

Self-monitored exercise at three different RPE intensities in treadmill vs field running

RUGGERO CECI and PETER HASSMÉN

*Division of Perception and Psychophysics,
Department of Psychology,
University of Stockholm,
S-106 91 Stockholm, SWEDEN*

ABSTRACT

CECI, R. and P. HASSMÉN. Self-monitored exercise at three different RPE intensities in treadmill vs field running. *Med. Sci. Sports Exerc.*, Vol. 23, No. 6, pp. 732-738, 1991. The aims of the present study were a) to compare the outcome of running exercise performed on a treadmill (laboratory) and an outdoor track (field) using an RPE production protocol and b) to study this kind of protocol used over time (3-5 wk). A group of 11 healthy male subjects participated, with ages varying from 33 to 65 yr (mean = 42.9 ± 11.0 yr). Two test sessions consisting of both treadmill and track exercise were performed in a rotated order to control for sequential effects. All subjects exercised according to an identical protocol: two successive trials (3 min each) at RPE 11 (light exertion), followed by a RPE 13 (somewhat hard) trial (11 min) and, finally, a RPE 15 (hard) trial (5 min). Results show significantly different levels of heart rate (HR), blood lactate, and velocity at the three RPE levels. Large differences were also observed in all measured variables between field and laboratory. These differences were consistent over time. A high internal consistency, measured by test-retest reliability ($\alpha > 0.9$), was obtained for both velocity and HR between the first two trials at RPE 11. In conclusion, the RPE method functioned well as a means of monitoring and regulating exercise intensity.

EXERCISE REGULATION, PERCEIVED EXERTION,
RUNNING VELOCITY, HEART RATE, BLOOD LACTATE,
PSYCHOPHYSICAL PRODUCTION

The process of self-monitoring and self-regulation in physical exercise deals with how well individuals are capable of adjusting the intensity of any exercise modality in order to reach a level that is best suited to their state of health, fitness, or any other limiting factor, such as instructions from a trainer or a test leader concerning how hard the work should be (10,20,24,29). Subjectively adjusting the exercise intensity can be seen as a continuous, as well as simultaneous, process involving monitoring of internal cues (e.g., perceived exertion, proprioception, and respiration) as well as external cues (e.g., velocity, and wind resistance). This self-monitoring leads to self-regulation, i.e., adjusting the exercise intensity.

In certain groups of patients, for example cardiac and pulmonary, it is of great interest to develop methods

that offer reliable and safe guidelines for physical training (3,6,8,10,12,22,24). Also, for healthy people and the "ordinary exerciser," such methods can be of help during everyday training, especially when they perform an activity which is predominantly of an aerobic character.

Previous studies (3,7,9,11,15,18,29) have shown that self-regulation of exercise, in which subjects are asked to produce exercise intensities based on feelings of perceived exertion, seems to function well in a number of exercise modes investigated. However, various methods have been used in the different studies: either purely verbal instructions (e.g., "slow jog" or "preferred speed") or purely numerical ones, such as percentage of maximal intensity (e.g., "50% or 75% of max."). Ekblom et al. (17) showed that both untrained and trained subjects could produce different intensity levels in a number of variables (i.e., velocity, step rate, heart rate, and blood lactate, as well as perceived exertion) based on four different verbal instructions (i.e., "normal walking," "fast walking," "slow jogging," and "comfortable jogging").

It is also possible to utilize the 15-graded Ratings of Perceived Exertion (RPE) scale (5,6) as a method of self-regulation. This scale has become a generally accepted subjective method in *estimation* studies, that is, studies in which subjects are asked to rate the degree of exertion they perceive as related to a certain physical intensity. Subjects are typically asked to rate an overall (undifferentiated) or local (differentiated) feeling of exertion (28). Depending upon the type of physical exercise, it should be possible to decide which sort of exertion rating is best suited to the purpose of the study. Likewise, subjects could be asked to *produce* a certain work level by using the same scale method (i.e., psychophysical production).

Another method, often used, is the training or target heart rate (THR). This method allows the subjects/patients to monitor their heart rate (HR) by palpation of the radial or carotid arteries, thereby keeping track of exercise intensity. The accuracy of such a method

has been investigated by Chow and Wilmore (12). As compared with a recorded electrocardiogram, they found that the THR method did not differ in terms of accuracy from a RPE method (55.3% vs 48.5%). Other investigators (15,19) suggest a combination of HR and RPE during a graded exercise test, or field training, to reduce overshooting in THR during initial training for individuals who are unfit or suffering from disease. It was found that an average rating of 12–13 seems to correspond to the upper limit of THR, especially at an early stage of rehabilitation (19).

A previous study (30), using exertion ratings from the RPE scale in order to produce a certain exercise intensity during treadmill level running, found no differences in either speed or HR between a production protocol and an estimation protocol. However, a HR difference was found in a comparison of data from the treadmill and from a field situation when the subjects were asked to produce an intensity corresponding to RPE 13 during horizontal running. It was suggested that the feeling of exertion during running outdoors could be reduced by other interfering perceptions, such as feelings of wind resistance, visual input, etc.

Many investigations have utilized running as the mode of exercise. A benefit of this specific exercise is that the variability in the intensity itself is fairly large (ranging from very slow jogging up to extremely fast running). However, it is not necessary to restrict “self-regulatory methods” to running only. In earlier investigations, walking, skiing (downhill as well as cross-country), and cycling have been studied (7,9,12,17,21,23).

An interesting question is how such a production protocol is related to some physiological responses—or costs—as well as performance variables. Instead of using only one RPE level for exertion production, as above, several levels could be used. In a recent study (18), it was found that a RPE range between 11 and 15 would correspond to a range of about 60–80% of $\dot{V}O_{2max}$. This is well in agreement with the American College of Sports Medicine’s recommended exercise intensity for healthy, fit individuals (1). It would also be of interest to further study whether the magnitudes of the measured variables (i.e., HR, blood lactate, and velocity) obtained from treadmill running are comparable to those obtained from outdoor field running.

Thus, the aim of the present investigation was to determine how the RPE scale—with three specific intensity levels (i.e., RPE 11, 13, and 15)—functions as a *regulatory method* to obtain effective, and possibly significantly different, exercise intensities during horizontal running. It was also of interest to study the reproducibility over time as well as the within-test reliability concerning the reproduction of one of the intensity levels (RPE 11) after a short time of rest. Finally, it was hypothesized that, based on earlier find-

ings (30), the production method during treadmill running would produce different intensity levels, that is, lower levels of velocity and physiological strain, compared with running on an outdoor track at the same RPE levels.

METHODS

Twelve physically active males were used as subjects in this study. All reported running, with an average frequency of two to three times per week, as their primary mode of training. The group was fairly heterogeneous with regard to both body characteristics and fitness levels. Owing to an injury between sessions, one of the subjects was unable to complete the entire test procedure. Thus, the original 12 subjects were reduced to 11 subjects with the following characteristics: ages varied between 33 and 65 yr (mean = 42.9 ± 11.0 yr), mean height was 181.5 ± 7.9 cm, and mean body mass was 74.1 ± 11.4 kg.

The apparatus used for the tests included an electronically braked cycle ergometer (Elema AM 361), a treadmill (Quinton instruments; 18-54), and a “Sporttester” (model PE 3000) for measuring heart rates (HR). The determination of blood lactate (HLA) levels was made from blood samples obtained from fingertip blood sampling, subsequently analyzed according to an enzymatic fluorometric method (21).

The overall procedure consisted of two test sessions of running exercise, each separated by a mean time of 27.3 ± 10.9 d of unsupervised training. During this intervening time, the subjects were asked to train according to the RPE scale at least twice per week. (This was confirmed by personal training logs kept by the subjects.) Prior to participation in the study, all subjects performed a standardized cycle ergometer test for the determination of HR responses after 5 min of exercise on a power level of either 150 W or 200 W. The goal was to reach HRs somewhere between 120 and 170 beats·min⁻¹. At this point, each subject provided informed written consent. During the last session, the same individual power levels were given as a post-test. The purpose of the pre- and post-tests on the cycle ergometer was to detect changes in HR reactions as a sign of fitness alterations between sessions.

During the initial test session, all subjects were instructed to start with either treadmill or field running. Hence, at the second session they switched to the alternate activity. In order to avoid sequential effects, subjects were randomly assigned to start with either of these two exercise activities (henceforth referred to as situations).

HR and running velocity (v) were measured during each separate trial for both treadmill and field running. HR was also measured at rest and was monitored continuously during the entire exercise period. Subjects

were not made aware of their individual HR levels until after the last test session. HLa samples were taken at rest and directly after each new intensity level, according to the RPE levels used as instructions (see Treadmill and Field subsections). RPE control estimates were made by the subjects after each trial. This was done as a means of checking the subjects' perceived change (e.g., overshoot), if any, from the intended/instructed intensity level.

Subjects were specifically asked to produce (and rate) an overall feeling of exertion since the purpose of this study was to examine an exercise modality that activates a major part of the body. The rest period between treadmill and field exercise was 20 min. Times on the treadmill and distances on the outdoor track were chosen so that the total amount of work performed would be about the same.

Treadmill. The subjects were instructed to adjust the velocity on a level treadmill (by a hand-held device) so that they experienced the exertion corresponding to 11 ("light exertion") on the RPE scale at the end of a 3 minute interval. After a short rest (1–2 min), they were asked to reproduce the task in exactly the same way. Next, they were asked to produce an intensity that corresponded to 13 ("somewhat hard") on the scale for 11 min. Finally, they were asked to produce an intensity corresponding to 15 ("hard") for 5 min. Subjects were allowed about 1–2 min of rest between all four trials.

Field. The field tests took place on a 500 m outdoor track with minor vertical grade differences. Subjects were asked to run one lap (500 m) and regulate their exertion to correspond to RPE 11. After a rest (1–2 min), they repeated the same procedure at RPE 11. Next, they ran four complete laps (2000 m) at RPE 13 and, finally, two laps (1000 m) at RPE 15. Between each trial they were allowed 1–2 min of rest.

The adjustments of velocity made during each exercise trial were not intended to last more than approximately $\frac{3}{4}$ of the full exercise time. Therefore, during the last $\frac{1}{4}$ of each trial, the subjects were expected to have reached their subjectively "correct" exercise level. Blood was collected immediately after each trial for subsequent lactate analysis. RPE control ratings were also given at the end of each trial. For the field part, time was registered for calculation of velocity, whereas, for the treadmill, velocity was measured directly at the end of each trial.

In general, the shorter RPE 11 intensity trials were designed as "warming-up" periods before the two longer trials. Also, the time difference between the RPE 13 and RPE 15 trials was "built in" to the design for two major reasons. The first was to keep the overall test time relatively short, so that the subjects would not be too exhausted, especially during the last trial in both situations. As the two situations were performed during

the same session (day), the total exercise time was close to 1 h. Second, in order to allow a more thorough description of a "steady state" situation, during the relatively longer period of moderate exercise at RPE 13, four different measurements were made at every 3rd min of exercise. These data will be analyzed and reported elsewhere. (In this study, data obtained during the last of these four measurements have been used.)

Statistics. In the statistical analysis, *three-factor* ANOVAs for repeated measures—group by situation by intensity—were calculated according to the standard procedure (BMDP2V (4)). Also, the analysis of time effects—time by situation by intensity—was calculated according to the same procedure. Linear regression analysis, Pearson product-moment correlation coefficients, and Cronbach's alpha (13) were adopted for calculations of equations for the HR and HLa relations with velocity, reproducibility (internal consistency), and reliability between tests (test-retest), respectively. In the evaluation of the *P*-values obtained from the correlation coefficients in Table 1, a "two-tailed" probability distribution was assumed. In addition, an intra-class *r* coefficient and Student's *t*-test were calculated to detect possible changes in HR values between pre- and post-tests on the cycle ergometer.

RESULTS

Descriptive data for the dependent variables are presented in Figures 1–3, which include results from the first and second sessions. There were no significant differences in any of the measured variables from the two sessions as a result of the rotated order in which the subjects were administered the two exercise situations. Thus, the group that started exercising on the treadmill, and then continued in the field, did not differ (in terms of *v*, HR, or HLa) from those proceeding in the opposite order. This was the case for both session 1 and session 2.

Pre- and post-test HR values from the cycle tests were strongly correlated ($r_{xy} = 0.862$, and intraclass $r = 0.896$) and did not differ significantly. Furthermore, subjects verbally confirmed that no changes had occurred in their exercise habits during the time intervening sessions 1 and 2.

TABLE 1. Pearson product-moment correlation coefficients for velocity (*v*), heart rate (HR), and blood lactate (HLa) between sessions 1 and 2 for the two situations (treadmill and field) and at the three RPE levels (*N* = 11).

<i>r_{xy}</i>	Treadmill			Field		
	11	13	15	11	13	15
<i>v</i>	0.90***	0.80***	0.94***	0.94***	0.88***	0.98***
HR	0.67**	0.79***	0.87***	0.41	0.68**	0.82***
HLa	−0.04	0.62*	0.80***	0.92***	0.60*	0.75***
(N = 6)						

* *P* < 0.05; ** *P* < 0.02; *** *P* < 0.01.

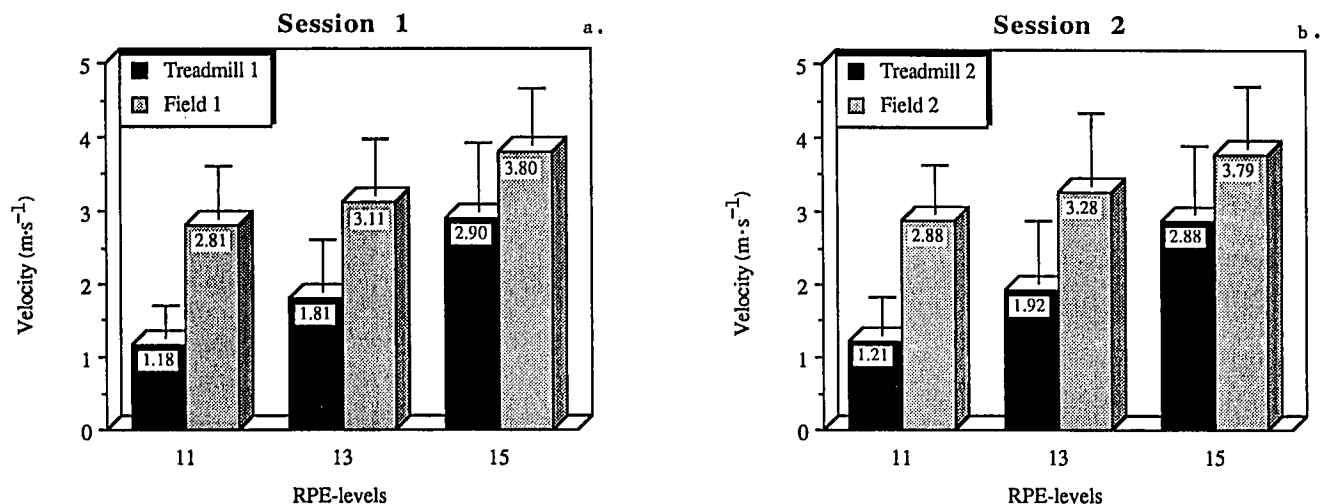


Figure 1—The obtained velocities (in $\text{m}\cdot\text{s}^{-1}$) at the three RPE levels during sessions 1 (a) and 2 (b) are shown for both treadmill and field running. Mean values are shown and standard deviations indicated for each bar; $N = 11$.

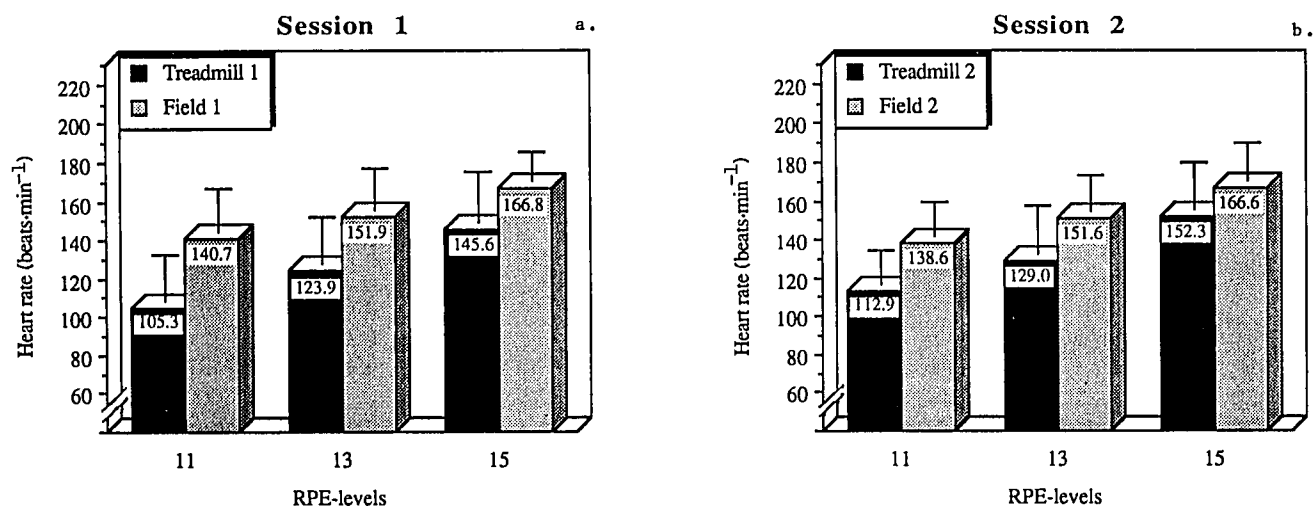


Figure 2—The obtained heart rates (in $\text{beats}\cdot\text{min}^{-1}$) from sessions 1 (a) and 2 (b) are shown at the three RPE levels for both treadmill and field running. Mean values are shown and standard deviations indicated for each bar; $N = 11$.

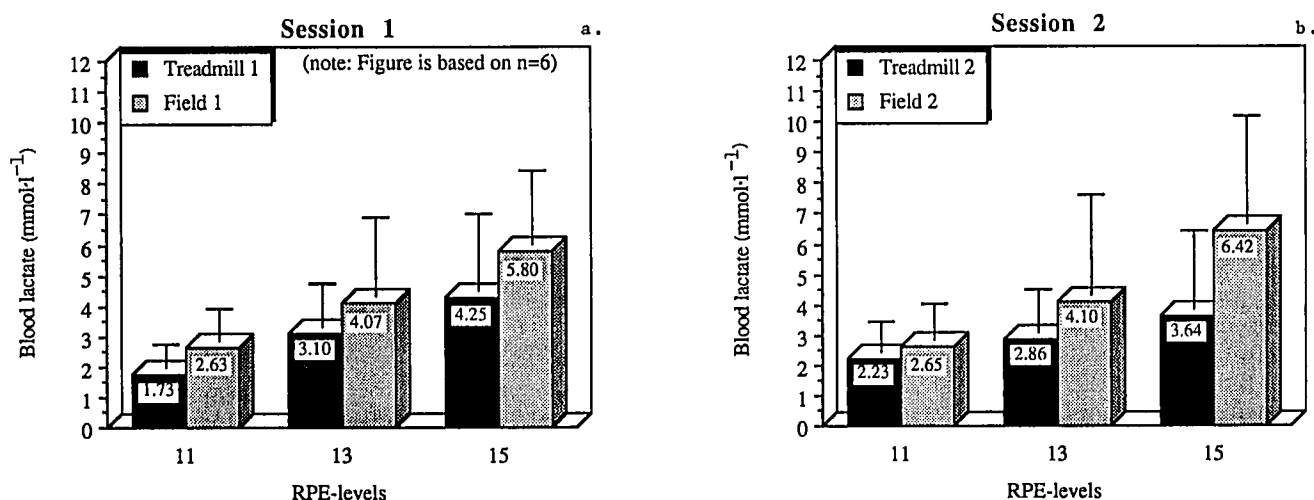


Figure 3—Blood lactate concentrations (in $\text{mmol}\cdot\text{l}^{-1}$) from sessions 1 (a) and 2 (b) are shown at the three RPE levels for both treadmill and field running. Mean values are shown and standard deviations indicated for each bar; $N = 6$ (a) and $N = 11$ (b).

In Figure 1, velocity (in $\text{m}\cdot\text{s}^{-1}$) is presented in relation to the three RPE levels. HR (Fig. 2) and HLa (Fig. 3) are shown in a similar fashion.

A significant difference was found between all variables obtained at the three different subjective intensity levels used as instructions (RPE 11, 13, and 15) for both session 1 ($P < 0.02$) and session 2 ($P < 0.003$).

RPE control estimates did not deviate to any large extent from the intended RPE levels. Obtained average standard deviations were approximately 0.35 and 0.21 in treadmills 1 and 2, respectively. In the field situation, the standard deviations were 0.31 and 0.39 in sessions 1 and 2, respectively.

The difference between treadmill and field exercise was highly significant, especially in velocity and HR data. This difference was consistent over variables and time; that is, values of v ($P < 0.001$), HR ($P < 0.001$), and HLa ($P < 0.05$), in both sessions 1 and 2, were significantly higher in the field situation despite the fact that subjects were given identical instructions in the two situations.

For v values, there was no significant difference over time, that is, from session 1 to session 2. For HR, however, there was a significant difference ($P < 0.025$) between sessions 1 and 2 on the treadmill but not in the field (Figs. 1 and 2).

Since HLa samples were partly damaged, lactate concentrations were analyzed for six of the total group of subjects. It was found that HLa data did not differ significantly between sessions 1 and 2, during either treadmill or field conditions (Fig. 3).

A high test-retest reliability was established for both situations and sessions (over time) through the calculation of Cronbach's alpha coefficients on RPE 11 data. Both v and HR levels could be reproduced with alpha coefficients ≥ 0.9 . Also, Pearson product-moment correlation coefficients (r_{xy}) for the same data were found

to be of similar magnitudes, with a tendency to increase during session 2.

Likewise, r_{xy} calculations were made on data obtained from the different variables between sessions 1 and 2 (see Table 1). These coefficients were found to be very high in general, with a tendency toward higher values in the field situation and at the highest intensity level (RPE 15). Velocity data gave consistently higher correlations compared with HR and HLa data.

In Figure 4, linear regression analyses were made on data plots from HR values related to speed from both sessions. It can be seen that regression coefficients for treadmill data differ from field coefficients. r_{xy} values were also calculated and were found to be significantly higher ($P < 0.05$) in the field situation in session 2 as compared with session 1. Correlations were not significantly higher in the treadmill situation as compared with the field situation.

Wind velocity, temperature, and humidity were measured. Both temperature and humidity were significantly different between the laboratory and field situations. In addition, mean wind velocities of about $4.30 \text{ m}\cdot\text{s}^{-1}$ were measured in the outdoor situation. However, there was no significant difference in either temperature or humidity over time, for either treadmill or field.

DISCUSSION

The aim of the present study was to investigate the functionality of the RPE scale as a means of regulating exercise intensity during running, as well as to compare exercise performed on a treadmill with a field situation over a period of 4 wk. The results obtained (mainly presented in Figs. 1–3 and Table 1) show significantly different intensity levels in all main variables (i.e., v ,

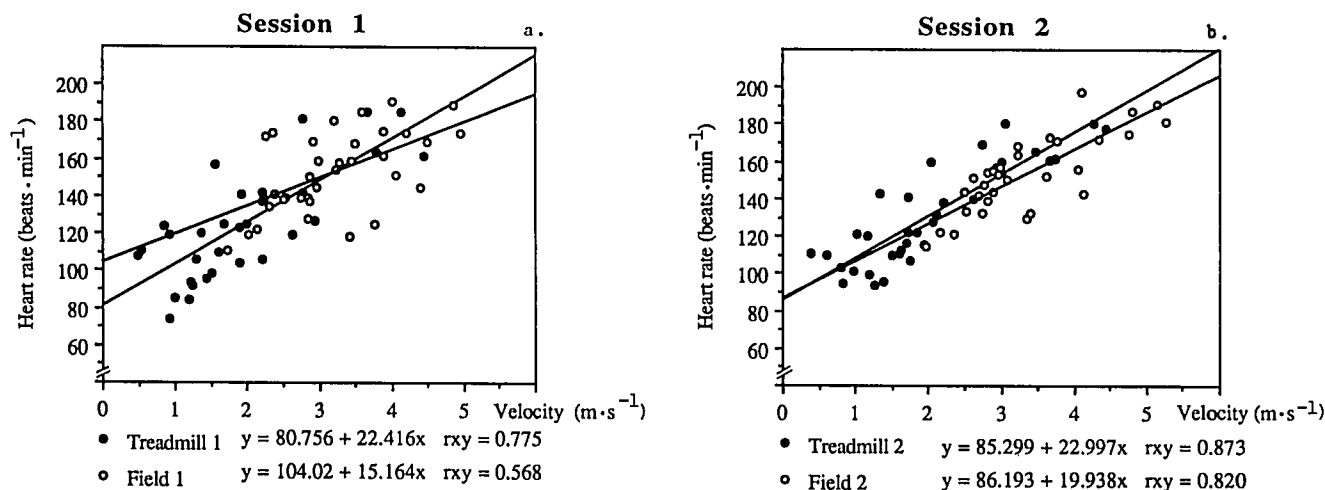


Figure 4—A comparison between the obtained treadmill and field heart rates (in $\text{beats}\cdot\text{min}^{-1}$), from the three different RPE levels, in relation to velocity (in $\text{m}\cdot\text{s}^{-1}$) during sessions 1 (a) and 2 (b). Linear regressions have been calculated.

HR, and HLa) in relation to the scale levels used on the RPE scale. These results are in agreement with previous studies where different verbal instructions have been used (9,11,16,17). While these studies have demonstrated the possibility of producing such exercise intensities based solely on verbal or numerical instructions, few studies have used RPE intensities and tested incremental differences.

Two different measures of reliability have been considered in this study. First, a test-retest reliability was calculated according to the alpha coefficient between the two successive RPE 11 intensities. It was evident from this analysis that a high reproducibility existed for all dependent variables in the study. Furthermore, this calculation showed an apparent increase of intra-reliability in the second test session.

For the second measure of reliability, product-moment correlations were calculated between variable values from session 1 and session 2. The coefficients from these calculations were presented in Table 1 for all three intensities investigated. For v , the coefficients were around 0.90 and 0.93 for treadmill and field running, respectively. This implies that there was a high internal consistency in the data between sessions; i.e., the subjects were able to reproduce, with fairly high precision, a certain velocity based on a verbal/numerical instruction of perceived intensity after a period of 4 wk. Furthermore, it seems that this reproduction functioned even better in the field situation.

Figure 4 shows HR related to treadmill and outdoor running velocities, from both sessions. The obtained correlation coefficients were slightly (but not significantly) higher in the treadmill than in the field situation. In session 2, however, the magnitudes of the correlation coefficients between situations are more equal (0.82 vs 0.87). Furthermore, in session 2 a significantly higher correlation was obtained in the field situation as compared with session 1. Although these results should be treated with some caution, it could be the case that the higher correlations are a result of the field training performed by the subjects. It should be noted that Figure 4 is based on data in which the same individuals appear on three different occasions, that is, data derived from all three RPE levels.

The question remains of whether the pronounced difference between laboratory and field—or “environmental effect”—was obtained owing to extraneous perceptual mechanisms, such as the processing of external information vs internal cues (27). Some factors could act as “reducers” of relevant sensory input through involvement of “concurring” senses (e.g., vision, auditory noise, and thermal sensations). This may seem to be in opposition to the RPE *gestalt* concept put forward in the earlier work by Borg (5). However, it should be pointed out that the perception of a *gestalt* is dependent upon the components of the stimulus configuration;

thus, if those components are altered, the perceptual configuration will also be affected (Borg, personal communication, 1990).

Previous studies (25,26) have investigated the impact of climatic factors on RPE and different physiological parameters (e.g., HR, ventilation, and oxygen uptake). According to these studies, RPE is more or less unaffected by alterations in temperatures between 0° and 20°C. Since humidity varied within normal limits during the tests (50–80% relative humidity), it should have had no effect on perceived exertion or physiological responses at the actual temperatures. Nor should wind velocity have influenced the results to any great extent; the measured wind velocities—in the field condition—were well below the limits that have been found to cause excessive energy loss, as studied by Davies (14). Furthermore, there seems to be general agreement that the oxygen demand for horizontal running is similar for both the treadmill and field situations at velocities not exceeding 4.3 m·s⁻¹ (2,18,31). In the present study, the highest mean velocities were typically around 3.9 m·s⁻¹ in the field and just above 2.8 m·s⁻¹ in the laboratory.

Thus, even though some external factors may have influenced the way these subjects perceived exertion in the field situation, there was a clear difference between the two situations. This leads to the suggestion that it is crucial whether a prescription of exercise intensity, based on the RPE scale, is based on the treadmill or upon a test performed in a more natural setting. The latter is preferred if the exercise is intended for the same environment. However, it is not common to perform clinical tests, for example with cardiac patients, in such uncontrolled situations as offered in the field. A solution might then be to make corrections in the data collected in the laboratory to be safely used for outdoor exercise. From the data collected in the present study, it seems that a subtraction with approximately two RPE units *from* the treadmill *to* the field situation yields corresponding levels in both velocities and physiological strain. This is clearly seen in Figures 1–3 when comparing the results, mainly between the RPE 13 and 15 levels.

According to ACSM guidelines (1), exercise intensity should vary between 65% and 90% of maximal heart rate reserve to reach optimal effectiveness. Naturally this applies to healthy people. Patients, if allowed to exercise, should probably keep to the lower end of this range. It seems, from the results of this study, that training intensity according to the RPE scale should be kept at or below RPE 13 in the field and RPE 15 on the treadmill, especially for exercise prescriptions intended for individuals who are unfit or suffering from disease.

In conclusion, using RPE ratings as a way of monitoring and regulating exercise intensity seems to func-

tion well. The results showed a high level of consistency in the data, both within and between sessions. There were great absolute differences between results from the treadmill and those from the outdoor track. Generally, the values obtained during the outdoor run were significantly higher than those for the treadmill run; this holds for all measured variables. Obviously this could result in problems regarding how hard a subject/patient really is exercising in the field. However, with this

caution in mind, training according to the RPE scale might be preferable since the subjects will not constantly be forced to monitor their heart rates.

This study was supported by a research grant to Prof. Gunnar Borg from the Bank of Sweden Tercentenary Foundation (No. 85/291).

Address for correspondence: Ruggero Ceci, Division of Perception and Psychophysics, Department of Psychology, University of Stockholm, S-106 91 Stockholm, Sweden.

REFERENCES

1. AMERICAN COLLEGE OF SPORTS MEDICINE. *Guidelines for Exercise Testing and Prescription*, 3rd Ed. Philadelphia: Lea & Febiger, 1986, pp. 31-71.
2. BASSETT, D. R., JR., M. D. GIESE, F. J. NAGLE, A. WARD, D. M. RAAB, and B. BALKE. Aerobic requirements of overground versus treadmill running. *Med. Sci. Sports Exerc.* 17:477-481, 1985.
3. BIRK, T. J. and C. A. BIRK. Use of ratings of perceived exertion for exercise prescription. *Sports Med.* 4:1-8, 1987.
4. BMDP. *Statistical Software*. Berkeley: University of California, 1981.
5. BORG, G. A. V. *Physical performance and perceived exertion*. Lund, Sweden: Gleerup, 1962.
6. BORG, G. A. V. Perceived exertion as an indicator of somatic stress. *Scand. J. Rehabil. Med.* 2-3:92-98, 1970.
7. BORG, G. A. V. Ett enkelt konditionstest för gemene man. *Reports from the Institute of Applied Psychology, the University of Stockholm* 10:1-7, 1970.
8. BORG, G. A. V. and H. LINDERHOLM. Perceived exertion and pulse rate during graded exercise in various age groups. *Acta Med. Scand. Suppl.* 472:194, 1967.
9. BORG, G. A. V., A. HERBERT, and R. CECI. Some characteristics of a simple run test and its correlation with a bicycle ergometer test of physical working capacity. *Reports from the Department of Psychology, the University of Stockholm* 625:1-10, 1984.
10. BURKE, E. J. and M. L. COLLINS. Using perceived exertion for the prescription of exercise in healthy adults. In: *Clinical Sports Medicine*, R. C. Cantu (Ed.). The Collamore Press, D.C. Heath and Company, 1984, pp. 93-105.
11. CECI, R., G. A. V. BORG, P. BORG, and S.-E., JOHANSSON. Perceived exertion, heart rate and blood lactate in downhill skiing as compared to cross-country skiing—a pilot study. In: *The Perception of Exertion in Physical Work*, G. Borg and D. Ottoson (Eds.). Wennergren International Symposium Series 46:303-314, 1986.
12. CHOW, R. J. and J. H. WILMORE. The regulation of exercise intensity by ratings of perceived exertion. *J. Cardiac Rehabil.* 4:382-387, 1984.
13. CHRONBACH, L. J. Coefficient alpha and the internal structure of tests. *Psychometrika* 16:297-334, 1951.
14. DAVIES, C. T. M. Effects of wind assistance and resistance on the forward motion of a runner. *J. Appl. Physiol.* 4:702-709, 1980.
15. DISHMAN, R. K., R. W. PATTON, J. SMITH, R. WEINBERG, and A. JACKSON. Using perceived exertion to prescribe and monitor exercise training heart rate. *Int. J. Sports Med.* 8:208-213, 1987.
16. EDGREN, B. and G. A. V. BORG. The reliability and stability of the indicators in a simple run test. *Reports from the Institute of Applied Psychology, the University of Stockholm* 57:1-37, 1975.
17. EKBLOM, B., W. C. DAY, L. H. HARTLEY, F. MOORE, and R. WEAR. Reproducibility of exercise prescribed by pace description. *Scand. J. Sports Sci.* 1:16-19, 1979.
18. ESTON, R. G., B. L. DAVIES, and J. G. WILLIAMS. Use of perceived effort ratings to control exercise intensity in young healthy adults. *Eur. J. Appl. Physiol.* 56:222-224, 1987.
19. GUTMANN, M. C., R. W. SQUIRES, M. L. POLLOCK, C. FOSTER, and J. ANHOLM. Perceived exertion-heart rate relationship during exercise testing and training in cardiac patients. *J. Cardiac Rehabil.* 1:52-59, 1981.
20. HAGE, P. Perceived exertion: one measure of exercise intensity. *Physician Sportsmed.* 9:136-146, 1981.
21. LOWRY, O. H. and J. V. PASSONNAU. *A Flexible System of Enzymatic Analysis*. New York: Academic Press, 1972.
22. MORGAN, W. P. and G. A. V. BORG. Perception of effort in the prescription of physical activity. In: *The Humanistic and Mental Aspects of Sports, Exercise and Recreation*, T. T. Craigh (Ed.). Chicago: American Medical Association, 1977, pp. 126-129.
23. MYLES, W. S. and D. MACLEAN. A comparison of response and a production protocols for assessing perceived exertion. *Eur. J. Appl. Physiol.* 55:585-587, 1986.
24. NOBLE, B. J. Clinical applications of perceived exertion. *Med. Sci. Sports Exerc.* 14:406-411, 1982.
25. NOBLE, B. J., K. F. METZ, K. B. PANDOLF, and E. CAFARELLI. Perceptual responses to exercise: a multiple regression study. *Med. Sci. Sports* 4:104-109, 1972.
26. PANDOLF, K. B., E. CAFARELLI, B. J. NOBLE, and K. F. METZ. Perceptual responses during prolonged work. *Percept. Mot. Skills* 35:975-985, 1972.
27. PENNEBAKER, J. W. and J. M. LIGHTNER. Competition of internal and external information in an exercise setting. *J. Pers. Soc. Psychol.* 39:165-174, 1980.
28. ROBERTSON, R. J., R. L. GILLESPIE, J. MCCARTHY, and K. D. ROSE. Differentiated perceptions of exertion: Part II. Relationship to local and central physiological responses. *Percept. Mot. Skills* 49:691-697, 1979.
29. SMUTOK, M. A., G. S. SKRINAR, and K. B. PANDOLF. Exercise intensity: subjective regulation by perceived exertion. *Arch. Phys. Med. Rehabil.* 61:569-574, 1980.
30. VAN DEN BURG, M. T. C. and R. CECI. A comparison of a psychophysical estimation and a production method in a laboratory and a field condition. In: *The Perception of Exertion in Physical Work*, G. Borg and D. Ottoson (Eds.). Wennergren International Symposium Series 46:35-46, 1986.
31. VAN INGEN SCHENAU, G. J. Some fundamental aspects of the biomechanics of overground versus treadmill locomotion. *Med. Sci. Sports Exerc.* 12:257-261, 1980.