*Journal of Digital Media & Culture Technology* Vol.1, No.2, December (2021), pp.69-76
*ISSN 2983-0664(p) 2983-0850(e)* *http://dx.doi.org/10.29056/jdmct.2021.12.01*

# Evaluating Maximum Oxygen Intake and Exercise Intensity Using a Decision Tree Approach: Towards Personalized Exercise Prescription

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## Abstract

With escalating rates of obesity and related health issues due to sedentary lifestyles and poor dietary habits, precise prescription of exercise intensity has gained utmost importance. Traditional methods of determining exercise intensity rely on statistical formulas, which may not accurately reflect individual differences. The purpos of this study is to present an innovative approach utilizing the Decision Tree method and the Classification and Regression Tree (CART) algorithm to estimate exercise intensity, drawing on biometric data including maximum oxygen uptake, oxygen intake reserve, maximum heart rate, and heart rate reserve. The approach was tested on 20 men with relative exercise intensity determined using the Heart Rate Reserve (HRR). Results revealed that this approach could accurately estimate maximum oxygen uptake up to 70% HRR with an error rate less than 10%.

Keyword : Exercise intensity, Decision Tree, Heart Rate Reserve, Personalized Exercise Prescription

## 1. Introduction

With the shift in physical activities from active pursuits to a sedentary lifestyle, driven by advancements in transportation and urbanization, the amount of physical exertion has significantly diminished. Combined with the excessive intake of high-calorie foods, this lifestyle has led to a spike in overweight and obese populations. Obesity is now a key factor in the rise of heart diseases and various chronic illnesses such as hypertension, arteriosclerosis, angina pectoris, myocardial infarction, diabetes and stroke [1-3].

Physical fitness is the capacity to perform occupational, leisure and daily activities without undue fatigue and it is comprised of cardiopulmonary endurance, musculoskeletal strength, and flexibility. Cardiopulmonary endurance, in particular, is an important factor in prescribing exercise, and is assessed by measuring maximum oxygen uptake or oxygen consumption during aerobic exercises [4]. There are two methods for estimating oxygen intake during exercise: direct and indirect methods. The direct

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*Received(July 22, 2021), Review Result(1st: August 18, 2021), Accepted(December 3, 2021), Published(December 31, 2021)*

method involves analyzing the breathing gas through a mask worn during exercise, while the indirect method calculates estimates based on variables such as heart rate and exercise duration. The direct method is reliable but costly due to the need for specialized equipment and trained operators. It is also inconvenient to wear gas analysis instruments. On the other hand, the indirect method relies on statistical formulas generated for specific groups, which may lead to less reliability if the characteristics and environment of the group differ.

Measuring maximum oxygen intake is risky for the general public and individuals with low physical fitness due to the high exercise loads involved. Previous studies on measuring maximum oxygen intake at low intensity have focused on specific groups such as overweight adults, stroke patients, the elderly, and children [5-7]. Establishing appropriate exercise intensity for the general public is crucial for reducing risks [8]. Setting the exercise intensity accurately during physical examinations is important to ensure valid results. Excessive intensity may lead to premature termination of the test and the inability to observe significant responses. Conversely, if the exercise intensity is too low, the test may last longer and focus more on endurance rather than aerobic exercise.

The purpose of this study is to determine the appropriate exercise intensity by comparing the maximum oxygen intake measured using Decision Tree with the maximum oxygen intake calculated using a formula based on preliminary heart rate.

## 2. Relative Studies

The strength of aerobic exercise prescription can be categorized into absolute strength, which considers factors such as distance, weight, angle and relative strength, which considers the body’s reaction to external load. Traditionally, exercise intensity can be measured using parameters such as maximum oxygen uptake, oxygen intake reserve, preliminary heart rate percentage and maximum heart rate percentage.

### 2.1 Maximum oxygen uptake

Maximum oxygen uptake refers to the maximum amount of oxygen consumed per unit time, which represents the difference between the oxygen content in the arteries and veins. Oxygen uptake during exercise reflects the energy production capacity of the muscles. A higher maximum oxygen uptake indicates a greater ability to produce energy. It is commonly used as a measure of cardiopulmonary endurance, particularly for longer duration and higher intensity exercises.

### 2.2 Oxygen intake reserve

Oxygen intake reserve is the difference between oxygen intake at a steady state and oxygen intake measured during exercise. It represents the additional oxygen consumed during exercise compared to the individual's baseline. Since it takes into account the individual's oxygen intake at rest, it can serve as an indicator of relative exercise intensity.

### 2.3 Maximum heart rate (HRmax)

Maximum heart rate, measured during exercise at maximum load, reflects the functional limit of the heart. Generally, maximum heart rate decreases with age. In cases where it is not directly measured, a common method is to estimate maximum heart rate as 220 minus the individual's age.

### 2.4 Heart Rate Reserve (HRR)

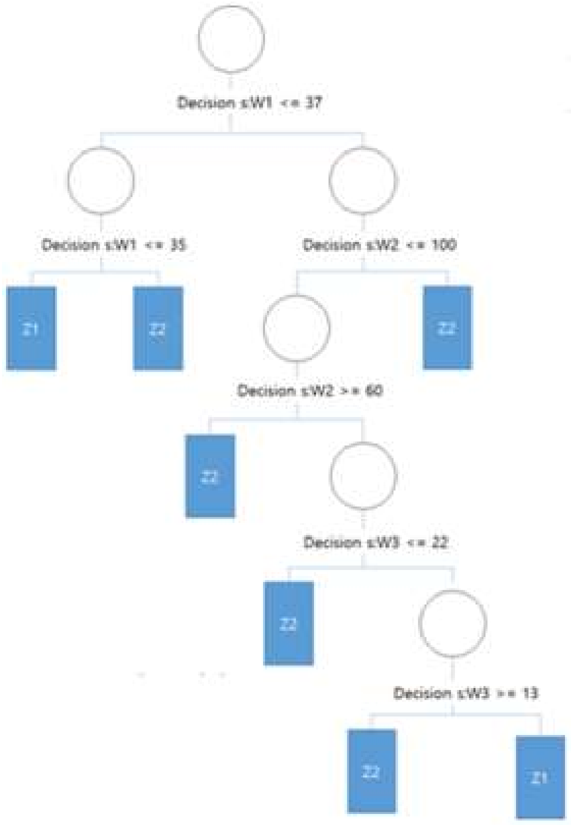
Heart Rate Reserve (HRR) is the difference between maximum heart rate and resting heart rate. It represents the range of heart rate variability for an individual, often used in the Karvonen method. HRR is considered a better reflection of exercise intensity than the absolute heart rate. The HRR method can be used to determine the target heart rate based on exercise intensity using a specific equation [9]. The MET (metabolic equivalent) is a unit that measures energy consumption. 1 MET corresponds to the energy consumption at rest, which is equivalent to an oxygen uptake of 3.5 mL/kg/min [10]. The Rate of Perceived Exertion (RPE) is a subjective numerical rating of perceived exertion. While it relies on subjective judgment, it has been suggested that maximum oxygen uptake can be estimated reasonably well in appropriate settings using RPE [11].

Since the absolute exercise load varies for each individual, it is necessary to express exercise intensity in relative terms. To align with individual perceptions, everyday adjectives are converted into numerical values to differentiate between intensity levels.

## 3. Exercise Prescription Strength Determination Method based on Decision Tree

This study used a Decision Tree approach in order to determine the appropriate exercise intensity by comparing the measured maximum oxygen uptake with the maximum oxygen uptake calculated using a formula based on preliminary heart rate. This method allows for utilizing a combined examination of biological information and employing a learning-based approach such as classification and regression tree (CART) analysis [12-15].

The CART algorithm is a non-parametric technique that generates a classification or regression tree depending on whether the dependent variable is categorical or numeric. It constructs a decision tree based on a splitting rule, aiming to select the optimal split that results in the purest child node among all possible partitions. The classification decision-making process using the CART algorithm can be summarized as follows. The training dataset for simulation is created based on the biometric information mentioned earlier, including variables such as maximum oxygen uptake (W1), oxygen intake reserve (W2), maximum heart rate (W3), and heart rate reserve (Z class). The CART algorithm continues the partitioning procedure until no further divisions are possible, as it lacks a termination rule. The outcome of applying the CART algorithm to the learning dataset as shown in [Table 1] can be represented as shown in [Fig. 1].




[Fig. 1] Final decision tree

[Table 1] Training data set

| Dm | W1 | W2 | W3 | Z |
|---|---|---|---|---|
| D1 | 32 | 55 | 13 | Z2 |
| D2 | 37 | 65 | 15 | Z1 |
| D3 | 38 | 70 | 20 | Z1 |
| D4 | 33 | 58 | 15 | Z2 |
| D5 | 32 | 59 | 16 | Z2 |
| D6 | 33 | 60 | 19 | Z2 |
| D7 | 36 | 85 | 22 | Z1 |
| D8 | 37 | 90 | 19 | Z1 |

Proposal in this paper involved calculating the error matrix (Confusion Matrix) for evaluating the diagnostic technique of dangerous situations by constructing 50 random sets for the test dataset. As shown in [Table 2], the results of the error matrix calculation showed high true positive (TP) and true negative (TN) values, indicating accurate predictions, while false positive (FP) and false negative (FN) values were low, indicating minimal errors.

[Table 2] Confusion matrix result

| Confusion matrix | Proposed method |
|---|---|
| True Positive | 42 |
| False positive | 2 |
| True Negative | 44 |
| False Negative | 1 |

In this study, relative exercise intensity was determined using the Heart Rate Reserve (HRR), and the maximum oxygen uptake was estimated for different exercise intensity ranges based on data from 20 men (average age 26.9 ± 2.2). HRR was calculated as the difference between an individual's maximum heart rate and resting heart rate. Maximum heart rate was determined using the 220-age method. Experimental results demonstrated that the estimated maximum heart rate closely matched the calculated values from the equation.

The estimation equation for HRR, reflecting exercise intensity, was derived by calculating HRR at 10% intervals from 0-60% to 0-90%, and the estimated maximum oxygen uptake was compared with the measured maximum oxygen uptake. It was observed that a significant estimation accuracy (error rate less than 10%) was achieved up to 70% HRR. In addition, increasing the proportion of highly correlated data within the HRR range of 0-20% helped improve the estimation of maximum oxygen uptake. The error rate decreased from 9.46 ± 8.34% to 6.01 ± 3.40%.

## 4. Discussion

The results of this study hold considerable significance in the academic field of fitness and health, particularly in relation to exercise prescription and personalization. Firstly, the adoption of a Decision Tree approach utilizing the CART algorithm demonstrates a significant advancement in determining the appropriate exercise intensity. Traditionally, exercise intensity prescription has relied largely on standard physiological measures and generalized guidelines. This research represents a significant step forward by showing that an artificial intelligence-based approach can be used effectively to personalize exercise intensity based on individual biological information [16]. Secondly, the application of CART to develop a decision tree for exercise intensity offers a nuanced understanding of the relationship between various biometric variables such as maximum oxygen uptake, oxygen intake reserve, maximum heart rate, and heart rate reserve. Thirdly, the use of an error matrix or confusion matrix to evaluate the accuracy of the Decision Tree approach adds another layer of depth to the study. Finally, the research provides evidence for improved estimation of maximum oxygen uptake, a key parameter in determining exercise intensity by increasing the proportion of highly correlated data within a particular Heart Rate Reserve (HRR) range. The method proposed could be critical in the design of exercise programs, especially for populations with low physical fitness or those at risk where precise estimation of maximum oxygen uptake at low exercise loads is necessary.

## 5. Conclusion

In this study, the relative exercise intensity was set by using the Heart Rate Reserve, and the maximum oxygen uptake was estimated for each exercise intensity section based on the data of 20 men. The research was designed in order to determine the appropriate exercise intensity by comparing the maximum oxygen intake value measured using Decision Tree and the maximum oxygen intake calculated by the formula for estimation of exercise intensity using preliminary heart rate. The results illustrates meaningful insights by suggesting a reliable estimation range even at relatively low exercise loads. However, the study is based on data from only 20 men with an average age of 26.9 ± 2.2. The limited sample size and lack of diversity (gender, age, varying levels of fitness and health status) may affect the generalizability of the findings. The model needs to be tested and validated with a larger and more diverse population sample to confirm its applicability to the wider population. Future research addressing these limitations and the successful application of machine learning techniques in exercise prescription could pave the way for further exploration of technology-enabled individualized exercise programs.

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