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Rate of perceived exertion as a predictor of physiological variables during jogging

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CERTIFICATE OF APPROVAL

MASTER OF SCIENCE RESEARCH PROJECT

This is to certify that the Research Project of

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submitted in partial fulfillment of the requirements for the degree of Master of Science in the School of Health, Physical Education, and Recreation at Ithaca College has been approved.

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RATE OF PERCEIVED EXERTION AS A PREDICTOR
OF PHYSIOLOGICAL VARIABLES
DURING JOGGING

by

Leslie M. Leonard

An Abstract

of a project submitted in partial fulfillment
of the requirements for the degree of
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Project Advisor: Dr. A. Craig Fisher

ABSTRACT

Rate of perceived exertion (RPE) was examined as a predictor of physiological variables during jogging. Subjects for this study were 14 healthy volunteers who participated in an adult fitness program at Cornell University. Four successive .6 km runs of various speeds set by the instructor and unknown to the subjects were randomly assigned. All data were recorded immediately following each run. RPE was chosen as the predictor variable. The physiological variables selected as outcome variables were ventilation, heart rate, oxygen consumption, carbon dioxide production, oxygen pulse, and respiratory quotient. Canonical correlation analysis between RPE and the outcome variables revealed a significant multivariate relationship, $R_c = .64$, $\chi^2 (7) = 26.61$, $p < .001$. RPE accounted for 41% of the variance of the physiological variables. The only variable with a significant univariate relationship with RPE was heart rate, $r (13) = .44$, $p < .05$. RPE should not be used as the sole predictor of workload effort, but in addition to other evaluatory methods.

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A Research Project Presented to the Faculty

of the School of Health, Physical

Education and Recreation

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Chapter 1

INTRODUCTION

In order to evaluate an individual's reaction to any workload, it is necessary to know the physiological and psychological status of the body. Years of research have allowed us reasonable accuracy in assessing most physiological measurements using complex machines and expensive devices. However, if we could quantitatively measure subjective symptoms of physical exertion through a single verbal response we could save a great deal of wasted time, energy, and expense.

The pioneering work of Gunnar Borg in 1962 (Borg, 1962) provided such a verbal response, namely, a scale of numbers which enables an individual to communicate the intensity of perceived exertion of work effort on the bicycle ergometer. This scale is called the Rate of Perceived Exertion (RPE). Along with Borg, several other investigators (Michael & Hackett, 1972; Noble & Borg 1971; Noble, Metz, Pandolf, Bell, Cafarelli, & Sime, 1973) reported correlations between perceived exertion and heart rate during treadmill and bicycle work to range between .61 and .90.

Since Borg's initial link of work intensity with perceived exertion many other investigators have tried to find out which internal factors serve as further links among physical stimuli, feelings, and verbal responses. Noble and Borg in 1971, as well as other investigators (Michael & Hackett, 1972; Noble et al., 1973; Pandolf, Cafarelli, Noble, & Metz, 1972), reported correlations between perceived exertion and heart rate during ergometer and treadmill work. Oxygen uptake, similar to heart rate, has been shown to be linearly related to RPE (Noble & Borg, 1971). However, it has been found (Pandolf & Noble, 1973; Stamford & Noble, 1974) not to be a primary factor in setting perceptual intensity.

Subjective awareness of ventilation is very acute (Bakers & Tenney, 1970), therefore, it is understandable that ventilation has been found to be a significant factor in perceiving exertion during increasing workloads (Cafarelli & Noble, 1976; West, Ellis, Campbell, 1975). At higher levels of exercise, ventilation was the most powerful physiological cue (Edwards, Melcher, Hesser, Wigertz, & Ekelund, 1972; Michael & Hackett, 1972), especially above 70% V_e max.

Another physiological factor linked to RPE has been lactic acid, but with contradictory results. Investigators (Edwards et al., 1972; Morgan & Pollock, 1976) have shown high correlations between perceived exertion and lactic acid during continuous and intermittent exercise, but Kay and Shephard (cited in Borg, 1973) found limited correlation between these variables.

Other factors believed to affect RPE are drugs, activity duration, and threshold levels. Drugs are definitely an interfering factor (Hueting & Poulus, 1970). RPE was found to increase over a number of hours even though heart rate was kept constant (Bell, Noble, Drash, & Metz, 1975; Noble et al., 1973; Soule & Goldman, 1973). Another important interfering factor is threshold level. A threshold level is speculated to exist (Pandolf et al., 1972) for detection of major cardiorespiratory and metabolic changes, sometimes as high as 200 kpm/min. for bicycle ergometers. There is a point below which exercise levels do not stimulate heart rate, ventilation, and oxygen consumption enough for individuals' sensory perception to pick up feedback cues.

In all previous studies of RPE, physiological factors have been related to workloads on bicycle ergometers, treadmills, swimming flumes, and stationary lifting. The aim of this study was to test physiological reactions and their relationship to RPE during jogging laps around a .20 km track.

Statement of Problem

In this investigation the objective was to identify the physiological factors that are related to perceived exertion.

Scope of Problem

Measurements of selected physiological variables and perceived exertion were obtained on 14 participants in an adult fitness program. All subjects were involved in the program at least 8 wks. prior to testing. The selected variables were measured intermittently during four successive .60 km runs at various speeds set by the instructor, and unknown to the subjects. Canonical correlation analysis between the predictor variable (perceived exertion) and the outcome variables (physiological data) was conducted.

Major Null Hypothesis

There will be no significant multivariate relationship between RPE as a predictor variable and seven physiological measures as outcome variables.

Minor Null Hypotheses

1. There will be no significant relationship between RPE and heart rate.

2. There will be no significant relationship between RPE and minute pulmonary ventilation (l/min.).

3. There will be no significant relationship between RPE and oxygen consumption (ml/kg).

4. There will be no significant relationship between RPE and

oxygen consumption (1/min.).

5. There will be no significant relationship between RPE and oxygen pulse.

6. There will be no significant relationship between RPE and respiratory quotient.

7. There will be no significant relationship between RPE and carbon dioxide production (1/min.).

Assumptions of Study

1. The subjects were representative of healthy average adults who participate in jogging.

2. Subjects adhered to dietary and exercise restrictions prior to testing.

Definition of Terms

1. Rate of perceived exertion (RPE). The subjective rating of the intensity of work being performed based on Borg's (1962) 15-point category scale.

2. Minute pulmonary ventilation (V_e). The amount of air exhaled during normal breathing.

3. Heart rate (HR). The heart rate taken immediately at the end of each submaximal workload.

4. Submaximal workload: One of four .60 km runs given in succession with a 1- to 2-min. rest separating runs.

5. Volume of oxygen consumption ($\dot{V}O_2$). The amount of oxygen consumed during each submaximal workload.

6. Volume of carbon dioxide production ($\dot{V}CO_2$). The amount of carbon dioxide expired during each submaximal workload.

7. Oxygen pulse (O_2Pulse). The oxygen consumed per heart beat during each submaximal workload.

8. Respiratory quotient (RQ). The volume of carbon dioxide expired divided by the volume of oxygen inspired.

Delimitations of Study

1. The number of subjects was delimited to 14 healthy, semi-active adults who participated in an adult fitness program.

2. The palpation technique was the only means used to determine heart rate in this investigation and was taken immediately after each workload.

3. Intermittent varying submaximal runs were the only means used to assess selected physiological variables and RPE.

Limitations of Study

1. Results can be generalized only to healthy, semi-active adults.

2. Assessment of heart rate obtained by palpation after workloads was not compared to assessment during exercise by some other method (e.g., EKG).

3. Data obtained from this study were not related to other modes of exercise.

Chapter 2

REVIEW OF LITERATURE

Lack of agreement between the objective and subjective evaluations of physiological effects of activity among patients and doctors stimulated Borg to research psychophysical problems of physical work (Borg, 1973). Through observation and experimentation Stevens developed ratio scaling methods that described general variations of perceptual intensities in 1957 (Borg, 1973). Borg studied the Stevens' scaling methods to try to adapt them to estimating the perception of workload intensities during exercise. Borg (1973) found that:

> Subjective perception of the force applied (or perceived pedal resistance) followed by a positively accelerating function could be described by the following expression: $R = a+c \cdot S^n$, where R is the subjective force, a is the basic perceptual "noise", c is a measure-constant, and S the power in kpm/min. The exponent "n" was found to be 1.6. (p. 91)

Then, with further studies, he found similar results for longer workloads as well, and published a book Physical Performance and Perceived Exertion. Using ratio scaling methods other investigators found that subjective intensity varied according to positively accelerated functions with many different kinds of physical workloads (Eisler, 1962; Stevens & Galanter, 1957; Stevens & Mack, 1959). By 1962, through the work of Borg and others, a linear relationship between perceptual intensity and physical work effort was empirically verified. This review of literature will concentrate on cardiovascular and cardiorespiratory factors and their relationship to RPE.

Heart Rate

One of the problems of the psychophysical scaling methods was that they were not applicable to inter-individual comparisons necessary for clinical and therapeutic assessment. Borg (1962), understanding this, devised a scale based on the ranges of work intensity, assuming that perceptual "noise" levels at maximum levels would be similar for all subjects. The measurement constant, $\underline{c}$, in Stevens scale could be solved as $\underline{c} = \frac{R_{t-a}}{S_t^n}$ where R_{t-a} is equal for all subjects and S_t and n may be determined empirically for each individual if t stands for the terminal (maximal) level. However, this was a complicated system for inter-individual comparisons, and Borg began using a 21-point graded category scale after much trial and error. Using the graded category scale, Borg (1973) reported correlations of .80 and .90 with heart rates in healthy males, when workloads were varied.

Still later (Borg & Linderholm, 1967), the 21-point graded category scale was changed once more. The 21 points were narrowed to 15, ranging in sequential order from 6 to 20 with simple word responses associated with every other number. Word responses ranged from "very, very, light" (6) to "very, very, hard" (20), with work difficulty expressed linearly with increasing numerical value. For middle aged, healthy males, moderate to hard work on bicycle ergometers is expected to elicit a RPE value 10 times higher than heart rate. Studies comparing other experimental scales (Borg, 1962; Tornvall, 1963) with the 15-point category scale, or Rate of Perceived Exertion (RPE) scale as it was called, found the RPE scale to be the most reliable.

In 1972, Pandolf, Cafarelli, Noble, and Metz investigated the relationship of heart rate to the RPE scale using "five treatments of various workloads in neutral and hot-dry environments to elicit unequal cardiac frequencies for unequal workloads" (p. 275). In the study, heart rate was increased by heat when no significant differences in RPE were found between equal workloads, leading Pandolf et al. (1972) to conclude that heart rate was not the sole influence on perceived exertion, but that other parameters existed as well.

The relationship of RPE to heart rate during varying treadmill workloads was observed by Noble, Metz, Pandolf, Bell, Cafarelli, and Sime in 1973. Subjects ran and then walked at the same varying speeds. Below velocities of 4 mph, RPE was greater for running then for walking, and the opposite was true for over 4 mph. RPE generally paralleled heart rates, however, local muscle discomfort at high velocities appeared to play a greater role in perceived exertion than heart rate.

In 1973, the validity and reliability of the Borg RPE scale was re-examined (Skinner, Hutsler, Bergsteinova, & Buskirk, 1973). To test the validity eight lean and eight obese subjects were given different randomly assigned workloads to find whether they could perceive small differences in work intensity. These results were compared to those obtained during progressive exercise normally used with the RPE scale. Reliability was determined by testing each subject twice with each protocol. There were no significant differences in any of the variables between the two types of protocols. Analysis of variance revealed no significant differences in any of the variables studied (HR, RPE, V_e, $\dot{V}O_2$). For heart rate and RPE high reliability coefficients were found during progressive testing (_r_ = .87 and _r_ = .80) and during random testing (_r_ = .91 and _r_ = .78). In this investigation, as in others reported earlier, heart rate was a significant factor in perception of exertion, but not the sole factor.

In a multiple regression study (Noble et al., 1973), six highly fit male students between the ages of 18 and 22 were studied. Five trials of bicycle ergometer work lasting 30 min. each were given and data recorded at three time points (5-, 15-, and 30 min.) during each trial. The data were submitted to a forward selection regression analysis and any variable contributing 5% or more was considered a significant contribution to the analysis. Ventilatory variables were more readily perceived than heart rate during exercise. In the first 5 min., $\dot{V}_e$, $\dot{V}O_2$, RQ, RR accounted for 59% of the variance of RPE; $\dot{V}_e$, $\dot{V}CO_2$ accounted for 69% of the variance at 15 min.; and RR, $\dot{V}_e$, $\dot{V}O_2$ accounted for 46% of the variance after 30 min. Heart rate added 5.7%, 3.6%, and 3.5% to the variance of RPE, respectively, at all three time points. At 5 min. all eight physiological variables produced a multiple of .81. The bivariate _r_ between heart rate and RPE was .40, lower, Noble et al. (1973) believed, than in other experiments by Borg (1962) and Skinner, Borg, and Buskirk (1969) who reported bivariate _r_'s of .85 (6 min.) and .90 (4 min.), respectively, because workloads in the former study were of increments of 199 kpm/min. rather than the 300 kpm/min. increments incorporated in the studies of Borg (1962) and Skinner et al. (1969). This multiple regression analysis reiterates that more than heart rate seems to be involved in the predictions of RPE.

Ventilation

Individual's control of expiratory muscles is partially voluntary (Bergstrom, Halttunen, & Vilijanen, 1972), therefore one's awareness of ventilation is apparent and known to be reasonably well perceived. In 1975, West, Ellis, and Campbell observed ventilation during exercise and found that subjects were more aware of tidal volume than frequency of ventilation, and that awareness increased as ventilation increased.

Edwards, Melcher, Hesser, Wigertz, and Ekelund (1972) studied continuous and intermittent work on the bicycle ergometer. RPE was highly correlated with ventilation (r's = .87-.94) during both types of work. Ventilation was also suggested to play a more important role at higher workloads.

When physiological responses were compared for similar workloads on treadmill running and bicycling (Michael & Eckardt, 1972; Michael & Hackett, 1972), ventilation was significantly different in each activity even though subjects perceived their work effort to be the same. This means that other cues appeared to be an influencing factor on RPE.

Skinner et al. (1973), when testing 16 males of different weight classifications and using progressively increasing workloads as well as random workloads, found high reliability coefficients for both ventilation (r = .68, .74) and RPE (r = .80, .78).

In Noble et al.'s (1973) regression study ventilation accounted for the greatest variance in RPE at 5- and 15 min. of bicycle work effort (31.2% and 55.5%, respectively) and the second greatest after 30 min. (13.5%).

In a study similar to that of Horstman, Morgan, Cymerman, and Stokes (1975), Cafarelli and Noble (1976) studied the importance of ventilation during bicycling and running. Ventilation became more important in the perception of exertion at higher workloads, and not important at all at low workloads.

It appears that ventilation is an important factor in effort perception at high levels but has little effect at lower levels of effort, when other factors prove to be better cues.

Oxygen Consumption

Oxygen consumption, or oxygen uptake, has been studied as another influencing factor on perceived exertion. Noble and Borg (1971) reported a linear relationship between oxygen intake and perceived exertion, similar to the relationship between heart rate and RPE. Michael and Hackett (1972) reported results in which 10 females were asked to run on a treadmill at a selected speed that would fatigue them in 15 min., then were later asked to repeat the same work effort on a bicycle. The oxygen consumption was almost double for treadmill work, leading Michael and Hackett to conclude that cues of work effort on the bicycle were derived from other factors than oxygen consumption.

In 1973, Pandolf and Noble used common oxygen uptakes (550-, 775-, 1075 kgm/min.) and bicycle speeds of 40-, 60-, and 80 rpm to measure changes in perceived exertion. At the same power output, changes in speed related negatively to RPE leaving Pandolf and Noble to claim that local factors acted as interfering cues in perceiving exertion. Stamford and Noble (1974), in a similar study, reiterated that RPE was not a good predictor of oxygen intake.

Noble et al. (1973), in a regression study, showed a relationship between RPE and oxygen consumption, but oxygen consumption did not appear to be a significant contribution in the regression analysis, except during the first 5 min. of exercise (16.9% at 5 min.; .4% at 15 min.; .2% at 30 min.). In 1973 Skinner et al. compared lean and obese persons' RPE first when body weight was supported by bicycle ergometry and secondly when transported by treadmill walking. They found RPE to be a good predictor of oxygen uptake on the treadmill, but on the bicycle all subjects rated the workloads harder at the same oxygen uptake. Also Morgan (1973), employing a modified Borg scale, experimented with bicycle workload effort. He found that normal subjects were capable of consistently identifying differences in workloads by Borg's scale and that subjective estimates mirrored actual metabolic costs of work being performed, except under the conditions of hypnotic suggestion, neurosis, or anxiety. Robertson, Hiatt, Gillespie, and Rose (1975) studied males with similar aerobic capacities, whom they divided into two perceptual groups referred to as augmenters (those who perceived a 1.5 in. block larger than it was) and reducers (those who perceived it smaller). Robertson et al. (1975) found a significant relationship between oxygen intake and RPE, mostly at higher levels of workload.

Carbon Dioxide Production

The amount of carbon dioxide produced during physical work and its relationship to perceived exertion has not received much investigatory effort. Robertson et al. (1975), studying the influence of augmentation and reduction on perceived exertion, found significant differences between each group's perception of exertion and $\dot{V}CO_2$, but in both augmenters and reducers there was a linear relationship between RPE and $\dot{V}CO_2$. In Noble et al.'s (1973) multiple regression analysis, $\dot{V}CO_2$ was one of four variables that contributed to the 79% variance in RPE at 15 min. of exercise ($\dot{V}CO_2$ contributed 9.5% variance by itself). At 5- and 30 min. of exercise, $\dot{V}CO_2$ contributed less than 1% of the variance. Carbon dioxide production appears to be a significant predictor of RPE at the peak of exercising but then its strength lessens as the workload continues. Carbon dioxide production seems only to have a secondary influence on RPE.

Respiratory Quotient

Respiratory Quotient (RQ) is the volume of carbon dioxide expired, divided by the volume of oxygen consumed. Noble et al. (1973) have shown RQ to contribute to perceived exertion on a secondary level. During the 5th min. of a 30-min. bicycle ergometer test, RQ contributed 5.4% of the variance in RPE and was the third most important contributing factor in the regression equation. As work effort increased, RQ decreased in contribution from .8% at 15 min. (fifth factor) to 2.3% at 30 min. (sixth factor). RQ's influence as a cue for perceived exertion is still questionable and under examination.

Summary

Rate of perceived exertion scales were constructed by Borg to subjectively measure feelings, heart rate, and work effort. Further studies investigating perceived exertion have shown that RPE is a reflection of a multitude of various physiological cues, some more primary than others, depending on workloads and activity situations. Of all the cues, RPE has been found to be a better predictor of heart rate and ventilation.

Chapter 3

METHODS AND PROCEDURES

This chapter defines the selection of subjects, fitness program, testing instruments, methods of data collection, scoring of data, treatment of data, and summary.

Selection of Subjects

Seven males and seven females between the ages of 24 and 46 served as subjects. They were volunteers involved in an adult fitness program at Cornell University, in Ithaca, New York, during the spring semester of 1978. The subjects had at least 8 wks. prior training in the program. Subjects possessing extreme levels of fitness were excluded from the investigation.

Adult Fitness Program

The spring 1978 adult fitness program was a succession of a program carried on for 2 years by Dr. Edmund Burke at Barton Hall, Cornell University. Each semester it was free and open to any person interested in attending. Before individuals began the program, consent forms were signed, and a doctor's permission was required. An Astrand bicycle test was given and skinfold measurements, age, weight, and previous history of health and exercise were recorded. The sessions were held three times a week at 9 a.m., and were initiated with a 15-min. warm-up of exercises. Following the warm-up, each participant then checked his or her own exercise prescription and continued that particular interval jogging program. A cool-down period was required and each person was required to record his or her lap time, heart rate, RPE, and number of laps. The instructor was available for consultation and advice.

Testing Instruments

The following equipment and apparatus were used in this study: (a) a Kofranyi-Michaelis respirometer, which was portable and light-weight; (b) a three-way plastic valve to direct the subject's expired air into the respirometer while still allowing room air to be inhaled; (c) a nose clip to insure that all air was expired through the mouthpiece; (d) a rubber mouthpiece for a better seal between subject's mouth and the three-way valve; (e) plastic tubing with air tight rubber connectors attached to the respirometer and the three-way valve; (f) a helmet to attach the mouthpiece and tubing so as not to interfere with free movement of the arms and shoulders; (g) a barometer to record air pressure; (h) a stop watch for recording lap times; (i) a Beckman gas analyzer to analyze the content of oxygen and carbon dioxide in the expired air; (j) Borg's 15-point category RPE scale for measuring perceived exertion; (k) an indoor .2 km running track; and finally (l) an assistant to set the pre-selected running paces.

Method of Data Collection

Beginning at 9 a.m. testing took place on the .2 km track at Barton Hall, Cornell University. All subjects had participated a minimum of 8 wks. in an interval training program. Subjects were asked to refrain from eating, smoking, and exercise 2 hours prior to testing. Subjects were oriented to the equipment, and experienced breathing through a mouthpiece while wearing a nose clip. With the equipment on, the subject was led through a 15-min. warm-up exercise and a slow jog around the track. Prior to testing, the respirometer was readjusted to the subject when necessary and the equipment carefully checked. Subjects were reminded to maintain a steady pace with the assistant throughout the testing. Subjects were told how heart rate would be recorded and were shown a poster of the RPE scale. They were instructed that, at the end of each run, they were to point to the number that best estimated their overall effort.

Four sets of three .2 km laps were run by each subject, all of the sets being paced to a time unknown by the subject. Each set was run at a randomly selected speed, and followed by a .2 km walking cool-down. Before each set of laps a collection bag was attached to the respirometer. The respirometer and stop watch were started simultaneously with the running. At the end of the .6 km run the time and volume of air were recorded. Heart rate was taken immediately, as was perceived exertion and temperature. Within 1 hour, each of the four collection bags containing samples of expired air was analyzed for oxygen and carbon dioxide content by using the precalibrated Beckman E-2 Oxygen Analyzer and Beckman LB-1 Carbon Dioxide Analyzer.

Scoring of Data

Once the percentages of oxygen and carbon dioxide were determined through gas analyses of expired air samples, they were entered as was heart rate, ventilation, barometric pressure, time of runs, RPE, temperature of expired air, and subject's weight, into a computer program designed by Ken Rodgers. The analysis was carried out at the computer center at Ithaca College.

Treatment of Data

Rate of perceived exertion was the selected predictor variable. The selected outcome variables were: (a) volume of ventilation (l/min.); (b) volume of oxygen consumed (l/min.); (c) volume of oxygen consumed (ml/kg); (d) heart rate (bpm); (e) volume of carbon dioxide produced (l/min.); (f) oxygen pulse; and (g) respiratory quotient. A canonical correlation with accompanying intercorrelations of all variables was used to determine overall significance. For all tests the significance level was set at .05.

Chapter 4

ANALYSIS OF DATA

The raw data scores from all physiological measures plus pressure, time of runs, RPE, temperature of expired air, and subject's weight were used in a computer program designed by Ken Rodgers. After preliminary analysis, data results were treated by canonical correlation analysis to assess the multivariate relationship between RPE and the seven physiological measures. Results of the canonical correlation analysis led to the rejection of the null hypothesis that there will be no significant multivariate relationship between RPE as a predictor variable and physiological measures as outcome variables, $R_c = .64$, $\chi^2 (7) = 26.61$, $p < .001$. RPE accounted for 41% of the variance in the physiological variables.

Intercorrelations of RPE and the seven physiological variables are presented in Table 1. The following results concerning the seven minor null hypotheses were obtained. In all cases, a coefficient .44 was needed to indicate a significant relationship at the .05 level, one-tailed test.

1. The minor null hypothesis that there will be no significant relationship between RPE and heart rate was rejected, $r (13) = .44$, $p < .05$.

2. The minor null hypothesis that there will be no significant relationship between RPE and respiratory quotient was accepted, $r (13) = .05$, $p > .05$.

3. The minor null hypothesis that there will be no significant relationship between RPE and oxygen consumption (l/min.) was accepted, $r (13) = -.02$, $p > .05$.

Table 1

Intercorrelations of Rate of Perceived Exertion and Physiological Variables

Variables	2	3	4	5	6	7	8
1. RPE	.44*	.05	.17	-.02	.33	-.15	-.01
2. HR		.36	.45*	.19	.34	-.16	.32
3. RQ			.24	.09	.01	-.06	.46*
4. V_e				.84**	.50*	.68**	.87**
5. $\dot{V}O_2$ (1/min.)					.66**	.92**	.90**
6. $\dot{V}O_2$ (ml/kg)						.54*	.52*
7. O_2 Pulse							.77**
8. $\dot{V}CO_2$							

*$p < .05$.

**$p < .01$.

4. The minor null hypothesis that there will be no significant relationship between RPE and oxygen consumption (ml/kg) was accepted, $\underline{r}$ (13) = .33, $\underline{p} > .05$.

5. The minor null hypothesis that there will be no significant relationship between RPE and oxygen pulse was accepted, $\underline{r}$ (13) = −.15, $\underline{p} > .05$.

6. The minor null hypothesis that there will be no significant relationship between RPE and carbon dioxide production was accepted, $\underline{r}$ (13) = −.01, $\underline{p} > .05$.

It appears that the significant correlation between RPE and heart rate accounted for much of the significant multivariate relationship between RPE and the physiological variables.

Summary

Physiological variables were computed from raw scores obtained from all subjects during all trials. A canonical correlation analysis with accompanying intercorrelations of all variables was run on the predictor variable (RPE) and seven outcome variables to test for the multivariate relationship between RPE and the physiological variables. The major null hypothesis that there will be no significant multivariate relationship between RPE and the physiological variables was rejected with an $\underline{R}_c$ of .64. RPE accounted for 41% of the physiological variables variance. The minor null hypothesis concerning RPE and heart rate was also rejected. The other minor null hypotheses between RPE and RQ, V_e, $\dot{V}O_2$, O_2 pulse, and $\dot{V}CO_2$, respectively were all accepted.

Chapter 5

DISCUSSION OF RESULTS

Canonical correlation analysis revealed a significant multivariate relation between the predictor variable (RPE) and the outcome measures (HR, RQ, V_e, $\dot{V}O_2$(1/min.), $\dot{V}O_2$ (ml/kg), O_2 pulse, $\dot{V}CO_2$), $\underline{R}_c = .64$, χ^2 (7) = 26.61, $\underline{p} < .001$. RPE accounted for 41% of the variance in the physiological variables and was a significant predictor of the various physiological measures utilized in this study. This finding is in agreement with Noble et al.'s (1973) study, in which regression analysis of various physiological measures (V_e, $\dot{V}O_2$, RQ, HR, $\dot{V}CO_2$, Tr, Ts) showed a multiple $\underline{R}$ of .81 and accounted for 66% of the variance in perceived exertion after the first 5 min. After 15 min. the reported $\underline{R}$ was .90 and accounted for 80% of the variance, and after 30 min. $\underline{R}$ was .73 and accounted for 53% of the variance.

Although the $\underline{R}_c$ of .64 was statistically significant, there remained 59% unexplained variance in the physiological variables. Several possible reasons could account for this variance. One expressed in previous literature is workload differentiation. Pandolf et al. (1972) speculated that work increments might have to be as high as 200 kpm/min. for perceptual discrimination in bicycle ergometry. Noble et al. (1973) found that RPE remained approximately the same between workloads that elicited 48% and 60% of max $\dot{V}O_2$ (a difference of 199kpm/min.), while heart rate, V_e, and $\dot{V}O_2$ increased linearly. In this current study the average workload differentiation was 15 sec. in lap time for a .6 km run. Examining the raw data, between-trial mean RPE's fluctuated only 1 point and, in nine of the 14 subjects, the same RPE was offered for at least two of the four workloads, whereas heart rate increased linearly in all of the subjects with repeating heart rates occurring only four separate times. This appears to support the previous speculations of a threshold level for perceptual discrimination of physiological measures.

Another possible cause of the unexplained variance could be the duration used in this study. Four trials were used discontinuously with 1-2 min. intervals. The average time was 3.11 min. per trial. This time duration might not have been long enough to allow complete perceptual awareness of the physiological state. Perhaps, warm-up exercise (3 min. of activity at an estimated 70% of aerobic power) is desirable before attempting the direct measurement of oxygen consumption (Astrand & Rodahl, 1977). A more intense warm-up might also enhance one's accuracy in RPE reporting, due to the fact that a threshold level might be surpassed. If this is the case, then trial runs at only 3.11 min. would account for the large unexplained variance between RPE and the physiological measures. Noble et al. (1973) suggested in their regression study that the selected physiological variables explained less variance with RPE at 5 min. of exercise than at 15 min., due to the "transient state during the early stages of exercise" (p. 108).

A final suggestion for the unexplained variance is that training might be necessary before using any means of perceptual scaling. In this study, healthy adults, all of whom had 8 wks. of previous interval jogging participation, were told to choose a number that reflected their total body awareness to the exercise to indicate their RPE, without any pretraining in the recognition of exertional feelings. Some of the subjects could have been what Robertson et al. (1975) referred to as augmenters or reducers, and this characteristic might have affected the validity of this study. That is, augmenters would tend to accentuate their perception of exertion, whereas reducers would minimize the intensity of their perceptual cues. However, the use of RPE in evaluation in most fitness programs involves no such training, and none was used in this study. Also, the intervals of jogging and the workloads of this study are similar to exercise prescription used in programs today. Therefore, it is suggested that the use of RPE for evaluation and prediction of physiological variables during interval jogging is credible, but should be used in conjunction with other measures or only after subjects are trained in scaling their perceptions.

Relationship of RPE to the Physiological Variables

It appears that the significant correlation between RPE and heart rate (r = .44) accounted for much of the significant multivariate relationship between RPE and the physiological variables. The other r's ranged from -.01 to .33 with RPE, none of which were statistically significant.

The significant relationship between RPE and heart rate replicated previous findings (Borg, 1962; Borg & Linderholm, 1967; Docktor & Sharkey, 1971; Skinner, Borg, & Buskirk, 1969). Borg (1962), Borg and and Linderholm (1967), and Docktor and Sharkey (1971) previously found correlations ranging between .75 and .90 between perceived exertion and heart rate. Skinner, Borg, and Buskirk (1969) reported bivariate r's of .85 (6 min.) and .90 (4 min.), respectively, between RPE and heart rate from several work trials. However, in Noble et al.'s (1973) study, the bivariate r between RPE and heart rate was only .40 and, during the first 5 min. of exercise heart rate, heart rate accounted for only 5.7% of the variance in RPE. In Noble et al.'s (1973) study and in this current study perhaps the time duration of the trials and lower workload increments accounted for the significant, but lower, relationships.

The ventilation data, unlike heart rate, disagreed with most of the literature (Bakers & Tenney, 1970; Bergstrom, Haltunen, and Vilijanen, 1972; Noble et al., 1973; West, Ellis, & Campbell, 1975). However, there are a few studies with findings that paralleled those in this study. In Cafarelli and Noble's (1976) study it was suggested that ventilatory cues do not make significant contributions until 70% $\dot{V}O_2$ max is reached. Subjects are apparently unable to detect increases in ventilation (20-30 l/min.) at lower levels of work. Local muscular discomfort undoubtedly predominates at lower work intensities. Edwards et al. (1972), in examining perceptual responses to continuous and intermittent work on the bicycle at 1,000 kpm/min., found that subjects rated work 17 or 18 on the RPE scale when ventilation was only 40% max V_e. This reiterates speculation that V_e plays a more important role at higher workloads. In the Michael and Hackett (1972) study, selected workload efforts by subjects were equal between treadmill and bicycle exercise, but ventilation was significantly different when effort was thought to be equal. This indicated that subjects did not use ventilation cues to equate exercises. At lower levels of exercise, ventilation is masked by other more intense simuli.

Oxygen consumption data were also in disagreement with most previous literature (Noble & Borg, 1971; Noble et al., 1973; Skinner et al., 1973). On the other hand, oxygen consumption's lack of relationship with RPE did correspond to Pandolf and Noble's (1973), using similar oxygen consumption levels on bicycle ergometers for all subjects, found RPE to be higher at a faster pedalling rate (although oxygen intake remained constant). Stamford and Noble (1974) also showed exercise at constant oxygen intake levels not to result in equal RPE responses. Further research would be necessary to evaluate fully oxygen intake's influence on RPE.

Finally, carbon dioxide production, shown in this study as an insignificant variable in predicting RPE, was in accordance with Noble et al.'s (1973) study. At 5 min. of exercise, carbon dioxide production contributed less than 1% of the variance in RPE.

It appears that during interval jogging the physiological variables in this study were all affected by time duration of trials and by workload increments.

Summary

Results found RPE to be a significant predictor of the physiological variables, with heart rate the major cue. However, since the physiological variables contributed to only 41% variance of RPE, RPE should not be used as the sole predictor of workload effort during interval running.

Chapter 6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS FOR FURTHER STUDY

Summary

Fourteen participants of an adult fitness program, with 8 wks. prior training, volunteered as subjects for this study. Each subject ran four successive .60 km trials at various speeds set by the instructor and unknown to the subjects, with measurement and data recorded immediately following each trial. Rate of perceived exertion was selected as the predictor variable, with ventilation, heart rate, oxygen consumption, carbon dioxide production, oxygen pulse, and respiratory quotient chosen as outcome variables. Canonical correlation analysis between the predictor variable and the outcome variables revealed a significant multivariate relationship, $R_c = .64$, $\chi^2\ (7) = 26.61$, $p < .001$. RPE accounted for 41% of the variance of the physiological variables. The only variable with a significant bivariate relationship with RPE was heart rate, $r\ (13) = .44$ $p < .05$. Use of RPE for evaluation or prediction of physiological variables during interval jogging should be used with other measures and after subjects are trained in scaling their perceptions. RPE should not be used as the sole predictor of workload effort.

Conclusions

1. Taking into consideration that RPE accounts for 41% of the variance in the physiological output, it is a significant predictor of physiological output.

2. Heart rate is a salient cue in predicting exertion.

3. RPE cannot predict ventilation, oxygen consumption, carbon dioxide production, oxygen pulse, and respiratory quotient during submaximal workloads.

Recommendations for Further Study

More research is needed on the effects of both psychological and physiological variables on perceived exertion. It is recommended that the study be repeated with various modifications.

1. Greater workload variation would allow for more perceptual differentiation, and is recommended.

2. Workloads of greater intensity would tend to surpass the RPE threshold level, and are recommended.

3. Experience in perceiving exertional levels might improve psychological differentiation and, therefore, enhance the ability to utilize the RPE scale.

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