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Are heart rate monitors valuable tools for diagnosing arrhythmias in endurance athletes?

Running head:

HRMs as athlete arrhythmia diagnostic tools?

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Abstract

Millions of physically active individuals worldwide use heart rate monitors (HRMs) to control their exercise intensity. In many cases, the HRM indicates an unusually high heart rate (HR) or even arrhythmias during training. Unfortunately, studies assessing the reliability of these devices to help control HR disturbances during exercise do not exist. We examined 142 regularly training endurance runners and cyclists, aged 18-51, with unexplained HR abnormalities indicated by various HRMs to assess the utility of HRMs in diagnosing exertion-induced arrhythmias. Each athlete simultaneously wore a Holter electrocardiogram (ECG) recorder and an HRM during typical endurance training in which they had previously detected “arrhythmias” to verify the diagnosis. Average HRs during exercise were precisely recorded by all types of HRMs. No signs of arrhythmia were detected during exercise in approximately 39% of athletes, and concordant HRs were recorded by the HRMs and Holter ECG. HRMs indicated surprisingly high short-term HRs in 45% of athletes that were not detected by the Holter ECG and were artifacts. In 15% of athletes, single ventricular/supraventricular beats were detected by the Holter ECG but not by the HRM. We detected a serious tachyarrhythmia in the HRM and Holter ECG data with concomitant clinical symptoms in only one athlete, who was forced to cease exercising. We conclude that the HRM is not a suitable tool for monitoring heart arrhythmias in athletes and propose an algorithm to exclude the suspicion of exercise-induced arrhythmia detected by HRMs in asymptomatic, physically active individuals.

Keywords: HRMs, strength training, long-distance running, cycling, exertion rhythm disorders, Holter ECG.

Introduction

The key to the effective training of endurance athletes in disciplines such as the triathlon, cycling and long-distance running is to perform the training within a specific range of heart rate (HR) values. For this reason, heart rate monitors (HRMs) have become an indispensable tool for athletes in achieving their training objectives.[1] HR is a useful indicator of physiological adaptation and effort intensity. Therefore, heart rate (HR) monitoring is an important component of cardiovascular fitness assessments and training programs.[2] Similar to conventional electrocardiogram (ECG) devices, the HRMs used by athletes determine their HRs by receiving the main electrical field produced by the heart muscle through electrodes placed on a transmitter belt (chest strap transmitter) attached to the chest; the signal is then transmitted by a probe to a digital recorder (DR), most commonly a special wristwatch, via telemetry. Thus, an HRM may also function as a Global Positioning System (GPS). In recent years, we observed the extensive use of sports HRMs by cardiac patients performing physical activities, particularly running and cycling, as primary and secondary methods for preventing cardiovascular diseases, including coronary heart disease and hypertension.[3] HRMs have been designed for use by healthy athletes with a baseline sinus rhythm, but they have also captured exercise-induced arrhythmia.[4] However, information about the morphology of the QRS complex has not been reported, and atrial signals have not been detected.[4] During medical consultations at the Center for Sports Cardiology (CSC) in Pułtusk, doubts repeatedly arose regarding the reliability of results generated by HRMs during running or cycling training that suggested an "arrhythmia", particularly in situations where clinical symptoms were not observed and when only unspecified symptoms typical of an anxiety disorder were observed.

Because of the increasing popularity in the use of HRMs by athletes and cardiac patients using running or cycling as primary and secondary methods for preventing cardiovascular diseases and because of the many reports of suspected arrhythmia based on HRM indications, we decided to perform a systematic investigation among CSC study subjects.[5]

Purpose

The aim of our study was to test the hypothesis that most unexpected increases in values measured by HRMs during training, which are interpreted by athletes as "arrhythmias", are likely artifacts.

Materials

One hundred and forty-two men and women aged 18-51, with an average age of 26 (SD 6.9) years, participated in the study. These people were referred to the Center for Sports Cardiology due to suspected cardiac arrhythmias identified based on HRM indications during sports training. Thirty-three of the participants were athletes who were referred by family physicians, 26 were referred by cardiologists, 25 were referred by sports physicians, and the remaining 58 people came to the center without a referral (Table 1). The absolute criterion for inclusion in the study was that an "arrhythmia" had been detected on the HRM (an unexpected increase in HR on the HRM) during endurance training. Table 2 summarizes the results obtained from the HRMs during a previous training session in which an unexpected increase in HR on an HRM occurred in this group of athletes.

Characteristics of the group

Most of the 142 people were amateur runners (102 people) who mainly participated in street races at distances from 5 km up to and including marathon distances. Thirty-one amateur cyclists were included in this group.

Nine participants in the study group were competitive athletes in sports clubs who regularly trained for long-distance running. The characteristics of the tested athletes' training are shown in Table 3.

Symptoms

With one exception, none of the athletes recorded any disturbing or unexpected clinical symptoms. Most of the "arrhythmias" indicated by the HRMs occurred during the initial phase of training, which was not intense and the athlete had not yet tired from training.

Clinical symptoms occurred only in one athlete; at the end of intense exercise with an HR of 167 beats per minute (bpm), the athlete noted a sudden increase in HR to 220-230 bpm, which caused a decrease in exercise tolerance and prevented its continuation. After a few minutes of inactivity, the HR decreased to 140 bpm, which allowed the athlete to continue training. Thereafter, he no longer intensified his exertion and completed his training with a much smaller burden.

Tests performed before the study

Prior to arriving at the CSC, all athletes underwent an ECG for diagnostic purposes. Eighty athletes underwent 24-hour ECG monitoring using the Holter method, which did not show any abnormally fast heart rhythms or significant cardiac arrhythmias. None of the athletes simultaneously wore the HRM strap and a recording device. Two athletes were subjected to electrophysiological tests (EPs), which did not reveal the cause of the possible arrhythmias observed on the HRM.

Methods

Each athlete was given an ECG Holter monitor to wear while simultaneously being connected to their own heart monitoring system, namely, the HRM on which the athlete had initially detected arrhythmia, to verify that a cardiac arrhythmia had occurred during training and to eliminate any technical problems (artifacts) with the transmission of data. The ECG Holter test was performed using the CardioPoint-Holter recorder, model H300 SW (BTL). The results were analyzed using CardioPoint-Holter software. Athletes used their own HRMs; similar devices have been commonly available on the market since 2009. The HRMs used in this study included 15 different types of devices, which are recognized by the sports market as professional equipment. None presented values and graphs such as R-R intervals (the "beat-to-beat" measuring function). Below is a list of the types of HRMs used by the examined athletes:

1. Garmin – FORERUNNER 620 GPS HRM, FORERUNNER 910 XT GPS HRM, FORERUNNER 310 XT GPS HRM, FORERUNNER 305 XT GPS HRM, FORERUNNER 220 GPS HRM, FORERUNNER 15 GPS HRM, and FORERUNNER 920XT HRM,
2. Polar – Rcx5 GPS G5, RCX5 RUN HRM, S 625, and RS300X HRM,
3. Suunto – Ambit3 Sport GPS HRM and Vector Black HRM, and
4. Timex - Ironman T5K720 and Personal Trainer Hrm T5K738.

All athletes were subjected to a baseline 12-lead ECG measurement prior to training with the Holter and HRM. The athletes were told to perform the same training as they had performed when they had previously recorded the arrhythmia on their HRMs. The training performed was continuous running or cycling over various distances at various speeds, depending on the athlete's fitness level. The Holter ECG monitor was placed on the athlete's body in the Holter test laboratory immediately prior to the test. Athletes used their own HRMs, placing and turning them on in the presence of a medical assistant. Training began with the simultaneous activation of the HRM, which typically occurred a few minutes after the Holter ECG monitor was placed. Both devices were stopped and removed immediately after training, and the results were analyzed. Fig. 1 shows an image of an athlete who was wearing the Holter ECG monitor and HRM just before the test.

The results were analyzed by two teams.

a) Holter data were analyzed by cardiologists at a Holter test laboratory, and
b) HRM data were examined by analysts who were trained in analyzing data from HRMs after transmission to a computer or directly from the training history stored in the HRM.

All athletes provided written informed consent to participate in the study.

Statistical analyses

Statistical analyses were performed using the t-test while considering the appropriate assumptions of this test concerning the homogeneity of the variances of the compared variables (using Levene's test) and the normal distribution of both compared variables (using the Shapiro-Wilk test). If the distribution of at least one of the compared variable was statistically significantly different from the normal distribution (the homogeneity of variances was fulfilled in all cases), the statistical analysis was performed using a nonparametric test (Mann-Whitney U-test). Significance was established at $P < 0.05$. Statistical analyses were performed using STATISTICA software, version 12.

Results

All athletes underwent baseline 12-lead ECG prior to training with the Holter and HRM and exhibited normal sinus rhythms without arrhythmias. The average duration of the test, starting from the moment when the HRM was turned on (usually just after the Holter ECG monitor was placed), was 59 min. The test results are described below.

GROUP I

We did not identify any cardiac arrhythmias during exercise in this group (n = 56, ca. 39% of all participants), and we did not identify any differences between the Holter ECG and HRM data. None of the athletes reported any unusual clinical symptoms. The average HR recorded by the HRM was 143 bpm (av. min: 65 bpm; av. max: 164 bpm; observed values: 60 – 180 bpm), and the average HR that was simultaneously measured by the Holter monitor was 144 bpm (av. min: 65 bpm; av. max: 164 bpm; observed values: 58 – 181 bpm). These differences were not statistically significant (av.: $t = -0.60$; $P > 0.05$; min: $t = 0.06$, $P > 0.05$; max: $t = 0.07$, $P > 0.05$). This group consisted of 36 runners and 20 cyclists.

GROUP II

We observed discrepancies between the Holter ECG monitor and HRM data obtained from this group (n = 21, ca. 15% of all participants). Single ventricular and supraventricular beats were detected in the athletes by the Holter ECG monitors, which were not detected by the HRMs. None of the athletes reported any unusual clinical symptoms. The average and maximum HRs recorded by the HRMs and Holter ECG monitors were approximately the same. The average HR recorded by the HRM was 142 bpm (av. min: 65 bpm; av. max: 163 bpm; observed values: 61 – 182 bpm), and the average HR that was simultaneously recorded by the Holter monitor was 143 bpm (av. min: 65 bpm; av. max: 163 bpm; observed values: 58 – 183 bpm). These differences were not statistically significant (av.: $t = -0.26$, $P > 0.05$; min: $U = 217.5$, $P > 0.05$; max: $t = 0.16$, $P > 0.05$). This group consisted of 16 runners and 5 cyclists.

GROUP III

In this group (n = 64, ca. 45% of all athletes), we once again observed discrepancies between the Holter ECG and HRM data. The HRM readouts indicated a surprisingly high short-term HR. Short-term increases in HR were detected in the HRM readouts of the athletes (max: 236 bpm with a maximum duration of 3 min; av.: 199 bpm for an average of 68 s); these increases were not observed in the Holter data at the time of their occurrence (Fig. 2 C and D). None of the athletes reported any unusual clinical symptoms. The average HR measured by an HRM was 150 bpm (av. min: 64 bpm; av. max: 199 bpm; observed values: 61 – 236 bpm). The average HR that was simultaneously measured by the Holter monitor was 145 bpm (av. min: 63 bpm; av. max: 162 bpm; observed values: 58 – 171 bpm). This group comprised 59 runners and 5 cyclists. The observed maximal values obtained from the HRM (from 180 to 236 bpm) were not actual HR values but were consequences of the devices functioning incorrectly. Thus, after considering the methodological aspects of this problem, we did not perform a statistical analysis of the maximal and average values. Nevertheless, the differences in the minimal values (from the initial part of training) were not statistically significant (Min: $t = 1.07$, $P > 0.05$).

GROUP IV

We detected only serious tachyarrhythmia during exercise in one athlete, a cyclist, using both the HRM and the Holter ECG monitor (n = 1, ca. 0.7% of all athletes). In the 68th minute of intensive training, an unjustified increase in the HR of the athlete from 167 to 225 bpm was detected on the HRM. This increase was also observed in the Holter ECG data, with changes in the sinus tachycardia rhythm of 167 bpm to an atrio-ventricular nodal re-entry tachycardia (AVNRT) rhythm of 227 bpm. Restoration of the sinus rhythm in the Holter data occurred in parallel to the observed decrease in rhythm on the HRM observed after 4 minutes of rest (Fig. 2 A and B). Because of the clinical symptoms manifesting as a sudden decrease in exercise capacity, the athlete was forced to cease training. After the tachycardia passed, the athlete continued to train for another 23 min at a much lower intensity. The observed HR measured by an HRM in this athlete was 156 bpm (min: 59 bpm; max: 225 bpm), and the observed HR that was simultaneously measured by the Holter monitor was 158 bpm (min: 58 bpm; max: 227 bpm).

A statistical analysis was not performed because this change was observed only in one athlete.

The complete data analyzed for the athletes, as reported to the Center for Sports Cardiology, are shown in Appendix 1.

The complete HRM and Holter ECG data obtained by testing the athletes at the Center for Sports Cardiology are shown in Appendix 2.

A comparison of the results obtained using the HRM and the Holter ECG monitor is presented in Table 4.

Discussion

Heart Rate Monitors (HRMs) and their applicability in endurance training

HRMs designed for use in sports aid in controlling exercise intensity by instantaneously displaying the HR. Currently, many athletes find it almost impossible to conduct training or compete without an HRM. Athletes use the percentage of the maximum HR achieved during training to determine the range of training, e.g., running (4 levels - E (easy), M (marathon race pace), T (threshold), and I (intervals)); these data inform the athletes when the workout is aerobic and when and by how much its anaerobic component increases. We have also observed the extensive use of sports HRMs by cardiac patients who use physical activity as a primary and secondary method for preventing cardiovascular diseases, including coronary heart disease and hypertension.[3] Patients with cardiovascular disease must stay below the ventilatory threshold.[6]

HR is an important parameter that is closely monitored both by competitive endurance athletes and amateur athletes during training.[2] Unfortunately, almost no ECG, Holter or other equipment is available that is not prone to artifacts. This problem occurs in HRMs as well. The data quality largely depends on the device used. Some HRM devices with “beat-to-beat” measurements and data storage capabilities (i.e., some Polar types) do permit accurate heart rhythm analyses.[4,7,8] However, these devices are also prone to artifacts that are often similar to a “beat”. For HRMs with a “beat-to-beat” measuring function that we used in our other studies, we still do not know whether we observed the R-R distance or only the “artifact peak to artifact peak”. Information about the morphology of the QRS complex is not available, and no atrial signals are detected. Therefore, these devices do not precisely distinguish between supraventricular tachycardia (SVT) and ventricular arrhythmia (VA). For example, an AVNRT might produce a signal that appears identical to VA on an HRM.[4] HR variability (the beat-to-beat variation of RR intervals) decreases with increasing intensity.[9] Researchers cannot accurately determine whether heart rate variability (HRV) results from premature atrial or ventricular contraction or an irregular sinus rhythm. Devices without an R-R measurement function are incapable of capturing singular ventricular or supraventricular beats.

In HRMs, electrodes are placed in the belt of the device, which is attached to the chest, and provide ECG readings that are related to changes in the electric field produced by the heart. These values are then transmitted by the transmitter probe in the same belt to a recorder that collects the data via telemetry. The saved data on the recorder is then read from the recorder itself or transferred to a computer for further analysis.

The value of HRMs in detecting "arrhythmias" based on the results of our own study

All athletes who reported to the Center for Sports Cardiology for a check-up decided to be assessed because they feared having to discontinue their training in the future for health reasons. Most of the athletes studied had no symptoms during the "arrhythmia" on the HRM, but some had unspecified symptoms that suggested anxiety disorders following the observed disturbances on the HRM. Therefore, with the exception of one athlete, the indications of the HRM in the form of sudden increases in HR values in the tested athletes (which were the reason for their visits to the CSC) were ordinary technical disturbances of the device, which are commonly referred to as artifacts and were mistakenly interpreted as an abnormal heart rhythm.

In the conducted study, 39% of participants did not exhibit cardiac arrhythmia during exercise, and no differences between the Holter ECG and HRM data were identified. In 15% of participants, we observed discrepancies between the ECG Holter and HRM readouts. Single ventricular and supraventricular beats were detected in the athletes using the Holter ECG monitor, but these beats were not detected by the HRMs. In 45% of athletes, we once again observed discrepancies between the Holter ECG and HRM data. The HRM readouts indicated a surprisingly high short-term HR. Short-term increases in HR were detected in the HRM readouts of the athletes, which were not reflected in the Holter examination at the time of their occurrence. We observed only serious tachyarrhythmia during exercise in one athlete in both the HRM and Holter ECG readouts. During intensive training, an unjustified increase in the HR of this athlete from 167 bpm to 225 bpm was detected on the HRM. This increase was also observed in the Holter ECG data as changes in the sinus tachycardia rhythm from 167 bpm to an AVNRT rhythm of 227 bpm. Restoration of the sinus rhythm was observed in the Holter data in parallel to the observed decrease in rhythm on the HRM after a period of rest. The athlete was forced to cease training due to clinical symptoms and the sudden decrease in exercise capacity.

As confirmed by the research conducted here (Group I, II and IV athletes), in the absence of artifacts, HRMs are valuable tools for controlling the intensity of training by accurately specifying the heart rhythm, thus enabling training plans to be created. In contrast, clear symptoms or a decrease in performance (as exhibited by the athlete with AVNRT) and associated changes in HR measured on the HRM (unexplained HR abnormalities) should lead the physician to perform further cardiac examinations to obtain a diagnosis. The standard procedure in treating suspected arrhythmia based on HRM indications in symptomatic and asymptomatic athletes is shown in Fig. 3.

The main reasons for incorrect readouts of HRMs during endurance exercises

Interference with data transmission can occur at several stages: at the level of the belt electrodes, at the level of the transmitter probe, or at the level of the receiver, which is typically attached to the athlete's forearm.

For the Holter recorder, problems in obtaining correct readouts of heart function are typically caused by the electrodes peeling off due to perspiration. These disturbances can be easily recognized by the person reading the Holter results and are rarely confused with actual cardiac arrhythmias (Fig. 2E and F).

Athletes reported their observations at different times of the year; thus, they wore different types of sportswear, which may affect the conduction between the belt that receives heart stimuli and the receiver (DR). When an asymptomatic athlete who experiences unexplained increases in HR, the source of the artifacts must be identified. All factors that might create artifacts, i.e., within the HRM and from the external environment, should be considered.

In the case of the belt, interference may be caused by the following factors:

- poor adhesion of the belt of the HRM to the skin,
- a dead battery,
- an inadequately wet HRM belt, which explains the greater interference at the beginning of the training when the athlete is not yet perspiring,
- other factors, such as hair on the skin of the chest, and
- bras worn by female athletes—an underestimated problem that causes interference in women; the lower edge of bras can deform the HRM strap that lies below it, disturbing conduction.

For watch-DRs, the causes of interference in reception and registration that simulate cardiac arrhythmias may include the following:

- the electromagnetic field being produced by the belt is too weak or the DR being placed at too great a distance from the belt,
- thick clothing, e.g., clothing worn during winter workouts or clothing manufactured from materials (such as nylon and t-shirts containing synthetic materials) that generates an electromagnetic field that interferes with signals sent from the belt when rubbed during training,

- athletes being in close proximity to devices that generate a strong electromagnetic field, such as electric traction devices, during training, and
- the presence of a second HRM on another athlete, a mobile phone, a standard television or any other nearby electromagnetic field-generating device.

Arrhythmias in athletes and leisure time sports enthusiasts

Although most athletes are familiar with artifacts, athletes or their coaches or doctors occasionally request a diagnosis, despite the absence of clinical symptoms. The answer to the question, “Are the asymptomatic, self-limiting “arrhythmias” detected using an HRM real arrhythmias or artifacts?” may save the athlete’s life. Arrhythmias have been observed in athletes with “healthy hearts”, but it is not a negative prognostic factor and does not constitute grounds for abstaining from sporting activities.[10,11] Cardiac arrhythmia is also not uncommon in healthy non-athletes.[12-15] In most young patients without structural heart disease, short runs of atrial tachycardia, ventricular tachycardia or atrial fibrillation do not require treatment. However, if signs of structural heart disease or symptoms are observed, or if the CHA2DS2-VASc score is greater than or equal to 1 with the need for anticoagulant treatment, artifacts should be distinguished from real arrhythmias. Exercise-related palpitations, vertigo and syncope may be caused by benign etiologies but may also herald life-threatening arrhythmias. Therefore, the precise diagnosis of these findings is essential and potentially lifesaving but is often a challenge for sports physicians and cardiologists.[4] Endurance training does not cause increased mortality but can trigger a lethal arrhythmia, which reveals itself more frequently in athletes with heart disease than in non-training patients with heart disease.[16] For this reason, arrhythmia and the associated increased risk of sudden death in athletes, particularly in young people compared to their inactive peers, are reasons for developing eligibility guidelines for sports and for developing procedural rules in the event that irregularities are detected during athlete monitoring tests.[17]

Application of HRMs in athletes with symptomatic and asymptomatic arrhythmias

During the course of the study, athletes reported having repeatedly experienced a sudden decrease in performance during training combined with a feeling of palpitations or “discomfort” in the chest with a simultaneous unexpectedly high HR measured by their HRM; this event prevented further exertion. The clinical symptoms and “arrhythmia” measured by the HRM subsided after a short rest. However, this event was often associated with very heavy training, sometimes with participation in a competition, which increased the athletes’ emotions as they maximally exerted themselves. In all but one case, we failed to replicate the clinical symptoms observed during training and did not observe a simultaneous decrease in capacity with arrhythmia confirmed by the Holter ECG data and unexpected changes in HR measured by the HRM.

During the testing with HRMs, several athletes experienced clinical symptoms of arrhythmia; however, we could not interpret the Holter ECG data due to the presence of artifacts. These athletes were not included in the study for various reasons. When clinical symptoms occur, further testing must be conducted (Fig. 3). Symptomatic athletes with a previous diagnosis who, despite confirmed paroxysmal exertion arrhythmia, return to training and frequently participate in competitions, often without a doctor's consent, should certainly use HRMs. We recommend that athletes with paroxysmal atrial fibrillation (AF) or paroxysmal atrial flutter (AFL) (which may be particularly dangerous for athletes) should use HRMs as a device to monitor and control HR. Frequent attacks of AF or AFL occur in athletes, active people and patients above a certain basic HR.[18,19] In such cases, the HRM should be the primary auxiliary tool used to control HR in both symptomatic and asymptomatic persons.

A separate problem involves patients with an implanted cardioverter defibrillator (ICD); HRMs should be used to ensure that these athletes do not exceed the heart rate above which arrhythmia is likely to occur. Many people, particularly veteran athletes who are often addicted to sport, continue to train, despite the physiological restrictions placed on them by doctors; these people often train very intensively and compete in tournaments.[20,21] HRMs are useful for evaluating the HR of adolescents with congenital syndromes extending from arrhythmia provoked by effort.[22] Tele-electrocardiography utilizing appropriate applications on mobile phones represents a possible solution for immediately diagnosing cardiac arrhythmias as they occur in athletes, with the possibility of rapidly implementing treatment.[23] Several new and effective technologies for the wireless monitoring of arrhythmias have been developed, validated and are currently available for patient care, e.g., Real-Time Smart Phone Monitoring, ECG Patch Monitoring, Injectable Loop Recorders and Device-tailored monitors, among others;[24,25,26] these technologies can also be used by athletes.

Strengths and limitations of our study

The main strengths of our study are the simultaneous registration of HR by wearable leadless HRMs during exercise in a relatively large group of asymptomatic leisure time and competitive male and female athletes (runners and cyclists) with suspected exercise-induced cardiac arrhythmias. We analyzed the recorded HR data during typical endurance training using 15 devices made by recognized manufacturers and compared them to data obtained simultaneously using the “gold standard” Holter ECG monitor during the same exercise. We have not identified a similar study in the available scientific literature.

Our study also has some limitations. Although the initial examination included 142 athletes with abnormal findings, only 65 of those athletes had an abnormal HRM reading during our study. The protocol did not identify the event the other 77 athletes had experienced in the past. Our observation was limited to only one typical endurance training session with a duration of approximately 60 minutes. We did not separately analyze the data from the different commercially available devices, and we did not analyze or compare the data obtained from the HRMs and Holter monitors during exercise in cardiac patients or in healthy, untrained individuals.

Despite these limitations, we believe that the results of our study are important for physicians, coaches and large groups of leisure time and competitive sportspersons. Our data strongly suggest that surprisingly high HR values revealed by wireless HRMs during exercise in asymptomatic athletes without any malicious symptoms of exercise intolerance are mostly artifacts and are not grounds to recommend that athletes stop training or perform further time-consuming and mostly expensive medical diagnostics. In such cases, i.e., in recreational or competitive athletes with episodes of surprisingly high HRs during exercise, we propose that the proper function of the HRM device should be carefully controlled. If we exclude the typical error of HRM registration as described above, then the simultaneous monitoring of HR during typical endurance training with HRMs and Holter monitors is recommended. The algorithm presented in Fig. 3 might be of practical value in further medical diagnostics.

Perspectives

A physically active lifestyle is widely promoted for healthy individuals and large groups of patients.[27] Millions of physically active individuals worldwide use HRMs to control exercise intensity.[25,26] False “arrhythmias” or surprisingly high bursts of HR during exercise can induce fear in physically active individuals and might cause them to reduce or even abstain from training or to seek unnecessary, time-consuming and costly medical diagnostics.

Thus, further studies should examine whether newly developed or improved HRMs yield fewer false HR measurements during exercise. Further studies should also address the following question: Are HRMs valuable tools for monitoring arrhythmias in symptomatic endurance athletes?

Studies verifying the value of newly developed mobile devices, such as ECG Patch Monitoring or Time Smart Phone Monitoring, Injectable Loop Recorders, Device-tailored monitors and other devices, in diagnosing exercise-induced arrhythmias in large groups of competitive and recreational athletes, untrained apparently healthy individuals and cardiac patients would be interesting. Based on the recent studies,[5, 28] as well as on many other previously published papers, competitive sportspersons are not immune to cardiac arrhythmias and the risk of sudden death.

Conclusions

1. The value of HRMs for detecting arrhythmias in runners and cyclists is not supported by the results of this study. This study has shown that "arrhythmias" measured by HRMs (an unexpected increase in HR measured by the HRMs) during typical endurance training in asymptomatic athletes, cyclists and runners, is an artifact.
2. Because several potential causes of artifacts have been observed, athletes should be aware that HRMs may record short bursts of inappropriate increases in HR (in greater than 45% of athletes in this cohort). In the absence of symptoms, these readings are unlikely to represent significant arrhythmia. Thus, the users should ensure that they test their equipment prior to seeking medical advice.
3. Our methodology of performing a baseline 12-lead ECG and then performing a concurrent recording with a Holter monitor and an HRM during training appears to be an excellent method for examining athletes with repeated or even asymptomatic episodes of unusually high HRs ("arrhythmias"). In most cases, the recordings are likely to reveal a normal sinus rhythm and reassure the athlete.

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Tables

Table 1. Sample characteristics.

Gender	Average age (± SD) [years]	Coefficient of variation (dispersion)	Number of athletes	Referral			
				Family physician	Cardiologist	Sports medicine physician	No referral
Male	26.7 (± 7.4)	27.7% (moderate)	104	27	16	17	44
Female	25.4 (± 5.4)	21.3% (moderate)	38	6	10	8	14

Table description:
[SD] – standard deviation

Table 2. Summary of the data obtained from the HRMs used by the athletes enrolled in the study, including "arrhythmias" detected by HRMs during endurance training.

Statistical parameter	Age [years]	Maximum HR measured by the HRM/short term-tachyarrhythmia [bpm]	Maximum HR (empirical value) [bpm]	Expected HR for the training phase [bpm]	Difference between the maximum HR measured by the HRM and the expected HR [bpm]	Duration of tachy-arrhythmia [sec]
Average	26.3	209	193	156	53	134
Median	25.0	209	194	155	52	125
Standard deviation (SD)	6.9	12.6	9.1	7.7	11	40.1
Coefficient of variance (CV)	26.2%	6.0%	4.7%	4.9%	20.9%	29.9%
Dispersion level	Moderate	Low	Low	Low	Moderate	Moderate
Max	51	240	211	169	79	248
Min	18	188	169	130	36	48

Table description:
[bpm] – beats per minute
[HR] – heart rate
[HRM] – heart rate monitor
[h/week] – hours per week
[sec] – seconds

Table 3. Characteristics of the training.

Type of activity	Number of athletes	Average number of km covered during training (± SD) [km/week]	Coefficient of variation (dispersion level)	Average training time (± SD) [h/week]	Coefficient of variation (dispersion level)
Amateur runners	102	42.5 (± 2.4)	5.6% (low)	7.0 (± 1.6)	22.9% (moderate)
Competitive runners	9	103.0 (± 12.1)	11.7% (low)	11.0 (± 1.4)	12.7% (low)
Amateur cyclists	31	247.7 (± 43.6)	17.6% (low)	8.8 (± 0.8)	9.1% (low)

Table description:
[SD] – standard deviation
[km/week] – kilometers per week
[h/week] – hours per week

Table 4. Comparison of the results obtained using the HRMs and the Holter ECG monitors.

Group	Number of athletes	Minimum HR during training [bpm]			Maximum HR during training [bpm]			Average HR during training [bpm]		
		HRM indications (average value)	Holter ECG indications (average value)	P-value	HRM indications (average value)	Holter ECG indications (average value)	P-value	HRM indications (average value)	Holter ECG indications (average value)	P-value
GROUP I	56	65.0	65.0	0.95 (NS)	164.4	164.3	0.95 (NS)	143.1	144.0	0.55 (NS)
GROUP II	21	64.7	64.8	0.95 (NS)	163.3	162.9	0.87 (NS)	142.5	143.0	0.79 (NS)
GROUP III	64	64.0	63.4	0.29 (NS)	199.4	162.4	-	150.4	144.6	-
GROUP IV	1	59.0	58.0	-	225.0	227.0	-	156.0	158.0	-

Table description:
[bpm] – beats per minute
[HR] – heart rate
[HRM] – heart rate monitor
[ECG] – electrocardiogram

Figure legends

Figure 1. Athlete at the beginning of the test with Holter ECG and HRM.

Figure 2. A. HR on HRM (Garmin Forerunner 910XT HR) during cycling with AVNRT. The red arrow shows a sudden increase in HR from 164 to 225 bpm and then a decrease to 145 bpm after 4 minutes of rest. B. The same patient with AVNRT at 227 bpm, as determined using the Holter at the same time as in Figure 2 A. C. Artifacts (red arrow) observed on the HRM suggest "tachyarrhythmia" at 230 bpm. D. HR of 145 bpm without arrhythmia, as determined using the Holter at the same time as in Figure 2 C. E. Artifacts observed on the Holter – without problems to identify. F. HRM data for the sportsman from Figure 2 E, showing an HR of 96 bpm measured at the same time without disturbances (marked with a red arrow) at the beginning of the 1 km run (first 10-15 seconds).

Figure 3. Standard procedure for dealing with suspected "arrhythmia" based on HRM indications.

Figures

Figure 1

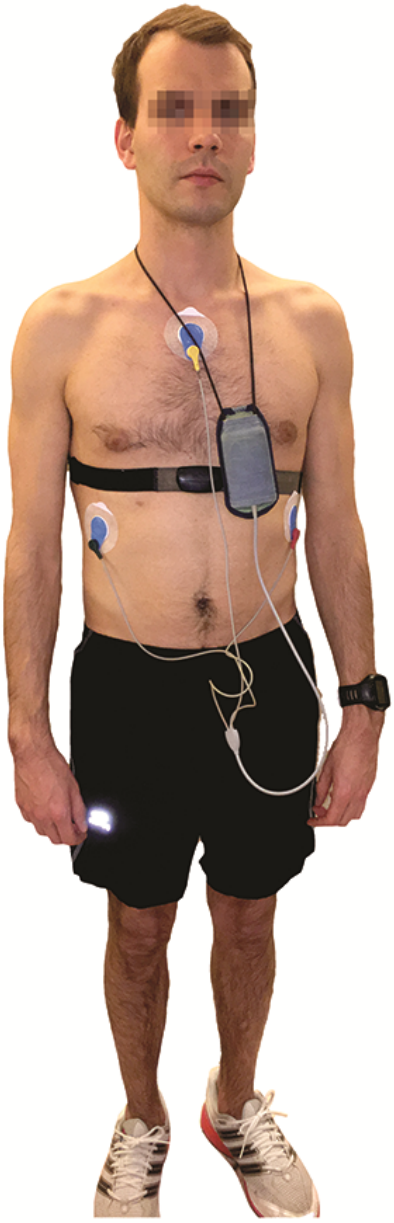


Figure 2

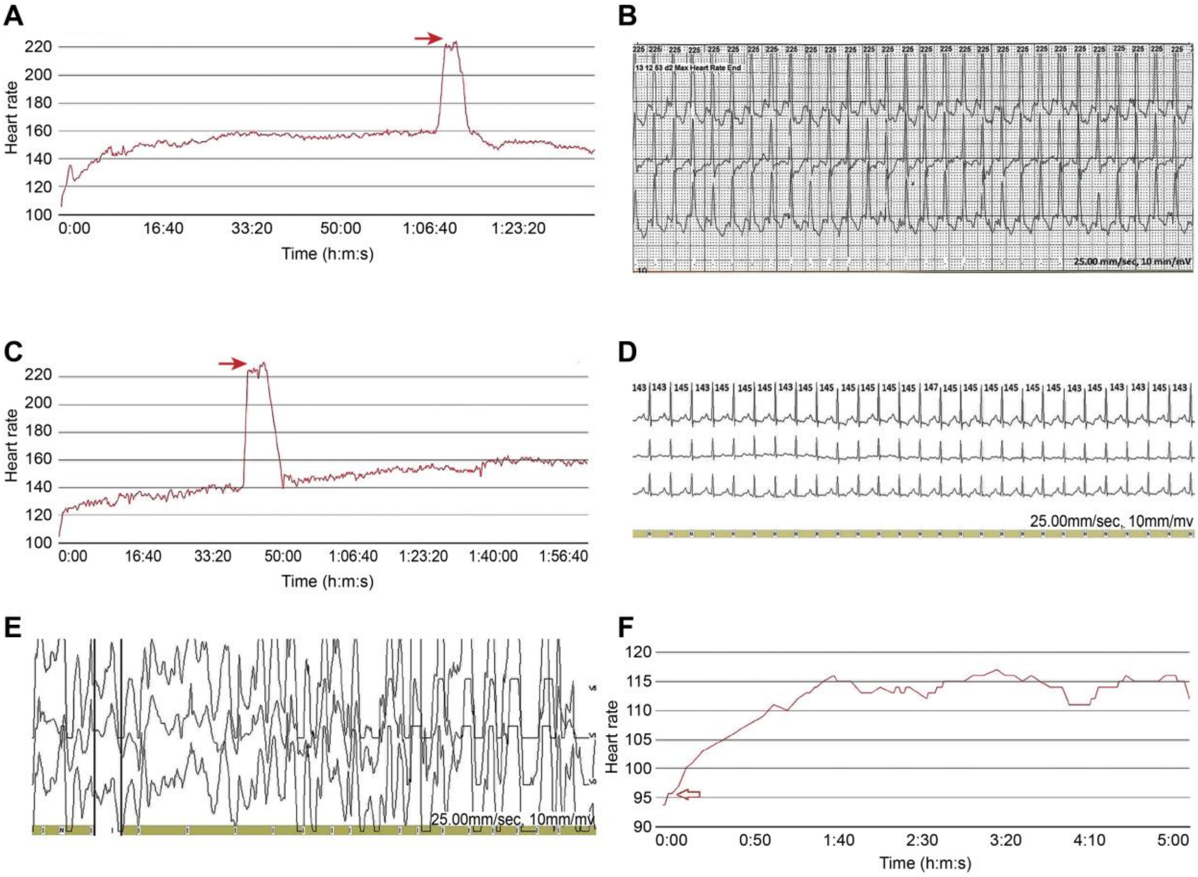
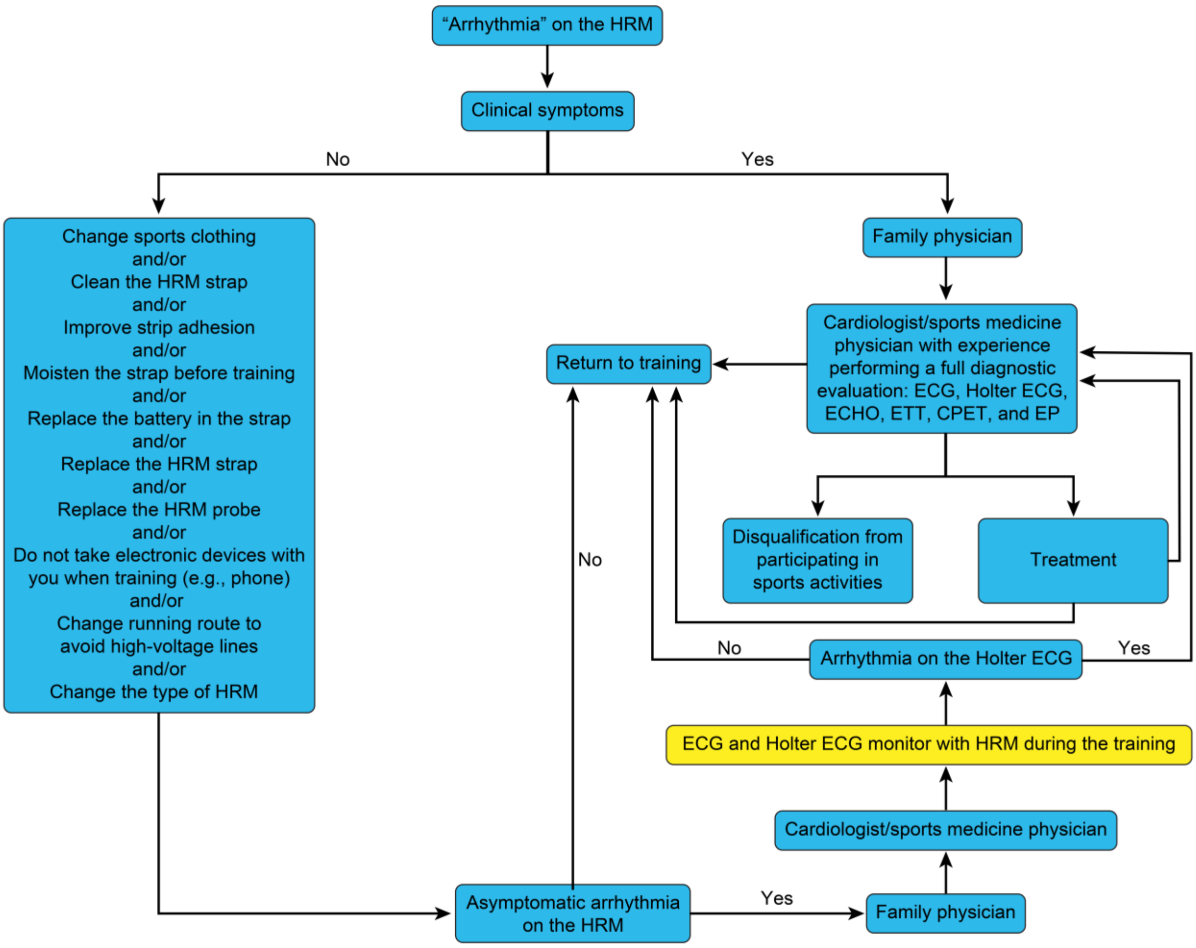

A
220
200
180
160
140
120
100
Heart rate
0:00
16:40
33:20
50:00
1:06:40
1:23:20
Time (h:m:s)
B
25.00 mm/sec, 10 mm/mV
C
220
200
180
160
140
120
100
Heart rate
0:00
16:40
33:20
50:00
1:06:40
1:23:20
1:40:00
1:56:40
Time (h:m:s)
D
25.00mm/sec, 10mm/mv
E
25.00mm/sec, 10mm/mv
F
120
115
110
105
100
95
90
Heart rate
0:00
0:50
1:40
2:30
3:20
4:10
5:00
Time (h:m:s)

Figure 3


"Arrhythmia" on the HRM
Clinical symptoms
No
Yes
Change sports clothing
and/or
Clean the HRM strap
and/or
Improve strip adhesion
and/or
Moisten the strap before training
and/or
Replace the battery in the strap
and/or
Replace the HRM strap
and/or
Replace the HRM probe
and/or
Do not take electronic devices with you when training (e.g., phone)
and/or
Change running route to avoid high-voltage lines
and/or
Change the type of HRM
Family physician
Cardiologist/sports medicine physician with experience performing a full diagnostic evaluation: ECG, Holter ECG, ECHO, ETT, CPET, and EP
Return to training
Disqualification from participating in sports activities
Treatment
No
No
Arrhythmia on the Holter ECG
Yes
ECG and Holter ECG monitor with HRM during the training
Cardiologist/sports medicine physician
Asymptomatic arrhythmia on the HRM
Yes
Family physician

Appendix 1. Complete results obtained from the analysis of data reported by athletes to the CSC in Pułtusk.

Athlete	Gender	Age [years]	Maximum HR measured by the HRM/short term-tachyarrhythmia [bpm]	Empirical maximum HR observed in the athlete [bpm]	Expected HR resulting from the training phase [bpm]	Difference between the maximum HR measured by the HRM and the expected HR [bpm]	Duration of tachyarrhythmia [m:s]	Referral
1	Male	25	192	196	153	39	02:04	no referral
2	Male	23	240	199	165	75	02:01	family physician
3	Male	26	211	197	142	69	02:21	no referral
4	Male	23	191	201	151	40	02:16	family physician
5	Male	27	221	198	148	73	01:45	cardiologist
6	Male	21	193	205	150	43	02:05	family physician
7	Male	32	224	195	159	65	03:36	cardiologist
8	Male	18	216	210	157	59	01:56	sports medicine physician
9	Male	41	204	188	167	37	01:50	family physician
10	Male	35	201	195	160	41	03:23	family physician
11	Male	36	220	195	153	67	02:00	sports medicine physician

12	Male	38	210	194	167	43	02:26	family physician
13	Male	51	229	185	155	74	01:54	family physician
14	Male	26	198	189	152	46	03:38	sports medicine physician
15	Male	29	225	189	167	58	02:11	family physician
16	Male	31	228	191	149	79	02:20	no referral
17	Male	21	191	188	155	36	01:43	cardiologist
18	Male	22	203	181	162	41	03:31	family physician
19	Male	36	226	190	156	70	02:23	no referral
20	Male	35	215	191	164	51	01:39	family physician
21	Male	20	212	181	165	47	02:15	family physician
22	Male	20	194	184	154	40	03:28	family physician
23	Male	25	201	184	163	38	01:40	family physician
24	Male	26	217	193	153	64	02:19	sports medicine physician
25	Male	21	199	191	159	40	00:52	sports medicine

								physician
26	Male	28	221	177	155	66	03:34	family physician
27	Male	48	199	184	161	38	01:46	family physician
28	Male	29	198	194	149	49	01:47	family physician
29	Male	23	205	200	153	52	00:48	cardiologist
30	Male	25	196	199	154	42	02:04	no referral
31	Male	28	208	197	159	49	02:15	family physician
32	Male	31	196	195	149	47	01:48	sports medicine physician
33	Male	20	188	207	149	39	03:35	no referral
34	Male	18	197	210	158	39	02:13	sports medicine physician
35	Male	31	198	198	152	46	01:44	cardiologist
36	Male	19	194	211	150	44	02:02	family physician
37	Male	20	207	211	158	49	02:13	cardiologist
38	Male	26	198	206	155	43	01:49	sports medicine physician
39	Male	28	201	194	152	49	02:08	cardiologist

40	Male	21	225	187	150	75	01:45	no referral
41	Male	35	215	196	158	57	01:57	no referral
42	Male	39	206	190	159	47	02:03	sports medicine physician
43	Male	31	209	195	157	52	01:42	cardiologist
44	Male	20	191	192	152	39	02:27	sports medicine physician
45	Male	25	223	188	160	63	02:22	sports medicine physician
46	Male	21	189	181	151	38	02:18	cardiologist
47	Male	26	207	186	153	54	01:56	no referral
48	Male	29	197	187	157	40	02:16	cardiologist
49	Male	31	216	188	150	66	01:03	no referral
50	Male	35	213	174	154	59	01:20	no referral
51	Male	34	226	174	150	76	02:09	family physician
52	Male	27	200	180	158	42	03:21	sports medicine physician
53	Male	21	202	198	154	48	02:09	no referral
54	Male	24	194	194	158	36	02:00	cardiologist
55	Male	23	222	205	155	67	02:03	sports medicine

								physician
56	Male	29	195	200	155	40	01:46	no referral
57	Male	19	227	187	156	71	02:08	family physician
58	Male	24	193	184	152	41	02:10	no referral
59	Male	18	219	193	158	61	01:51	no referral
60	Male	20	227	205	152	75	01:49	no referral
61	Male	23	197	201	149	48	01:59	cardiologist
62	Male	29	190	206	152	38	02:07	sports medicine physician
63	Male	23	193	202	152	41	01:52	no referral
64	Male	21	228	200	165	63	01:50	no referral
65	Male	19	200	179	152	48	02:05	no referral
66	Male	25	224	194	166	58	02:02	family physician
67	Male	23	197	195	151	46	03:33	sports medicine physician
68	Male	20	229	197	167	62	02:14	no referral
69	Male	36	204	180	152	52	01:58	family physician
70	Male	34	201	181	156	45	01:51	family physician

71	Male	19	201	195	145	56	01:42	sports medicine physician
72	Male	23	191	190	153	38	03:24	family physician
73	Male	25	200	187	152	48	01:55	sports medicine physician
74	Male	21	212	190	154	58	01:53	no referral
75	Male	20	219	190	156	63	03:26	cardiologist
76	Male	28	213	181	152	61	02:18	no referral
77	Male	36	195	172	155	40	02:07	no referral
78	Male	25	223	182	161	62	03:20	family physician
79	Male	23	206	196	164	42	02:06	cardiologist
80	Male	22	230	196	152	78	01:41	cardiologist
81	Male	19	202	198	162	40	02:12	no referral
82	Male	27	202	195	161	41	01:59	family physician
83	Male	26	217	193	157	60	01:47	cardiologist
84	Male	23	211	192	154	57	02:06	family physician
85	Female	25	214	203	148	66	02:12	family physician
86	Female	31	189	203	145	44	03:30	cardiologist

87	Female	21	196	190	153	43	01:54	family physician
88	Female	19	199	192	152	47	01:11	cardiologist
89	Female	28	199	208	155	44	03:22	cardiologist
90	Female	24	214	209	155	59	02:11	cardiologist
91	Female	23	200	205	157	43	01:43	sports medicine physician
92	Female	26	199	205	130	69	02:17	cardiologist
93	Female	27	208	211	151	57	02:17	sports medicine physician
94	Female	40	205	205	147	58	03:32	sports medicine physician
95	Female	32	209	173	130	79	02:25	sports medicine physician
96	Female	21	222	193	150	72	01:58	cardiologist
97	Female	25	196	189	142	54	02:01	family physician
98	Female	20	193	193	150	43	01:57	family physician
99	Female	19	200	193	148	52	01:55	sports medicine physician

100	Female	23	194	188	148	46	01:52	no referral
101	Female	24	190	186	149	41	02:24	cardiologist
102	Female	31	210	178	151	59	02:10	family physician
103	Female	34	218	174	151	67	01:44	no referral
104	Female	20	192	187	149	43	04:08	no referral
105	Female	18	218	201	158	60	01:48	sports medicine physician
106	Female	30	195	188	138	57	03:27	family physician
107	Female	31	195	186	152	43	03:29	cardiologist
108	Female	26	203	190	139	64	03:37	cardiologist
109	Female	24	198	191	148	50	02:14	family physician
110	Female	25	220	189	153	67	01:53	family physician
111	Female	23	192	190	150	42	03:25	cardiologist
112	Female	36	192	176	148	44	02:19	no referral
113	Male	23	217	197	152	65	01:59	no referral
114	Male	24	219	196	166	53	02:07	no referral
115	Female	21	219	199	167	52	03:34	no referral
116	Male	25	220	195	169	51	01:52	no referral

117	Male	30	218	190	167	51	01:50	no referral
118	Male	31	218	189	165	53	02:05	no referral
119	Female	32	211	188	164	47	01:46	no referral
120	Female	19	228	201	169	59	01:47	no referral
121	Male	18	222	202	165	57	02:02	no referral
122	Male	45	198	175	145	53	03:33	no referral
123	Female	33	211	187	166	45	00:48	no referral
124	Female	20	228	200	169	59	02:04	no referral
125	Male	50	195	170	153	42	02:14	no referral
126	Male	51	197	169	152	45	01:58	no referral
127	Male	18	230	202	167	63	01:51	no referral
128	Male	32	209	188	156	53	01:42	no referral
129	Female	22	221	198	163	58	02:15	no referral
130	Male	22	220	198	168	52	03:24	no referral
131	Female	24	220	196	168	52	01:48	no referral
132	Male	24	219	196	165	54	01:55	no referral
133	Male	25	219	195	161	58	01:53	no referral
134	Male	26	219	194	164	55	03:26	no referral
135	Female	27	219	193	152	67	03:35	no referral
136	Male	25	221	195	168	53	02:18	no referral
137	Female	22	228	198	168	60	02:13	no referral

138	Male	23	224	197	168	56	02:07	no referral
139	Male	21	222	199	165	57	03:20	no referral
140	Female	19	222	201	169	53	01:44	no referral
141	Male	25	217	195	168	49	02:06	no referral
142	Male	18	230	202	168	62	01:41	no referral

Table description:
[bpm] **–** beats per minute
[HR] **–** heart rate
[HRM] **–** heart rate monitor
[m:s] **–** minutes and seconds

Appendix 2. Full results obtained from the analysis of HRM and Holter ECG data obtained by testing athletes at the CSC in Pułtusk.

					HRM indications during the test [bpm]				Holter ECG monitor indications during the test [bpm]			
Athlete	**Gender**	**Age [years]**	**Runner/cyclist**	**Results - group**	**Minimum value [bpm]**	**Maximum value [bpm]**	**Average value [bpm]**	**Duration of the longest tachyarrhythmia [m:s]**	**Minimum value [bpm]**	**Maximum value [bpm]**	**Average value [bpm]**	**Duration of tachyarrhythmia [m:s]**
1	Male	25	runner	I	65	179	152	-	66	178	152	-
2	Male	23	runner	I	60	164	145	-	58	155	144	-
3	Male	26	runner	I	62	152	137	-	62	152	136	-
4	Male	23	runner	I	65	171	143	-	64	171	145	-
5	Male	27	runner	I	65	160	134	-	67	160	134	-
6	Male	21	runner	I	66	177	155	-	66	179	157	-
7	Male	32	runner	I	68	164	139	-	67	165	140	-
8	Male	18	runner	I	70	179	160	-	70	181	162	-
9	Male	41	runner	I	63	153	133	-	63	154	135	-
10	Male	35	runner	I	65	159	134	-	64	159	136	-
11	Male	36	runner	I	66	150	133	-	68	151	134	-
12	Male	38	runner	I	67	157	135	-	67	158	136	-
13	Male	51	runner	I	66	154	131	-	67	153	133	-
14	Male	26	runner	I	60	163	143	-	62	163	143	-
15	Male	29	runner	I	69	167	150	-	69	167	150	-
16	Male	31	runner	I	67	165	139	-	66	166	140	-

17	Male	21	runner	I	66	156	138	-	68	156	139	-
18	Male	22	runner	I	66	174	159	-	66	172	161	-
19	Male	36	runner	I	62	176	143	-	63	176	145	-
20	Male	35	runner	I	61	151	134	-	63	153	136	-
21	Male	20	runner	I	60	178	156	-	60	176	157	-
22	Male	20	runner	I	67	172	158	-	68	171	159	-
23	Male	25	runner	I	68	153	141	-	66	154	142	-
24	Male	26	runner	I	63	175	157	-	63	175	159	-
25	Male	21	runner	I	70	164	138	-	71	166	137	-
26	Male	28	runner	I	69	166	140	-	67	164	141	-
27	Male	48	runner	I	62	151	132	-	62	152	133	-
28	Male	29	runner	I	64	160	139	-	65	161	139	-
29	Male	23	runner	I	69	173	151	-	67	171	150	-
30	Female	25	runner	I	64	165	137	-	64	165	137	-
31	Female	31	runner	I	65	162	141	-	66	162	143	-
32	Female	21	runner	I	69	170	147	-	71	168	149	-
33	Female	19	runner	I	63	168	143	-	63	169	144	-
34	Female	28	runner	I	63	153	131	-	64	151	133	-
35	Female	24	runner	I	67	173	149	-	65	172	150	-
36	Female	23	runner	I	64	167	144	-	64	169	146	-
37	Male	23	cyclist	I	61	170	147	-	62	170	147	-

38	Male	24	cyclist	I	70	163	142	-	68	161	143	-
39	Female	21	cyclist	I	63	175	148	-	63	176	148	-
40	Male	25	cyclist	I	61	168	142	-	62	169	144	-
41	Male	30	cyclist	I	62	161	149	-	60	162	149	-
42	Male	31	cyclist	I	67	157	133	-	67	158	134	-
43	Female	32	cyclist	I	62	161	135	-	63	161	135	-
44	Female	19	cyclist	I	69	171	155	-	67	171	157	-
45	Male	18	cyclist	I	61	177	151	-	61	178	152	-
46	Male	45	cyclist	I	61	159	136	-	63	154	138	-
47	Female	33	cyclist	I	68	155	139	-	70	156	140	-
48	Female	20	cyclist	I	64	166	142	-	64	168	144	-
49	Male	50	cyclist	I	68	150	134	-	67	150	136	-
50	Male	51	cyclist	I	62	156	132	-	60	155	132	-
51	Male	18	cyclist	I	64	158	136	-	64	157	138	-
52	Male	32	cyclist	I	66	158	139	-	65	160	139	-
53	Female	22	cyclist	I	63	180	161	-	61	178	159	-
54	Male	22	cyclist	I	64	164	145	-	64	165	146	-
55	Female	24	cyclist	I	68	169	155	-	67	169	157	-
56	Male	24	cyclist	I	70	168	149	-	68	168	150	-
1	Male	25	runner	II	63	165	149	-	65	163	149	-
2	Male	28	runner	II	62	159	139	-	60	157	141	-

3	Male	31	runner	II	68	163	138	-	67	162	139	-
4	Male	20	runner	II	68	182	150	-	68	183	152	-
5	Male	18	runner	II	62	173	157	-	63	174	158	-
6	Male	31	runner	II	70	151	132	-	72	149	134	-
7	Male	19	runner	II	69	163	151	-	70	162	149	-
8	Male	20	runner	II	66	167	148	-	68	169	150	-
9	Male	26	runner	II	64	160	148	-	64	160	146	-
10	Male	28	runner	II	61	161	142	-	58	163	143	-
11	Male	21	runner	II	61	175	149	-	61	175	149	-
12	Male	35	runner	II	63	156	139	-	61	154	141	-
13	Female	26	runner	II	64	163	137	-	63	162	138	-
14	Female	27	runner	II	61	162	143	-	63	160	143	-
15	Female	40	runner	II	62	154	144	-	63	153	143	-
16	Female	32	runner	II	64	159	132	-	65	160	134	-
17	Male	25	cyclist	II	68	162	145	-	67	163	145	-
18	Male	26	cyclist	II	70	158	134	-	69	159	135	-
19	Female	27	cyclist	II	67	160	133	-	66	159	131	-
20	Male	25	cyclist	II	64	165	135	-	66	163	136	-
21	Female	22	cyclist	II	61	171	147	-	61	171	148	-
1	Male	39	runner	III	61	196	147	00:20	61	161	145	-
2	Male	31	runner	III	61	186	147	00:48	58	166	144	-

3	Male	20	runner	III	67	186	159	00:52	69	155	155	-
4	Male	25	runner	III	67	198	149	01:03	68	161	144	-
5	Male	21	runner	III	61	201	146	01:11	60	165	140	-
6	Male	26	runner	III	61	187	145	02:11	61	169	137	-
7	Male	29	runner	III	63	191	147	01:20	62	161	139	-
8	Male	31	runner	III	61	198	145	01:39	60	162	138	-
9	Male	35	runner	III	61	197	151	01:40	59	159	144	-
10	Male	34	runner	III	62	236	150	03:00	61	160	142	-
11	Male	27	runner	III	61	205	170	01:20	61	164	164	-
12	Male	21	runner	III	61	200	145	01:43	62	164	138	-
13	Male	24	runner	III	62	199	146	01:42	64	163	139	-
14	Male	23	runner	III	64	201	147	00:48	64	158	144	-
15	Male	19	runner	III	66	185	146	00:32	65	161	143	-
16	Male	24	runner	III	65	212	146	00:52	63	162	142	-
17	Male	18	runner	III	61	192	145	01:03	59	160	139	-
18	Male	20	runner	III	70	180	147	01:24	70	162	140	-
19	Male	23	runner	III	65	208	164	00:48	67	158	160	-
20	Male	29	runner	III	63	209	166	00:31	64	162	163	-
21	Male	23	runner	III	68	203	150	00:52	68	158	146	-
22	Male	21	runner	III	61	213	145	01:03	61	153	137	-
23	Male	19	runner	III	62	208	151	01:11	64	165	144	-

24	Male	25	runner	III	67	212	146	01:01	69	168	140	-
25	Male	23	runner	III	61	180	146	01:20	59	164	138	-
26	Male	20	runner	III	65	210	147	00:23	67	161	145	-
27	Male	36	runner	III	65	202	147	00:48	65	171	142	-
28	Male	34	runner	III	69	202	145	00:52	66	161	140	-
29	Male	19	runner	III	63	200	148	01:03	65	164	141	-
30	Male	23	runner	III	66	199	147	01:39	66	159	140	-
31	Male	25	runner	III	61	195	154	01:42	59	163	148	-
32	Male	21	runner	III	65	194	153	01:42	63	164	145	-
33	Male	20	runner	III	67	213	152	01:23	65	165	144	-
34	Male	28	runner	III	62	226	146	01:44	61	157	138	-
35	Male	36	runner	III	70	224	151	01:44	59	170	143	-
36	Male	25	runner	III	66	187	147	01:44	67	159	140	-
37	Male	23	runner	III	61	207	146	00:48	60	162	141	-
38	Male	22	runner	III	66	189	156	00:52	66	156	151	-
39	Male	19	runner	III	63	185	156	01:03	61	166	150	-
40	Male	27	runner	III	61	193	148	01:11	58	155	142	-
41	Male	26	runner	III	64	210	155	02:11	63	164	147	-
42	Male	23	runner	III	66	213	171	01:20	64	163	165	-
43	Female	21	runner	III	61	192	145	00:48	58	159	140	-
44	Female	25	runner	III	67	209	151	00:52	69	170	146	-

45	Female	20	runner	III	63	182	145	01:03	65	166	139	-
46	Female	19	runner	III	64	217	146	01:11	65	169	140	-
47	Female	23	runner	III	64	201	145	02:00	64	160	137	-
48	Female	24	runner	III	62	208	145	01:20	62	162	139	-
49	Female	31	runner	III	64	184	165	00:48	62	161	159	-
50	Female	34	runner	III	63	204	145	00:48	61	171	140	-
51	Female	20	runner	III	68	183	145	00:52	68	163	140	-
52	Female	18	runner	III	62	182	160	01:03	61	167	153	-
53	Female	30	runner	III	69	206	147	00:48	68	167	142	-
54	Female	31	runner	III	68	202	146	00:48	66	150	142	-
55	Female	26	runner	III	69	225	154	00:52	68	165	149	-
56	Female	24	runner	III	64	205	146	01:03	65	168	140	-
57	Female	25	runner	III	65	211	150	00:48	67	156	144	-
58	Female	23	runner	III	62	184	149	00:25	60	167	146	-
59	Female	36	runner	III	63	191	148	00:48	63	153	143	-
60	Male	23	cyclist	III	64	190	155	00:52	65	163	150	-
61	Male	21	cyclist	III	65	181	155	01:03	66	167	148	-
62	Female	19	cyclist	III	61	188	162	00:29	59	168	158	-
63	Male	25	cyclist	III	62	203	147	00:32	61	157	143	-
64	Male	18	cyclist	III	63	183	158	01:11	62	161	151	-
1	Male	29	cyclist	IV	59	225	156	04:00	58	227	158	04:00

Table description:
[bpm] – beats per minute
[ECG] – electrocardiogram
[m:s] – minutes and seconds