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

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1INTRODUCTION

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. HR is a useful indicator of physiologic adaptation and effort intensity. Therefore, heart rate (HR) monitoring is an important component of cardiovascular fitness assessments and training programs.

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. HRMs have been designed for use by healthy athletes with a baseline sinus rhythm, but they have also captured exercise-induced arrhythmia. However, information about the morphology of the QRS complex has not been reported, and atrial signals have not been detected. 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.

2 | 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.

3 | MATERIALS

In all, 142 men and women aged 18-51 years, 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. In total, 33 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.

3.1 | 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. In all, 31 amateur

### 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 |

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 tachycardia (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 tachycardia (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                          |

bpm, beats per minute; HR, heart rate; HRM, heart rate monitor; sec, seconds.
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.

3.2 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.

3.3 Tests performed before the study

Prior to arriving at the CSC, all athletes underwent an ECG for diagnostic purposes. In total, 80 athletes underwent 24-hour ECG monitoring using the Holter method, which did not show any abnormal 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 electrophysiologic tests (EPs), which did not reveal the cause of the possible arrhythmias observed on the HRM.

4 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 Industries Limited, London, England). 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 920 XT 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. Figure 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.

1. Holter data were analyzed by cardiologists at a Holter test laboratory, and
2. HRM data were examined by analysts who were trained in analyzing data from HRMs after transmission to a

| Type of activity        | Number of athletes | Average number of km covered during training (±SD) [km/wk] | Coefficient of variation (dispersion level) | Average training time (±SD) [h/wk] | 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)                            |

h/wk, hours per week; km/wk, kilometers per week; SD, standard deviation.
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All athletes provided written informed consent to participate in the study.

4.1 | 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 non-parametric test (Mann-Whitney U-test). Significance was established at $P<.05$. Statistical analyses were performed using STATISTICA software, version 12 (StatSoft Poland, Krakow, Poland, http://www.statsoft.pl/).

5 | 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 minutes. The test results are described below.

5.1 | 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.: $t=−.60$, $P>.05$; min: $t=.06$, $P>.05$; max: $t=.07$, $P>.05$). This group consisted of 36 runners and 20 cyclists.

5.2 | 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.: $t=−.26$, $P>.05$; min: $t=.06$, $P>.05$; max: $t=.16$, $P>.05$). This group consisted of 36 runners and 20 cyclists.

5.3 | Group III

In this group (n=64, ca. 45% of all athletes), we once again observed discrepancies between the Holter ECG and HRM

FIGURE 1 Athlete at the beginning of the test with Holter ECG and HRM
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 minutes; av.: 199 bpm for an average of 68 seconds); these increases were not observed in the Holter data at the time of their occurrence (Figure 2C,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: $t=1.07$, $P > .05$).

### 5.4 | 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 (Figure 2A,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 minutes 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 was 145 bpm (min: 63 bpm; max: 162 bpm).

![Figure 2](image-url)

**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 min of rest. (B) The same patient with AVNRT at 227 bpm, as determined using the Holter at the same time as in (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 (C). (E) Artifacts observed on the Holter — without problems to identify. (F) HRM data for the sportsman from (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 s).
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.

6 | DISCUSSION

6.1 | Heart rate monitors and their applicability in endurance training

Heart Rate Monitors (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, for example, 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 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. Patients with cardiovascular disease must stay below the ventilatory threshold.

HR is an important parameter that is closely monitored both by competitive endurance athletes and amateur athletes during training. 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. 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. HR variability (the beat-to-beat variation of RR intervals) decreases with increasing intensity. 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.

6.2 | 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.

| 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                             | .95 (NS) | 164.4                             | 164.3                             | .95 (NS) | 143.1                             | 144.0                             | .55 (NS) |
| Group II | 21               | 64.7                             | 64.8                             | .95 (NS) | 163.3                             | 162.9                             | .87 (NS) | 142.5                             | 143.0                             | .79 (NS) |
| Group III | 64              | 64.0                             | 63.4                             | .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                             | —         |

bpm, beats per minute; ECG, electrocardiogram; HR, heart rate; HRM, heart rate monitor.
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) indicate 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 Figure 3.

6.3 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 (Figure 2E,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, that is, 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, for example, 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.

6.4 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
Cardiac arrhythmia is also not uncommon in healthy non-athletes. 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. 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. 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.

### 6.5 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 (Figure 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. 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 physiologic restrictions placed on them by doctors; these people often train very intensively and compete in tournaments.

HRMs are useful for evaluating the HR of adolescents with congenital syndromes extending from arrhythmia provoked by effort. 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. Several new and effective technologies for the wireless monitoring of arrhythmias have been developed, validated, and are currently available for patient care, for example, Real-Time Smart Phone Monitoring, ECG Patch Monitoring, Injectable Loop Recorders and Device-tailored monitors, among others; these technologies can also be used by athletes.

6.6 | 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, that is, 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 Figure 3 might be of practical value in further medical diagnostics.

7 | PERSPECTIVES

A physically active lifestyle is widely promoted for healthy individuals and large groups of patients. Millions of physically active individuals worldwide use HRMs to control exercise intensity. 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, as well as on many other previously published papers, competitive sportspersons are not immune to cardiac arrhythmias and the risk of sudden death.

8 | CONCLUSION

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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APPENDIX 1
Complete results obtained from the analysis of data reported by athletes to the CSC in Pultusk

| 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 (min: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     |

(Continues)
| 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 (min:s) | Referral |
|---------|--------|-------------|---------------------------------------------------------------|-----------------------------------------------|-----------------------------------------------|------------------------------------------------|-----------------------------------|---------|
| 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 |
| 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 (min:s) | 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 |
| 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 (min:s) | Referral |
|---------|--------|-------------|---------------------------------------------------------------|-----------------------------------------------|--------------------------------------------------|----------------------------------------------------------------|---------------------------------|---------|
| 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 |
| 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 (min:s) | 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                                           | 53                                           | 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                                           | 47                                           | 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 |

bpm, beats per minute; HR, heart rate; HRM, heart rate monitor; min: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

| Athlete | Gender | Age (years) | Runner/cyclist | Results (group) | HRM indications during the test (bpm) | Holter ECG monitor indications during the test (bpm) |
|---------|--------|-------------|----------------|----------------|--------------------------------------|---------------------------------------------------|
|         |        |             |                |                | **Minimum value (bpm)** | **Maximum value (bpm)** | **Average value (bpm)** | **Duration of the longest tachyarrhythmia (min:s)** | **Minimum value (bpm)** | **Maximum value (bpm)** | **Average value (bpm)** | **Duration of tachyarrhythmia (min: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 | — |

(Continues)
### APPENDIX 2  (Continued)

| Athlete | Gender | Age (years) | Runner/cyclist | Results (group) | HRM indications during the test (bpm) | Holter ECG monitor indications during the test (bpm) |
|---------|--------|-------------|----------------|-----------------|---------------------------------------|-------------------------------------------------|
|         |        |             |                |                 | Minimum value (bpm) | Maximum value (bpm) | Average value (bpm) | Duration of the longest tachyarrhythmia (min:s) | Minimum value (bpm) | Maximum value (bpm) | Average value (bpm) | Duration of tachyarrhythmia (min:s) |
| 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                  | —                     |

(Continues)
### APPENDIX 2  (Continued)

| Athlete | Gender | Age (years) | Runner/ Cyclist | Results (group) | HRM indications during the test (bpm) | Holter ECG monitor indications during the test (bpm) |
|---------|--------|-------------|-----------------|----------------|--------------------------------------|-----------------------------------------------|
|         |        |             |                 |                | Minimum value (bpm) | Maximum value (bpm) | Average value (bpm) | Duration of the longest tachyarrhythmia (min:s) | Minimum value (bpm) | Maximum value (bpm) | Average value (bpm) | Duration of tachyarrhythmia (min:s) |
| 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                  | —                           |
| Athlete | Gender | Age (years) | Runner/cyclist | Results (group) | HRM indications during the test (bpm) | Holter ECG monitor indications during the test (bpm) |
|---------|--------|-------------|----------------|-----------------|---------------------------------------|--------------------------------------------------|
|         |        |             |                |                 | Minimum value (bpm) | Maximum value (bpm) | Average value (bpm) | Duration of the longest tachyarrhythmia (min:s) | Minimum value (bpm) | Maximum value (bpm) | Average value (bpm) | Duration of tachyarrhythmia (min:s) |
| 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                      | 144                  | —                   |
| 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                  | —                   |
## APPENDIX 2

| Athlete | Gender | Age (years) | Runner/ Cyclist | Results (group) | HRM indications during the test (bpm) | Holter ECG monitor indications during the test (bpm) |
|---------|--------|-------------|----------------|-----------------|--------------------------------------|---------------------------------------------|
|         |        |             |                |                 | Minimum value (bpm) | Maximum value (bpm) | Average value (bpm) | Minimum value (bpm) | Maximum value (bpm) | Average value (bpm) | Duration of tachyarrhythmia (min:s) |
| 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 |

bpm, beats per minute; ECG, electrocardiogram; min:s, minutes and seconds.