The relationship between rating of perceived exertion and physiological exertion at different swimming speeds

NOMURA Takeo and SHONO Tomoki*

The purpose of this study was to clarify the relationship between the rating of perceived exertion (RPE) and heart rate (HR), oxygen uptake ($\dot{V}O2$) and blood lactate concentration (BLa) at different swimming speeds. Fifteen well trained Japanese male college swimmers were used as subjects. The exercise was front crawl swimming using a Swimming flume. There were significant correlations between RPE and HR ($r=0.868$, $p<0.01$), %HRmax ($r=0.891$, $p<0.01$), %$\dot{V}O2max$ ($r=0.898$, $p<0.01$). The relationship between RPE and BLa showed a logarithmic relationship ($r=0.825$, $p<0.01$). Consequently, RPE seems to be an effective indicator of training intensity in swim training. Between 3 and 5 mmol/1 of BLa, there was a turning point, so that the result may be limited to an intensity up to 6 mmol/1. The RPE might give good information for coaches from the usual view point of HR or time.

Key words : RPE, Heart rate, Oxygen uptake, Blood lactate concentration, Swim training perscription

有酸素的な全身持久泳において，主観的運動強度の指標としての RPE scale と生理的運動強度の対応性を明らかにするために，回流水槽にて３種類の最大下泳と最大泳を男子競泳選手15名（年齢18〜23歳，平均20.1歳，400M 自由形最高記録：４分11秒〜45秒）を被験者として行なった。また，水泳運動の特性である，上肢・下肢・呼吸等の部分的な RPE との関係を検討することにより，RPE が水泳トレーニングにおいて有効な指標となり得るかどうかを考察した。その結果，RPE と心拍数との間に $r=0.868$ ($p<0.01$)，%HRmax との間に $r=0.891$ ($p<0.01$)，%$\dot{V}O2max$ との間に，$r=0.898$ ($p<0.01$)，血中乳酸値との間に $r=0.825$ ($p<0.01$) の如く，主観的運動強度（RPE）と生理的運動強度との間に高い相関が得られ，RPE は水泳トレーニング強度の客観的指標となり得ると推察された。さらに，血中乳酸濃度が３〜５mmol/1にて RPE の変換点がみられた。従って，６mmol/1を越えない強度において，RPE scale は有効な指標となりえると考えられた。RPE は心拍数やタイムとともにコーチにとって有用な情報を与えてくれ，その有用性を認めた。

1 Introduction

To evaluate the athlete's physical strain, perceived exertion has been introduced as a good indicator[1,2]. It has been reported that there are high correlations between rating of perceived exertion (RPE) and physiological parameters such as heart rates[2,3], $\dot{V}O2$[3]. However, there have been very few research studies conducted with well trained swimmers concerning relationship between RPE and physiological parameters[3].

The purpose of this study was (1) to verify the relationship between RPE and physiological parameters ($\dot{V}O2$, HR, BLa), (2) whether RPE is a good indicator of physical strain, (3) furthermore, to establish swim training prescriptions using RPE during different types of swim training.

2 Methods

Fifteen Japanese male swimmers (best 400m freestyle time ranged 4-min. 11sec-4-min. 45sec) were chosen as subjects. A summary of the

*別府女子短期大学
Beppu women's junior college

Table. 1 Physical characteristics and physiological responses of subjects.

Subject	Age (years)	Height (cm)	Weight (kg)	Best Time	V̇O2max (l/min.)	V̇O2max/weight (ml/kg/min.)	HRmax (bpm)
N.H.	22	162.0	56.0	4'21"	3.83 (3.61)*	68.4	192
S.T.	19	179.0	67.0	4'12"	4.21 (4.59)	62.8	183
Y.S.	19	180.0	72.4	4'12"	4.30 (3.89)	59.4	201
M.Y.	19	182.4	75.6	4'15"	4.70 (4.84)	62.1	187
S.K.	20	172.0	69.0	4'13"	4.51 (4.41)	65.4	190
K.W.	20	172.0	67.0	4'15"	4.04 (3.82)	60.3	190
T.M.	20	174.5	58.0	4'21"	4.08 (3.88)	70.3	179
Y.O.	21	171.0	61.5	4'19"	3.91 (3.98)	63.6	190
Y.I.	23	177.0	67.0	4'12"	4.34 (4.71)	64.8	177
K.N.	18	170.0	62.3	4'34"	3.74 (3.89)	60.0	192
S.S.	20	175.0	75.0	4'45"	4.19 (4.33)	55.8	192
N.K.	21	177.0	78.0	4'11"	4.26 (4.62)	54.6	184
Y.O.	22	187.0	74.5	4'33"	4.49 (4.51)	60.3	187
Y.K.	18	180.0	77.0	4'27"	4.71 (4.83)	61.1	203
N.N.	20	171.0	66.0	4'38"	3.93 (3.68)	59.5	198
Mean	20.1	175.3	68.4	4'23"6	4.22 (4.24)	61.9	189.7
S.D.	1.5	6.1	6.9	11.5	0.30 (0.43)	4.2	7.4

* Data in parentheses is first trial of maximal oxygen uptake during swimming.

Table. 2 Japanese scale for rating of perceived exertion and Borg's original scale.[1)]

20		
19	Very, very hard	(非常にきつい)
18		
17	Very hard	(かなりきつい)
16		
15	Hard	(きつい)
14		
13	Somewhat hard	(ややきつい)
12		
11	Fairly light	(楽である)
10		
9	Very light	(かなり楽である)
8		
7	Very, very light	(非常に楽である)
6		

physical characteristics is given in Table. 1.

Maximal oxygen uptake (V̇O2max) test was performed using swim flume. The subjects were required to swim front crawl. Water temperature was kept between 25. 3 to 26. 7℃. Following 4-min. warm-up (at 60% of the individual's best 400m record), the subjects swam, starting from 50% of his best 400m time. Every 1-min., swim speed was increased 10% up to 80% of his 400m maximal speed. After that, the increment of the swim speed was raised by 5 % up to volitional effort. The perceived exertion test was performed 4-6 days after the V̇O2max-test. All subjects were required to do three submaximal swims (65%, 75% and 85% of best 400m time). Each swim consisting of 6-min. was performed randomly with more than 10-min. rest between each swim. After that, a maximal swim test was performed using a progressive method to the same protocol (see Fig. 1) as the V̇O2max test.

RPE scale by Borg translated in Japanese (see Table. 2) was used immediately after the swim tests. Then the subjects were asked to reply partial-RPE (arm, leg and respiration) and

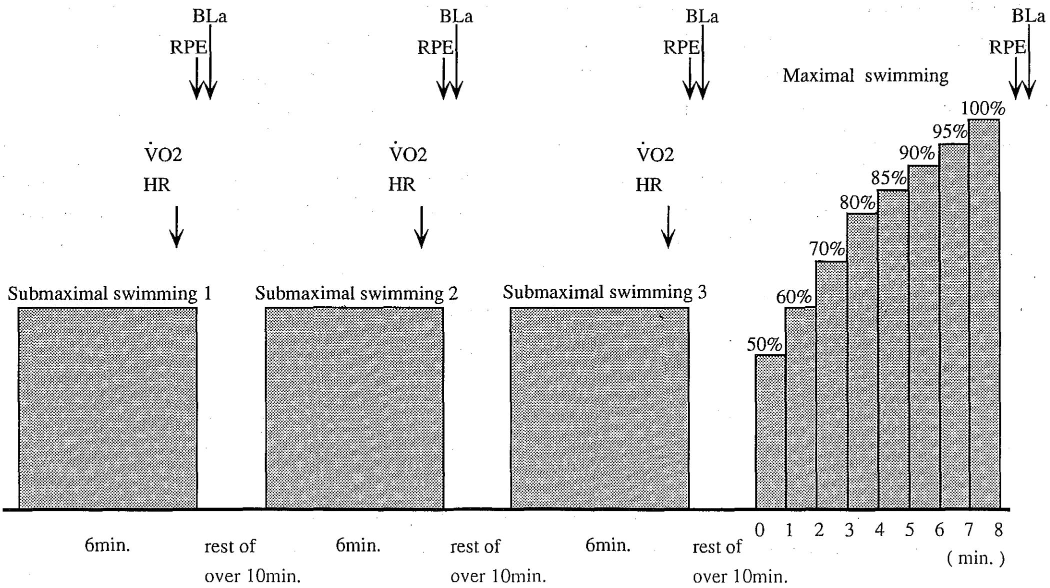

Fig. 1 Protocol for determination of RPE and physiological measurements at present study.

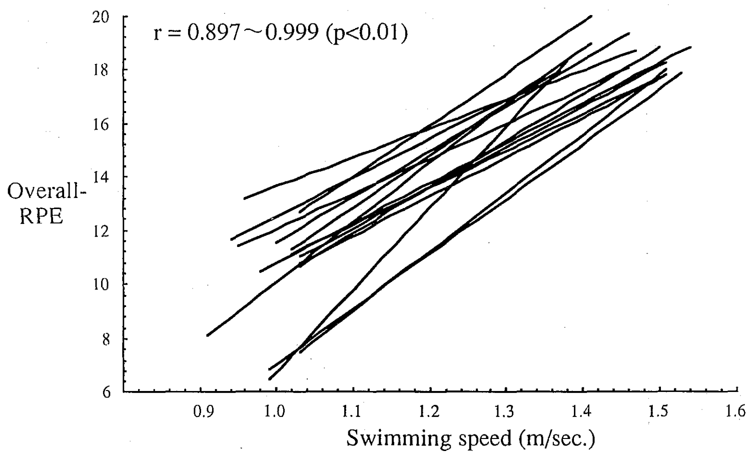

Fig. 2 Regression lines between swimming speed and overall-RPE in each subjects.

overall-RPE. HR was measured every 10sec by a water proof ECG telemetry system (Senoh ; heart checker 108 system). V̇O2 was measured via an auto metabolic measurement system (Minato ; Aero-monitor AE-280). During submaximal swim, V̇O2 was measured every 30sec until steady state level was obtained. At the maximal swim test, V̇O2 was recorded every 15sec until the subjects volitional effort.

3 Results and Discussion

3. 1 Relationship between swim speed and overall-RPE

The relationship between swim speed and overall-RPE in each individual showed high correlation (r＝0. 897-0. 999). However, inter-individual had variability because of individual differences in swim ability and stroke mechanics (see Fig. 2).

Miyashita et al.[5] reported that there is a linear relationship between swim speed and RPE, but it is unlike a land exercise such as walking because of the great individual difference of stroke efficiency in swim technique. Present results seem to support previous research.

3. 2 Relationship between overall-RPE and partial-RPE (arm, respiration and leg)

The relationship between overall-RPE and partial-RPE (arm, respiration and leg) is given in Fig. 3. Respiration-RPE showed the highest correlation with overall-RPE ($r=0.967$, $p<0.01$). The respiration-RPE also had higher correlation with physiological parameters such as HR ($r=0.868$, $p<0.01$), $\%\dot{V}O2max$ ($r=0.898$, $p<0.01$) than arm-RPE and leg-RPE.

Relatively lower rating scales were observed in leg-RPE compared with overall-RPE. Propulsion of crawl stroke is mostly produced by arm stroke. It is also commonly seen that at a given speed the energy cost of the leg kick was much greater than that of arm stroke. Therefore, overuse of leg kick seemed less contributive to propulsion because of metabolic disadvantage during submaximal speed. Well-trained swimmers learned this mechanism from their practical experience. This was observed through VTR that the subjects minimize energy costs without changing the kick or decrease the number of leg kick. However, when swim speed exceeded the level of aerobic metabolism such as 100m, 200m race, the leg kick was needed to assist the high body position and propulsion so that the rate of leg-RPE might increase significantly.

During submaximal intensity (RPEscale of 6 to 17), arm-RPE showed relatively high rating. However, at the nearly maximal level the rating showed almost the same as a respiration-RPE. Arm-RPE showed higher rating than leg-RPE from low intensity up to the maximal level. The present submaximal swimming test lasted 6-min. so that the swimmers naturally tended to save the energy cost of the leg kick. Ekblom et al.[3] reported that at the same level of $\dot{V}O2$ during bicycle ergometer exercise, arm-RPE was higher than

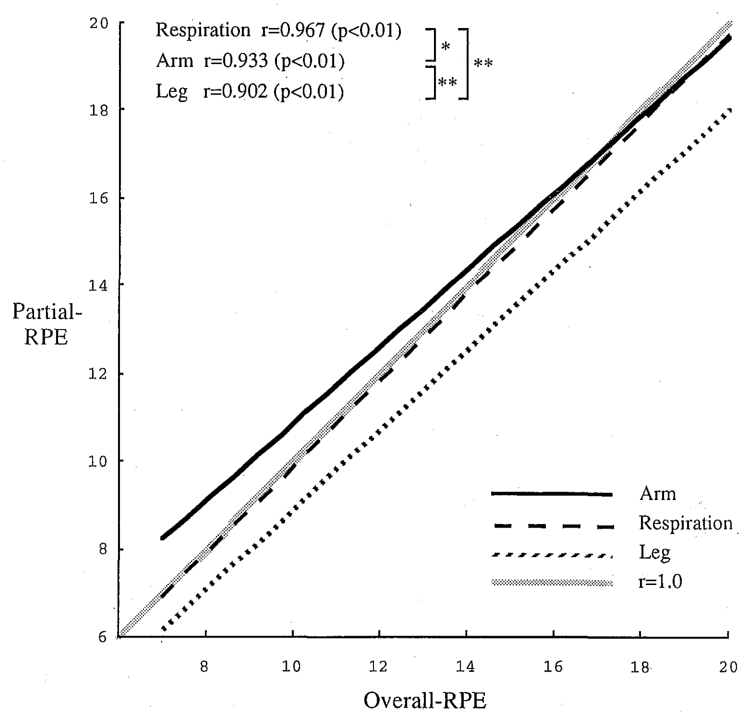

Fig. 3 Regression lines between overall-RPE and partial-RPE (arm, respiration, leg) during swimming. (*$P<0.01$, **$P<0.001$)

the leg-RPE. Pivarnik et al.[8] also reported that HR and RPE were significantly greater in arm exercise than leg exercise. This present study also revealed that crawl arm greatly contributed to propulsion and that per stroke during the submaximal swim speed subjects controlled the number of kicks or minimized metabolic energy cost of the leg kick.

3. 3 Relationship between overall-RPE and heart rate

Regression equation of $Y=0.132X-7.287$ ($r=0.868$, $p<0.01$) was obtained between HR and overall-RPE (see Fig. 4A). From the regression line, HR at RPE13, RPE15, RPE17 were 154bpm, 169bpm, 184bpm, respectively. Borg[1] reported that RPE scale would be 1/10 of HR during land exercise. However, present results showed lower HR than 1/10. It has been reported that lower HRs were obtained in swim exercise than land exercise at the same $\dot{V}O2$ because of higher stroke volume observed in the water exercise[6]. Present results obtained during swimming exercise were similar to that reported by Miyashita et al.[5].

In the relationship between relative HR (%HRmax) and RPE, the regression equation of $Y=0.265X-8.637$ ($r=0.891$, $p<0.01$) was obtained (see Fig. 4B). But there was no significant difference in correlation coefficient between actual HR ($r=0.868$) and %HRmax ($r=0.891$). Onodera ed al. reported that there was higher cor-

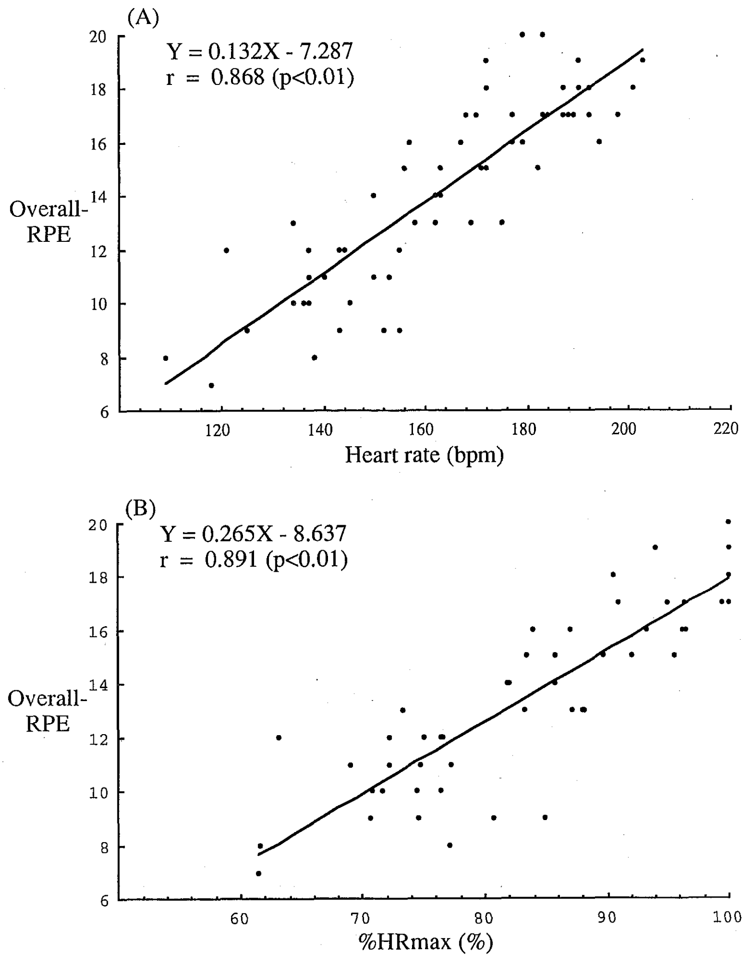

Fig. 4 Relationship between heart rate (A), %HRmax (B) and oveall-RPE during submaximal and macimal swimming.

relation between % HRmax and overall-RPE than actual HR and RPE during swim training.[7] Because present subjects were all well-trained college male swimmers, same age, weight etc. they are almost a homogeneous group.

3. 4 Relationship between overall-RPE an oxygen uptake

There was significant correlation between V̇O2 (ml/kg/min) and overall-RPE ($Y = 0.265X + 1.361$, $r = 0.899$, $p < 0.01$). Similar correlation was observed with %V̇O2max ($Y = 0.176X + 0.417$, $r = 0.898$, $p < 0.01$) (see Fig. 5A, 5B). It has been reported that metabolical parameter (HR and V̇O2) respond directly to physical strain[6]. The present study revealed that relative V̇O2 (%V̇O2max) has reponded more directly to physical strain than RPE[6].

3. 5 Relationship between overall-RPE and blood lactate concentration

The relationship between BLa and overall-RPE showed a logarithmic relationship. The regression curve of $Y = 4.219 \log X + 9.269$ and the correlation coefficient of $r = 0.825$ ($p < 0.01$) were obtained (see Fig. 6). From Fig. 6, there was a turning point around 3-5mmol/1 of BLa and 14-16 of RPE. The relationship between BLa and overall-RPE in each individual was given in Fig. 6A. Eleven out of 15 of the subjects were in the range of 14-16 of RPE. Therefore, 14-16 of RPE seemed to be an effective indicator of OBLA.

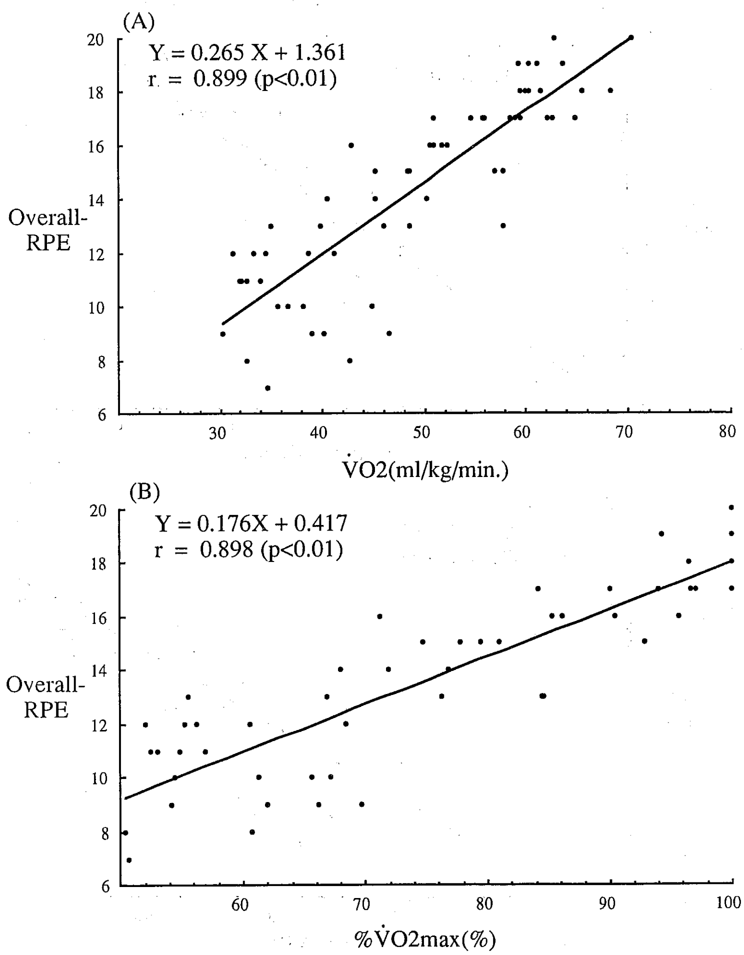

Fig. 5 Relationship between V̇O2(A), %V̇O2max(B) and oveall-RPE during submaximal and maximal swimming.

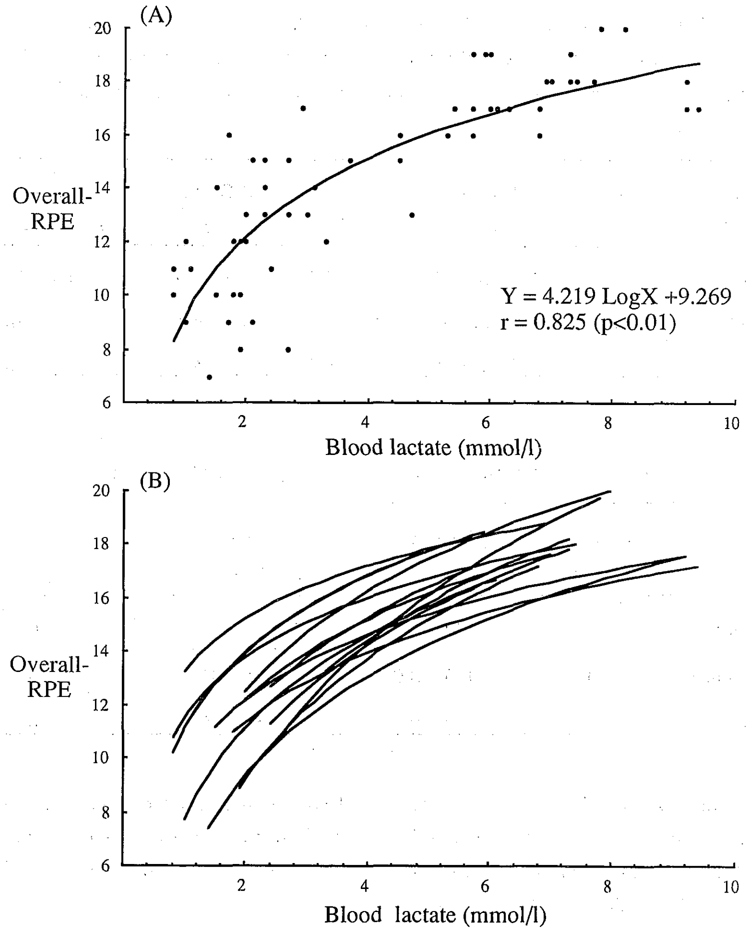

Fig. 6 Regression curve between blood lactate concentration and oveall-RPE(A) and each individual regressions(B).

Maglischo[4] classified training to encourage an improvement in aerobic endurance in swimming into three types (maintenance, developmental, overload). He set the upper limit of aerobic endurance at 5-6mmol/1 of BLa. When BLa is over 6mmol/1, RPE scale seems to plateau even though BLa increased. Therefore, it might not be useful to evaluate of BLa individual strain which is over the 6mmol/1.

3.6 Application of RPE to swim training

From results of the present study, it is known that there is a high correlation between RPE and physiological indication (HR, $\dot{V}O2$, BLa) during swimming. Therefore, RPE seems to be an effective indicator of training intensity in swimming, and RPE might give additional information about the swimmers from different points of view such as swimmers conditioning and stroke technique.

According to classification by Maglischo[4], maintenance aerobic training corresponds to speeds that will produce BLa of 2mM/1. It was reported that these speeds are the minimum training speed that will encourage an improvement in aerobic endurance. Developmental aerobic training corresponds to a speed that will be the BLa of 3 to 4mM/1. Since these speeds were as fast as swimmers can swim without the rapid accumulation of BLa, these gave a proper overload to the aerobic metabolic processes. Occasionally, swim training just above OBLA, i.e. BLa of 5 to 6mM/1 is necessary.

Table. 3 The values (Mean±S.D.) of RPE, heart rate, %HRmax, speed (%of 400m best record), %V̇O2max in each subject at the blood laclate concentration of 2, 4, 6mmol/1 (The values were calculated from relationship between the blood lactate concentration and each parameter in each subject.).

BLa (mmol/l)	RPE	Heart rate (bpm)	%HRmax (%)	%V̇O2max (%)	Speed (% of 400m best record)
2mmol/l	11.7±2.0	146.2±14.1	77.3±7.5	64.6±9.6	71.1±6.0
4mmol/l	15.1±1.3	169.9±11.3	89.5±4.2	83.9±4.5	81.4±4.0
6mmol/l	17.1±1.1	182.2±11.5	96.1±3.7	94.3±4.3	89.4±6.6

Table. 4 Guidelines for training to encourage an improvement in aerobic endurance.

	Blood lactate (mmol/l)	Heart rate (bpm)	Speed (% of 400m best record)	RPE
Maintenance	2	130~160	65~75	10~13
Developemental	4	160~180	75~85	14~16
Overload	6	170~190	85~95	16~18

This type of training is so called overload aerobic training, which is suited to develop the maximal oxygen comsumption. Table. 3 shows the values calculated from the relationship of BLa and RPE, HR, % HRmax, % V̇O2max, swimming speed in each subject at BLa of 2, 4, 6mM/1.

Using the classification by Maglischo[4], guidelines for training to encourage an improvement in aerobic endurance were made (see Table. 4). It has been found that BLa and HR obtained as physiological data, swimming speed (time in actual training) as performance data and RPE as perceived data were highly correlated with each other. If we could evaluated these parameters correctly, then swimmers can establish proper training intensity which is suited to the purpose of each training session. Moreover, all RPE data of the training sessions are recorded in a training log, it might be useful for conditioning of the swimmers. If the data is inspected carefully, for example, The time has not changed but HR and RPE has increased, or HR and RPE increased, and time became slower, then this information could be important in discovering abnormalities of conditioning or stroke deficiency.

References

1) Borg GAV (1973) : Perceived exertion : a note on 'history' and methods. Med Sci Sports 5 : 90-93.
2) Borg GAV (1982) : Psychophysical bases of perceived exertion. Med Sci Sports 14 : 377-381.
3) Ekblom B and Goldbarg AN (1971) : The influence of physical training and other factor on the subjective rating of perceived exertion. Acta Physiol Scand 83 : 399-406.
4) Maglischo EW (1988) : The application of energy metabolism to swimming training. Swimming Science V, Human Kinetics Books : 209-218
5) Miyashita M and Onodera K (1978) : Rating of perceived exertion in swimming. Rep Res cent Phys ed 6 : 96-99

6) Nomura T (1977) : Cardio-pulmonary characteristics during land and swimming exercise. J Authrop soc Nippon 85 : 209-218
7) Onodera K and Miyashita M (1976) : A study on Japanese scale for rating of perceived exertion in endurance exercise. Jap J Phys Educ 21 : 191-203
8) Pivarnik J M, Grafner T R and Elkins ES (1988) : Metabolic, thermo-regulatory, and psychophysiological responses during arm and leg exercise. Med Sci Sports Exerc 20 : 1-5