Into-the-Field Assessment of Maximal Heart Rate during Exercise

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Abstract

Exercise is normally recommended for its beneficial effects on health; however, exercising at very high heart rate (HR) may increase the risk of cardiac events. Theoretical maximal HR (TMHR) is subject dependent and may be easily computed through several formulas; according to the guidelines, recommended target HR range during a stress test for clinical evaluation is 50 to 85% of TMHR. Considering the new widely diffused use of wearable sensors, an into-the-field assessment of the highest HR (HHR) reached during exercise is now possible. Thus, the present study aims to assess HHR during uncontrolled exercise and to relate it to TMHR. To this aim, 178 HR series were acquired through wearable sensors from 122 athletes, while practicing 15 different sports. TMHR was assessed by applying seven well-known mathematical formulae. Percentage of athletes whose HHR overcame 85% of TMHR (i.e., recommended target HR range during a stress test) and TMHR were computed. Moreover, HHR and TMHR distributions were compared by paired T-Student test (statistical significance at 0.05). HHR of 90% or more of athletes overcame 85% of TMHR. HHR of 39% or more of athletes overcame TMHR. Thus, HHR normally approaches, and sometimes overcomes, TMHR when exercising.

1. Introduction

Exercise is normally recommended for its beneficial effects on health. Indeed, exercise has been shown to improve cardiovascular health [1], to enhance mental well-being [2], to increase longevity [3] and to reduce risk of chronic diseases [4].

However, there are still concerns on the training intensity needed to obtain such beneficial effects, considering that the relationship between exercise intensity and health outcomes is complex [5]. When considering high-intensity exercise, it has to be noted that it is associated to very high heart rates (HR), which may pose a risk of adverse cardiac events, such as ischemia [6]. Thus, it is essential to careful monitor the exercise intensity with the aim to maximize the health benefits while minimizing the potential risks.

In clinics, the "potential" highest HR is usually assessed by the theoretical maximal heart rate (TMHR), which is subject-specific and can be easily calculated by applying mathematical formulae [7-13]. According to clinical guidelines, the recommended target HR range during a stress test for clinical evaluation is between 50 to 85% of TMHR [14, 15]. This range aims to find a tradeoff between the health benefits of exercise and potential risks associated with overexertion.

In recent years, the use of wearable sensors has revolutionized the field of exercise and sport. Considering that these devices can continuously monitor HR and other physiological parameters, they allow to accurately collect real-world data [16]. Wearable technology enables an into-the-field assessment of exercise practitioners, providing insights related to their health beyond the controlled environment of a clinical setting.

Specifically, this technology may allow a precise assessment of the "real" highest heart rate (HHR) achieved during different exercise tasks and of its relationship with the computed TMHR. However, this comparison was never performed. Analyzing the into-the-field HHR reached during uncontrolled exercise can provide insight about the degree of training intensity of each individual and its potential implications for cardiac health. These findings can be useful for refining exercise guidelines, developing targeted interventions, and promoting safe exercise practices across diverse populations.

Thus, the present study aims to assess HHR during uncontrolled exercise measured into-the-field by wearable sensor and to relate it to TMHR, estimated by the most used mathematical formulae available in the literature.

2. Material and Methods

2.1. Data

Data used in this analysis come from Sport DB and Sport DB 2.0, which are two collections of datasets, acquired through wearable sensors and portable devices [17], [18]. They include 294 cardiorespiratory datasets from 201 subjects while practicing 18 different sports (i.e., AER: aerial skills, AMF: American football; ATH: athletics; BAS: basketball; CFIT: cardio fitness; CRO: CrossFit; CYC: cycling; FIT: fitness; FUT: futsal; JOG: jogging; MID: middle-distance running; RUN: running; SKA: speed skating; SOC: soccer; TEN: tennis; TRE: trekking; VOL: volleyball; ZUM: Zumba) during training and competition. Each dataset includes demographic data, cardiorespiratory signals and training note file. Demographic data (Table 1) are sex, age, weight, height, smoking habit, alcohol consumption, caffeine consumption, weekly training rate, presence of diseases and dietary supplement consumption. Cardiorespiratory signals are electrocardiogram, HR series, RR-interval series, and/or breathing-rate series, and they were acquired through the BioHarness 3.0 by Zephyr, the KardiaMobile by AliveCor, the Kardia 6L by AliveCor, the Polar M400 by Polar, and heart-rate sensor H7 by Polar. Acquisitions followed a sport-dependent training protocol, that is described in the training note file. All subjects gave their informed consent prior to data collection and acquisitions, undertaken in compliance with the ethical principles of Helsinki Declaration and approved by the institutional expert committee (Prot.n.0029692, released on February 05th, 2024). For this study, only cardiorespiratory datasets including age information and HR series were considered.

2.2. Theoretical Maximal Heart Rate

In the literature, TMHR can be estimated by seven well-known subject-specific mathematical formulae, whose mathematical definition is as follows:

Gulati [7]: $TMHR_G = 206 - 0.88 \cdot Age$ (1)

INBAR [8]: $TMHR_I = 205.8 - 0.685 \cdot Age$ (2)

Karvonen [9]: $TMHR_K = 220 - Age$ (3)

Londeree [10]: $TMHR_L = 206.3 - 0.711 \cdot Age$ (4)

Miller [11]: $TMHR_M = 217 - 0.85 \cdot Age$ (5)

Nes [12]: $TMHR_N = 211 - 0.64 \cdot Age$ (6)

Tanaka [13]: $TMHR_T = 208 - 0.7 \cdot Age$ (7)

2.3. Statistical Analysis

Each HR series was characterized by computing the HHR. Moreover, the seven TMHR and their 85% (i.e., recommended target HR range during a stress test) were estimated for each subject.

Distributions of HHR, 0.85·TMHR and TMHR computed by the seven mathematical formulas are reported as mean value ± standard deviation (μ±σ).

Table 1. Summary of the demographic SportDB and SportDB 2.0.

Sport	n.subjects/ n.datasets	Sex (M/F)	Age (years)	Weight (kg)	Height (cm)	Smoker (N/Y/n.a.)	Alcohol (N/Y/n.a.)	Training Rate (times per week)
AER	3/3	0/3	25±3	53±4	159±1	0/0/3	0/0/3	n.a.
AMF	15/15	15/0	24±4	95±15	182±7	9/6/0	0/15/0	3±0
ATH	10/30	3/27	18±2	59±5	169±9	30/0/0	15/15/0	5±1
BAS	42/42	31/11	22±4	79±14	185±10	27/15/0	5/37/0	5±1
CFIT	6/6	3/3	32±13	71±20	172±13	4/2/0	1/5/0	3±2
CRO	19/28	19/9	29±6	72±12	176±7	15/13/0	6/22/0	4±1
CYC	12/12	10/2	33±16	n.a.	n.a.	12/0/0	0/0/12	n.a.
FIT	8/8	6/2	25±5	71±14	173±7	4/4/0	4/4/0	4±1
FUT	7/7	7/0	22±3	69±8	179±8	4/3/0	1/6/0	4±0
JOG	5/19	10/9	32±15	59±10	170±5	12/0/7	0/0/19	n.a.
MID	10/10	10/0	37±16	70±8	177±3	9/1/0	2/8/0	4±1
RUN	10/20	18/2	22±2	69±6	178±7	11/9/0	2/18/0	3±1
SKA	1/4	F	22	58	170	N	Y	5
SOC	22/43	22/0	27±7	72±7	177±4	32/6/5	0/29/14	3±1
TEN	9/19	11/8	43±13	60±10	170±6	18/1/0	0/8/11	3±1
TRE	3/9	0/9	26±1	58±5	162±1	9/0/0	0/0/9	n.a.
VOL	13/13	0/13	23±3	71±8	173±5	11/2/0	0/13/0	4±1
ZUM	6/6	1/5	35±9	66±17	174±14	0/0/6	0/0/6	n.a.
Overall	201/294	187/107	27±10	71±13	176±9	211/62/21	36/184/74	4±1

AER: aerial skills; AMF: American football; ATH: athletics; BAS: basketball; CFIT: cardio fitness; CRO: CrossFit; CYC: cycling; F: female; FIT: fitness; FUT: futsal; JOG: jogging; M: male; MID: middle-distance running; n.a.: not available; N: no; RUN: running; SKA: speed skating; SOC: soccer; TEN: tennis; TRE: trekking; VOL: volleyball; Y: yes; ZUM: Zumba.

Moreover, 0.85·TMHR and TMHR distributions were compared with the HHR distributions by paired T-Student test (statistical significance at 0.05). Finally, distributions of the difference (δ) between 0.85·TMHR and HHR distributions and TMHR and HHR distributions, and percentages (%P) of HHR overcame 85% of TMHR and TMHR were computed.

3. Results

After considering the inclusion criteria, 178 HR series acquired from 122 athletes, while practicing 15 different sports (AER, AMF, BAS, CRO, CYC, FIT, JOG, MIN, RUN, SKA, SOC, ZUM, TEN, TRE) were considered for the analysis.

Distributions of HHR, 0.85·TMHR and TMHR are reported in Table 2, together with the results of the statistical analysis. An example of the analysis is reported in Figure 1. HHR was significantly higher than all 0.85·TMHR ($P<0.01$), $TMHR_G$ ($P<0.01$), $TMHR_I$ ($P<0.05$) and $TMHR_L$ ($P<0.01$), but not significantly different from $TMHR_K$ ($P=0.90$), $TMHR_M$ ($P=0.40$), $TMHR_N$ ($P=0.37$), and $TMHR_T$ ($P=0.11$). Differences are positive for all 0.85·TMHR (δ>27bpm), $TMHR_G$ (δ=10bpm), $TMHR_I$ (δ=5bpm), $TMHR_L$ (δ=5bpm) $TMHR_T$ (δ=3bpm); it is zero for $TMHR_K$, and negative for $TMHR_M$ (δ=-2bpm) and $TMHR_N$ (δ=-2bpm). HHR of 90% or more of athletes overcame 85% of TMHR, while HHR of 39% or more of athletes overcame TMHR.

4. Discussion

The present study evaluated the HHR obtained in athletes measured into-the field by wearable sensors and its relationship with the TMHR and the 85% TMHR, this latter commonly used to evaluate the health condition of the subject during the stress test.

Table 2. Distributions of HHR, 0.85·TMHR and TMHR, together with the results of statistical analysis

	μ±σ (bpm)	δ (bpm)	%P
HHR	189±23	-	-
0.85·$TMHR_G$	153±9**	37±25	94
0.85·$TMHR_I$	158±7**	33±25	93
0.85·$TMHR_K$	162±10**	28±25	91
0.85·$TMHR_L$	158±7**	33±25	93
0.85·$TMHR_M$	163±8**	27±25	90
0.85·$TMHR_N$	164±6**	27±25	90
0.85·$TMHR_T$	160±7**	31±25	92
$TMHR_G$	180±10**	10±25	66
$TMHR_I$	186±8*	5±25	53
$TMHR_K$	191±12	0±26	39
$TMHR_L$	186±8**	5±25	55
$TMHR_M$	192±10	-2±25	39
$TMHR_N$	192±7	-2±25	39
$TMHR_T$	188±8	3±25	48

*: P lower than 0.05; **: P lower than 0.01.

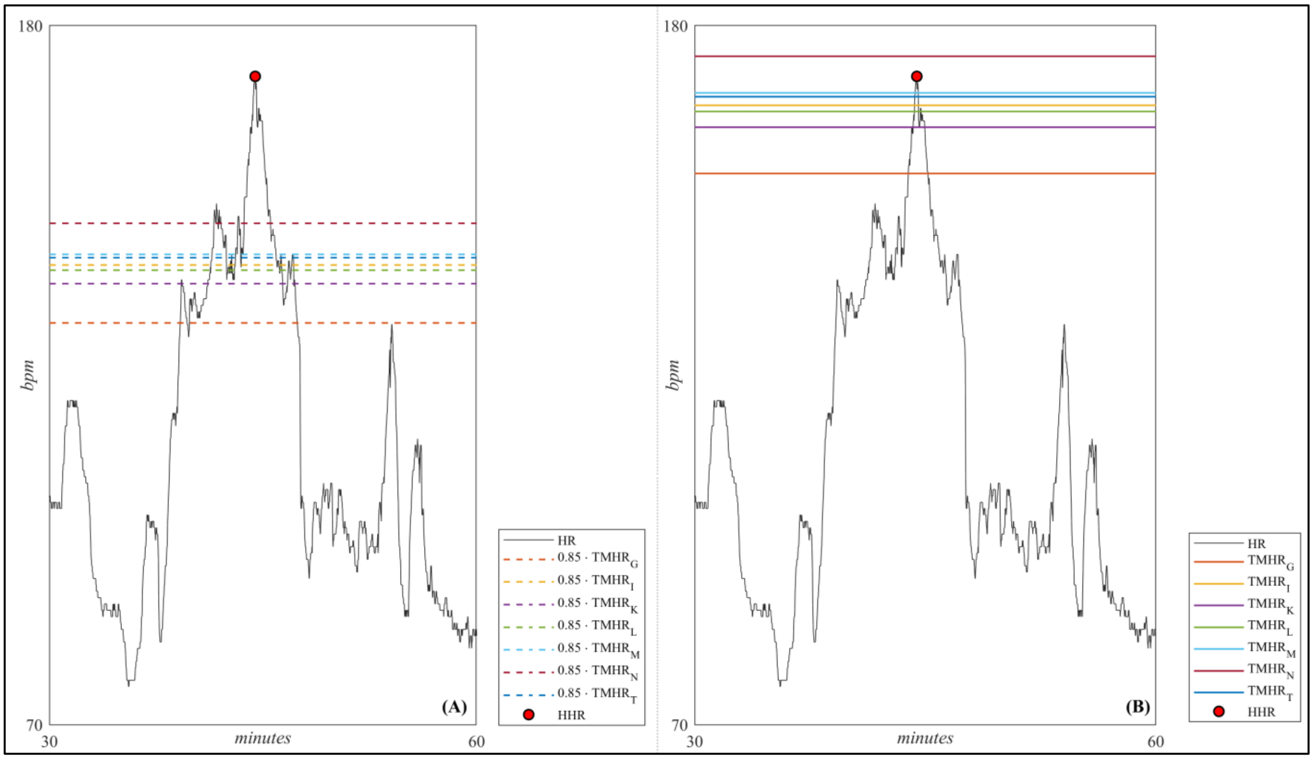

Figure 1. Example of the HHR (red dots), 0.85·TMHR (lines in panel A) and TMHR computation (lines in panel B).

The study findings underscore the high-intensity of exercise that is usually performed into-the field, revealing that a not negligible number of athletes exceed recommended HR thresholds. Indeed, the HHR of 90% or more of athletes exceeded 85% of TMHR, regardless of the formula used to calculate TMHR. Furthermore, HHR exceeded the TMHR in 39% or more of the athletes, with significant variations depending on the TMHR formula used. Statistical comparisons revealed that HHR is statistically higher than TMHR when using three out of seven formulas, suggesting that some TMHR formulas may underestimate the true maximal HR achieved during exercise. Thus, formulas like those offered by Karvonen's [9], Miller's [11], Nes's [12], and Tanaka's [13], provide more accurate TMHR estimation. Thus, these formulas may help in interpretation of training intensity recommendations, thereby enhancing safety. These findings are relevant in the context of the widespread of the use of wearable sensors, which provide real-time monitoring of physiological parameters during exercise. The study highlights the importance of utilizing accurate TMHR formulas to set appropriate HR targets in training programs and to monitor athletes effectively.

However, it is important to note limitations in this study. The sample includes athletes from 15 different sports, which may not be representative of the general population. Additionally, the study did not account for individual variability in fitness levels, which can significantly influence HR responses to exercise. Future research should consider a more diverse population and explore the impact of different fitness levels on the relationship between HHR and TMHR.

5. Conclusion

The study demonstrates that athletes often exceed recommended HR limits while performing uncontrolled exercise, with significant variations depending on the TMHR formula used.

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