

Selection of Suitable Maximum-heart-rate Formulas for Use with Karvonen Formula to Calculate Exercise Intensity

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Abstract: The Karvonen formula, which is widely used to estimate exercise intensity, contains maximum heart rate, HR_{max} , as a variable. This study employed pedaling experiments to assess which of the proposed formulas for calculating HR_{max} was the most suitable for use with the Karvonen formula. First, two kinds of experiments involving an ergometer were performed: an all-in-one-day experiment that tested eight pedaling loads in one day, and a one-load-per-day experiment that tested one load per day for eight days. A comparison of the data on 7 subjects showed that the all-in-one-day type of experiment was better for assessing HR_{max} formulas, at least for the load levels tested in our experiments. A statistical analysis of the experimental data on 47 subjects showed two of the HR_{max} formulas to be suitable for use in the Karvonen formula to estimate exercise intensity for males in their 20s. In addition, the physical characteristics of a person having the greatest impact on exercise intensity were determined.

Keywords: Borg CR10 scale, Karvonen formula, exercise intensity, maximum heart rate, pedaling, statistical analysis.

1 Introduction

Two common measures of exercise intensity are oxygen intake and heart rate^[1, 2]. Oxygen intake is the amount of oxygen that the body takes in during respiration; and oxygen intake per kilogram of body weight per minute, $\dot{V}O_2$, can be used to calculate exercise intensity^[3]. On the other hand, heart rate, HR , is used in the Karvonen formula to calculate exercise intensity^[3]. While the measurement of oxygen intake needs expertise and a large apparatus, heart rate is easy to measure with a small instrument and even in a remote fashion^[4]. So, the Karvonen formula is widely used in the fields of rehabilitation and physical training.

One of the variables in the Karvonen formula is maximum heart rate, HR_{max} , which is the heart rate a person has when he pushes his body to the limit. Since directly measuring HR_{max} not only takes a great deal of time, but also imposes a heavy physical burden on the subject, a simple, convenient formula based on a person's age^[5] is extensively used nowadays^[6-8] to calculate it:

$$HR_{max} = 220 - \text{age} \quad (1)$$

where "age" is the age of the subject. However, Robert and Landwehr^[5] pointed out that (1) does not always yield the correct HR_{max} . Although several methods have been

proposed to improve the accuracy, none of them is widely recognized; and their range and conditions of use are not clear.

The aim of this study was to select the methods of calculating the HR_{max} of a person pedaling a cycle ergometer that are suitable for use with the Karvonen formula. We measured a person's heart rate while he was pedaling under various loads, and obtained his rating of perceived exertion (RPE) before and after each pedaling experiment from a questionnaire. Then, based on a comparison of the data from the experiments and questionnaires, we chose the most appropriate methods of calculating HR_{max} . To ensure accuracy and to determine how the work load immediately prior to exercise influences exercise intensity, we performed two kinds of pedaling experiments: an all-in-one-day (AIOD) experiment that tested all pedaling loads in one day, and a one-load-per-day (OLPD) experiment that tested one load per day for several days. Then, we examined the differences in exercise intensity between these two kinds of experiments, and assessed whether or not the OLPD experiment was needed. Finally, based on the experimental and questionnaire data, we made clear the degree of influence of some of a person's physical characteristics on exercise intensity.

In this study, the advisability of the experiments was first assessed by the ethics committee of the Tokyo University of Technology. Prospective subjects for the experiments were given an oral explanation and descriptive printed material on how the data and personal information acquired during the experiments would be handled, and their consent

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was obtained before their participation in the experiments was allowed. All the subjects were students, who were covered by personal accident insurance for students pursuing education and research, which was provided by Japan Educational Exchanges and Services. This paper is a considerable improvement over our previous one^[9]. We substantially refined and expanded the work by collecting experimental data and performing a thorough investigation of the selection of physical characteristics that are related to exercise intensity.

2 Exercise intensity and HR_{max}

Exercise intensity indicates the degree of difficulty of exercise. There are two kinds of exercise intensity: Physiological exercise intensity and RPE.

Even though RPE is a subjective measure, it is in good agreement with the physiological exercise intensity^[10]; and it is commonly used to obtain a subject's impression of the degree of difficulty. The Borg CR10 scale^[11] (Fig. 1) is used as a measure of RPE. It has the advantage that its relationship to exercise intensity is intuitively understandable. It has values in the range [0, 10], with larger values indicating greater intensity.

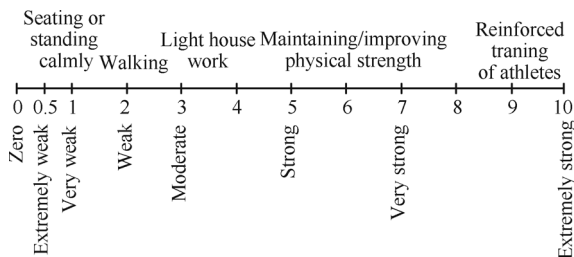


Fig. 1 Borg CR10 scale^[11]

The physiological exercise intensity is based on a physiological index related to oxygen intake or heart rate^[12].

Let the maximum oxygen intake be $\dot{V}O_{2max}$. Then, the relative oxygen intake is

$$\dot{V}O_2 \% = \frac{\dot{V}O_2}{\dot{V}O_{2max}} \times 100 \% \tag{2}$$

$\dot{V}O_2$ increases as exercise intensity increases, making it suitable for the evaluation of physiological exercise intensity. Since this method needs a large apparatus and takes a long time, it is mainly used in well-equipped laboratories and is difficult to use outdoors. Furthermore, the measurement of $\dot{V}O_{2max}$ pushes the body to the limit, which can entail some danger to the subject.

In contrast, it is much easier and cheaper to measure HR than $\dot{V}O_2$. This is why the heart-rate-based Karvonen formula is widely used in rehabilitation, physical training, and other fields. The relationship between $\dot{V}O_2$ and HR is

$$\dot{V}O_2 = HR \times AVDO_2 \times SV \tag{3}$$

¹ $BMI = \frac{W}{H^2}$ where W (kg) is body weight and H (m) is height.

where $AVDO_2$ is the arteriovenous oxygen difference; and SV is stroke volume, which is the volume of blood pumped out of one ventricle of the heart with each beat. It is known that $AVDO_2$ and SV converge to particular values regardless of the exercise load, and HR increases as exercise intensity increases. Since $\dot{V}O_2$ is proportional to HR , we can use HR instead of it to calculate exercise intensity^[13].

This study is focused on the Karvonen formula,

$$HRR \% = \frac{HR - HR_r}{HR_{max} - HR_r} \times 100 \% \tag{4}$$

where HR_r is the subject's heart rate at rest and $\%HRR$ is the heart rate reserve (HRR).

We first measure a subject's heart rate, HR . Then, we calculate the HRR for the RPE. HRR is in the range [0, 100], and it is proportional to a value on the Borg CR10 scale, B_{10} ^[11,14]:

$$HRR = 10 \times B_{10} \tag{5}$$

Remark 1. The calculation of $\%HRR$ in (4) uses only two parameters: maximum heart rate and the heart rate at rest; that is, it does not take into consideration a subject's height, weight, body mass index (BMI)¹, or other physical characteristics. Thus, the calculated value of $\%HRR$ may be less accurate for an older person than for a younger person^[15]. The final goal of our research is to improve the Karvonen formula by incorporating information on physical characteristics so as to adapt $\%HRR$ individually to each subject.

HR_{max} in the Karvonen formula is often calculated using (1). However, questions have arisen concerning the accuracy of the HR_{max} given by (1). Robert and Landwehr^[5] verified the original data used to obtain (1) and pointed out that it was possible that (1) might not give the correct HR_{max} . A large number of studies have attempted to improve (1). Inbar et al.^[16], for example, had 1424 healthy subjects perform treadmill exercises. They clarified that HR_{max} decreases by 0.685 bpm per year due to aging, and proposed the formula

$$HR_{max} = 205.8 - 0.685 \times \text{age} \tag{6}$$

Miller et al.^[17] showed the equation

$$HR_{max} = 217 - 0.85 \times \text{age} \tag{7}$$

based on exercise by 86 obese and 51 normal-weight adults. Tanaka et al.^[18] pointed out the problem that insufficient data on the elderly was used to derive maximum-heart-rate formulas. They examined 351 samples involving 492 groups and 18712 subjects, and came up with

$$HR_{max} = 208 - 0.7 \times \text{age} \tag{8}$$

Gulati et al.^[19] speculated that HR_{max} should be different for men and women. They carried out exercise tests on 5437 asymptomatic women and came up with

$$HR_{max} = 206 - 0.88 \times \text{age} \tag{9}$$

Londeree and Moeschberge^[20] pointed out that (4) does not account for a person's physical characteristics (weight, height, etc.) and thus may not yield the correct HR_{\max} . Taking age, sex, load level, and other factors into consideration, they suggested

$$HR_{\max} = 206.3 - 0.711 \times \text{age} \quad (10)$$

based on data collected from world-class athletes.

So, there are many methods of calculating HR_{\max} ; and we need to determine which of them are suitable for use in the Karvonen formula. Furthermore, since (4) does not contain any personal information except heart rate, the calculated exercise intensity may not be accurate for each person^[15].

3 Pedaling exercise and analysis

This study employed a pedaling exercise on a cycle ergometer to achieve two goals:

1) to compare (1) and (6)–(10), and find the ones most suitable for calculating exercise intensity for a pedaling exercise; and

2) to show the degree of relationship between exercise intensity and physical characteristics by dividing the relationships into two groups based on linear and nonlinear correlations.

This section explains the pedaling exercises used in this study and presents an analysis of the data obtained.

3.1 Experiments

We used a cycle ergometer (Programmable Ergometer AFB6008; Alinco, Inc.) for pedaling experiments and a photoelectric pulsometer (Pulse Coach Neo HR-40; Japan Precision Instruments, Inc.) to record a person's pulse rate during an experiment (Fig. 2). The ergometer calculates the work load and displays the result on a panel. Note that pulse rate is the same as heart rate for healthy people. All the experiments were carried out in our laboratory.



Fig. 2 Left: programmable ergometer, AFB6008; Right: photoelectric heart rate meter, Pulse Coach Neo HR-40

The ergometer can be set to any of 16 pedaling loads (1)–(16) by pushing up or down buttons. It is necessary to identify the relationship between pedaling load and actual work load so that readers can understand what a particular

pedaling load means. Thus, prior to the pedaling experiments, we performed preliminary experiments on pedaling load in which two subjects (age: 22 years old; sex: male; health: good) pedaled the ergometer for 5 minutes at a speed of about 60 rpm. The experimental results (Fig. 3) show that the work load increases 15 W for every unit increase in pedaling load.

In the main pedaling experiments, due to fatigue and scheduling considerations, subjects were only tested at eight of the sixteen load levels: 1, 3, 5, 7, 9, 11, 13, and 15.

Our daily experience tells us that fatigue influences exercise intensity. However, we could not find any reports related to this issue. So, we examined this issue through two kinds of experiments: AIOD and OLPD. An AIOD experiment tested all eight pedaling loads in one day, and an OLPD experiment tested one load per day for eight days. 47 subjects (university students; age: 20–29; sex: male; health: good) took part in the AIOD experiment, and 7 of them also took part in the OLPD experiment (Tables 1 and 2). Note that the average weight of most Japanese males is 66.75 kg for the age range 20–24 and 66.57 kg for the range 25–29^[21]. A *t*-test on the difference between the subjects' weights and the average value of the statistical data^[21] shows that, for a *p*-value of 0.05, there is no significant difference between them.

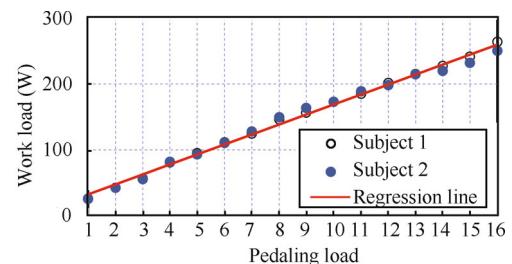


Fig. 3 Work load vs. pedaling load

Table 1 47 subjects for all-in-one-day (AIOD) experiment (SD: standard deviation)

	Min	Max	Average	SD
Age (year)	20	29	23.1	2.7
Height (cm)	158	185	172.3	6.2
Weight (kg)	41	92	66.3	12.4
HR_r (bpm)	62	100	78.3	10.4
Health	Good	Good	Good	—

Table 2 7 subjects for one-load-per-day (OLPD) experiment (SD: standard deviation)

	Min	Max	Average	SD
Age (year)	21	22	21.3	0.5
Height (cm)	158	178	168.0	8.2
Weight (kg)	49	76	61.6	11.2
HR_r (bpm)	66	98	82.6	11.4
Health	Good	Good	Good	—

The procedures for the two types of experiments are given below.

AIOD experiment:

Step 1. Before the experiment, give the subject a questionnaire (Fig. 9 in Appendix) to collect data on physical characteristics.

Step 2. Mount the pulsometer on the subject's hand and have the subject take a one-min rest.

Step 3. Set the sampling time for the measurement of pulse rate to 4s.

Step 4. Measure the pulse rate at rest for 1 minute and repeat the measurement 5 times.

Step 5. Set the load of the ergometer to Level 1.

Step 6. Have the subject pedal the ergometer at a speed of about 60rpm for 5 minutes, and record the pulse rate (Fig. 4).

Step 7. After the experiment, use a questionnaire (Fig. 10 in Appendix) to collect data on perceived exercise intensity (PEI). Give the subject a 5-min rest and then record the pulse rate.

Step 8. Increase the load level by 2 and go to Step 6. Repeat Steps 6–8 up to the maximum load or until the subject feels that he has reached the limit of his strength.

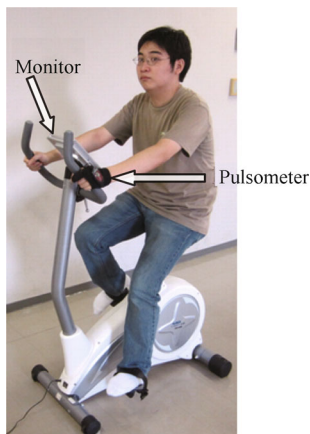


Fig. 4 Photograph of experiment in progress

The post-experiment questionnaire asks a subject to choose an appropriate level on the Borg CR10 scale. This is taken to be his RPE.

OLPD experiment:

Step 1. Give the subject a questionnaire before the experiment (Fig. 9 in Appendix).

Step 2. Set the load of the ergometer to Level 1 on the first day and increase the load level by 2 on each succeeding day (2nd day: Level 3; 3rd day: Level 5; etc.).

Step 3. Have the subject pedal the ergometer at a speed of 60 rpm for 5 minutes and record the pulse rate.

Step 4. Give the subject a questionnaire (Fig. 10 in Appendix) after the experiment to obtain the PEI. This is the end of the experiment for that day.

Step 5. Repeat Steps 1–4 for 8 days or until the subject feels that he has reached the limit of his strength.

We call the exercise intensity calculated from the Karvonen formula plus the experimental data the calculated exercise intensity (CEI), and we call the value obtained from

the questionnaire the PEI. We performed a least-squares analysis of the CEI and PEI and examined the relationship between exercise intensity and work load. Two parameters are used to describe the relationship between CEI (or PEI) and work load (Fig. 5): the slope, a_c (or a_p), and the ordinate intercept, b_c (or b_p).

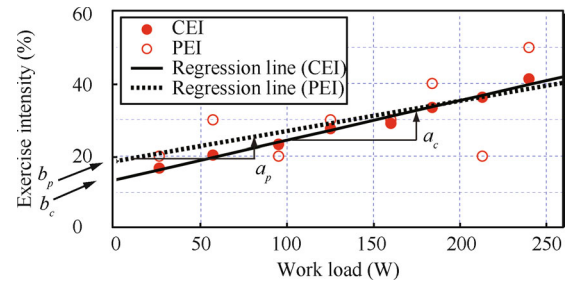


Fig. 5 Experimental results and regression lines of CEI and PEI

3.2 Analysis of experimental data

First, we compared the AIOD and OLPD results to determine the effect of immediately preceding work load on present exercise intensity. We identified the parameters a_c and b_c , and a_p and b_p for both AIOD and OLPD using the HR_{max} calculated from (1) to determine if the settings in the experiments were suitable or not.

Since the subjects involved in the experiments were healthy (they neither underwent treatment at a hospital nor took medication), and since the pedaling loads in the experiments were so light that they did not interfere with daily life, significant fatigue did not accumulate in the body. Thus, we only needed to consider the recovery time for very short-term fatigue.

The 4 parameters (a_c, b_c, a_p, b_p) were calculated for each subject for the AIOD and OLPD experiments. A t -test on the differences between the parameters for AIOD and OLPD showed that, for a p -value of 0.05, there was no significant difference in exercise intensity between the two types of experiments. And a comparison of the parameters for AIOD and OLPD (Table 3) revealed the differences to be very small. Thus, we can conclude that the effect of immediately preceding work load on present exercise intensity is very small for our pedaling experiments in the range of work loads we used, and that the OLPD experiment is unnecessary for this study.

Next, we used the AIOD experiment to select appropriate methods of calculating HR_{max} based on data collected from 47 subjects. Two criteria for the selection were examined: $(a_c - a_p)$ and $(b_c - b_p)$. A variance analysis of these two variables for (1) and (6)–(10) showed that they resulted in the selection of the same methods. So, we used only $(a_c - a_p)$ and carried out the selection as follows:

Procedure for selecting methods of calculating HR_{max} :

Step 1. Calculate HR_{max} using (1) for Subject 1, and obtain $a_c^{(1)}(1)$.

Step 2. Calculate the slope of PEI, $a_p(1)$, for Subject 1.

Step 3. Calculate $\Delta a^{(1)}(1) := [a_c^{(1)}(1) - a_p(1)]^2$.

Table 3 Mean and standard deviation of parameters of CEI and PEI for AIOD and OLPD

	a_c			b_c			a_p			b_p		
	AIOD	OLPD	Diff.	AIOD	OLPD	Diff.	AIOD	OLPD	Diff.	AIOD	OLPD	Diff.
Average	0.297	0.301	-0.004	1.320	0.253	1.067	0.249	0.253	-0.004	25.587	17.041	8.546
SD	0.077	0.094	0.068	5.066	0.079	5.129	0.098	0.079	0.118	10.457	7.499	12.201

Step 4. Do Steps 1–3 for all the subjects, and calculate $\Delta a^{(1)}(i) := [a_c^{(1)}(i) - a_p(i)]^2, i = 2, \dots, 47$.

Step 5. Calculate the mean value and the variance of $\Delta a^{(1)}(i), i = 1, \dots, 47$.

Step 6. Do Steps 1–5 using (6)–(10) one by one.

Step 7. Analyze the results obtained in Steps 1–6, and assess the suitability of using the formulas to calculate HR_{max} .

First, we examined the correlation between the Borg-CR10-based PEI and the CEI obtained from (1) and (6)–(10). Analysis of the data shows that all the coefficients for the correlation between PEI and CEI are larger than 0.995. This means that they are strongly correlated. Next, an *F*-test shows that, for a *p*-value of 0.05, there is no significant difference for any $\Delta a^{(j)}, (j = 1, 4, 5, \dots, 8)$, and that (1) and (7) give the smallest $\Delta a^{(j)}$ among the 6 methods. Thus, (1) and (7) are the most suitable methods of calculating exercise intensity for males in their 20s (Table 4).

We also examined the relationship between exercise intensity and the following physical characteristics:

- 1) Height (*H*) (m).
- 2) Weight (*W*) (kg).
- 3) Hours of sleep (*HS*) (h).
- 4) Heart rate at rest (HR_r) (bpm).
- 5) BMI (kg/m^2).

Table 4 Mean and standard deviation of $\Delta a^{(j)} (j = 1, 4, 5, \dots, 8)$ for various HR_{max} formulas (SD: standard deviation)

HR_{max} formulas	Average	SD
Equation (1): $HR_{max} = 220 - \text{age}$	0.011	0.017
Equation (6): $HR_{max} = 205.8 - 0.685 \times \text{age}$	0.014	0.022
Equation (7): $HR_{max} = 217 - 0.85 \times \text{age}$	0.011	0.017
Equation (8): $HR_{max} = 208 - 0.7 \times \text{age}$	0.013	0.020
Equation (9): $HR_{max} = 206 - 0.88 \times \text{age}$	0.016	0.025
Equation (10): $HR_{max} = 206.3 - 0.711 \times \text{age}$	0.014	0.022

Table 5 Correlation coefficients between exercise intensity and parameters of physical characteristics ($p < 0.05$)

	$b_c^{(1)}$	a_p	b_p	<i>H</i>	<i>W</i>	<i>HS</i>	HR_r	HR_m	ΔHR	BMI
$a_c^{(1)}$	-0.558	0.437	0.031	0.015	-0.426	0.052	0.455	0.725	0.435	-0.504
$b_c^{(1)}$	—	-0.319	0.170	-0.212	-0.024	-0.278	-0.384	-0.190	0.056	0.069
a_p	—	—	-0.583	-0.052	-0.346	0.212	0.237	0.117	-0.035	-0.375
b_p	—	—	—	0.064	0.049	-0.117	0.111	0.186	0.115	0.027
<i>H</i>	—	—	—	—	0.506	0.128	0.129	-0.036	-0.119	0.149
<i>W</i>	—	—	—	—	—	0.192	0.021	-0.216	-0.230	0.926
<i>SH</i>	—	—	—	—	—	—	0.044	0.043	0.015	0.159
HR_r	—	—	—	—	—	—	—	0.324	-0.316	-0.045
HR_m	—	—	—	—	—	—	—	—	0.795	-0.255
ΔHR	—	—	—	—	—	—	—	—	—	-0.227

The parameters for excise intensity were:

- 1) Slope (a_p) and ordinate intercept (b_p) of PEI.
- 2) Slope (a_c) and ordinate intercept (b_c) of CEI.
- 3) The highest heart rate recorded during an experiment (HR_m).
- 4) The difference between the highest heart rate and the heart rate at rest ($\Delta HR = HR_m - HR_r$).

We calculated the correlation coefficients for 55 combinations of items in the two groups (Table 5). The number of subjects is $n = 47$, and the number of degrees of freedom is $n - 2 = 45$. So, when there is no correlation, $t_{0.05} = 2.014$ for a *p*-value of 0.05. This gives the critical value for correlation:

$$r = \frac{t_{0.05}}{\sqrt{n - 2 + t_{0.05}^2}} = 0.288. \tag{11}$$

That is, there is a significant correlation between two items if the correlation coefficient is larger than r . Sorting the items in descending order of correlation coefficient yields

- 1) $a_c: HR_m, b_c, \text{BMI}, HR_r, a_p, \Delta HR$, and *W*.
- 2) $b_c: HR_r$ and a_p .
- 3) $a_p: b_p, \text{BMI}$, and *W*.
- 4) $b_p: \text{None}$.

Some relationships are illustrated in Figs. 6–8. Fig. 6 shows that a_c decreases as BMI increases. Thus, a larger BMI means less sensitivity to an increase in work load. Fig. 7 also shows the same tendency in the relationship between a_p and BMI. So, the larger a person's BMI is, the slower the increase in his heart rate is as the work load increases.

Fig. 8 shows that, when HR_m is large, a_c is large. Note that the correlation coefficient for these two items is larger than that for a_c and BMI, and the amount of scatter is small. So, the CEI is more sensitive to an increase in work load if a person can endure a larger HR_m during exercise.

Furthermore, we calculated the correlation ratios to examine the nonlinear relationships between the parameters^[22]. For each of the four parameters for excise

intensity (a_c, b_c, a_p, b_p), we calculated its correlation ratio with ten other parameters for a total of 34 pairs (Table 6). A correlation ratio in the range $[0.5, 0.7]$ indicates a non-linear relationship between two items. Sorting the items in descending order of correlation ratio yields:

- 1) a_c : HR_m, a_p, b_c, BMI , and W .
- 2) b_c : HR_r .
- 3) a_p : b_p, HR_m , and BMI .
- 4) b_p : None.

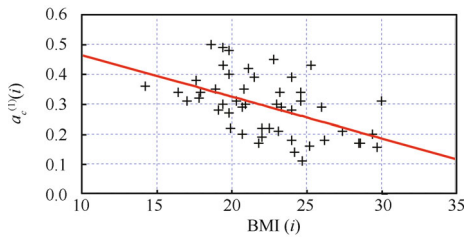


Fig. 6 Calculated slope vs. BMI (i : subject, $i \in \{1, \dots, 47\}$)

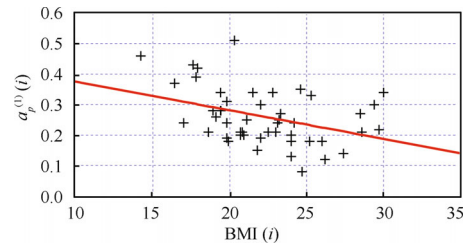


Fig. 7 Slope of RPE vs. BMI (i : subject, $i \in \{1, \dots, 47\}$)

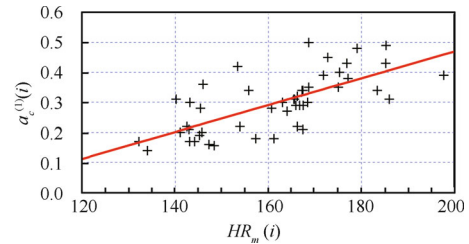


Fig. 8 Maximum heart rate at experimental vs. calculated slope (i : subject, $i \in \{1, \dots, 47\}$)

Before-experiment questionnaire

Date (YY/MM/DD): _____ Starting time: _____

Thank you very much for filling in the questionnaire. We promise that we will handle the personal information given in the questionnaire as follows:

- 1) It will not be used for any purpose other than for this research.
- 2) The information will not be given to any third party.
- 3) The questionnaires will be stored securely to prevent disclosure, falsification, loss, and other hazards.

1. Please provide the following information:

Name	Age	Sex	Height (cm)	Weight (kg)	Blood pressure (High/Low)

2. What is your physical condition? very good / good / bad

3. If the answer to the above question is bad, please give some details.

⋮

9. How many hours a day do you usually sleep? _____

⋮

17. Please provide information on your exercise routine in the table below. The last column is PEI, which means "perceived exercise intensity." For this item, write a number from 0 to 10 based on the chart below.

Please refer to the following rating scale and choose the perceived exercise intensity:

Rating scale: 0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Zero	Very weak (Resting)	Very weak (Walking)	Moderate (Housework)	Somewhat strong (Housework)	Strong (Light perspiration)	Strong (Moderate perspiration, Sustainable)	Very strong (Heavy perspiration, Doubt about ability to continue)	Very strong (Difficulty continuing, Thirst)	Very very strong (Impossible to continue, Difficulty breathing)	Extreme (Severe pain)
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Kind of exercise	Duration/Repetitions	Frequency	Months	PEI
e.g. Running	0.5 - 1 h	Every other day	3 months	4
e.g. Abdominal stretches	50 times	Every day	1 month	7

Thank you very much for your cooperation.

Fig. 9 Questionnaire before experiment

Table 6 Correlation ratio between exercise intensity and the parameters of physical characteristics

	$b_c^{(1)}$	a_p	b_p	H	W	HS	HR_r	HR_m	ΔHR	BMI
$a_c^{(1)}$	0.601	0.673	0.416	0.320	0.546	0.216	0.436	0.693	0.421	0.583
$b_c^{(1)}$	—	0.379	0.177	0.278	0.377	0.315	0.608	0.280	0.167	0.363
a_p	—	—	0.691	0.314	0.574	0.362	0.289	0.579	0.456	0.576
b_p	—	—	—	0.160	0.274	0.283	0.211	0.274	0.162	0.289

After-experiment questionnaire

Name: _____ Age: _____ Sex: Male/Female

1. What was your perceived exercise intensity? Mark a number based on the following chart.

Rating scale: 0-----1-----2-----3-----4-----5-----6-----7-----8-----9-----10

Zero
 Very weak (Resting)
 Very weak (Walking)
 Moderate (Housework)
 Somewhat strong (Housework)
 Strong (Light perspiration)
 Strong (Moderate perspiration, Sustainable)
 Very strong (Heavy perspiration, (Impassable, difficult to continue))
 Very strong (Difficulty continuing, Thirst)
 Very very strong (Impassable, difficult breathing)
 Extreme (Severe pain)

Perceived exercise intensity: 2 · 3 · 4 · 5 · 6 · 7 · 8 · 9 · 10

For the use of person in charge only

Date (MM/DD): _____ Time: _____

Room temperature: _____ Humidity: _____

Fig. 10 Questionnaire after experiment

4 Conclusions

This study aimed to select the most suitable methods of calculating HR_{max} for use in the Karvonen formula, which provides an estimate of exercise intensity, and to examine the physical characteristics related to exercise intensity. We designed two kinds of pedaling experiments (AIOD, OLPD) and carried them out with male university students in their 20 s. Based on the results of experiments and questionnaires for 47 subjects, we chose the difference between the slopes of CEI and PEI as the critical variable, and selected formulas for calculating HR_{max} . We also analyzed the relationship between physical characteristics and the parameters for exercise intensity. The following points were clarified:

1) For a p -value of 0.05, there is no significant difference between the results of the AIOD and OLPD experiments. Thus, the OLPD experiment is unnecessary for the work loads used in these experiments; the AIOD experiment alone is sufficient.

2) Among the 6 methods of calculating HR_{max} that were tested, (1) and (7) were found to be the most suitable for male university students in their 20 s.

3) The physical characteristics that are linearly and non-linearly related to exercise intensity were clarified through an analysis of correlation coefficients and correlation ratios. These results will help in choosing the factors suitable for adapting the CEI to individuals.

This paper reports results on the selection of suitable methods of calculating HR_{max} for use with the Karvonen formula as applied to pedaling exercises for people in their 20 s. It is necessary to determine whether or not these methods are also suitable for other age groups. This will be examined and reported in the near future.

The final goal of our research is to modify the Karvonen formula by incorporating physical characteristics into it so as to adapt it to individuals. This is an interesting and challenging subject for future study.

Appendix

The main items in the before- and after-experiment questionnaires are shown in the following figures.

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