Experimental Selection and Verification of Maximum-Heart-Rate Formulas for Use with Karvonen Formula *

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Keywords: Borg CR10 Scale, Correlation Analysis, Karvonen Formula, Exercise Intensity, Maximum Heart Rate (MHR), Measure Of Exercise Intensity, Pedaling, Statistical Analysis.

Abstract: Maximum heart rate (MHR) is commonly used to estimate exercise intensity with the Karvonen formula, and there are several methods of calculating it. In this study, we used pedaling experiments on a cycle ergometer to evaluate methods of determining MHR in order to select the ones most suitable for the Karvonen formula. In the experiments, 43 subjects rode an aerobike. The results show that, for people in their 20s, two methods are suitable for estimating exercise intensity with the Karvonen formula. The main physical parameters affecting exercise intensity were also extracted, based on the experimental results.

1 INTRODUCTION

The Karvonen formula is a common measure of exercise intensity. It is given by (Karvonen et al., 1957; Hill et al., 2005)

$$\%HRR = \frac{HR - HR_r}{HR_{\max} - HR_r} \times 100\%, \quad (1)$$

where HR is the measured heart rate; $HR_{\max}$ is the maximum heart rate; HR_r is the heart rate at rest; and $\%HRR$ is the heart rate reserve, which is used to determine exercise intensity.

Heart rate is easy to measure with a small instrument. This is why the Karvonen formula is widely used in the fields of rehabilitation and physical training. One of the variables in the Karvonen formula, (1), is $HR_{\max}$, 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, as a convenience, one way of calculating it is based on the age of the subject (Robert and Landwehr, 2002):

$$HR_{\max} = 220 - \text{age}. \quad (2)$$

This is extensively used nowadays (Young-McCaughan and Arzola, 2007; Shenoy et al., 2010; Perez-Terzic, 2012).

However, (Robert and Landwehr, 2002) pointed out that (2) does not always yield the correct $HR_{\max}$ of a subject. 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 collected data on subjects' heart rate while they were pedaling under various loads, and data on subjects' rating of perceived exertion (RPE) from questionnaires given before and after each pedaling experiment. Then, based on a comparison of the data from the experiments and question-

*This work was supported by Health Science Center Foundation, Japan, JSPS KAKENHI under Grant-in-Aid for Scientific Research (B) 25280125, and the National Natural Science Foundation of China under Grant 61210011.

She J., Nakamura H., Makino K., Ohyama Y., Hashimoto H. and Wu M..
Experimental Selection and Verification of Maximum-Heart-Rate Formulas for Use with Karvonen Formula.
DOI: 10.5220/0004426905360541
In *Proceedings of the 10th International Conference on Informatics in Control, Automation and Robotics* (ICINCO-2013), pages 536-541
ISBN: 978-989-8565-71-6

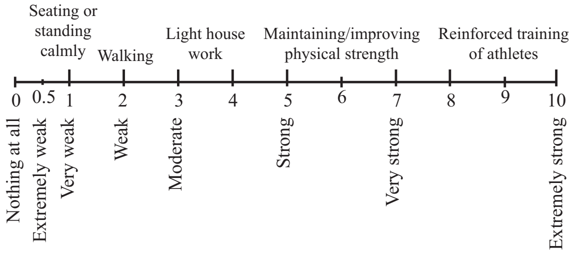

Figure 1: Borg CR10 scale.

naires, we chose the most appropriate methods of calculating $HR_{\max}$. To ensure accuracy, 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. Finally, based on the experimental and questionnaire data, we extracted the physical parameters that have the greatest impact on exercise intensity.

2 EXERCISE INTENSITY AND $HR_{\max}$

Exercise intensity indicates the degree of difficulty of exercise. The RPE is commonly used to obtain a subject's impression of the difficulty, and the Borg CR10 scale (Borg, 1998) (Fig. 1) is used as a measure of RPE. The value is in the range $[0,\ 10]$, with larger values indicating greater intensity.

This study focused on the Karvonen formula, (1), in which $\%HRR$ is in the range $[0,\ 100]$ and it is proportional to a value on the Borg CR10 scale, B_{10}:

$$HRR = 10 \times B_{10}. \tag{3}$$

$HR_{\max}$ in the Karvonen formula is often calculated using (2). However, questions have arisen concerning the accuracy of the $HR_{\max}$ given by (2). Robert and Landwehr verified the original data used to obtain (2) and pointed out that it was possible that (2) might not give the correct $HR_{\max}$ (Robert and Landwehr, 2002). A large number of studies have attempted to improve (2). Inbar et al., for example, had 1424 healthy perform treadmill exercises. They clarified that $HR_{\max}$ of a person decreases by 0.685 bpm per year due to aging, and proposed the following method of calculating $HR_{\max}$ (Inbar et al., 1994):

$$HR_{\max} = 205.8 - 0.685 \times \text{age}. \tag{4}$$

Miller et al. showed the equation

$$HR_{\max} = 217 - 0.85 \times \text{age} \tag{5}$$

based on exercise by 86 obese and 51 normal-weight adults (Miller et al., 1993). Tanaka et al. examined 351 samples involving 492 groups and 18712 subjects and came up with (Tanaka et al., 2001)

$$HR_{\max} = 208 - 0.7 \times \text{age}. \tag{6}$$

Gulati et al. speculated that $HR_{\max}$ should be different for men and women. They carried out exercise tests on 5437 asymptomatic women and came up with (Gulati et al., 2010)

$$HR_{\max} = 206 - 0.88 \times \text{age}. \tag{7}$$

Londeree and Moeschberge pointed out that (1) 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 in calculating $HR_{\max}$, they obtained

$$HR_{\max} = 206.3 - 0.711 \times \text{age} \tag{8}$$

based on data collected from world-class athletes (Londeree and Moeschberger, 1982).

Although there are many methods of calculating $HR_{\max}$, we need to determine which among them are suitable for calculating exercise intensity for use in the Karvonen formula. This study employed a pedaling exercise on a cycle ergometer to achieve two goals:

1) to compare (2) and (4) $\sim$ (8), and find the ones most suitable for calculating exercise intensity; and

2) to select the physical parameters that are strongly related to exercise intensity.

3 PEDALING EXERCISE AND ANALYSIS

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

3.1 Experiments

In this study, 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 the pulse during the experiments (Fig. 2). Note that a pulse rate is the same as the heart rate for healthy people. All the experiments were carried out in our laboratory.

Figure 2: Left: Programmable ergometer, AFB6008. Right: Photoelectric pulsometer, Pulse Coach Neo HR-40.

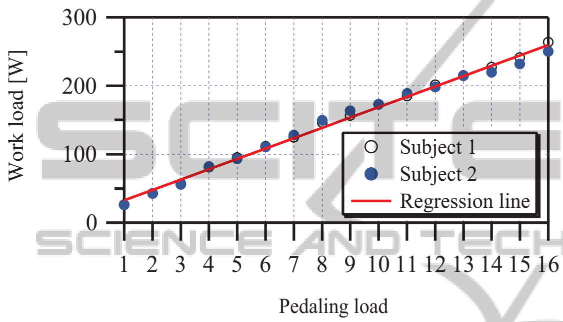

Figure 3: Work load vs. pedaling load.

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. 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. 43 subjects (university students; age: 20s; sex: male; health: good) took part in the AIOD experiment, and 7 of them also took part in the OLPD experiment. In Tables 1 and 2, SD means standard deviation.

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

Table 1: 43 Subjects for AIOD experiment.

	Max	Min	Avg.	SD
Age [yrs.]	20.0	29.0	23.5	2.7
Height [cm]	158.0	185.0	172.1	6.0
Weight [kg]	43.0	92.0	66.4	12.1
HR_r [bpm]	63.8	99.8	79.5	10.4
Health	Good	Good	Good	Good

Table 2: 7 Subjects for OLPD experiment.

	Max	Min	Avg.	SD
Age [yrs.]	21.0	22.0	21.3	0.5
Height [cm]	158.0	178.0	169.3	8.2
Weight [kg]	49.0	76.0	61.6	11.2
HR_r [bpm]	66.0	97.6	82.3	11.4
Health	Good	Good	Good	Good

AIOD Experiment:

Step 1) Set the sampling time for the measurement of pulse to 4 s.

Step 2) Before the experiment, give the subject a questionnaire to collect data on physical characteristics.

Step 3) Measure the pulse at rest for 1 minute and repeat the measurements 5 times.

Step 4) Set the load of the ergometer to Level 1.

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

Step 6) After the experiment ,use a questionnaire to collect data on perceived exercise intensity (PEI). Give the subject a 5-min rest and then record the pulse.

Step 7) Increase the load level by 2 and go to Step 5. Repeat Steps 5-7 up to the maximum load or until

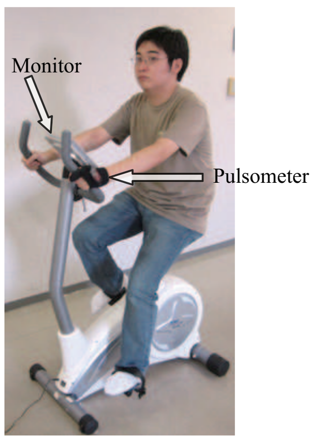

Figure 4: Photograph of experiment in progress.

Table 3: Mean and standard deviation of parameters for exercise intensity for AIOD and OLPD experiments.

	a_c			b_c			a_s			b_s		
	AIOD	OLPD	Diff.	AIOD	OLPD	Diff.	AIOD	OLPD	Diff.	AIOD	OLPD	Diff.
Avg.	0.2971	0.3014	−0.0043	1.3200	0.2529	1.0671	0.2486	0.2529	−0.0043	25.5871	17.0414	8.5457
SD	0.0767	0.0941	0.0675	5.0656	0.0791	5.1292	0.0982	0.0791	0.1180	10.4570	7.4991	12.2008

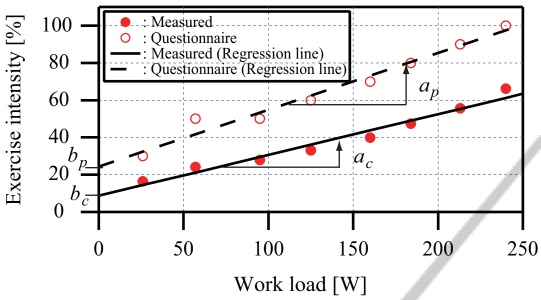

Figure 5: Slope of exercise intensity and intercept.

the subject feels that he has reached the limits of his strength.

The post-experiment questionnaire asks a subject to choose an appropriate level on the Borg CR10 scale. This is taken to be his RPE. In addition, the heart rate for the highest load is assumed to be the highest heart rate in the experiment and is denoted HR_m.

OLPD experiment:

Step 1) Give the subject a questionnaire before the experiment.

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.

Step 4) Give the subject a questionnaire after the experiment to obtain the perceived exercise intensity. 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 limits 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).

Table 4: Mean and standard deviation of $(a_c - a_p)$ for $HR_{\max}$ methods.

$HR_{\max}$ formulas	Avg.	SD
Eq.(2): $HR_{\max} = 220 - \text{age}$	0.0126	0.0176
Eq.(4): $HR_{\max} = 205.8 - 0.685 \times \text{age}$	0.0152	0.0228
Eq.(5): $HR_{\max} = 217 - 0.85 \times \text{age}$	0.0124	0.0176
Eq.(6): $HR_{\max} = 208 - 0.7 \times \text{age}$	0.0148	0.0212
Eq.(7): $HR_{\max} = 206 - 0.88 \times \text{age}$	0.0174	0.0256
Eq.(8): $HR_{\max} = 206.3 - 0.711 \times \text{age}$	0.0152	0.0228

3.2 Analysis of Experimental Data

First, we compared the AIOD and OLPD results to determine the effect of fatigue on 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 (2). These 4 parameters were calculated for each subject for the AIOD and the OLPD experiments. A t-test on the differences between the parameters for AIOD and OLPD showed that, at a significance of 5%, 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)) reveals the differences to be very small. Thus, we can conclude that the effect of fatigue on 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 $HR_{\max}$. Two criteria for the selection were examined: $(a_c - a_s)$ and $(b_c - b_s)$. A variance analysis of these two variables showed that they resulted in the selection of the same methods. So, we used only $(a_c - a_s)$ and carried out the selection as follows:

Procedure for Selecting Methods of calculating $HR_{\max}$:

Step 1) Calculate $HR_{\max}$ using (2) for Subject 1.

Step 2) Calculate a_c using the $HR_{\max}$ obtained in Step 1, and calculate a_p for Subject 1.

Step 3) Calculate $(a_c - a_p)$ and $(a_c - a_p)^2$.

Step 4) Do Steps 1-3 for all the subjects, and calculate the mean value of $(a_c - a_p)^2$.

Step 5) Do Steps 1-4 using (4) $\sim$ (7) one by one.

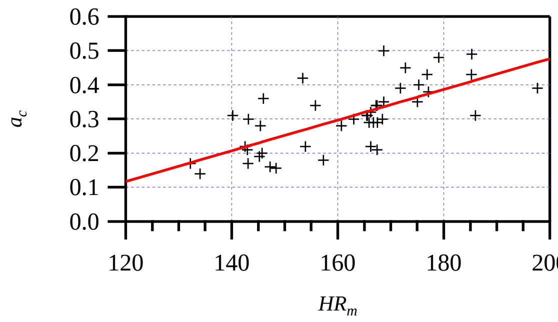

Figure 6: CEI slope vs. maximum measured heart rate.

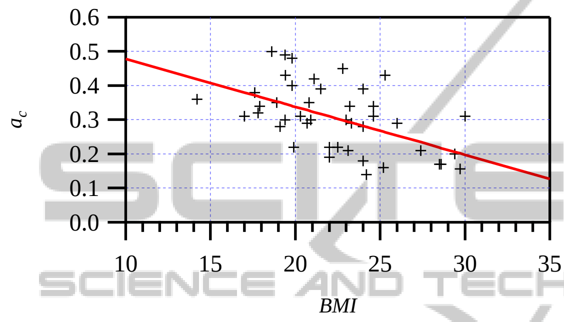

Figure 7: CEI slope vs. BMI.

Step 6) Analyze the variance of the mean values of $(a_c - a_p)^2$, and assess the suitableness of using the formulas to calculate $HR_{\max}$.

Analysis of the data shows that, at a significance level of 5%, there is no significant difference for any $(a_c - a_p)^2$, and that (2) and (5) give the smallest $(a_c - a_p)^2$ among these 6 methods. Thus, (2) and (5) are the most suitable methods of calculating exercise intensity for males in their 20s (Table 4).

In this study, we also examined the relationships between exercise intensity and the following physical parameters of the subjects: height (H [m]), weight (W [kg]), hours of sleep (HS [h]), heart rate at rest [bpm], and BMI[2] (body mass index).

The parameters for excise intensity are a_p and b_p for PEI, a_c and b_c for CEI, HR_m, $(HR_m - HRR)$, $(a_c - a_p)^2$, and $(b_c - b_p)^2$.

We calculated the correlation coefficients for each pair of the 13 parameters, and selected the coupled items to a_c, b_c, a_p, and b_p as follows (Table 5).

- a_c: HR_m (0.698), b_c (-0.544), BMI (-0.526), $(b_c - b_p)^2$ (-0.514), W (-0.408), and HR_r (0.382).
- b_c: $(b_c - b_p)^2$ (0.691) and HR_r (-0.350).
- a_p: b_p (-0.601) and BMI (-0.353).

[2] $BMI = \frac{W}{H^2}$.

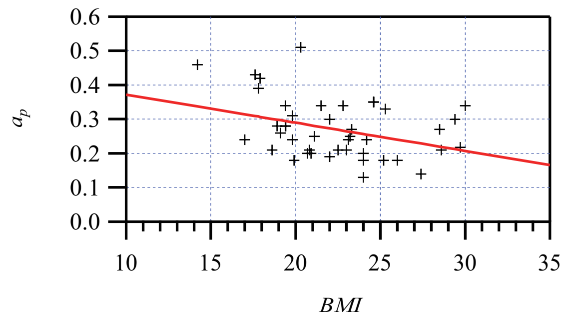

Figure 8: PEI slope vs. BMI.

- b_p: $(b_c - b_p)^2$ (-0.624).

Some relationships are illustrated in Figs. 6-8. Figure 6 shows that, when HR_m is large, a_c is large. So, the CEI is more sensitive to an increase in work load if a person can endure a larger HR_m during exercise. Figure 7 shows that a_c decreases as BMI increases. This means that, if the BMI of a person is large, he will not be very sensitive to an increase in the work load. Figure 8 also shows the same tendency in the relationship between a_p and BMI.

Since BMI gives an influence on both of a_c and a_p, incorporating this parameter in the Karvonen Formula has potential for the adaptation of it to an individual.

4 CONCLUSIONS

In this study, we selected the most suitable methods of calculating $HR_{\max}$ for use in the Karvonen formula, which yields an estimate of exercise intensity. We employed two kinds of pedaling experiments: AIOD and OLPD. Based on the results of experiments and questionnaires on fifteen subjects in their 20s, we selected the most suitable methods of calculating $HR_{\max}$ and extracted physical parameters that are strongly related to exercise intensity. The following points were clarified:

1. At a significance level of 5%, 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, (2) and (5) were found to be the most suitable for male university students in their 20s.
3. Incorporating BMI in the Karvonen formula may adapt it to an individual.

How to modify the Karvonen formula by incorporating BMI into it so as to adapt it to an individual is

Table 5: Correlation coefficients for exercise intensity vs. physical parameters ("**": $\rho < 0.01$ and "*": $\rho < 0.05$).

	b_c	a_s	b_s	H	W	HS	HR_r	HR_m	$HR_m - HRR$	$(a_c - a_s)^2$	$(b_c - b_s)^2$	BMI
a_c	−0.544	0.322	0.117	0.146	−0.408**	0.097	0.382*	0.698**	0.410**	0.573**	−0.514**	−0.526**
b_c	—	−0.285	0.134	−0.259	−0.045	−0.315*	−0.350*	−0.174	0.060	−0.180	0.691**	0.067
a_s	—	—	−0.601**	0.123	−0.272	0.273	0.145	−0.077	−0.165	−0.100	0.214	−0.353*
b_s	—	—	—	−0.031	−0.088	−0.116	0.135	0.249	0.148	0.293	−0.624**	−0.089
H	—	—	—	—	0.432**	0.112	0.202	0.136	−0.001	−0.014	−0.182	0.054
W	—	—	—	—	—	0.215	0.045	−0.132	−0.153	−0.178	0.029	0.922**
HS	—	—	—	—	—	—	0.091	0.094	0.029	−0.167	−0.164	0.183
HR_r	—	—	—	—	—	—	—	0.243	−0.413	0.169	−0.374	−0.053
HR_m	—	—	—	—	—	—	—	—	0.784**	0.351*	−0.319*	−0.224
$HR_m - HRR$	—	—	—	—	—	—	—	—	—	0.222	−0.060	−0.177
$(a_c - a_s)^2$	—	—	—	—	—	—	—	—	—	—	−0.356*	−0.197
$(b_c - b_s)^2$	—	—	—	—	—	—	—	—	—	—	—	0.118

a very important issue, and it will be examined in the near future.

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