Marx et al. (2018) *Int J Res Ex Phys*. 14(1):21-28.

Sponsored by:
Exercise and Sport Science Program
Western Colorado University

International Journal of Research in Exercise Physiology

Original Research Article

The Accuracy of Heart Rate-Based Zone Training using Predicted versus Measured Maximal Heart Rate

Amanda J. Marx[1], John P. Porcari[1], Scott Doberstein[1], Blaine E. Arney[1], Susan Bramwell[1], Carl Foster[1]
[1]Department of Exercise and Sport Science, University of Wisconsin-La Crosse, La Crosse, WI, USA

Abstract

Introduction: Heart rate (HR) based zone training has become an increasingly popular method of exercise training. However, the use of age-predicted maximal HR as a way to determine training zones has come under scrutiny. **Purpose:** The purpose of this study was to examine the accuracy of HR-based zone training using predicted maximal heart rate (PMHR) versus measured maximal heart rates (MMHR). **Methods:** Twenty-six college-aged subjects participated in the current study. Subjects completed two testing sessions: a PMHR-based zone training session and a maximal treadmill test to determine MMHR. The PMHR-based zone training session consisted of seven, 5-minute exercise bouts carried out at various percentages of PMHR. The achieved exercise HRs were then compared to zones that were calculated from MMHR, in order to determine what zone they would have been in if they had used MMHR instead of PMHR for the initial calculations. **Results:** Eighty-six percent (156/182) of the time subjects were within the correct training zone based upon PMHR. When subjects were not in the correct zone, they were never off by more than one zone and were within 1-4% of the correct zone. **Conclusion:** The current study suggests that for college-aged students, using PMHR to define training zones is relatively accurate; the majority of the time subjects were in the correct HR-based training zone. However, for those individuals who may not be able to get their HR into the upper zone (i.e., Zone 5), we advise the use of an RPE scale in conjunction with exercise HR in order to prevent overexertion.

Key Words: Exercise Prescription, Target Heart Rate, Zone Training

Introduction

Heart rate (HR) is widely used in a variety of settings for exercise prescription. Individuals are given a target HR range to exercise within, which is based upon percentages of their maximal heart rate (%HRmax) or heart rate reserve (%HRR)[1]. These target HR ranges are designed to get individuals into different "training zones", with each zone corresponding to a specific exercise intensity. The ranges of %HRmax and %HRR and corresponding intensities defined by the American College of Sports Medicine (ACSM)[1] for use in the general public are presented in Table 1. A similar scheme, for use in athletes, has been described by Edwards[2] (Table 2).

Table 1. Exercise training zones defined by the American College of Sports Medicine[1].

Intensity Zone	%HRmax	%HRR
Very Light	<57%	<30%
Light	57-63%	30-39%
Moderate	64-76%	40-59%
Vigorous	77-95%	60-89%
Maximal	96-100%	90-100%

Table 2. Exercise training zones described by Edwards[2].

Intensity Zone	%HRmax
Moderate activity	50-60%
Weight management	60-70%
Aerobic	70-80%
Anaerobic threshold	80-90%
Red-Line	90-100%

The incorporation of wearable technology into group fitness classes has made “zone training” one of the fastest growing trends in the fitness industry[3-4]. Target HR zones are calculated for each individual, with HRs often times projected on a screen to help guide participants. Specific colors represent the various zones and participants are encouraged to exercise within each zone for a given period of time. In order for these zones to be accurate, it is necessary to have an accurate measure of maximal HR.

The best way to determine maximal HR is with a graded maximal exercise test (GXT). However, many times it is not feasible to perform a GXT due to lack of time, equipment, or trained personnel. Therefore, regression equations have been developed to predict maximal HR, most of which are based on age. The most commonly used prediction equation is 220-age[5]. It is interesting to note that despite the widespread acceptance of this equation, the equation was not developed based upon original research. It was developed based upon a summary of published and unpublished studies available at the time by a group of experts[6]. Additionally, there is considerable individual variation when using the equation. The standard deviation of predicted maximal HR using the equation is reported to be ± 10-12 bpm and it consistently overestimates maximal HR in younger adults and underestimates maximal HR in older adults[6-7]. As such, a number of alternative equations have been developed. The equation by Gellish et al.[8] (207-.70 X age) is reported to provide more accurate estimates across a wide range of ages and has a standard deviation of ± 5-8 bpm. The equation developed by Gulati et al.[9] (206-.88 X age) has been shown to me more accurate in women, who generally have lower maximal HRs than men.

A potential problem with using predicted maximal HR (PMHR) for zone training is that because of individual variation in measured maximal HR (MMHR), there is no way to know if exercisers are exercising in the correct zone. While this may seem like a benign problem, it could have several undesired consequences. For instance, if someone has a higher MMHR than predicted, when zones are calculated based on PMHR they will be exercising at an intensity that is lower than intended and they will not achieve the desired benefits of training. Conversely, if someone has a lower MMHR than PMHR, they may have difficulty getting their HR into the top predicted zone and could overexert themselves, which could be potentially dangerous[10].

Because of the potential pitfalls in using PMHR for exercise prescription, the purpose of this study was to determine the accuracy of HR-based zone training using PMHR compared to MMHR. Specifically, target HR zones were calculated based on PMHR. Subjects then adjusted the exercise workload in order to achieve a HR in the middle of each zone. The achieved exercise HRs were then compared to zones that were calculated from MMHR, in order to determine what zone they would have been in if they had used MMHR instead of PMHR for the initial calculations.

Methods

Participants

Twenty-eight volunteers between the ages of 18-25 years volunteered to participate in this study. Each individual completed a PAR-Q and health history questionnaire designed to screen for cardiovascular and orthopedic contraindications to exercise and eligible candidates provided written informed consent. The study was approved by the University of Wisconsin-La Crosse Institutional Review Board for the Protection of Human Subjects.

Experimental Design

Each subject attended two testing sessions on separate days. Testing days were separated by at least 48 hours. On the first day, subjects completed a 35-minute exercise bout on a motorized treadmill. The 35-minute session was divided into seven, 5-minute exercise segments. The seven segments were carried out targeting five intensity zones. The five intensity zones that were used in this study were: Zone 1 = 50-59% PMHR; Zone 2 = 60-69% PMHR; Zone 3 = 70-79% PMHR; Zone 4 = 80-89% PMHR; and Zone 5 = 90-100% PMHR. PMHR was estimated using the equation of Gellish et al.[8] (PMHR=207-0.7 X age). Target HRs for each zone were calculated that corresponded to middle of that zone. The presentation order of the seven zones was identical for all subjects and was as follows: 1, 3, 2, 4, 2, 5, and 2. During pilot testing it was found that Zone 1 could not be reasonably achieved after the warm-up period, thus Zone 1 was not included in the later stages. Speed and grade of the treadmill were adjusted during each 5-minute segment in an attempt to achieve the target HR. Heart rate was monitored continuously during each exercise session using radiotelemetry (Polar Electro Oy, Port Washington, NY). The HRs at 4:30 and 5:00 during each 5-minute segment were averaged to determine the exercise HR for each of the seven segments. Ratings of perceived exertion (RPE) were assessed at the end of each 5-minute segment using the Borg 6-20 scale[11].

On the second testing day, subjects completed an incremental maximal exercise test on the treadmill to determine MMHR and maximal oxygen consumption (VO_2max). The test started at a self-selected walking or running speed and 0% grade. The grade was increased by 2.5% every 2 minutes until the subject reached volitional exhaustion. During the test HR was measured using radiotelemetry and expired air was measured using an AEI metabolic cart (AEI, Pittsburgh, PA). Prior to each test, the metabolic system was calibrated with gases of known concentrations (15.98% O_2, 4.12% CO_2) and with room air (20.94% O_2 and 0.03% CO_2) as per manufacture guidelines. Calibration of the pneumotachometer was conducted using a 3 liter calibration syringe. MMHR was defined as the highest HR observed at any point in the test and VO_2max was defined as the highest continuous 30-second of VO_2 during the test. In order to be considered a maximal test, subjects had to achieve two of the following criteria: 1) a plateau in oxygen consumption (< 150 ml/min) despite an increase in workload, 2) a HR within 10 bpm of predicted values, and 3) an RER > 1.15[12].

Statistical analyses

Standard descriptive statistics were used to determine baseline physical characteristics of the subjects and to summarize the data. Simple percentages were used to determine the frequency of times subjects were within the correct zone based on PMHR versus MMHR. Comparisons between PMHR and MMHR were made using a dependent t-test and Pearson product-moment correlation. Alpha was set at $p<0.05$ to achieve statistical significance. Data were analyzed using the Statistical Package for the Social Sciences (SPSS) Version 25.0 (Chicago, IL).

Results

Twenty-eight volunteers initially agreed to participate in the study. However, one subject did not meet the criteria for a maximal exercise test and one subjects' data was removed due to technical difficulties with the HR monitor so that completed data were not recorded. Descriptive characteristics of the 26 subjects who completed the study are presented in Table 3.

Table 3. Descriptive characteristics of the subjects (N=26).

	Female (n=13)	Male (n=13)
Age (yr)	21.2 ± 2.42	20.3 ± 1.11
Height (cm)	161.8 ± 4.18	180.9 ± 7.16
Weight (kg)	61.8 ± 5.36	84.6 ± 8.54
VO_2max (ml/kg/min)	50.9 ± 5.00	58.4 ± 5.53

Data are reported as mean ± standard deviation.

Average MMHR was 192 ± 6.6 bpm and average PMHR was 193 ± 1.3 bpm. There was no significant difference between MMHR and PMHR and the correlation between the two values was r=0.45. It was found that 12 subjects had a MMHR greater than their PMHR and 13 subjects had a MMHR less than their PMHR. For one subject PMHR and MMHR were identical. There were only four subjects who had a PMHR that was beyond one standard deviation of the reported predictive accuracy of the prediction equation (± 5-8 bpm). A graph of MMHR vs. PMHR is presented in Figure 1.

Rating of perceived exertion and HR data for all seven segments of the 35-minute treadmill exercise session are presented in Table 4. There was no significant difference in the mean exercise intensity for each zone when calculated based on MMHR or PMHR.

Table 4. Average RPE and HR data recorded during the seven different training zones.

Zone	RPE	%MMHR	%PMHR
1	7.6 ± 1.13	55 ± 2.51	55 ± 2.36
3	10.8 ± 1.81	77 ± 3.80	76 ± 2.89
2	9.4 ± 1.71	65 ± 3.06	64 ± 1.98
4	13.0 ± 2.28	87 ± 3.44	87 ± 1.90
2	9.5 ± 1.63	65 ± 3.51	64 ± 2.73
5	16.0 ± 2.78	96 ± 2.72	96 ± 1.79
2	8.7 ± 1.58	67 ± 3.45	65 ± 2.82

Data are reported as mean ± standard deviation.

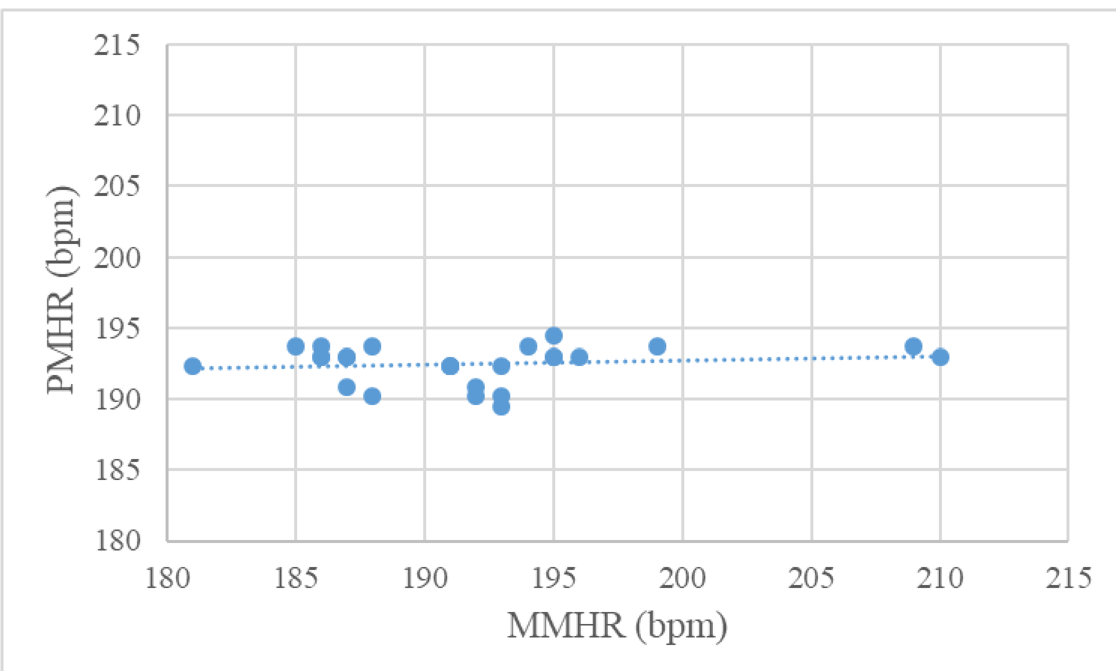

Figure 1. Relationship between MMHR and PMHR.

Eighty-six percent (156/182) of the time subjects exercise HRs were in the correct zone based upon their PMHR, whereas 14% (26/182) of the time subjects exercise HRs did not fall within the correct training zone based upon their PMHR. Of the 26 times that subjects were not in the correct zone, 21 times they were over the correct zone and 5 times they were under the correct zone. When subjects were not in the correct zone, they were never off by more than one zone and were within 1-4% of the lower or upper range of the targeted intensity range, respectively.

Discussion

The results of the current study found that when HR-based training zones were calculated based on PMHR, the majority of the time (86%) subjects were in the correct zone. When subjects exercise HRs did not fall within the correct zone, their HRs were never off by more than one zone. Even when they were not in the correct zone, they were never more than 1-4% above or below the targeted ranges. The main reason people were in the correct zone the vast majority of the time was that in 22 of 26 subjects there was very little difference between PMHR and MMHR. The reported accuracy of the equation used for PMHR in the current study was ± 5-8 bpm, and those 22 subjects had a PMHR that was within 8 bpm of MMHR. Thus, the calculated zones based on PMHR and MMHR were almost identical. This is also evident in Table 4, where it was found that there was no significant difference between the average intensity in each zone based upon PMHR and MMHR.

Another possible explanation for the above results is that the range of heart rates to be within a particular zone was quite large. For instance, for a 21 year-old subject, PMHR would be 192 bpm. To be within Zone 4 (80-89% of PMHR), HR could range from 153-171 bpm. The goal was to have subjects' HRs fall within the middle of each PMHR zone. Therefore, the target HR for this individual was 162 bpm. This individual would have to be off by ± 9 bpm to be outside the zone. Additionally, we only determined whether they were in the correct zone or not in the zone. One subject could be exercising at 80% of PMHR and another subject could be at 89% of PMHR and still be in the correct zone. When it comes to training benefits, that difference in exercise intensity could have a significant impact.

There was a relatively weak correlation (r = 0.45) between PMHR and MMHR. However, a factor to consider is the age range of subjects in the current study. Subjects were all college-aged students (18-25 years). This resulted in a relatively narrow range of PMHR (190-194 bpm), compared with the larger range of MMHR (181-210 bpm). This narrow range of PMHR likely contributed to the low correlation between PMHR and MMHR.

There were four subjects who had a sizable difference between PMHR and MMHR. Two subjects had a higher MMHR than PMHR (+15 and +17 bpm, respectively) and two subjects who had a lower MMHR than PMHR (-9 and -11 bpm, respectively). As mentioned previously, if someone has a MMHR that is significantly higher than PMHR, the zones calculated based upon PMHR will result in that person exercising at a lower intensity than desired. That is exactly what was seen in this study. The two subjects whose MMHR was significantly higher than PMHR were consistently either under or on the lower border of the correct zone, had they been calculated based upon MMHR. Additionally, their RPEs reflected the fact that they were not exercising as hard as would be expected for the targeted zone. For example, the average RPE when subjects exercised in Zone 5 (90-100% of maximal HR) was 16.0. The average RPE for the two individuals mentioned above was 13.5. Conversely, if individuals had a lower PMHR than MMHR, it was hypothesized that it would be difficult for those individuals to get into the correct zones. For the two individuals whose MMHR was significantly lower than PMHR, they were consistently either over or in the upper end of the desired zone. For Zone 5, one subject was exercising at 98% of MMHR and one subject was exercising at 100% of MMHR. The average RPE for Zone 5 was 16.0 and the RPEs for these two individuals were 17 and 18, respectively.

In practice, when individuals are given training zones based upon PMHR, they have no idea whether or not their exercise HRs are in the correct zone based on their true MMHR. This could result in them either exercising below the desired intensity, or conversely, overexerting themselves. A previous study in our laboratory examined the intensity of a Krankcylce exercise session[13]. The Krankcycle workout also utilized HR-based training zones which were based upon PMHR. It was observed that some subjects could not attain HRs in the highest training zone (Zone 5), despite strong verbal encouragement. Subsequent maximal exercise testing found that these individuals had a significantly lower maximal HR than predicted. Thus, it may be prudent to use an RPE scale in conjunction with target HRs to help keep individuals from overexerting themselves if they do have a much lower MMHR than PMHR.

There are a number of limitations to this study. First, this study used subjects within a narrow age range (18-25 years). Since zone training is often used by individuals of all ages, future studies may want to explore the accuracy of using PMHR in individuals across the age spectrum. Second, since this study used subjects of similar age, we only used one prediction equation to estimate maximal HR. We contemplated using several equations, but because the age range of our subjects was so small, all of the equations would have provided similar PMHR values. Thus, a future study may want to compare the accuracy of multiple equations for determining PMHR and subsequent training zones. Finally, subjects in this study were relatively fit based upon published norms[1], which likely made it easier for their HR to adjust to the changing workloads. Older or less fit subjects may take longer to either adjust to or stabilize within a specific zone.

One area that does not come into consideration with zone training is the metabolic character of the prescribed zones. It has been suggested that exercise intensity should be individualized based upon a threshold-based concept (i.e., relative to percentages of ventilatory threshold and/or respiratory compensation threshold) instead of based on relative-percentages of maximal HR[14-15]. Future research may want to compare HR-based training zones versus threshold-based training zones as they relate to individualizing exercise intensity.

CONCLUSIONS

In summary, the purpose of this study was to investigate the accuracy of HR-based zone training using PMHR versus MMHR. It was found that the majority of time subjects were within the correct HR zone. However, we would recommend the use of an RPE scale in conjunction with exercise HR to guide individual exercise intensity. This is especially important if subjects are working extremely hard based upon their perceived effort, but just cannot seem to get their HR into the higher zones (e.g., Zone 5). This could be potentially dangerous, especially for individuals with undiagnosed cardiac disease.

Address for Correspondence
John Porcari, Ph.D., Department of Exercise and Sport Science, 141 Mitchell Hall, University of Wisconsin- La Crosse, La Crosse, WI, United States, 54601. Phone: 608-785-8684; Email: jporcari@uwlax.edu.

References

1. Riebe D. (2018). *ACSM's Guidelines for Exercise Testing and Prescription (*10th ed). Baltimore, MD: Lippincott Williams & Wilkins.
2. Edwards, S. (1993). *The heart rate monitor book.* Port Washington, NY: Polar CIC.
3. The 10 Biggest Fitness Trends of 2018. Retrieved from http://www.self.com/story/top-fitness-trends-for-2018
4. Orangetheory Fitness. Retrieved from http://orangetheoryfitness.com
5. Fox III SM, Naughton JP, Haskell WL. (1971). Physical activity and the prevention of coronary heart disease. *Ann Clin Lab Res, 3,* 404-432.
6. Robergs RA, Landwehr R. (2002). The surprising history of the "HRmax=220-age" equation. *J Ex Physiol online, 5*(2), 1-10.
7. Tanaka H, Monahan KD, Seals DR. (2001). Age-predicted maximal heart rate revisited. *J Am Coll Cardiol, 37*(1), 153-156.
8. Gellish RL, Goslin BR, Olson RE, McCdonald A, Russi GD, Moudgil VK. (2007). Longitudinal modeling of the relationship between age and maximal heart rate. *Med Sci Sports Exerc, 39*(5), 822-829.
9. Gulati M, Shaw LJ, Thisted RA, Black HR, Merz CN, Arnsdorf MF. (2010). Heart rate response to exercise stress testing in asymptomatic women. The St. James Take Heart Project. *Circulation, 122*(2), 130-137.
10. Albert CM, Mittleman MA, Chae CU, Lee IM, Hennekens CH, Manson JE. (2000). Triggering of sudden death from cardiac causes by sudden exertion. *N Engl J M, 343*(19), 1355-1361.
11. Borg GA. (1973). Perceived exertion: a note on "history" and methods. *Med Sci Sports Exerc, 5*(1), 90-93.
12. Howley ET, Bassett DR, Welch HG. (1995). Criteria for maximal oxygen uptake: review and commentary. *Med Sci Sports Exerc, 27*(9), 1292-1301.
13. Boyer, B., Porcari, J.P., & Foster, C. (2010). Krank it Up! *Fitness Matters*, *16*(2), 6-9.
14. Wolpern AE, Burgos DJ, Janot JM, Dalleck LC. (2015). Is a threshold-based model a superior method to the relative percent concept for establishing individual exercise intensity? A randomized controlled trial. *Sports Sci Med Rehabil, 7*(16), 1-9.
15. Mezzani A, Hamm LF, Jones AM, McBride PE, Moholdt T, Stone JA, Urhausen A, Williams, MA. (2012). Aerobic exercise intensity assessment and prescription in cardiac rehabilitation. *J Card Rehabil Prev, 32*, 327-350.