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# Contribution of differentiated ratings of perceived exertion to overall exertion in women while swimming

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**Summary.** The purpose of this study was to identify, using multiple regression analysis, the contribution of differentiated ratings of perceived exertion to overall exertion ($RPE_O$) in women while swimming. Ten female subjects swam at submaximal and maximal intensities and the variables measured included oxygen uptake ($\dot{V}O_2$), heart rate ($f_c$), ventilation ($\dot{V}_E$), breathing frequency, tidal volume, blood lactate concentration ($[la^-]_b$), $RPE_O$, and four differentiated RPE. These four differentiated RPE were cardiac frequency rating ($RPE_C$), respiratory frequency rating ($RPE_R$), arm rating ($RPE_{arm}$), and leg rating ($RPE_{leg}$). These variables used the following equation based on $\dot{V}O_2$ – $R = a + c \cdot (S - b)^n$, where $R$ was the response to increasing exercise intensity ($S$) and a, b, and c were constants. The exponents (n) of $f_c$, $\dot{V}_E$ and $[la^-]_b$ were approximately 1.0, 2.0 and 3.3, respectively. The estimated exponents of $RPE_O$, $RPE_C$, $RPE_R$, $RPE_{arm}$ and $RPE_{leg}$ were approximately 2.4, 2.3, 2.2, 2.5 and 2.5, respectively. There was a highly significant relationship between the four differentiated RPE and their associated physiological responses. The results of this study showed that these interrelationships were clearly delineated. As the percentage maximal oxygen uptake (% $\dot{V}O_{2max}$) increased, the major contributing factor to $RPE_O$ changed. The $RPE_C$ was found to be the main contributing factor from 20% to 45% $\dot{V}O_{2max}$, but ceased to contribute beyond 50% $\dot{V}O_{2max}$. Above 45% $\dot{V}O_{2max}$, $RPE_{arm}$ was the major influence, and $RPE_R$ was the secondary influence from 66% to 96% $\dot{V}O_{2max}$. The $RPE_{leg}$ was the secondary contributing factor only from 27% to 35% $\dot{V}O_{2max}$. It was concluded that differentiated RPE contribution was dependent upon the intensity of exercise in women while swimming.

**Key words:** Differentiated ratings of perceived exertion – Overall exertion – Multiple regression analyses – Standardized $\beta$ coefficient – Tethered swimming

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## Introduction

The ratings of perceived exertion (RPE) as proposed by Borg (1962) have been an important indicator of physiological strain in healthy people as well as in pathological cases. The method most commonly used to determine the perception of exertion has been the 15-point RPE scale (Borg 1970), which complements well other measures of exercise intensity, and has proven its validity and reliability for various types of physical exercise in different circumstances.

Research in the field of RPE has been directed towards the identification of the sensory cues which provide direct input for the perception of exertion. Borg (1962) and Ekblom and Goldbarg (1971) have distinguished a local effect (a feeling of strain in the working muscle and/or joints) from a central effect (a feeling or sensation of strain primarily involving the cardiopulmonary system). When overall exertion ($RPE_O$) is rated the subjects have been shown to integrate the central and local effects with whatever weighting they consider appropriate.

Other studies (Pandolf et al. 1972; Noble et al. 1973; Kamon et al. 1974; Mihevic 1981; Kostka and Cafarelli 1982; Pandolf 1982; Carton and Rhodes 1985; Robertson et al. 1986) have suggested that central and local physiological variables provide the input for differentiated RPE and $RPE_O$, but the magnitude of their respective contributions have not been reported. Interrelationships between differentiated RPE and their associated physiological responses during physical exercise have been clearly defined. Subjective symptoms such as breathing difficulty ($RPE_R$), frequency of the heart ($RPE_C$) and exertion of strain in the arms ($RPE_{arm}$) or legs ($RPE_{leg}$), come from physiological responses during dynamic exercise. These should be accurately reflected in differentiated RPE.

Subjects in RPE experiments have been instructed to evaluate their total exertion or strain which has incorporated all differentiated strains. However, it is not known to what degree differentiated RPE have been related to their associated physiological responses, nor how these

**Table 1.** Subject's age, height, body mass, and maximal oxygen uptake ($\dot{V}O_{2max}$) in tethered swimming and best performances

| Subject | Age (years) | Height (cm) | Body mass (kg) | $\dot{V}O_{2max}$ ($l \cdot min^{-1}$) | Best records (min:s) | |
|---|---|---|---|---|---|---|
| | | | | | front crawl (100 m) | breaststroke (100 m) |
| 1 | 20.2 | 158.0 | 55.0 | 2.422 | 1:24.07 | 1:39.52 |
| 2 | 21.8 | 157.2 | 52.0 | 1.913 | 1:10.00 | 1:30.00 |
| 3 | 19.9 | 157.0 | 53.5 | 2.224 | 1:02.74 | 1:38.20 |
| 4 | 20.7 | 164.5 | 62.0 | 2.803 | 2:11.00 | 2:32.00 |
| 5 | 20.6 | 165.1 | 52.5 | 1.900 | 1:59.00 | 2:14.00 |
| 6 | 20.7 | 158.7 | 53.5 | 2.286 | 2:06.00 | 2:22.00 |
| 7 | 20.3 | 149.8 | 43.5 | 1.911 | 1:16.08 | 1:53.02 |
| 8 | 19.9 | 163.0 | 52.5 | 1.683 | 2:01.00 | 2:01.00 |
| 9 | 19.8 | 154.7 | 44.2 | 1.803 | 2:01.00 | 2:00.00 |
| 10 | 19.9 | 152.0 | 47.0 | 2.168 | 2:01.00 | 2:24.00 |
| Mean | 20.4 | 158.0 | 51.6 | 2.111 | 1:43.19 | 2:01.37 |
| SD | 0.6 | 4.8 | 5.2 | 0.32 | 25.17 | 20.26 |

have contributed to the evaluation of $RPE_O$. Hence, the purpose of the present study was to assess the magnitude of the contribution of differentiated RPE to the evaluation of $RPE_O$ in women while swimming, using multiple regression analyses.

## Method

*Subjects.* Ten female students studying physical education at the University of Hiroshima, Japan were the subjects. Subjects 2 and 3 were trained swimmers in the university team while the rest were students of other sports. University swimming education requires that all physical education students be able to swim in constant position under different resistances in a tethered flume of the same type as used in this study. However, it was observed that the lowest resistance (1.0 kg) was too small to make it possible for the subjects to swim properly since there was a tendency for the subject's legs to sink to the bottom of the flume. The subject's age, height, body mass, maximal oxygen uptake ($\dot{V}O_{2max}$) in tethered swimming and performance level are shown in Table 1.

*Procedure.* The water temperature in the flume was set at 30° C. The resting measurements were taken following a 30-min period sitting in a chair, and a 10-min period in which the subjects were immersed in the water to the level of the first thoracic vertebra. Thereafter, they began to swim the breaststroke against a resistance which started at 1.0 kg and was increased by 1.0 kg increments for stronger swimmers and 0.5 kg increments for weaker swimmers until they were no longer able to overcome the resistance unassisted for 2 min (3.5–6.0 kg). During the tests the subjects swam for 5 min and then rested for 10–20 min until their heart rate ($f_c$) returned to resting levels.

The subjects breathed through a gas collection apparatus consisting of a type of snorkel which was fitted on their heads with a metal headband. Expired gas to determine oxygen uptake ($\dot{V}O_2$) was collected into a Douglas bag during the last 5 min of the 10-min rest, the last minute of each 5-min test, and the last minute of the final 2-min test. At the same time, an electrocardiogram (ECG) and a respiration curve from a thermostat (Nihonkohden Co., Tokyo, Japan) were recorded. The $f_c$ from the QRS complex from the ECG tracing and breathing frequency ($f_b$) were counted during the last 30 s of each gas collection period. Mixed expired $O_2$ and $CO_2$ concentrations were determined using a mass spectrophotometer (Perkin-Elmer MGA-1100, Calif., USA) calibrated with gases previously analysed by the Micro-Scholander technique. Expired gas volume was measured using a calibrated dry-gas meter (Shinagawa Co. DS-15A-T, Tokyo, Japan) and ventilation ($\dot{V}_E$) calculated.

Within 1 to 2 min after finishing the test, finger-prick blood samples were taken for determination of blood lactate concentration $[la^-]_b$ (YSI model 23L, USA). While taking the blood samples, the subjects were also asked to rate the $RPE_C$, $RPE_R$, $RPE_{arm}$, and $RPE_{leg}$. The $RPE_O$, integrating the four differentiated RPE, was estimated using the Japanese version of the Borg's RPE scale (Borg 1970) found in Onodera and Miyashita (1977).

*Statistics.* Multiple regression analyses were made at each of 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 100% $\dot{V}O_{2max}$. Because the standardized $\beta$ coefficient in absolute terms could reasonably be regarded as having been a measure of the relative importance of independent variables (Snedecor and Cochran 1989), the standardized $\beta$ coefficients of the four differentiated RPE were chosen to describe how each contributed to $RPE_O$ and were interpreted as the relative contribution to $RPE_O$ in this study.

The following steps were taken to calculate the standardized $\beta$ coefficients of the four differentiated RPE, and to describe the individual physiological variables [$f_c$, $\dot{V}_E$, $f_b$, tidal volume ($V_T$) and $[la^-]_b$ and perceptual variables ($RPE_O$, $RPE_C$, $RPE_R$, $RPE_{arm}$ and $RPE_{leg}$) at a given % $\dot{V}O_{2max}$.

Firstly, the raw data were plotted as a function of $\dot{V}O_2$. The components of the individual power function were computed according to the equation described in Borg (1961, 1962) as $R = a + c \cdot (S - b)^n$. Borg used this power function to describe the relationship of the response ($R$) with the increasing exercise intensity ($S$) where c was a constant measurement and n was the exponent of the power function. The components a and b described the starting point of the curve, where a was the basic perception noise constant or physiological rest value and b was the starting point of the function on the $x$-axis.

Secondly, individual physiological and perceptual variables at 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 100% $\dot{V}O_{2max}$ were calculated from their individual power functions.

Arithmetic means at every 10% $\dot{V}O_{2max}$ were used to calculate the power function for the group and for drawing the figures. Linear regression analyses using the least square method in log-log coordinates were performed using the same arithmetic means.

## Results

### *Physiological responses while swimming*

Figure 1a–c show the relationships between $f_c$, $\dot{V}_E$ and $[la^-]_b$, and % $\dot{V}O_{2max}$ while swimming. The $f_c$ correlated with % $\dot{V}O_{2max}$ (Fig. 1a) in a linear fashion with an exponent of 1.0 ($r=0.999$). The $\dot{V}_E$ and $[la^-]_b$ were positively correlated with % $\dot{V}O_{2max}$ (Fig. 1b, c) in positive curvilinear relationships with exponents of 2.0 ($r=0.999$) and 3.3 ($r=0.999$), respectively.

### *Perceptual responses while swimming*

Table 2 shows the $RPE_O$ and the four differentiated RPE calculated from individual power functions at each 10% $\dot{V}O_{2max}$ while swimming. The increase in $RPE_O$ and the four differentiated RPEs with increase in % $\dot{V}O_{2max}$ showed positively accelerating curves with an exponent of 1.5 ($r=0.999$; $RPE_O$), 1.5 ($r=0.999$; $RPE_C$), 1.4 ($r=0.999$; $RPE_R$), 1.5 ($r=0.997$; $RPE_{arm}$) and 1.6 ($r=0.999$; $RPE_{leg}$). Because the RPE-scale was designed to show a linear relationship with power, $f_c$ and $\dot{V}O_2$ (Borg 1970), the RPE scale does not show the "true" form of the growth function [true according to the psychophysiological scaling theory and previous ratio scaling experiments (Borg 1982; Borg et al. 1985)]. Therefore, the CR-10 scale with ratio properties was developed to measure the perceived intensities and combined the advantages of level determinations in category ratings with function determinations in ratio scaling (Borg 1982; Borg et al. 1985). Since there was a demonstrated relationship between the RPE scale and a category ratio scale of 1:1.6 (Borg and Johansson 1985), the exponents obtained above have been multiplied by a factor of 1.6 to get a rough estimate of the truer exponents. If a ratio scale like magnitude estimation or the CR-10 scale had been used, the exponents should have been multiplied by a constant k = 1.6 to estimate the power function. Using this formula the resulting exponents would be 2.4 for $RPE_O$, 2.3 for $RPE_C$, 2.2 for $RPE_R$, 2.5 for $RPE_{arm}$ and 2.5 for $RPE_{leg}$.

Table 3 gives the correlation coefficients of values obtained over the entire stimulus range between $RPE_O$ and the four differentiated RPE, as well as between the four differentiated RPE and their associated physiological responses. The correlation coefficients were high and significant.

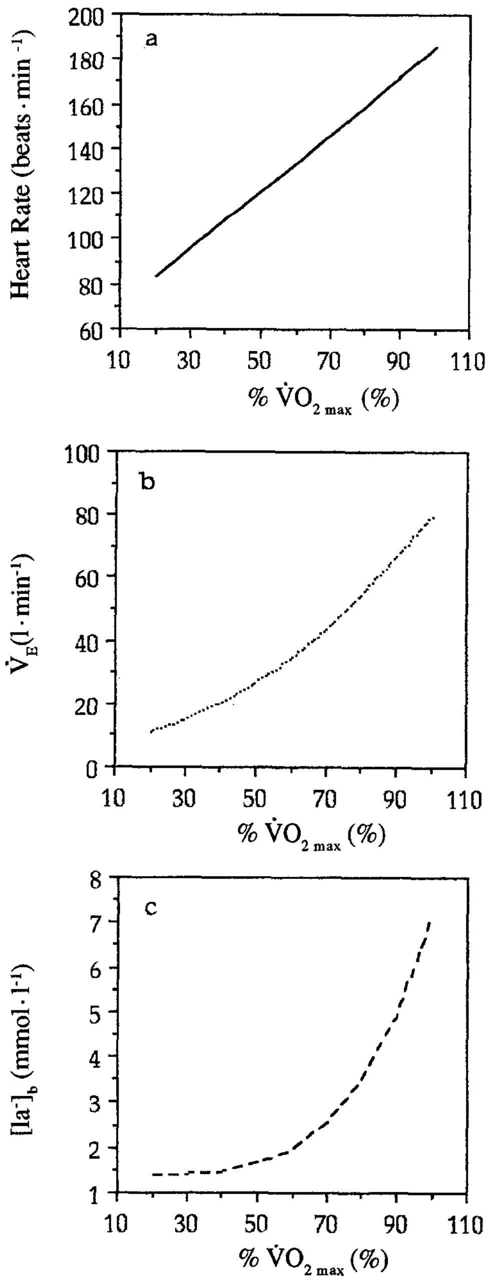


**Fig. 1.** Relationship of heart rate ($f_c$) (**a**), ventilation ($\dot{V}_E$) (**b**) and blood lactate concentration ($[la^-]_b$) (**c**) in relation to: percentage maximal oxygen uptake (% $\dot{V}O_{2max}$), and power functions:
$f_c = 58.0 + 1.0943 \cdot \% \dot{V}O_{2max}^{1.0}$ ($r=0.999$)
$\dot{V}_E = 7.6 + 0.0088 \cdot \% \dot{V}O_{2max}^{2.0}$ ($r=0.999$)
$[la^-]_b = 1.4 + 0.0000025 \cdot (\% \dot{V}O_{2max} - 20)^{3.3}$ ($r=0.999$)

### *Contribution of differentiated RPE to overall exertion*

Table 4 shows the results of the multiple regression analyses at each 10% $\dot{V}O_{2max}$. Multiple correlation coefficients ($r$) were high, and the standard error of estimates ranged from 0.230 to 0.441. Figure 2 shows the change of standardized $\beta$ coefficients of the four differentiated RPE in absolute terms in the multiple regression analysis. The $RPE_C$ and $RPE_R$ were inversely related to $RPE_O$ at any given % $\dot{V}O_{2max}$. $RPE_C$ and $RPE_R$ were relatively high and showed approximately the same contribution at 20% $\dot{V}O_{2max}$. The $RPE_C$, however, was the main contributing factor in $RPE_O$ up to 45% $\dot{V}O_{2max}$ while $RPE_R$ began to decrease at the same point. The $RPE_C$ suddenly decreased from 50 to 80% $\dot{V}O_{2max}$ while $RPE_R$ abruptly increased from 60% to 80% $\dot{V}O_{2max}$. Above 80% $\dot{V}O_{2max}$ there was a tendency for $RPE_C$ to increase and $RPE_R$ to decline in their contributions to $RPE_O$. The $RPE_R$ was the secondary contributor from 66% to 96% $\dot{V}O_{2max}$. In the case of $RPE_{arm}$, it was relatively

**Table 2.** Overall exertion and four differentiated RPE at each 10% $\dot{V}O_{2max}$ calculated by individual power function. Power functions of the group were calculated from arithmetic means

| % $\dot{V}O_{2max}$ | $RPE_O$ | | $RPE_C$ | | $RPE_R$ | | $RPE_{arm}$ | | $RPE_{leg}$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | mean | SD | mean | SD | mean | SD | mean | SD | mean | SD |
| 20 | 7.74 | 0.83 | 7.48 | 0.78 | 7.60 | 0.88 | 7.57 | 0.86 | 7.43 | 0.90 |
| 30 | 8.59 | 1.32 | 8.41 | 1.10 | 8.64 | 1.20 | 8.40 | 1.29 | 8.25 | 1.24 |
| 40 | 9.54 | 1.67 | 9.44 | 1.35 | 9.74 | 1.44 | 9.29 | 1.68 | 9.20 | 1.51 |
| 50 | 10.61 | 1.89 | 10.58 | 1.50 | 10.93 | 1.58 | 10.27 | 2.00 | 10.27 | 1.67 |
| 60 | 11.80 | 1.97 | 11.82 | 1.55 | 12.21 | 1.61 | 11.37 | 2.23 | 11.48 | 1.73 |
| 70 | 13.15 | 1.93 | 13.18 | 1.52 | 13.59 | 1.54 | 12.61 | 2.34 | 12.83 | 1.67 |
| 80 | 14.64 | 1.79 | 14.66 | 1.42 | 15.08 | 1.41 | 14.05 | 2.29 | 14.35 | 1.52 |
| 90 | 16.30 | 1.58 | 16.26 | 1.34 | 16.68 | 1.28 | 15.74 | 2.02 | 16.03 | 1.31 |
| 100 | 18.12 | 1.45 | 17.98 | 1.38 | 18.39 | 1.32 | 17.75 | 1.52 | 17.88 | 1.21 |

Power functions:
$RPE_O = 6.6 + 0.0120 \cdot \% \dot{V}O_{2max}^{1.5}$ ($r = 0.999$)
$RPE_C = 6.3 + 0.0146 \cdot \% \dot{V}O_{2max}^{1.5}$ ($r = 0.999$)
$RPE_R = 6.3 + 0.0196 \cdot \% \dot{V}O_{2max}^{1.4}$ ($r = 0.999$)
$RPE_{arm} = 6.5 + 0.0091 \cdot \% \dot{V}O_{2max}^{1.5}$ ($r = 0.997$)
$RPE_{leg} = 6.4 + 0.0090 \cdot \% \dot{V}O_{2max}^{1.6}$ ($r = 0.999$)

RPE, ratings of perceived exertion; $RPE_O$, overall exertion; $RPE_C$, cardiac frequency rating; $RPE_R$, respiratory frequency rating; $RPE_{arm}$, arm rating; $RPE_{leg}$, leg rating; % $\dot{V}O_{2max}$, percentage maximal oxygen uptake

**Table 3.** Correlation coefficients between overall exertion and four differentiated RPE, and between four differentiated RPE and their associated physiological responses. Correlations were based on values obtained over the entire stimulus range

| Differentiated | RPE | $RPE_C$ | $RPE_R$ | $RPE_{arm}$ | $RPE_{leg}$ |
|---|---|---|---|---|---|
| $RPE_O$ | | 0.97** | 0.97** | 0.98** | 0.98** |
| Physiological responses | $f_c$ | 0.87** | | | |
| | $f_b$ | | 0.85** | | |
| | $\dot{V}_E$ | | 0.67* | | |
| | $V_T$ | | 0.45 | | |
| | $[la^-]_b$ | | | 0.73* | 0.78** |

* $P < 0.05$, ** $P < 0.01$; $f_b$, breathing frequency; $V_T$, tidal volume; for other definitions see Table 2 and Fig. 1

**Table 4.** Results of the multiple regression analyses at each 10% $\dot{V}O_{2max}$

| % $\dot{V}O_{2max}$ | Standardized $\beta$ coefficient | | | | $r$ | $r^2$ | SEE |
|---|---|---|---|---|---|---|---|
| | $RPE_C$ | $RPE_R$ | $RPE_{arm}$ | $RPE_{leg}$ | | | |
| 20 | 0.340 | 0.305 | 0.258 | 0.097 | 0.999 | 0.998 | 0.397 |
| 30 | 0.428 | 0.272 | −0.089 | 0.389 | 0.999 | 0.999 | 0.359 |
| 40 | 0.538 | −0.070 | 0.452 | 0.082 | 0.999 | 0.999 | 0.441 |
| 50 | 0.533 | −0.139 | 0.616 | −0.009 | 0.999 | 0.999 | 0.418 |
| 60 | 0.353 | 0.095 | 0.598 | −0.045 | 0.999 | 0.999 | 0.383 |
| 70 | 0.153 | 0.344 | 0.581 | −0.075 | 0.999 | 0.999 | 0.333 |
| 80 | −0.031 | 0.518 | 0.604 | −0.089 | 0.999 | 0.999 | 0.262 |
| 90 | −0.105 | 0.481 | 0.654 | −0.029 | 0.999 | 0.999 | 0.230 |
| 100 | 0.348 | −0.118 | 0.618 | 0.153 | 0.999 | 0.999 | 0.429 |

For definitions see Table 2

low from 20% to 30% $\dot{V}O_{2max}$ but it abruptly increased at 30% $\dot{V}O_{2max}$ up to 50% $\dot{V}O_{2max}$ and thereafter remained as the main contributing factor. The $RPE_{leg}$ was the lowest contributing factor overall except from 27% to 35% $\dot{V}O_{2max}$.

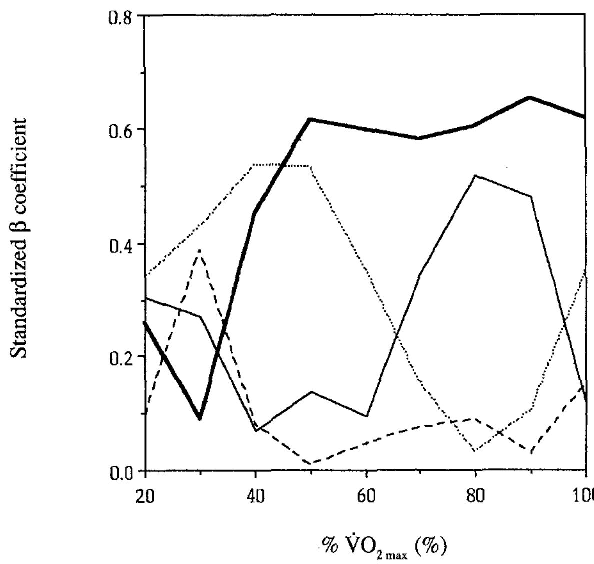


**Fig. 2.** Changes of standardized $\beta$ coefficients of four differentiated ratings of perceived exertion obtained from multiple regression analyses in relation to percentage maximal oxygen uptake (% $\dot{V}O_{2max}$). ....... Cardiac frequency rating; —— breathing frequency rating; ——— arm rating; ---- leg rating

## Discussion

### *Physiological responses while swimming*

The $f_c$ when related to % $\dot{V}O_{2max}$ increased linearly and $\dot{V}_E$ and $[la^-]_b$ increased exponentially. These results were consistent with previous studies (McArdle et al. 1971; Holmér et al. 1974; Nadel et al. 1974; Kurokawa et al. 1984). The $[la^-]_b$ in this study, where the exponent of the equation was 3.3, was similar to that of Borg et al. (1987a, b) where the exponents were 3.5 and 2.5 for cycling, 3.2 for running, 5.0 for walking, and 2.5 for arm cranking.

*Perceptual responses while swimming*

The RPE scale was designed to indicate a linear relationship between $RPE_O$ and $f_c$, $\dot{V}O_2$ and objective assessment of exercise intensity (Borg 1970). There was a linear relationship among these variables in cycling and running on a treadmill where power or speed was used as the measurement of objective exercise intensity. But the relationship was not linear in walking (Borg et al. 1987a), where RPE increased in a positively exponential curve with an exponent of 1.9. In this study, $RPE_O$ did not show a linear relationship with $\dot{V}O_2$ and the exponent estimated for $RPE_O$ was 2.4, suggesting that the magnitude of $RPE_O$ increased more steeply at higher exercise intensities. The nonlinear relationship in this case was explained as being the result of the mechanical efficiencies of subjects' walking, i.e. higher speed walking was not an efficient way of moving. If free swimming had been included in this study, the increase in free swimming speed would have led to an exponential increase of body drag in the water and a decrease of the mechanical efficiency. The energy costs in terms of $\dot{V}O_2$ have been found to increase exponentially with speed in walking (Anderson 1978; Inman 1981) and free swimming (Holmér 1974). The present study, however, differs in its explanation of the existence of a nonlinear relationship. Tethered swimming occurred and the subjects swam in a constant position against resistance. Body drag and mechanical efficiency therefore could not be estimated, because the swimming speed was zero but $\dot{V}O_2$ showed a linear relationship with resistance in this study. The exponential increase in $RPE_O$ may have been influenced by local factors instead of body drag and mechanical efficiency, especially, at higher exercise intensities.

Correlation coefficients between $RPE_O$ and the four differentiated RPE, and between the four differentiated RPE and their associated physiological responses were high and significant. Correlation of $RPE_R$ with $\dot{V}_E$, $f_b$ and $V_T$ in the present study decreased in the following order: $f_b$ ($r=0.85$), $\dot{V}_E$ ($r=0.67$) and $V_T$ ($r=0.45$). Pandolf et al. (1972), Noble et al. (1973), and Kamon et al. (1974) have directly examined the importance of $f_b$ and $\dot{V}_E$ as cues for $RPE_O$. They have demonstrated the correlations of $\dot{V}_E$ and $f_b$ with perception of effort in neutral conditions where $r$ ranged from 0.47 to 0.65 and in heated conditions where $r$ ranged from 0.56 to 0.78.

The neurophysiological pathway for $RPE_R$ during exercise is not totally understood. The changes found in $f_b$ (Robertson et al. 1979) and/or $V_T$ (Wolkove et al. 1981) may influence $RPE_R$. At higher exercise intensities the changes in $RPE_R$ were in response to changes in $f_b$ rather than in $V_T$ under alkalosis (Robertson et al. 1986), because at higher exercise intensities $f_b$ increased while $V_T$ reached a plateau. In this study, $f_b$ was strictly coupled to the movements of the arms and legs. It has been found that as $f_b$ increases during exercise, neuromotor signals reflecting changes in inspiratory muscle force and the duration of its development are sent to the sensory cortex (Killian et al. 1982). It was concluded that throughout the exercise intensity $f_b$ and $\dot{V}_E$ had a closer relationship with $RPE_R$ than with $V_T$.

The $RPE_{arm}$ and $RPE_{leg}$ are classified as local ratings, generated by the input of local physiological responses. Specifically, using $[la^-]_b$ samples from the subjects, the present study showed a strong correlation between $[la^-]_b$ and $RPE_{arm}$ ($r=0.73$), and $[la^-]_b$ and $RPE_{leg}$ ($r=0.78$). These results were consistent with Robertson et al. (1986) who have found that signs of exertion during arm cranking and leg pedalling were linked to blood pH and plasma buffering.

*Contribution of differentiated RPE to overall exertion*

The changes of the standardized $\beta$ coefficients in absolute terms describe the potential relationships between the four differentiated RPE and $RPE_O$. The $RPE_C$ was the main contributing factor from 20% to 45% $\dot{V}O_{2max}$. At these intensities the subjects exhibited little strain or exertion: thus they may have evaluated their $RPE_O$ using $RPE_C$. The relative contribution of the $RPE_C$, however, showed a tendency to decline beyond 50% $\dot{V}O_{2max}$.

The $RPE_{leg}$ was a secondary contribution only at around 30% $\dot{V}O_{2max}$. This exercise intensity in the present study corresponded to the lowest resistance (1.0 kg) in tethered swimming. It was observed that at this exercise intensity there was a tendency for the subjects' legs to sink to the bottom of the flume and this sensation rather than physical strain allowed them to evaluate their $RPE_O$.

The $RPE_{arm}$ was the principal component of $RPE_O$ beyond 45% $\dot{V}O_{2max}$. Cafarelli (1977) has demonstrated that local factors (ratings) provide primary sensory signals, and central factors (ratings) act as amplifiers or gain modifiers. Cafarelli et al. (1977) have also investigated the relative magnitudes of local and central components in the perception of effort and have observed that at no instance did central ratings exceed local ratings during exercise. In their study, central ratings ranged in magnitude from 30% to 40% of local ratings. Similarly, the present study also showed that local ratings were the dominant influence while swimming.

It should, however, be noted that $RPE_{leg}$ did not contribute to $RPE_O$ beyond 35% $\dot{V}O_{2max}$. It can be also concluded that the physical condition of the arms and legs of the subjects while swimming contributed to $RPE_O$. While swimming in itself is an exercise involving the whole body, coordination of arms and legs is particularly important in breaststroke, i.e. relative loads in both arms and legs should be identical. In this study, the leg condition in eight out of the ten subjects was superior to that of their arms. Thus, the local rating $RPE_{arm}$ was a major component of $RPE_O$ exhibiting an exponential increase if plotted. In exercise intensities 45%–66% $\dot{V}O_{2max}$ swimming in itself is perceived to be uncomfortable yet tolerable as far as $RPE_{arm}$ was concerned.

From 66% to 96% $\dot{V}O_{2max}$, $RPE_R$ was a secondary contributing factor to $RPE_O$. An exercise intensity of around 60% $\dot{V}O_{2max}$ was accompanied by a change in respiratory responses from isocapnic buffering to respiratory compensation for metabolic acidosis (Wasserman 1978). This isocapnic buffering of metabolic acidosis at higher exercise intensities has been linked to $RPE_R$ (Robertson 1982; Robertson et al. 1986). In the present study, however, the increase in $\dot{V}_E$ was not abrupt at around 60% $\dot{V}O_{2max}$, because the relationship between $\dot{V}_E$ and % $\dot{V}O_{2max}$ as a power function was used for descriptive purposes. Nonetheless, the isocapnic buffering to respiratory compensation for metabolic acidosis did take place at a certain exercise intensity. The $\dot{V}_E$ drive beyond this exercise intensity contributed to major signs of exertion. Therefore, $RPE_R$ was a contributor. Because central ratings acted as an amplifier in evaluating $RPE_O$ in proportion to aerobic demand (Cafarelli 1977), the magnitude of the contribution was not as much as $RPE_{arm}$ which was a localized perception. It should be noted that, for women, swimming beyond 60% $\dot{V}O_{2max}$ may require painful or unpleasant effort involving both excessive arm movements and difficulty in breathing.

In conclusion, the standardized $\beta$ coefficients of multiple regression analyses were useful in the study of the contribution of the four differentiated RPE to $RPE_O$ at different exercise intensities. The contributions of the four differentiated RPE to $RPE_O$ varied as the exercise intensity increased and in response to physiological processes. The changes in the contributing factors were dependent upon exercise intensity and were symptomatic of the start of $RPE_O$. At higher exercise intensities, the varying physiological conditions of the arms and legs of the subjects and $f_b$ appeared to be the primary causes in determining $RPE_O$ while swimming.

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