 doi:10.20944/preprints202008.0508.v1

Article

Is Continuous ECG Recording on Heart Rate Monitors the Most Expected Function by Endurance Athletes, Coaches, and Doctors?

Robert Gajda [1,*]

[1] Center for Sports Cardiology at the Gajda-Med Medical Center in Pułtusk, ul. Piotra Skargi 23/29, 06-100 Pułtusk, Poland

* Correspondence: gajda@gajdamed.pl; Tel.: +48-604286030, Fax: +48-23-6920199

Abstract: Heart Rate Monitors (HRMs) are an indispensable tool for controlling training parameters of healthy athletes. They became a source of information about stress heart rhythm disturbances, recognized as unexpected increases in heart rate (HR), which can be life-threatening for athletes. Most HRMs do not recognize the type of arrhythmia, confusing them with artifacts. The aim of the study was to assess the usefulness of ECG recording functions by sports HRMs among endurance athletes, coaches, and physicians in comparison with other basic and hypothetical functions. We conducted 3 surveys among endurance athletes (76 runners, 14 cyclists, and 10 triathletes), as well as 10 coaches and 10 sports doctors to obtain information on how important ECG recording is, and what functions of HRMs should be improved to meet their expectations in the future. The respondents were asked questions regarding use and hypothetical functions, as well as preference for HRM type (optical/strap). For athletes, the 4 most important functions were distance traveled, pace, instant heart rate, and information about reaching the oxygen threshold. ECG recording was the 8th and 9th most important for momentary and continuous, respectively. Coaches opined more importance to ECG recording. Doctors placed ECG recording as most important. All participants preferred optical HRMs to strap HRMs. Research on the improvement and implementation of HRM functions shows slightly different preferences of athletes compared to coaches and doctors. Suspected arrhythmia increases the value of the HRM's ability to record ECGs during training by athletes and coaches. For doctors, this is the most desirable feature in any situation. Considering the expectations of all groups continuous ECG recording during training will significantly improve the safety of athletes.

Keywords: Heart rate monitor, ECG, portable/wearable monitoring system, heart rate variability, long-term assessment, arrhythmia, QARDIO MD VSI system.

1. Introduction

Heart Rate (HR) monitoring during training in endurance sports is a standard, and one element of controlling intensity. It was introduced into training long before the advent of HRMs. Originally, athletes used a sweep-handed watch and, directly after stopping, the pulse was measured—usually on the radial artery—to gain knowledge of the intensity range of the training [1]. The appearance of strap HRMs was a revolution. Additional functions related to the global positioning system (GPS) allowed control of the length of the route and speed of the athlete's movement and, consequently, many other parameters, such as energy expenditure during training [2]. Originally less perfect and burdened with artifacts, with time HRMs showed increased precision of the recorded parameters. In addition, functions such as determining altitude above sea level, water resistance, and GPS enabled ease of training in all conditions and scenarios [3]. The ability to measure HR in water was another great step enabling swimmers and triathletes to control their training [4].

Heart rate variability (HRV) is one such function that makes it possible to indirectly evaluate the cause of arrhythmia indicated by an HRM, thus allowing the type of arrhythmia to be

 doi:10.20944/preprints202008.0508.v1

determined [5]. In practice, the assessment of the distance of the R-R points in an ECG—as indicated by the HRV function—does not allow the cause of the rhythm variability to be determined. The inability to determine whether we are dealing with supraventricular arrhythmia, ventricular arrhythmias, or an ordinary artifact significantly limits the value of the diagnosis. The possibility of missing a life-threatening ventricular arrhythmia remains highly likely [6]. The emergence of the possibility of ECG recording—which is already offered by some HRMs in conjunction with smartphones equipped with appropriate applications—was a civilization leap. With the ECG application the Apple Watch Series 5 can generate an ECG similar to a single-lead electrocardiogram. This was a momentous achievement for a wearable device that can provide critical data for athletes and their doctors; however, the problem of having to stop training to record the ECG remained [7]. Another important function of HRMs, relatively rarely used, is the measurement of HR at rest and at night. Resting HR is the observed and analyzed indicator of the athlete's form—the lower the HR at rest and during sleep, the greater the form [8]. Recently, HRMs have become available that enable continuous ECG recording without interrupting training. This gives you full control of the ECG recording with simultaneous medical supervision—online data transmission—but the software is currently only available for physicians and hospitals [9].

As HRMs were developed for healthy athletes, the question of their use in ECG recording has become pertinent. The Holter ECG is used to assess arrhythmias and can not only recognize the type of arrhythmia, but also indicate the location with high probability [10]. Many athletes use HRMs daily and have observed unexpected increases in HR during training, suggesting arrhythmias. For this reason, they often undergo extensive and often unnecessary diagnostic testing, including electrophysiological tests. Ninety-nine percent of the anomalies in HR are due to technical problems (artifacts) mimicking arrhythmia [11]. Therefore, a further investigation into the value of ECG monitoring within HRMs for athletes, coaches, and doctors was required.

The aim of this study was to investigate the opinions on the development of HRMs amongst endurance athletes, coaches, and doctors to determine whether the ECG recording function is considered most important.

2. Materials and Methods

2.1. Group characteristics

We conducted three surveys among 100 endurance athletes aged 21–57 years (35.5±4.5) who use sports HRMs daily and are under the care of our Sports Medicine Clinic. The study group included 76 long-distance runners (50 males, 26 females), 14 cyclists (11 males, 3 females), and 10 triathletes (9 males, 1 female). Most of the athletes were under long-term observation—up to 10 years—and participated in previous studies related to the use of HRMs, including their usefulness in the assessment of arrhythmias or exercise intensity [12–14]. The same surveys were conducted among 10 coaches aged 26–60 years (47.0±7.5), and 10 doctors (33–60, 52.0±7.0) training and examining endurance sportsmen on a daily basis.

Questionnaire One contained 11 questions concerning the validity of the usefulness of individual functions, even hypothetical ones, possessed by modern HRMs in a typical situation and the hypothetical assumption of suspicion of arrhythmias in an athlete. The interviewers, assessing the importance of the functions possessed by HRMs, assigned importance from 1–11, where 1 point (p.) meant the highest and 11 the least important function. The questions concerned functions such as: 1) distance; 2) speed/pace; 3) current HR; 4) average training HR; 5) amount of calories consumed during training (active kcal); 6) recording of the current ECG "on demand"; 7) continuous ECG recording; 8) the moment of reaching anaerobic threshold (AT) (lactate threshold); 9) altitude [meters above sea level (MASL)]; 10) HRV; and 11) 24-hour HR measurement.

The conditions for inclusion of athletes in the study was the use of HRMs—regardless of the brand—for a minimum of 2 years and at least minimal personal experience with strap and optical HRMs. Some athletes have been using HRMs for more than 10 years (Table S3). The second

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 24 August 2020 doi:10.20944/preprints202008.0508.v1

questionnaire asked about preferences of HRMs—optical (OHRM) versus strap (SHRM)—by athletes, coaches, and doctors in everyday training versus training with the hypothetical assumption of suspicion of heart rhythm disturbances in the athlete (Table 2). Both types of HRMs are assumed to be valid and resistant to artifacts. Such an assumption was adopted due to common concerns among respondents about artifacts that distort the actual HR values, to a greater extent OHRMs and are familiar to their users [11].

Knowing the results of the preferences in the use of HRMs, all surveyed groups in Questionnaire Three were asked in detail about the reason for these preferences (OHRM versus SHRM selection).

2.2.7. *Statistical Analysis*

Normal distributions were analyzed using the Shapiro–Wilk test. Because such variables as age, experience with OHRMs (years) and experience with SHRMs (years) characterized lack of the normal distribution, the descriptive statistics were established by median and quarter deviation. Correlation between ranks of HRM functions were measured by Spearman's rank correlation coefficient. Statistical significance of differences between OHRM/SHRM preferences by health status of athletes (healthy vs. suspicion of arrhythmia) was established using chi-square tests. Average rank of HRM individual function for every group was set using the mean value. All statistical calculations were performed using STATISTICA 12 (StatSoft, Krakow, Poland). The significance level was set at p <0,05.

2.2. *Ethical Approval*

This study was approved by the ethical review board of the Bioethics Committee of the Healthy Lifestyle Foundation in Pułtusk (EC 6/2020/medicine/sports, approval date: 01.07.2020). The athletes provided their written informed consent to participate in the analysis and for their data to be published.

3. Results

Analyzed answers to Questionnaire One can be found in Table 1.

The data analysis shows that each of the studied groups—athletes, coaches, and doctors—have slightly different expectations regarding the importance of the possessed and hypothetical functions, and thus the preferred direction of HRM development. There is strong positive correlation between ranks of athletes and coaches (r = 0.93), low negative correlation between ranks of doctors and athletes (r = -0.27), and little negative correlation or even lack of correlation between ranks of coaches and doctors (r = -0.13).

For athletes, the most important functions are the accuracy of the measurements for distance, speed/pace, and current HR and the indication of the moment of reaching anaerobic threshold (first to fourth place, respectively). ECG recording is 8th and 9th (on demand and continuous, respectively). Coaches selected the same first four important functions as athletes, only differing on the importance of ECG recording (7th and 8th, respectively). Doctors assessed the usefulness of ECG recording completely differently, placing it in positions 1 (continuous recording) and 2 ("on demand"). The 24-hour HR measurement capability and the HRV function were 3rd and 4th place, respectively.

The same questions, asked in the case of a hypothetical risk of cardiac arrhythmia, gave different relevance, especially for athletes and coaches. For athletes, the fourth most important function was continuous ECG recording, with the first three places remaining unchanged. For coaches, ECG recording (continuous and "on demand", respectively) were promoted to 3rd and 4th place. Doctors invariably rated the functions describing the work of the heart highly (ECGs, 24-hour HR measurement, and HRV). All the compared groups characterized a positive correlation of given ranks (strong among athletes and coaches, medium among other groups: athletes/coaches, r = 0.84; athletes/doctors, r = 0.55; doctors/coaches, r = 0.60).

Table 1. Cumulative results of the survey conducted among athletes, coaches, and doctors regarding the assessment of the importance of individual functions possessed by modern HRMs. Two situations are covered: standard use of HRMs and use with the hypothetical assumption of suspected athlete arrhythmia.

		The importance of the function: Healthy athlete			The importance of the function: Suspicion of arrhythmia		
No.	Function	Athletes [ranking]	Coaches [ranking]	Doctors [ranking]	Athletes [ranking]	Coaches [ranking]	Doctors [ranking]
1	Distance	1 (1.1)	1 (1.1)	8 (7.9)	1 (1.4)	5 (4.6)	7 (7.0)
2	Speed/pace	2 (2.0)	2 (2.2)	9 (8.9)	2 (1.8)	1 (1.6)	6 (5.9)
3	Actual HR	3 (3.1)	3 (3.0)	6 (5.8)	3 (3.3)	2 (2.4)	5 (5.2)
4	Average HR	5 (5.0)	5 (5.3)	7 (7.2)	7 (6.7)	9 (8.6)	8 (8.0)
5	Active kcal	7 (6.9)	10 (10.2)	10 (10.0)	10 (10.1)	11 (10.0)	11 (10.9)
6	"On demand" ECG	8 (8.2)	7 (6.9)	2 (2.0)	5 (4.9)	4 (3.4)	2 (2.0)
7	Continuous ECG record	9 (9.1)	8 (8.1)	1 (1.1)	4 (4.2)	3 (3.0)	1 (1.0)
8	AT	4 (4.0)	4 (3.7)	5 (5.0)	9 (9.0)	6 (7.0)	9 (8.7)
9	Attitude MASL	10 (9.9)	9 (8.6)	11 (10.9)	11 (10.3)	10 (9.1)	10 (10.1)
10	HRV	11 (10.7)	11 (10.6)	4 (4.1)	8 (8.6)	8 (8.4)	4 (3.9)
11	24H HRM	6 (6.1)	6 (6.3)	3 (3.1)	6 (6.0)	7 (7.9)	3 (3.1)

Data presented as ranking (mean ranking). Scale rankings 1–11 with decreasing importance of functions. AT, anaerobic threshold; MASL, meters above sea level; HRV, heart rate variability; 24H HRM, 24-hour heart rate measurement.

The second survey concerned the preferences in the use of HRMs—OHRM versus SHRM—by athletes, coaches, and doctors in a typical situation and the hypothetical assumption of suspicion of cardiac arrhythmias in the athlete (Table 2). It was hypothetically assumed that both types of HRMs are 100% resistant to artifacts and always indicate correctly assessed parameters. In everyday use, athletes, coaches, and doctors all favored OHRMs (62%, 60%, and 60%, respectively). In the hypothetical situation of heart rhythm disorders, the preference of all groups increased in favor of OHRMs (84%, 90%, and 100%, respectively). Observed differences were statistically significant (p <0,001).

Table 2. Preferences for the use of HRMs (optical / strap) by athletes, coaches, and doctors in a typical situation and under the hypothetical assumption of suspicion of arrhythmia in an athlete. Equal and full resistance to artifacts was assumed.

	Healthy athlete			Suspicion of arrhythmia			P-value*		
	Athletes	Coaches	Doctors	Athletes	Coaches	Doctors	Athletes	Coaches	Doctors
Prefer OHRM	62%	60%	60%	84%	90%	100%	<0.001	<0.001	<0.001
Prefer SHRM	38%	40%	40%	16%	10%	0%			

*Comparing results of healthy with suspicion of arrhythmia. OHRM, optical heart rate monitors; SHRM, strap heart rate monitors.

Questionnaire Three asked the reason for the preferred HRM (OHRM versus SHRM) assuming that both have the same functions and the same resistance to artifacts. The collective results are presented in Table 3.

Table 3: Reasons for preferential use of the wrist-worn optical heart rate monitor (HRM) versus chest strap HRMs by athletes, coaches, and doctors, assuming have the same functions and the same resistance to artifacts.

	Athletes	**Coaches**	**Doctors**
Average age (years)	35,5+/-4,5	47,0+/-7,5	52,0+/-7,0
Experience with OHRM (avg. years)	1,3+/-0,5	3,0+/-0,8	2,5+/-1,0
Experience with SHRM (avg. years)	5,3+/-2,0	6,3+/-1,8	5,5+/-1,0
PREFERENCES [OHRM = 1, SHRM = 2]			
Comfort of use during training	1 (88%)*	1 (80%)	1 (80%)
Comfort of use around the clock	1 (95%)	1 (90%)	1 (100%)
Battery life	1 (75%)	1 (60%)	1 (70%)
Skin abrasions from the strap belt	1 (93%)	1 (100%)	1 (100%)
Trend / Fashion	1 (67%)	1 (60%)	1 (60%)
Habit	2 (89%)	2 (90%)	2 (90%)
Confidence in the accuracy of indications	2 (96%)	2 (90%)	2 (90%)
Result: OHRM versus SHRM	5/2	5/2	5/2

*Percentage of votes obtained; 1 = Reason for OHRM preference; 2 = Reason for SHRM preference. OHRM, optical HRM; SHRM, strap HRM.

The survey shows that the two main reasons for selecting optical HRM are related to the 24/7 comfort of use. The habit and confidence in the indications would be the reason for choosing the strap-HRM. Most of the answers (5: 2) support the preferred use of optical HRMs in the future. The characteristics of the group and the detailed answers of each respondent to most of the questions asked are found in Table S1.

 doi:10.20944/preprints202008.0508.v1

4. Discussion

4.1. Analysis of results

The analysis of information obtained from 120 people (athletes, coaches, and sports doctors) with many years of experience in personal use of HRM showed different expectations regarding the direction of development of the functions of modern HRMs. The participation in previous HRM studies on the differentiation of arrhythmias with artifacts was not without significance when answering the questionnaires. The potential health condition of an athlete using an HRM had an impact on the assessment and usefulness of the individual functions of HRMs. While for athletes the most important function was to assess the distance, speed, accuracy, and heart rate during training, the inclusion of potential heart disease with accompanying cardiac arrhythmias "shifted" the continuous ECG recording function quite clearly in the hierarchy of importance (from 9 to 4). This approach seems perfectly justified. Athletes put their training first. Being 'healthy,' they do not treat HRMs as medical devices protecting their health. For coaches the important elements of HRMs were: speed and accuracy in measuring the route; heart rate during training; and the possibility of determining the oxygen threshold. Regardless of the athlete's health, coaches only appreciated the possibility of continuous ECG recording by HRMs slightly higher than athletes. This can also be understood by the assumption that trained healthy athletes aim to achieve sports results and not be subject to permanent cardiological control. Doctors, regardless of whether they were dealing with healthy athletes or those suspected of heart rhythm disturbances, put the possibility of continuous ECG recording in first place. This is explained by the fact that this is a professional group associated with the training process, for whom the health of athletes is of paramount importance over results. All three groups preferred the use of OHRMs (versus SHRMs) provided they were reliable (resistance to artifacts), which is still difficult to find today. The indicated reason for such a choice was, among others, the ease of use of OHRMs, both in training and in everyday life (Table 3).

4.1. History of pulse control. From "fingers on the radial artery" to advanced ECG recording technologies.

Currently, no HRM in the world has all the functions about the importance of which respondents were asked. The indication of the moment of reaching oxygen threshold during training by HRMs is a purely theoretical and hypothetical function, no less highly desired by athletes and coaches.

The first reports of commercial medical devices for measuring heart rate came from the beginning of the 18th century [15]. Partially reliable HR control during training appeared with the widespread introduction of sweep hand watches more than two hundred years ago. The athlete had to stop and—most often observing the indications of the watch for ten seconds and then multiplying by 6—calculate the value of the heart rate, most often assessing the pulse on the radial artery. In this way, he obtained the heart rate value at the peak of exercise, which allowed him to determine the load in its last phase. There was no opportunity to determine average heart rate during training, so training was evaluated as a whole.

For doctors, observing the pulse on the radial artery was a factor in making diagnoses long before the advent of classic watches and had nothing to do with competitive sports [16]. A skilled physician ascertained a potential arrhythmia and was even able to determine its speed. All HRMs today record heart rate alone. However, this is not enough to establish a complete diagnosis of the origin of the rhythm and potential threats to the life and health of the athlete when pathological. There is no chance to determine whether the arrhythmia at a given time is caused by numerous harmless supraventricular beats—or atrial fibrillation—or whether it is a life-threatening ventricular tachycardia [17].

Commonly used SHRMs, which have been on the market for many years, indicate the correct HR value, but in the event of an arrhythmia are still not a reliable source of information about its type. The introduction of assessing heart rate variability (HRV) to HRMs allows for the determination of rhythm "regularity", but still does not answer the question of whether the regularity or complete arrhythmia is the result of supraventricular or ventricular beats, or ordinary artifacts [18]. SHRMs are based on the assessment of the main electric field produced during contraction of the ventricles. Thus, they estimate the distance of R-R points without identifying P-wave morphology or the QRS complex [19]. Such a function is completely useless in the case of *commotio cordis*, the mortality rate of which—regardless of the type of HRMs or the device controlling the work of the heart (except for the cardioverter-defibrillator)—is very high. However, healthy athletes do not have a cardioverter-defibrillator [20].

OHRMs have been on the market for about 10 years. The principle of their operation is common and the accuracy of their measurement is related to the chest SHRM. The principle of optical pulse monitor is completely different to what it was at first. While SHRMs work similarly to an ECG, OHRMs use a phenomenon called photoplethysmography (PPG): shining light through the skin and measuring the amount of light that is scattered by blood flow. PPG sensors are based on the fact that light entering the body will scatter in a predictable manner as the blood flow dynamics change, such as with changes in blood pulse rates (heart rate) or with changes in blood volume (cardiac output). In practice, the optical HR sensor located on the underside of the watch illuminates the blood vessels in the wrist tissue by means of LEDs, measuring the amount of light dispersed by the blood flow. The advantage of a wrist pulse measurement is convenience - the ability to measure HR without having to wear a separate strap, or other sensors, to measure the pulse. Such a watch must be placed directly on the skin. No material should be worn between the sensor and the skin and occasionally the watch must be worn higher on the wrist than a normal wristwatch. As the sensor reads the blood flow through the blood vessels, the more tissue to determine a reading from, the more accurate the measurement [12]. OHRMS, in their primary function, are only able to determine rhythm regularity and thus indirectly try to establish the diagnosis (e.g. complete arrhythmia—suspicion of atrial fibrillation [21].

The use of smartphones for arrhythmia monitoring is another leap for ECG utilization and arrhythmia detection—effectively bringing the technology to any smartphone user. Smart wearable technology, while very common, is mostly limited to activity tracking and exercise motivation. Rhythm strip generating smartphone products—Kardia Mobile by AliveCor and ECG Check by Cardiac Designs—are more powerful for arrhythmia detection than wearable monitors. These products, which have been studied in a variety of situations, rely on an external device with metal sensors to create a rhythm strip, which is usually Lead I. A different subset of smartphone products utilizes photoplethysmography through a phone camera and light to detect atrial fibrillation. Together, these products are creating a paradigm shift in rhythm detection and monitoring [7,22].

New electrodes built into the back crystal and digital crown on Apple Watch Series 4 work together with the ECG app to enable customers to take an ECG like a single-lead reading (Figure 1). To take an ECG recording at any time, or following an irregular rhythm notification, users launch the new ECG app on Apple Watch Series 4 and hold their finger on the digital crown. As the user touches the digital crown, the circuit is complete and electrical signals across the heart are measured. After 30 seconds, the heart rhythm is classified as either AFib, sinus rhythm, or inconclusive. All recordings, their associated classifications, and any noted symptoms are stored securely in the Health application on iPhone. Users can share a PDF of the results with physicians. Although, as in the case of the Apple Watch, it is only a record of one limb lead, it can clearly recognize both the P wave and the QRS complex. This recording fully corresponds to the classic single Lead 1 ECG recording (Figure 1). The biggest weakness of this function is that you must stop to record, which is against the idea of training [23].

However, the development of technology has brought new solutions and HRMs with applications enabling constant ECG recording during training to market (Figure 2). The QARDIO MD VSI system (exactly QardioCore ECG with QardioMD remote monitoring cloud based portal) can be described as a typical strap HRM, with the difference that the information from the transmitter (strap) is transferred to the receiver, which is the Qardio mobile app on iPhone. With a delay of about 3 minutes, information from the mobile phone is sent to the “cloud”. Downloading information to the Monitoring Center (Hospital, Clinic with QardioMD remote monitoring cloud based portal) allows you to control not only the ECG recording which is recorded continuously, but

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 24 August 2020 doi:10.20944/preprints202008.0508.v1

also recognize automatically life-threatening heart rhythm disorders . The inconvenience of carrying a phone during training is a minor difficulty compared to the enormous amount of information stored, which is transferred online to the "cloud" with a slight delay. The Monitoring Center offers an ECG recording of 3 limb leads with automated arrhythmia detection and the possibility of manual assessing PQ, QT, and ST segments. It seems a matter of time until it will be possible to automatically diagnose stress ischemia with the QardioMD VSI system. Preliminary studies have shown that it is a system of comparable diagnostic value to the standard 3 Lead Holter ECG monitor [24].

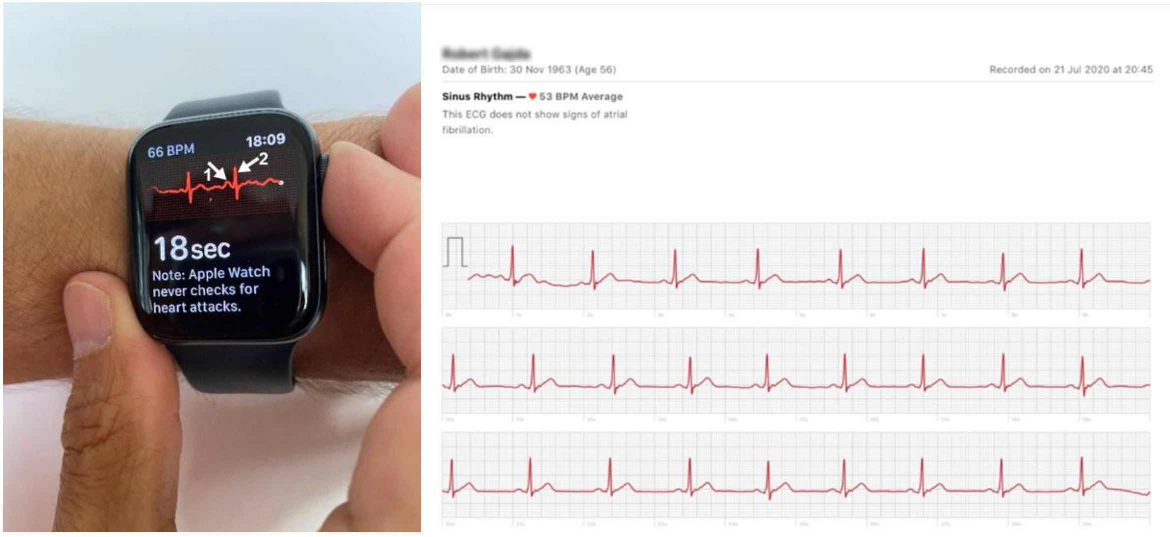

Figure 1. ECG on Apple Watch, I-Phone. (**A**) On the screen, a temporary ECG trace with the morphology of the II limb lead of a classic ECG. Visible: SR 66 bpm. Visible P waves (arrow 1) and QRS complexes (arrow 2). (**B**) ECG record sent to iPhone; image from the phone screen. Touching the Apple Watch Series 4 Digital Crown completes the circuit and electrical signals across the heart are measured.

A **B** **C**

Figure 2. QardioMD ECG solution (QARDIO MD VSI sytem). (**A**) QardioCore ECG - chest strap with electrode. (**B**) Qardio mobile app (ECG recording on iPhone) and chest strap (QardioCore ECG) with electrode. (**C**) ECG recording on QardioMD remote monitoring web based portal.

4.3. Strap HRMs or optical HRM

The surveyed athletes, coaches, and physicians answered this question unequivocally (Tables 2, 3). OHRM, provided that the indications are reliable. Wearing a chest strap is troublesome for athletes for a variety of reasons. From battery depletion artifacts, interference in the transmission between the strap and the receiver, to—the most important for ultramarathon runners—chafing of the skin during long hours of running by a moving strap [12,13]. It is also common to simply forget to put it on during training, which significantly changes the subsequent evaluation of the training. Therefore,

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 24 August 2020 doi:10.20944/preprints202008.0508.v1

OHRM is preferred on the condition of increasing accuracy of indications, which remains a problem [25]. In the past, an issue was the inability to measure heart rate by HRMs in water, which was a significant limitation for triathletes and swimmers. Currently, this problem does not exist [26]. OHRMs usually also have a longer battery life which, in 24- or 48-hour ultramarathons, is of great importance [27].

4.4. HRMs instead of the Holter ECG?

Sports HRMs were introduced to control the values of HR in healthy athletes and were not meant to be, or compete with, medical devices [28]; however, it is impossible to run daily with an ECG Holter just to verify periodic indications of incorrect values while training on HRMs. The algorithm for dealing with such cases has been developed [12]. However, HRMs should be considered as devices intended for athletes with useful and reliable medical functions, such as reliable ECG recording. Today's ECGs recorded by HRM are single limb lead (Apple Watch) or, as in the case of QARDIO MD VSI sytem, a 3 limb lead recording (Fig. 1A, B; Fig. 2C). However, this is an evolutionary leap, introducing devices "for measuring heart rate for healthy athletes" into advanced medical diagnostic tools in sports cardiology [7].

The trouble-free use of HRMs in everyday life makes them competitive in relation to professional equipment that requires special handling skills and professional knowledge of result interpretation (e.g. Holter ECG). It seems that it is only a matter of time before HRMs will be able to record a 12-lead ECG with the possibility of assessing any ECG features, including the ST segment, which will be extremely important for the diagnosis of exercise ischemia as in a classic exercise test [29]. Other data, such as measuring the QT interval or identifying the origin of ventricular beats, will become automatic information related to this recording.

Anyone, including the potentially healthy, top athlete, may experience life-threatening exercise arrhythmias [30]. The registration and early interpretation by HRMs used today by millions of active people may save lives in the future.

It seems that we are ahead of the days when the increasingly perfect ECG recorded on a typical sports HRM will be treated as a medical device necessary for safe, highly professional, and recreational training. The usefulness of these devices in cardiac rehabilitation is undisputed [31].

4.5. Bradyarrhythmia on HRMs - a lot to show off in terms of observing athletes.

Tachyarrhythmias are mentioned more often in terms of the usefulness of HRMs in the assessment of cardiac arrhythmias. However, wearing HRMs as in the case of OHRMs may contribute to the registration of not only fast rhythms during training, but also night bradyarrhythmia, which are a common rhythm disturbance in athletes of endurance disciplines [32]. Undoubtedly, this is a space where HRMs used by many athletes can contribute to the diagnosis of arrhythmias, if they are "recorded continuously" and data collected. Each of today's HRMs will register a decrease in the HR, but not everyone recognizes the mechanism in which this decrease occurred (conduction block or ordinary bradycardia). In asymptomatic, apparently healthy athletes at rest or during sleep, even 15 second pauses in the Holter ECG examination is common. Northcote et al. examined twenty male veteran endurance runners who underwent resting, exercise, and ambulatory electrocardiography. Six athletes had first degree heart block, four had Mobitz II second degree block, and three had complete heart block [33].

The "athlete's heart" and the accompanying bradycardia, or second-degree A-V block, are physiological adaptations to exercise [34]. However, a break of a few seconds is certainly a pathology that has the potential to be increasingly recognized by athletes using HRMs both in training and at rest (also in sleep). It is more comfortable to sleep with a watch on your wrist than with a strap on your chest. This is also the reason OHRMs seem to be a more common direction of development.

4.6 Other expectations from HRMs

The indication of the heart rate value for the diagnosis of the oxygen threshold is nowadays information obtained during the ergospirometric examination [35]. There is an enormous demand for this information by athletes and their coaches, but there is a need for a less complicated method. This function was ranked 4th among the surveyed athletes and coaches. There is a need and it cannot be ruled out that there will also be a method of determining this during training in the future.

4.7. Strength, Limitations, and Perspectives

The main limitation of the work is a relatively modest questionnaire that answers few questions and is conducted on a relatively small group of athletes, coaches, and doctors.

The main strengths of this work are that the group was representative to comment on the usefulness of HRMs. Most athletes have been under the care of a sports medicine clinic for 5–8 years, using HRMS all the time during their training. They have vast experience in using different HRMs, and know their strengths and weaknesses. Coaches and doctors know the athletes, cooperate with the Sports Cardiology Center in which these studies were conducted, and are up to date with the technology used by modern HRMs.

Perspectives: this is the improvement of the accuracy of indications already existing on the market of HRMs and certainly new technologies that will allow the widespread use of OHRMs with the function of 24-hour ECG recording, as well as other functions not yet available today, such as the expected oxygen threshold indicator. Certainly, there will be new common solutions other than the existing ones, allowing not only trouble-free recording of ECGs during training, but also informing the athlete, coach, and doctor online about potential threats in the form of heart rhythm disturbances and the emerging features of stress ischemia.

5. Conclusions

The conducted analysis indicates the diversity of expectations of athletes, coaches, and doctors as to the direction of development of modern HRMs. In the case of suspected heart rhythm disorders, the possibility of ECG recording is a priority feature for sports doctors. Considering all expectations, the paradigm will shift to include continuous ECG recording, especially during training. It seems users prefer OHRMs as they are more comfortable for endurance competitions as well as for non-training use.

Author Contributions: R.G. conceived of and designed the study; conducted and analyzed all examinations; and created the final version.

Funding: This research received no external funding.

Acknowledgments: The author would like to thank all athletes, coaches, and doctors who consented to the use of information from questionnaires in this study.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Almeida, M.; Bottino, A.; Ramos, P.; Araujo, C.G. Measuring Heart Rate During Exercise: From Artery Palpation to Monitors and Apps. *Int J Cardiovasc Sci* **2019**, *32*, 396-407. doi:10.5935/2359-4802.20190061.
2. De Müllenheim, P.Y.; Chaudru, S.; Emily, M.; Gernigon, M.; Mahé, G.; Bickert, S.; Prioux, J.; Noury-Desvaux, B.; Le Faucheur, A. Using GPS, accelerometry and heart rate to predict outdoor graded walking energy expenditure. *J Sci Med Sport* **2018**, *21*, 166-172. doi:10.1016/j.jsams.2017.10.004.
3. Li, R.T.; Kling, S.R.; Salata, M.J.; Cupp, S.A.; Sheehan, J.; Voos, J.E. Wearable Performance Devices in Sports Medicine. *Sports Health* **2016**, *8*, 74-78. doi:10.1177/1941738115616917.
4. Gajda, R.; Kowalik, E.; Rybka, S.; Rębowska, E.; Śmigielski, W.; Nowak, M.; Kwaśniewska, M.; Hoffman, P.; Drygas W. Evaluation of the Heart Function of Swimmers Subjected to Exhaustive Repetitive Endurance Efforts During a 500-km Relay. *Front Physiol* **2019**, *10*, 296. doi:10.3389/fphys.2019.00296.

5. Cassirame, J.; Vanhaesebrouck, R.; Chevrolat, S.; Mourot L. Accuracy of the Garmin 920 XT HRM to perform HRV analysis. *Australas Phys Eng Sci Med* **2017**, *40*, 831-839. doi:10.1007/s13246-017-0593-8.
6. Broux, B.; De Clercq, D.; Vera, L.; Ven, S.; Deprez, P.; Decloedt, A.; van Loon, G. Can heart rate variability parameters derived by a heart rate monitor differentiate between atrial fibrillation and sinus rhythm? *BMC Vet Res* **2018**, *14*, 320. doi:10.1186/s12917-018-1650-6.
7. Garabelli, P.; Stavrakis, S.; Po, S. Smartphone-based arrhythmia monitoring. *Curr Opin Cardiol* **2017**, *32*, 53-57. doi:10.1097/HCO.0000000000000350.
8. Gajda, R. Extreme Bradycardia and Bradyarrhythmias at Athletes. What will Technology Development Bring as a Help to Diagnosis Them? *Res Inves Sports Med* **2019**, *5*. doi:10.31031/RISM.2019.05.000617.
9. MindtecStore. QARDIOMD MOBILE ECG VITAL PARAMETERS MONITORING. Available online: https://www.mindtecstore.com/QardioMD-mobile-ECG-vital-parameters-monitoring (accessed on 5 August 2020).
10. Su, L.; Borov, S.; Zrenner, B. 12-lead Holter electrocardiography. Review of the literature and clinical application update. *Herzschrittmacherther Elektrophysiol* **2013**, *24*, 92-96. doi:10.1007/s00399-013-0268-4.
11. Gajda, R.; Biernacka, E.K.; Drygas, W. Are heart rate monitors valuable tools for diagnosing arrhythmias in endurance athletes? *Scand J Med Sci Sports* **2018**, *28*, 496-516. doi: 10.1111/sms.12917.
12. Gajda, R.; Biernacka, E.K.; Drygas, W. *The problem of arrhythmias in endurance athletes: are heart rate monitors valuable tools for diagnosing arrhythmias?* In *Horizons in World Cardiovascular Research*. Nova Science Publishers: New York, USA, 2009; 15, pp. 1-64.
13. Gajda, R.; Klisiewicz, A.; Matsibora, V.; Piotrowska-Kownacka, D.; Biernacka, E.K. Heart of the World's Top Ultramarathon Runner—Not Necessarily Much Different from Normal. *Diagnostics* **2020**, *10*, 73. doi:10.3390/diagnostics10020073.
14. Gajda, R. Heart Rate Monitor Instead of Ablation? Atrioventricular Nodal Re-Entrant Tachycardia in a Leisure-Time Triathlete: 6-Year Follow-Up. *Diagnostics* **2020**, *10*, 391. doi:10.3390/diagnostics10060391.
15. Pulse watch. Available online: https://en.wikipedia.org/wiki/Pulse_watch (accessed on 4 August 2020).
16. de Sá Ferreira, A.; Lopes, A.J. Pulse waveform analysis as a bridge between pulse examination in Chinese medicine and cardiology. *Chin J Integr Med* **2013**, *19*, 307-314. doi:10.1007/s11655-013-1412-z.
17. Müssigbrodt, A.; Richter, S.; Wetzel, U.; Van Belle, Y.; Bollmann, A.; Hindricks, G. Diagnosis of arrhythmias in athletes using leadless, ambulatory HR monitors. *Med Sci Sports Exerc* **2013**, *45*, 1431-1435. doi:10.1249/mss.0b013e31828ca1bf.
18. Gajda, R.; Drygas, W. Ventricular Arrhythmias in Endurance Athletes. Are Heart Rate Monitors Suitable Tools for their Diagnostics? *Res Inves Sports Med* **2019**, *5*. doi:10.31031/RISM.2019.05.000622.
19. Giles, D.A.; Draper, N. Heart Rate Variability During Exercise: A Comparison of Artefact Correction Methods. *J Strength Cond Res* **2018**, *32*, 726-735. doi:10.1519/JSC.0000000000001800.
20. Gajda, R. Commotio Cordis at Athletes – Under Recognized Problem. *Res Inves Sports Med* **2019**, *5*. doi:10.31031/RISM.2019.05.000615.
21. Gajda, R.; Biernacka, E.K.; Drygas, W. Atrial Fibrillation in athletes - easier to recognize today? *Res Inves Sports Med* **2019**, *5*. doi:10.31031/RISM.2019.05.000618.
22. Serhani, M.A.; T El Kassabi, H.; Ismail, H.; Nujum Navaz, A. ECG Monitoring Systems: Review, Architecture, Processes, and Key Challenges. *Sensor* **2020**, *20*, 1796. doi:10.3390/s20061796.
23. Massoomi, M.R.; Handberg, E.M. Increasing and Evolving Role of Smart Devices in Modern Medicine. *Eur Cardiol* **2019**, *14*, 181-186. doi:10.15420/ecr.2019.02.
24. Barr, C .; Comparison of Accuracy and Diagnostic Validity of a Novel Non-Invasive Electrocardiographic Monitoring Device with a Standard 3 Lead Holter Monitor and an ECG Patch over a 24 hours Period. (**2019**). J Cardiovasc Dis Diagn 2019, 7:5
25. Baek, H.J.; Shin, J. Effect of Missing Inter-Beat Interval Data on Heart Rate Variability Analysis Using Wrist-Worn Wearables. *J Med Syst* **2017**, *41*, 147. doi:10.1007/s10916-017-0796-2.
26. Olstad, B.H.; Bjørlykke, V.; Olstad, D.S. Maximal Heart Rate for Swimmers. *Sports* **2019**, *7*, 235. doi:10.3390/sports7110235.
27. Optical HR Armband Shootout: Polar OH1+, Scosche Rhythm 24, Wahoo TICKR FIT. https://www.dcrainmaker.com/2019/04/optical-heart-rate-sensor-armband-shootout-schosche24-polar oh1-wahoo-tickr-fit.html (accessed on 2 June 2020)

28. Karvonen, J.; Vuorimaa, T. Heart rate and exercise intensity during sports activities. Practical application. *Sports Med* **1988**, *5*, 303-311. doi:10.2165/00007256-198805050-00002.
29. Marcadet, D.M.; Pavy, B.; Bosser, G.; Claudot, F.; Corone, S.; Douard, H.; Iliou, M.C.; Vergès-Patois, B.; Amedro, P.; Le Tourneau, T.; Cueff, C. French Society of Cardiology guidelines on exercise tests (part 1): Methods and interpretation. *Arch Cardiovasc Dis* **2018**, *111*, 782-790. doi:10.1016/j.acvd.2018.05.005.
30. Biffi, A.; Maron, B.J.; Di Giacinto, B.; Porcacchia, P.; Verdile, L.; Fernando, F.; Spataro, A.; Culasso, F.; Casasco, M.; Pelliccia, A. Relation between training-induced left ventricular hypertrophy and risk for ventricular tachyarrhythmias in elite athletes. *Am J Cardiol* **2008**, *101*, 1792-1795. doi:10.1016/j.amjcard.2008.02.081.
31. Falter, M.; Budts, W.; Goetschalckx, K.; Cornelissen, V.; Buys, R. Accuracy of Apple Watch Measurements for Heart Rate and Energy Expenditure in Patients With Cardiovascular Disease: Cross-Sectional Study. *JMIR mHealth uHealth* **2019**, *7*, e11889. doi:10.2196/11889.
32. Doyen, B.; Matelot, D.; Carré, F. Asymptomatic bradycardia amongst endurance athletes. *Phys Sportsmed* **2019**, *47*, 249-252. doi:10.1080/00913847.2019.1568769.
33. Northcote, R.J.; Canning, G.P.; Ballantyne, D. Electrocardiographic findings in male veteran endurance athletes. *Br Heart J* **1989**, *61*, 155-160. doi:10.1136/hrt.61.2.155.
34. Bessem, B.; De Bruijn, M.C.; Nieuwland, W.; Zwerver, J.; Van Den Berg, M. The electrocardiographic manifestations of athlete's heart and their association with exercise exposure. *Eur J Sport Sci* **2018**, *18*, 587-593. doi:10.1080/17461391.2018.1441910.
35. Tran, D. Cardiopulmonary Exercise Testing. *Methods Mol Biol* **2018**, *1735*, 285-295. doi:10.1007/978-1-4939-7614-0_18.

Table S1.1. Cumulative results of the study groups (athlete, coaches, doctors) including function, sport discipline, gender, age, experience with HRMS, and answers to 11 questions in two situations of healthy athletes or those suspected of arrhythmia.

Respondent	Sport discipline	Gender [Male/ Female]	Age [years]	Experience with OHRMS [years]	Experience with SHRMS [years]	H/A	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11
Coach 1	N/A	M	45	0.5	6.5	H	1	3	4	5	10	7	8	2	9	11	6
Coach 2	N/A	M	51	3.5	6	H	1	2	3	5	11	7	9	4	8	10	6
Coach 3	N/A	M	48	2	5	H	1	2	3	7	10	5	8	4	9	11	6
Coach 4	N/A	M	54	3.5	5.5	H	1	2	3	5	10	8	7	4	9	11	6
Coach 5	N/A	M	26	1	4	H	1	2	3	5	10	7	8	4	6	11	9
Coach 6	N/A	M	51	2.5	8	H	2	3	1	5	10	7	8	4	9	11	6
Coach 7	N/A	M	46	3	8.5	H	1	2	4	5	10	7	8	3	9	11	6
Coach 8	N/A	M	36	3	9.5	H	1	2	3	6	9	7	10	4	8	11	5
Coach 9	N/A	M	60	2	10	H	1	2	3	5	11	8	7	4	9	10	6
Coach 10	N/A	M	34	4	3	H	1	2	3	5	11	6	8	4	10	9	7
Coach 1	N/A	M	45	0.5	6.5	A	5	1	2	9	11	4	3	6	10	8	7
Coach 2	N/A	M	51	3.5	6	A	4	1	2	6	9	5	3	11	10	8	7
Coach 3	N/A	M	48	2	5	A	5	3	2	7	11	4	1	6	9	8	10
Coach 4	N/A	M	54	4	5.5	A	4	1	5	9	7	2	3	6	10	8	11
Coach 5	N/A	M	26	1	4	A	5	2	1	9	8	4	3	6	10	11	7
Coach 6	N/A	M	51	3	8	A	5	1	2	9	11	4	3	10	6	8	7
Coach 7	N/A	M	46	3	8.5	A	3	1	2	9	11	4	5	6	7	8	10
Coach 8	N/A	M	36	3	9.5	A	5	4	2	8	11	1	3	6	10	9	7
Coach 9	N/A	M	60	2	10	A	5	1	2	9	11	4	3	7	10	8	6
Coach 10	N/A	M	34	4	3	A	5	1	4	11	10	2	3	6	9	8	7
Doctor 1	N/A	M	43	0.5	4	H	8	9	6	7	10	2	1	5	11	3	4
Doctor 2	N/A	M	51	4	5	H	7	8	6	9	10	2	1	5	11	4	3
Doctor 3	N/A	M	39	1.5	5.5	H	8	9	7	6	10	2	1	5	11	4	3
Doctor 4	N/A	M	59	2	7	H	9	8	6	7	10	2	1	5	11	4	3
Doctor 5	N/A	M	49	1.5	6.5	H	7	9	6	8	10	2	1	5	11	4	3
Doctor 6	N/A	M	60	4	9	H	8	9	6	7	10	2	1	5	11	4	3
Doctor 7	N/A	M	55	3.5	5.5	H	8	9	4	7	11	3	1	6	10	5	2
Doctor 8	N/A	M	33	1	5	H	8	9	6	7	10	1	2	5	11	4	3
Doctor 9	N/A	M	57	3	4.5	H	8	10	5	7	9	2	1	4	11	6	3
Doctor 10	N/A	M	53	3	10	H	8	9	6	7	10	2	1	5	11	3	4
Doctor 1	N/A	M	43	0.5	4	A	7	6	5	8	11	2	1	9	10	4	3
Doctor 2	N/A	M	51	4	5	A	7	6	5	8	10	2	1	9	11	4	3
Doctor 3	N/A	M	39	1.5	5.5	A	6	7	5	8	11	2	1	9	10	4	3
Doctor 4	N/A	M	59	2	7	A	9	6	5	7	11	2	1	8	10	4	3
Doctor 5	N/A	M	49	1.5	6.5	A	7	5	6	8	11	2	1	9	10	4	3
Doctor 6	N/A	M	60	4	9	A	7	6	5	8	11	2	1	9	10	4	3

Doctor 7	N/A	M	55	3.5	5.5	A	8	6	5	9	11	2	1	7	10	4	3
Doctor 8	N/A	M	33	1	5	A	7	6	5	8	11	2	1	9	10	3	4
Doctor 9	N/A	M	57	3	4.5	A	7	6	5	8	11	2	1	9	10	4	3
Doctor 10	N/A	M	53	3	10	A	7	5	6	8	11	2	1	9	10	4	3
Athlete	Runner 1	M	35	0.5	5	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Runner 2	M	31	3	2	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Runner 3	F	25	2	2.5	H	1	2	3	5	7	8	10	4	9	11	6
Athlete	Runner 4	M	35	0.75	6	H	1	3	2	5	7	8	9	4	10	11	6
Athlete	Runner 5	F	37	4	5	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Runner 6	F	39	1	5.75	H	1	2	3	5	7	9	11	4	8	10	6
Athlete	Runner 7	M	36	2	4	H	1	2	4	5	7	8	9	3	10	11	6
Athlete	Runner 8	M	41	1	9.5	H	1	2	3	5	7	8	10	4	9	11	6
Athlete	Runner 9	M	43	3	8	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Runner 10	F	28	3	2.5	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Runner 11	M	35	2	9	H	1	2	3	4	7	8	9	5	10	11	6
Athlete	Runner 12	M	29	1	3.5	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Runner 13	M	36	1.25	3.25	H	1	2	3	5	7	9	11	4	8	10	6
Athlete	Runner 14	M	37	1	10	H	1	3	2	5	7	8	9	4	10	11	6
Athlete	Runner 15	F	42	1.25	5.25	H	1	2	3	6	7	8	10	4	9	11	5
Athlete	Runner 16	M	36	3	8	H	1	2	3	5	7	9	8	4	11	10	6
Athlete	Runner 17	M	29	1	4.5	H	1	2	5	3	7	8	9	4	10	11	6
Athlete	Runner 18	M	29	2	5.5	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Runner 19	F	39	1	5	H	1	2	3	5	7	9	11	4	8	10	6
Athlete	Runner 20	M	27	3	2.75	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Runner 21	M	34	2	3	H	1	2	3	5	6	8	9	4	10	11	7
Athlete	Runner 22	F	39	2	8	H	1	2	3	4	7	8	9	5	10	11	6
Athlete	Runner 23	M	41	0.75	7.5	H	1	2	4	5	7	9	8	3	11	10	6
Athlete	Runner 24	M	21	0.25	2	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Runner 25	M	43	1	5.25	H	1	2	4	5	7	8	9	3	10	11	6
Athlete	Runner 26	F	44	3	6.5	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Runner 27	M	28	1	3.25	H	1	2	3	6	7	8	10	4	9	11	5
Athlete	Runner 28	M	31	0.5	3	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Runner 29	M	32	1.25	4	H	1	2	3	5	7	10	8	4	11	9	6
Athlete	Runner 30	M	35	1	7	H	2	1	3	5	7	8	9	4	10	11	6
Athlete	Runner 31	F	38	0.25	6.5	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Runner 32	M	36	1	4.25	H	1	2	3	5	7	6	9	4	10	11	8
Athlete	Runner 33	M	38	1.5	9	H	1	2	5	3	7	8	9	4	10	11	6
Athlete	Runner 34	M	28	1	3.75	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Runner 35	F	31	1	6.5	H	1	2	3	5	6	9	8	4	11	10	7
Athlete	Runner 36	M	27	3.5	2.5	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Runner 37	F	34	1	7.5	H	1	2	3	5	7	8	10	4	9	11	6
Athlete	Runner 38	M	34	1	8.5	H	1	2	5	3	7	8	9	4	10	11	6

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 24 August 2020 doi:10.20944/preprints202008.0508.v1

Athlete	Runner 39	M	40	2	4.25	H	1	2	3	5	7	10	8	4	11	9	6
Athlete	Runner 40	F	42	2	6.25	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Runner 41	M	57	1	10	H	1	2	3	5	6	8	9	4	10	11	7
Athlete	Runner 42	F	26	3	2	H	1	2	3	5	7	8	9	4	11	10	6
Athlete	Runner 43	F	33	2	5.5	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Runner 44	M	30	3	2.5	H	2	1	3	5	7	8	9	4	10	11	6
Athlete	Runner 45	F	33	1	3.5	H	1	2	3	7	5	8	9	4	10	11	6
Athlete	Runner 46	F	36	2	5	H	1	2	3	5	7	9	8	4	11	10	6
Athlete	Runner 47	M	44	1	5.25	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Runner 48	M	33	2.5	6.5	H	1	4	2	5	7	8	9	3	11	10	6
Athlete	Runner 49	M	38	2	9.25	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Runner 50	F	36	1	7.5	H	1	2	3	5	7	8	10	4	9	11	6
Athlete	Runner 51	M	36	3	7	H	1	2	3	5	7	6	9	4	10	11	8
Athlete	Runner 52	M	50	0.75	10	H	1	2	3	5	7	10	8	4	11	9	6
Athlete	Runner 53	F	45	0.5	6	H	1	2	3	4	7	8	9	5	10	11	6
Athlete	Runner 54	M	37	2	5	H	1	2	3	5	7	8	10	4	9	11	6
Athlete	Runner 55	M	37	2	6	H	1	2	3	5	6	8	9	4	10	11	7
Athlete	Runner 56	M	38	0.5	4.25	H	2	1	3	5	7	8	9	4	10	11	6
Athlete	Runner 57	M	40	0.25	8	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Runner 58	M	35	0.25	4	H	1	2	3	5	7	9	8	4	11	10	6
Athlete	Runner 59	F	36	2.5	6	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Runner 60	F	25	1.75	3.25	H	1	2	3	7	6	8	9	4	10	11	5
Athlete	Runner 61	M	31	0.75	5.5	H	1	2	3	5	7	8	10	4	9	11	6
Athlete	Runner 62	M	25	1.5	5.25	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Runner 63	F	31	0.25	3.5	H	1	2	3	5	7	8	10	4	9	11	6
Athlete	Runner 64	M	35	2	8	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Runner 65	M	28	2	2.25	H	1	2	3	5	7	8	10	4	9	11	6
Athlete	Runner 66	M	29	3	2.5	H	1	2	3	5	7	10	8	4	11	9	6
Athlete	Runner 67	M	38	3	6	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Runner 68	M	39	1	9	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Runner 69	F	30	1	4.25	H	1	2	3	5	6	7	9	4	10	11	8
Athlete	Runner 70	M	51	1	9	H	1	2	3	5	7	8	10	4	9	11	6
Athlete	Runner 71	F	22	0.5	3	H	1	3	2	5	7	8	9	4	10	11	6
Athlete	Runner 72	M	34	2	2	H	1	2	3	5	7	9	8	4	11	10	6
Athlete	Runner 73	F	34	1	9.5	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Runner 74	F	26	2.5	4.5	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Runner 75	M	43	2	9.5	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Runner 76	F	24	1	2.25	H	1	2	3	5	6	8	9	4	10	11	7
Athlete	Cyclist 1	M	24	1.5	2.25	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Cyclist 2	M	37	3	7	H	1	2	3	5	7	10	8	4	11	9	6
Athlete	Cyclist 3	M	27	2	5	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Cyclist 4	M	48	0.5	8.5	H	1	2	3	5	7	8	10	4	9	11	6

Athlete	Cyclist 5	M	26	3	3	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Cyclist 6	M	37	1	9	H	1	3	2	6	7	8	9	4	10	11	6
Athlete	Cyclist 7	M	39	3	10	H	1	2	3	5	6	7	9	4	10	11	8
Athlete	Cyclist 8	F	55	1	6.25	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Cyclist 9	M	38	0.75	7	H	1	2	3	5	7	8	9	6	10	11	6
Athlete	Cyclist 10	F	38	1	7.25	H	1	2	3	5	7	11	10	4	9	8	6
Athlete	Cyclist 11	M	40	2	5.25	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Cyclist 12	M	30	2	3.25	H	1	2	3	5	7	8	10	4	9	11	6
Athlete	Cyclist 13	M	30	2	3.25	H	1	2	3	7	6	8	9	4	10	11	5
Athlete	Cyclist 14	M	33	2	4.5	H	1	2	4	5	7	9	8	4	11	10	6
Athlete	Triathlete 1	M	40	4	7	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Triathlete 2	F	24	0.75	2.25	H	1	2	3	5	7	8	9	4	10	11	6
Athlete	Triathlete 3	M	27	1	4	H	1	2	3	5	7	8	10	4	9	11	6
Athlete	Triathlete 4	M	32	1.75	2.5	H	2	1	3	6	7	8	9	4	10	11	5
Athlete	Triathlete 5	M	39	1.75	6.75	H	1	2	3	5	7	8	10	4	9	11	6
Athlete	Triathlete 6	M	32	1.25	4.25	H	1	2	5	3	7	8	9	4	10	11	6
Athlete	Triathlete 7	M	39	2	9	H	1	2	3	5	7	11	10	4	9	8	6
Athlete	Triathlete 8	M	40	1	10	H	2	1	3	7	6	8	9	4	10	11	5
Athlete	Triathlete 9	M	41	0.5	8.5	H	1	2	3	5	7	9	8	4	11	10	6
Athlete	Triathlete 10	M	38	1	6.25	H	1	2	4	5	7	8	9	3	10	11	6
Athlete	Runner 1	M	35	0.5	5	A	1	2	3	8	10	5	4	9	11	7	6
Athlete	Runner 2	M	31	3	2	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Runner 3	F	25	2	2.5	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Runner 4	M	35	0.75	6	A	2	1	3	7	10	5	4	8	11	9	6
Athlete	Runner 5	F	37	4	5	A	1	2	5	7	11	3	4	9	8	10	6
Athlete	Runner 6	F	39	1	5.75	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Runner 7	M	36	2	4	A	2	1	3	7	9	5	4	10	8	11	6
Athlete	Runner 8	M	41	1	9.5	A	1	2	3	7	10	4	5	9	11	8	6
Athlete	Runner 9	M	43	3	8	A	1	2	5	7	10	3	4	9	11	8	6
Athlete	Runner 10	F	28	3	2.5	A	3	1	2	7	11	5	4	9	8	10	6
Athlete	Runner 11	M	35	2	9	A	1	2	3	7	10	5	6	9	11	8	4
Athlete	Runner 12	M	29	1	3.5	A	1	2	3	7	10	5	4	8	11	9	6

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 24 August 2020 doi:10.20944/preprints202008.0508.v1

Athlete	Runner 13	M	36	1.25	3.25	A	1	2	7	5	10	3	4	9	11	8	6
Athlete	Runner 14	M	37	1	10	A	2	1	3	7	10	5	4	9	11	8	6
Athlete	Runner 15	F	42	1.25	5.25	A	1	2	3	7	11	5	4	9	8	10	6
Athlete	Runner 16	M	36	3	8	A	3	1	2	7	10	5	4	9	11	8	6
Athlete	Runner 17	M	29	1	4.5	A	3	1	2	4	10	5	6	9	11	8	7
Athlete	Runner 18	M	29	2	5.5	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Runner 19	F	39	1	5	A	2	1	3	7	9	5	4	10	8	11	6
Athlete	Runner 20	M	27	3	2.75	A	1	2	5	7	10	3	4	9	11	8	6
Athlete	Runner 21	M	34	2	3	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Runner 22	F	39	2	8	A	1	2	3	7	11	5	4	9	8	10	6
Athlete	Runner 23	M	41	0.75	7.5	A	1	2	3	4	10	5	6	9	11	8	7
Athlete	Runner 24	M	21	0.25	2	A	1	2	7	3	10	5	4	9	11	8	6
Athlete	Runner 25	M	43	1	5.25	A	2	1	3	7	10	5	4	8	11	9	6
Athlete	Runner 26	F	44	3	6.5	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Runner 27	M	28	1	3.25	A	1	2	3	7	10	4	5	9	11	8	6
Athlete	Runner 28	M	31	0.5	3	A	2	1	3	7	10	5	4	9	11	8	6
Athlete	Runner 29	M	32	1.25	4	A	1	2	3	7	9	5	4	10	8	11	6
Athlete	Runner 30	M	35	1	7	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Runner 31	F	38	0.25	6.5	A	2	1	3	7	10	5	4	9	11	8	6
Athlete	Runner 32	M	36	1	4.25	A	1	2	3	6	10	5	4	9	11	8	7
Athlete	Runner 33	M	38	1.5	9	A	1	2	3	7	11	5	4	9	8	10	6
Athlete	Runner 34	M	28	1	3.75	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Runner 35	F	31	1	6.5	A	3	1	2	7	10	5	4	9	11	8	6
Athlete	Runner 36	M	27	3.5	2.5	A	1	2	3	7	9	5	4	10	8	11	6
Athlete	Runner 37	F	34	1	7.5	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Runner 38	M	34	1	8.5	A	2	1	3	7	10	5	4	9	11	8	6
Athlete	Runner 39	M	40	2	4.25	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Runner 40	F	42	2	6.25	A	1	2	7	3	10	5	4	9	11	8	6
Athlete	Runner 41	M	57	1	10	A	2	1	3	7	11	5	4	9	8	10	6
Athlete	Runner 42	F	26	3	2	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Runner 43	F	33	2	5.5	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Runner 44	M	30	3	2.5	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Runner 45	F	33	1	3.5	A	2	1	3	7	10	5	6	9	11	8	4
Athlete	Runner 46	F	36	2	5	A	1	2	3	7	9	5	4	10	8	11	6
Athlete	Runner 47	M	44	1	5.25	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Runner 48	M	33	2.5	6.5	A	1	2	3	8	10	5	4	9	11	8	6
Athlete	Runner 49	M	38	2	9.25	A	1	2	3	7	11	5	4	9	8	10	6
Athlete	Runner 50	F	36	1	7.5	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Runner 51	M	36	3	7	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Runner 52	M	50	0.75	10	A	2	1	3	7	10	5	4	9	11	8	6
Athlete	Runner 53	F	45	0.5	6	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Runner 54	M	37	2	5	A	1	2	3	5	10	6	4	9	11	8	7

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 24 August 2020 doi:10.20944/preprints202008.0508.v1

Athlete	Runner 55	M	37	2	6	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Runner 56	M	38	0.5	4.25	A	1	2	5	7	10	3	4	9	11	8	6
Athlete	Runner 57	M	40	0.25	8	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Runner 58	M	35	0.25	4	A	3	1	2	7	11	5	4	9	8	10	6
Athlete	Runner 59	F	36	2.5	6	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Runner 60	F	25	1.75	3.25	A	1	2	7	3	10	5	4	9	11	8	6
Athlete	Runner 61	M	31	0.75	5.5	A	1	2	3	7	11	5	4	9	8	10	6
Athlete	Runner 62	M	25	1.5	5.25	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Runner 63	F	31	0.25	3.5	A	1	2	3	7	9	5	4	10	8	11	6
Athlete	Runner 64	M	35	2	8	A	2	1	3	7	10	5	6	9	11	8	4
Athlete	Runner 65	M	28	2	2.25	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Runner 66	M	29	3	2.5	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Runner 67	M	38	3	6	A	1	2	7	5	10	3	4	9	11	8	6
Athlete	Runner 68	M	39	1	9	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Runner 69	F	30	1	4.25	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Runner 70	M	51	1	9	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Runner 71	F	22	0.5	3	A	3	1	2	7	9	5	4	10	8	11	6
Athlete	Runner 72	M	34	2	2	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Runner 73	F	34	1	9.5	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Runner 74	F	26	2.5	4.5	A	1	2	3	7	11	5	4	9	8	10	6
Athlete	Runner 75	M	43	2	9.5	A	5	1	2	7	10	3	4	9	11	8	6
Athlete	Runner 76	F	24	1	2.25	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Cyclist 1	M	24	1.5	2.25	A	1	2	3	7	11	5	4	8	10	9	6
Athlete	Cyclist 2	M	37	3	7	A	2	1	8	3	10	5	4	9	11	7	6
Athlete	Cyclist 3	M	27	2	5	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Cyclist 4	M	48	0.5	8.5	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Cyclist 5	M	26	3	3	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Cyclist 6	M	37	1	9	A	3	1	2	7	9	5	4	10	8	11	6
Athlete	Cyclist 7	M	39	3	10	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Cyclist 8	F	55	1	6.25	A	1	2	7	3	10	5	4	9	11	8	6
Athlete	Cyclist 9	M	38	0.75	7	A	1	2	3	7	8	5	4	9	10	11	6
Athlete	Cyclist 10	F	38	1	7.25	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Cyclist 11	M	40	2	5.25	A	1	2	3	7	11	5	4	8	10	9	6
Athlete	Cyclist 12	M	30	2	3.25	A	1	2	3	4	10	5	6	9	11	8	7
Athlete	Cyclist 13	F	30	2	3.25	A	1	2	3	7	11	5	4	9	8	10	6
Athlete	Cyclist 14	M	33	2	4.5	A	3	1	2	7	10	5	4	9	11	8	6
Athlete	Triathlete 1	M	40	4	7	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Triathlete 2	F	24	0.75	2.25	A	1	2	3	7	11	5	4	8	10	9	6
Athlete	Triathlete 3	M	27	1	4	A	2	1	5	7	10	3	4	9	11	8	6

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 24 August 2020 doi:10.20944/preprints202008.0508.v1

Athlete	Triathlete 4	M	32	1.75	2.5	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Triathlete 5	M	39	1.75	6.75	A	1	2	3	7	10	6	5	9	11	8	4
Athlete	Triathlete 6	M	32	1.25	4.25	A	1	2	3	7	11	5	4	9	8	10	6
Athlete	Triathlete 7	M	39	2	9	A	1	2	3	7	10	5	4	9	11	8	6
Athlete	Triathlete 8	M	40	1	10	A	2	1	3	7	11	5	4	9	8	10	6
Athlete	Triathlete 9	M	41	0.5	8.5	A	1	2	3	7	10	6	5	9	11	8	4
Athlete	Triathlete 10	M	38	1	6.25	A	1	2	3	7	10	5	4	9	11	8	6

Functions 1–11: F1, distance; F2, speed/pace; F3, current HR; F4, average training HR; F5, amount of calories consumed during training (active kcal); F6, recording of the current ECG "on demand"; F7, continuous ECG recording; F8, the moment of reaching the anaerobic threshold (AT) (lactate threshold); F9, altitude [meters above sea level (MASL)]; F10, heart rate variability (HRV); F11, 24-hour HR measurement. OHRM, optical Heart Rate Monitor; SHRM, strap Heart Rate Monitor; H/A, Healthy Athlete; A, Suspicion of arrhythmia; N/A, not applicable.

Table S1.2. Number of votes cast for functions by respondents and their percentage share depending on the situation: healthy athlete (**A**) versus suspected arrhythmia (**B**).

Table S1.2.1 A. Coaches - Healthy athlete

	F 1		F 2		F 3		F 4		F 5		F 6		F 7		F 8		F 9		F 10		F 11	
	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%
1 P	9	90%	0	0%	1	10%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
2 P	1	10%	8	80%	0	0%	0	0%	0	0%	0	0%	0	0%	1	10%	0	0%	0	0%	0	0%
3 P	0	0%	2	20%	7	70%	0	0%	0	0%	0	0%	0	0%	1	10%	0	0%	0	0%	0	0%
4 P	0	0%	0	0%	2	20%	0	0%	0	0%	0	0%	0	0%	8	80%	0	0%	0	0%	0	0%
5 P	0	0%	0	0%	0	0%	8	80%	0	0%	1	10%	0	0%	0	0%	0	0%	0	0%	1	10%
6 P	0	0%	0	0%	0	0%	1	10%	0	0%	1	10%	0	0%	0	0%	1	10%	0	0%	7	70%
7 P	0	0%	0	0%	0	0%	1	10%	0	0%	6	60%	2	20%	0	0%	0	0%	0	0%	1	10%
8 P	0	0%	0	0%	0	0%	0	0%	0	0%	2	20%	6	60%	0	0%	2	20%	0	0%	0	0%
9 P	0	0%	0	0%	0	0%	0	0%	1	10%	0	0%	1	10%	0	0%	6	60%	1	10%	1	10%
10 P	0	0%	0	0%	0	0%	0	0%	6	60%	0	0%	1	10%	0	0%	1	10%	2	20%	0	0%
11 P	0	0%	0	0%	0	0%	0	0%	3	30%	0	0%	0	0%	0	0%	0	0%	7	70%	0	0%

F, Function; VN, number of votes; P, place.

Table S1.2.1 B. Coaches – suspected arrhythmia

F 1		F 2		F 3		F 4		F 5		F 6		F 7		F 8		F 9		F 10		F 11	
VN	%	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 24 August 2020 doi:10.20944/preprints202008.0508.v1

1 P	0	0%	7	70%	1	10%	0	0%	0	0%	1	10%	1	10%	0	0%	0	0%	0	0%	0	0%
2 P	0	0%	1	10%	7	70%	0	0%	0	0%	2	20%	0	0%	0	0%	0	0%	0	0%	0	0%
3 P	1	10%	1	10%	0	0%	0	0%	0	0%	0	0%	8	80%	0	0%	0	0%	0	0%	0	0%
4 P	2	20%	1	10%	1	10%	0	0%	0	0%	6	60%	0	0%	0	0%	0	0%	0	0%	0	0%
5 P	7	70%	0	0%	1	10%	0	0%	0	0%	1	10%	1	10%	0	0%	0	0%	0	0%	0	0%
6 P	0	0%	0	0%	0	0%	1	10%	0	0%	0	0%	0	0%	7	70%	1	10%	0	0%	1	10%
7 P	0	0%	0	0%	0	0%	1	10%	1	10%	0	0%	0	0%	1	10%	1	10%	0	0%	6	60%
8 P	0	0%	0	0%	0	0%	1	10%	1	10%	0	0%	0	0%	0	0%	0	0%	8	80%	0	0%
9 P	0	0%	0	0%	0	0%	6	60%	1	10%	0	0%	0	0%	0	0%	2	20%	1	10%	0	0%
10 P	0	0%	0	0%	0	0%	0	0%	1	10%	0	0%	0	0%	1	10%	6	60%	0	0%	2	20%
11 P	0	0%	0	0%	0	0%	1	10%	6	60%	0	0%	0	0%	1	10%	0	0%	1	10%	1	10%

F, Function; VN, number of votes; P, place.

Table S1.2.2 A. Doctors – healthy athlete

	F 1		F 2		F 3		F 4		F 5		F 6		F 7		F 8		F 9		F 10		F 11	
	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%
1 P	0	0%	0	0%	0	0%	0	0%	0	0%	1	10%	9	90%	0	0%	0	0%	0	0%	0	0%
2 P	0	0%	0	0%	0	0%	0	0%	0	0%	8	80%	1	10%	0	0%	0	0%	0	0%	1	10%
3 P	0	0%	0	0%	0	0%	0	0%	0	0%	1	10%	0	0%	0	0%	0	0%	2	20%	7	70%
4 P	0	0%	0	0%	1	10%	0	0%	0	0%	0	0%	0	0%	1	10%	0	0%	6	60%	2	20%
5 P	0	0%	0	0%	1	10%	0	0%	0	0%	0	0%	0	0%	8	80%	0	0%	1	10%	0	0%
6 P	0	0%	0	0%	7	70%	1	10%	0	0%	0	0%	0	0%	1	10%	0	0%	1	10%	0	0%
7 P	2	20%	0	0%	1	10%	7	70%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
8 P	7	70%	2	20%	0	0%	1	10%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
9 P	1	10%	7	70%	0	0%	1	10%	1	10%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
10 P	0	0%	1	10%	0	0%	0	0%	8	80%	0	0%	0	0%	0	0%	1	10%	0	0%	0	0%
11 P	0	0%	0	0%	0	0%	0	0%	1	10%	0	0%	0	0%	0	0%	9	90%	0	0%	0	0%

F, Function; VN, number of votes; P, place.

Table S1.2.2 B. Doctors- suspected arrhythmia

	F 1		F 2		F 3		F 4		F 5		F 6		F 7		F 8		F 9		F 10		F 11	
	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%
1 P	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	10	100%	0	0%	0	0%	0	0%	0	0%
2 P	0	0%	0	0%	0	0%	0	0%	0	0%	10	100%	0	0%	0	0%	0	0%	0	0%	0	0%
3 P	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	1	10%	9	90%
4 P	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	9	90%	1	10%
5 P	0	0%	2	20%	8	80%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
6 P	1	10%	7	70%	2	20%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
7 P	7	70%	1	10%	0	0%	1	10%	0	0%	0	0%	0	0%	1	10%	0	0%	0	0%	0	0%
8 P	1	10%	0	0%	0	0%	8	80%	0	0%	0	0%	0	0%	1	10%	0	0%	0	0%	0	0%

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 24 August 2020 doi:10.20944/preprints202008.0508.v1

9 P	1	10%	0	0%	0	0%	1	10%	0	0%	0	0%	0	0%	8	80%	0	0%	0	0%	0	0%
10 P	0	0%	0	0%	0	0%	0	0%	1	10%	0	0%	0	0%	0	0%	9	90%	0	0%	0	0%
11 P	0	0%	0	0%	0	0%	0	0%	9	90%	0	0%	0	0%	0	0%	1	10%	0	0%	0	0%

F, Function; VN, number of votes; P, place.

Table S1.2.3 A. Athletes – healthy athlete

	F 1		F 2		F 3		F 4		F 5		F 6		F 7		F 8		F 9		F 10		F 11	
	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%
1 P	95	95%	5	5%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
2 P	5	5%	90	90%	5	5%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
3 P	0	0%	4	4%	86	86%	4	4%	0	0%	0	0%	0	0%	5	5%	0	0%	0	0%	0	0%
4 P	0	0%	1	1%	5	5%	3	3%	0	0%	0	0%	0	0%	91	91%	0	0%	0	0%	0	0%
5 P	0	0%	0	0%	4	4%	85	85%	1	1%	0	0%	0	0%	3	3%	0	0%	0	0%	6	6%
6 P	0	0%	0	0%	0	0%	4	4%	10	10%	2	2%	0	0%	1	1%	0	0%	0	0%	85	85%
7 P	0	0%	0	0%	0	0%	4	4%	89	89%	2	2%	0	0%	0	0%	0	0%	0	0%	5	5%
8 P	0	0%	0	0%	0	0%	0	0%	0	0%	78	78%	13	13%	0	0%	3	3%	2	2%	4	4%
9 P	0	0%	0	0%	0	0%	0	0%	0	0%	11	11%	67	67%	0	0%	17	17%	5	5%	0	0%
10 P	0	0%	0	0%	0	0%	0	0%	0	0%	5	5%	17	17%	0	0%	65	65%	13	13%	0	0%
11 P	0	0%	0	0%	0	0%	0	0%	0	0%	2	2%	3	3%	0	0%	15	15%	80	80%	0	0%

F, Function; VN, number of votes; P, place.

Table S1.2.3 B. Athletes – Suspicion of arrhythmia

	F 1		F 2		F 3		F 4		F 5		F 6		F 7		F 8		F 9		F 10		F 11	
	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%	VN	%
1 P	76	76%	24	24%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
2 P	15	15%	76	76%	9	9%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
3 P	8	8%	0	0%	79	79%	5	5%	0	0%	8	8%	0	0%	0	0%	0	0%	0	0%	0	0%
4 P	0	0%	0	0%	0	0%	3	3%	0	0%	2	2%	90	90%	0	0%	0	0%	0	0%	5	5%
5 P	1	1%	0	0%	5	5%	3	3%	0	0%	87	87%	4	4%	0	0%	0	0%	0	0%	0	0%
6 P	0	0%	0	0%	0	0%	1	1%	0	0%	3	3%	6	6%	0	0%	0	0%	0	0%	90	90%
7 P	0	0%	0	0%	6	6%	86	86%	0	0%	0	0%	0	0%	0	0%	0	0%	2	2%	5	5%
8 P	0	0%	0	0%	1	1%	2	2%	1	1%	0	0%	0	0%	6	6%	21	21%	70	70%	0	0%
9 P	0	0%	0	0%	0	0%	0	0%	8	8%	0	0%	0	0%	86	86%	0	0%	6	6%	0	0%
10 P	0	0%	0	0%	0	0%	0	0%	75	75%	0	0%	0	0%	8	8%	4	4%	13	13%	0	0%
11 P	0	0%	0	0%	0	0%	0	0%	16	16%	0	0%	0	0%	0	0%	75	75%	9	9%	0	0%

F, Function; VN, number of votes; P, place.

Table S1.3. Reasons for preferential use of the wrist-worn optical heart rate monitors (OHRMs) versus chest strap HRMs (SHRMs) by athletes, coaches, and doctors, assuming that both types of HRMs have the same functions and the same resistance to artifacts.

 doi:10.20944/preprints202008.0508.v1

Respondent	Sport discipline	Gender [Male/ Female]	Age [years]	Experience with OHRMS [years]	Experience with SHRMS [years]	R1	R2	R3	R4	R5	R6	R7
T 1	N/A	M	45	0.5	6.5	1	1	1	1	1	2	1
T 2	N/A	M	51	3.5	6	1	1	1	1	1	1	2
T 3	N/A	M	48	2	5	1	1	2	1	1	2	2
T 4	N/A	M	54	3.5	5.5	2	1	1	1	1	2	2
T 5	N/A	M	26	1	4	1	1	2	1	1	2	2
T 6	N/A	M	51	2.5	8	1	1	1	1	2	2	2
T 7	N/A	M	46	3	8.5	1	2	1	1	2	2	2
T 8	N/A	M	36	3	9.5	1	1	2	1	2	2	2
T 9	N/A	M	60	2	10	1	1	1	1	1	2	2
T 10	N/A	M	34	4	3	2	1	2	1	2	2	2
					OHRMS	80%	90%	60%	100%	60%	10%	10%
					SHRMS	20%	10%	40%	0%	40%	90%	90%
D 1	N/A	M	43	0.5	4	1	1	2	1	1	2	2
D 2	N/A	M	51	4	5	1	1	1	1	2	2	2
D 3	N/A	M	39	1.5	5.5	2	1	1	1	1	2	2
D 4	N/A	M	59	2	7	1	1	1	1	1	1	2
D 5	N/A	M	49	1.5	6.5	1	1	2	1	1	2	2
D 6	N/A	M	60	4	9	1	1	1	1	2	2	2
D 7	N/A	M	55	3.5	5.5	1	1	1	1	2	2	2
D 8	N/A	M	33	1	5	1	1	2	1	1	2	2
D 9	N/A	M	57	3	4.5	1	1	1	1	2	2	2
D 10	N/A	M	53	3	10	2	1	1	1	1	2	1
					OHRMS	80%	100%	70%	100%	60%	10%	10%
					SHRMS	20%	0%	30%	0%	40%	90%	90%
A	R 1	M	35	0.5	5	1	1	1	1	1	2	2
A	R 2	M	31	3	2	1	1	1	2	2	2	2
A	R 3	F	25	2	2.5	1	1	1	1	1	2	2
A	R 4	M	35	0.75	6	1	1	1	1	1	2	2
A	R 5	F	37	4	5	1	2	1	1	1	2	2
A	R 6	F	39	1	5.75	2	1	1	1	2	2	2
A	R 7	M	36	2	4	2	1	2	1	1	1	2
A	R 8	M	41	1	9.5	1	1	1	1	1	2	2
A	R 9	M	43	3	8	1	1	2	1	1	2	2
A	R 10	F	28	3	2.5	1	1	1	1	1	2	2
A	R 11	M	35	2	9	1	1	1	1	2	1	2
A	R 12	M	29	1	3.5	1	1	1	1	1	2	2
A	R 13	M	36	1.25	3.25	1	1	1	1	1	2	2
A	R 14	M	37	1	10	1	1	1	1	1	2	2

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 24 August 2020 doi:10.20944/preprints202008.0508.v1

A	R 15	F	42	1.25	5.25	1	1	1	1	1	2	2
A	R 16	M	36	3	8	1	1	1	1	2	2	2
A	R 17	M	29	1	4.5	2	1	1	1	1	2	2
A	R 18	M	29	2	5.5	1	1	1	1	1	1	2
A	R 19	F	39	1	5	2	1	1	1	2	2	2
A	R 20	M	27	3	2.75	1	1	1	1	1	2	2
A	R 21	M	34	2	3	1	1	1	1	1	2	2
A	R 22	F	39	2	8	2	1	1	1	1	2	2
A	R 23	M	41	0.75	7.5	1	1	2	1	1	2	2
A	R 24	M	21	0.25	2	1	1	2	1	1	2	2
A	R 25	M	43	1	5.25	1	1	2	1	1	2	2
A	R 26	F	44	3	6.5	2	1	1	1	2	1	2
A	R 27	M	28	1	3.25	1	1	1	2	1	2	2
A	R 28	M	31	0.5	3	1	1	1	1	2	2	2
A	R 29	M	32	1.25	4	1	1	1	2	1	2	2
A	R 30	M	35	1	7	1	1	1	1	1	2	2
A	R 31	F	38	0.25	6.5	2	1	2	1	2	2	2
A	R 32	M	36	1	4.25	1	2	1	1	2	1	2
A	R 33	M	38	1.5	9	1	1	1	1	2	2	2
A	R 34	M	28	1	3.75	1	1	1	1	1	2	2
A	R 35	F	31	1	6.5	1	1	1	1	1	2	2
A	R 36	M	27	3.5	2.5	1	1	2	1	2	2	2
A	R 37	F	34	1	7.5	1	1	2	1	1	2	2
A	R 38	M	34	1	8.5	1	1	1	1	1	2	1
A	R 39	M	40	2	4.25	1	1	2	1	2	1	2
A	R 40	F	42	2	6.25	1	1	2	1	1	2	2
A	R 41	M	57	1	10	1	1	1	1	1	2	2
A	R 42	F	26	3	2	1	1	1	1	1	2	2
A	R 43	F	33	2	5.5	1	1	1	1	1	2	2
A	R 44	M	30	3	2.5	1	1	1	1	1	2	2
A	R 45	F	33	1	3.5	1	1	1	1	1	2	2
A	R 46	F	36	2	5	2	1	1	1	2	2	2
A	R 47	M	44	1	5.25	1	1	1	1	1	2	2
A	R 48	M	33	2.5	6.5	1	1	2	2	2	2	2
A	R 49	M	38	2	9.25	1	1	1	1	2	2	2
A	R 50	F	36	1	7.5	1	1	1	2	1	2	2
A	R 51	M	36	3	7	2	1	1	1	1	2	2
A	R 52	M	50	0.75	10	1	1	1	1	2	2	2
A	R 53	F	45	0.5	6	1	1	1	1	2	2	2
A	R 54	M	37	2	5	1	1	1	1	1	2	1
A	R 55	M	37	2	6	1	1	1	1	2	2	2
A	R 56	M	38	0.5	4.25	1	1	1	1	1	2	2

A	R 57	M	40	0.25	8	1	1	2	1	1	2	1
A	R 58	M	35	0.25	4	1	1	1	1	1	2	2
A	R 59	F	36	2.5	6	1	2	1	1	1	2	2
A	R 60	F	25	1.75	3.25	1	1	1	2	1	2	2
A	R 61	M	31	0.75	5.5	1	1	1	1	1	2	2
A	R 62	M	25	1.5	5.25	1	1	1	1	1	2	2
A	R 63	F	31	0.25	3.5	1	1	1	1	1	2	1
A	R 64	M	35	2	8	1	1	1	1	1	2	2
A	R 65	M	28	2	2.25	1	1	1	1	2	2	2
A	R 66	M	29	3	2.5	2	1	2	1	2	2	2
A	R 67	M	38	3	6	1	1	2	1	2	2	2
A	R 68	M	39	1	9	1	1	2	1	2	1	2
A	R 69	F	30	1	4.25	1	1	1	1	1	2	2
A	R 70	M	51	1	9	1	1	1	1	2	2	2
A	R 71	F	22	0.5	3	1	1	1	1	1	2	2
A	R 72	M	34	2	2	1	1	1	1	1	2	2
A	R 73	F	34	1	9.5	1	2	2	1	2	2	2
A	R 74	F	26	2.5	4.5	2	1	1	1	2	2	2
A	R 75	M	43	2	9.5	1	1	1	1	1	1	2
A	R 76	F	24	1	2.25	1	1	1	1	2	2	2
A	C 1	M	24	1.5	2.25	1	1	1	1	1	2	2
A	C 2	M	37	3	7	1	1	2	1	2	2	2
A	C 3	M	27	2	5	1	1	1	1	1	2	2
A	C 4	M	48	0.5	8.5	2	1	1	1	1	2	2
A	C 5	M	26	3	3	1	1	1	1	2	2	2
A	C 6	M	37	1	9	1	1	2	1	1	2	2
A	C 7	M	39	3	10	1	1	1	1	1	2	2
A	C 8	F	55	1	6.25	1	1	2	1	1	2	2
A	C 9	M	38	0.75	7	1	1	2	2	1	2	2
A	C 10	F	38	1	7.25	1	1	1	1	1	2	2
A	C 11	M	40	2	5.25	1	1	1	1	1	2	2
A	C 12	M	30	2	3.25	1	1	1	1	1	2	2
A	C 13	M	30	2	3.25	1	1	2	1	2	2	2
A	C 14	M	33	2	4.5	1	1	1	1	2	2	2
A	TriA 1	M	40	4	7	1	1	2	1	2	2	2
A	TriA 2	F	24	0.75	2.25	1	1	1	1	2	2	2
A	TriA 3	M	27	1	4	1	1	1	1	1	1	2
A	TriA 4	M	32	1.75	2.5	1	1	1	1	1	2	2
A	TriA 5	M	39	1.75	6.75	1	1	1	1	1	2	2
A	TriA 6	M	32	1.25	4.25	1	2	1	1	1	2	2
A	TriA 7	M	39	2	9	1	1	2	1	1	1	2
A	TriA 8	M	40	1	10	1	1	1	1	1	2	2

A	TriA 9	M	41	0.5	8.5	1	1	2	1	1	2	2
A	TriA 10	M	38	1	6.25	1	1	2	1	2	1	2
					OHRMS	88%	95%	75%	93%	67%	11%	4%
					SHRMS	12%	5%	25%	7%	33%	89%	96%

N/A, not applicable; R, reason; R1, Comfort of use during training; R2, Comfort of use around the clock; R3, Battery life; R4, Skin abrasions from the strap belt; R5, Trend / Fashion; R6, Habit; R7, Confidence in the accuracy of indications. OHRM, optical HRM; SHRM, strap HRM; T, trainer (coach); A, athlete; triA, triathlete; C, cyclist; D, doctor; R, runner.