potential injury in contact sports. While many of the emerging wearable ECG devices focus on monitoring for older adults and individuals with known chronic conditions,<sup>20</sup> the HD-EKG may fit the need for a valid low-cost, practical screening tool to accurately assess HR and rhythm during sports activities and recovery. The HD-EKG may allow for the early detection and monitoring of arrhythmic conditions, which may be associated with SCD in sports participants.

### **Media-Friendly Summary**

While a rare event in sports, sudden cardiac death in young athletes is a tragedy that has growing awareness from the public, as well as the sports medicine field. Currently, the standard preparticipation screening tool is ineffective in correctly detecting and interpreting heart abnormalities in this population, and clinical testing may not be feasible for all athletes in the United States. However, with new wearable technology, monitoring both heart rate and rhythms during physical activity, particularly high intensity aerobic and anaerobic activities, may be more practical and provide greater insight into those athletes who are at greater risk of experiencing a cardiac incident, thereby reducing the rate of sudden cardiac death.

### **Acknowledgements**

We would like to thank Applied Advanced Technologies (AAT, Milwaukee, WI) for partially funding the study and for providing the HD-EKG device.

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