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PERCEIVED EXERTION AS PART OF A BEHAVIOURAL FEEDBACK SYSTEM FOR ARRANGEMENT OF STRAIN DURING PHYSICAL EXERCISE

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ABSTRACT

On the basis of a hypothetic system which enables human beings to arrange the degree of exertion in an advantageous manner, experiments with Borg's scale for ratings of perceived exertion are described. The perceived exertion can be scored with a good reproducibility and linearity, even in the very first experiments. For young girls it could be demonstrated that a learning process exists during adolescence. With increasing speed of pedalling rate between 40 and 100 rpm the perceived exertion for the same loads decreases, leading to higher degrees of exertion in experiments with the self-setting of performance. The results support the assumption, that as regards the metabolic processes during heavy exercise the human being can be compared rather to a very complicated cybernetic machine than to a simple engine.

In most physiological studies the transformation of energy in man during heavy exercise is regarded as similar to that of a machine. However, a strenuously working human being is more than a simple machine, he is able to arrange his degree of strain by means of a programme which is adjusted to a space of time or distances. Such phenomena are well known in sports (e.g. in a cycle race of 1 hour or in long-distance running) and can be also demonstrated in hard working labourers (e.g. miners, steel workers, saisonal work of farmers or lumber men). With regard to these adjustment phenomena the human being seems to be at least a cybernetic machine with a feedback system for advantageous arrangement of strain during heavy exercise.

This concept can be explained by means of the following hypothetic scheme[13] (Fig. 1) : Based on feedback information from the muscle and other parts of the body, an integrating centre arranges the degree of strain. The muscular innervation regulates not only the stereotype of movement, but also the degree of strain. The integrating centre is connected with a programme unit, but it is also influenced by endogenous stimuli, e.g. by stimuli in mortal fear which deliver the emergency reserves[5].

What are the proofs for such considerations? During World War II Kraut[8,9] observed the work intensity of miners and other hard working labourers. The

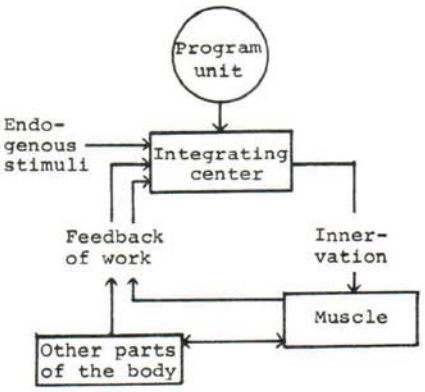

FIG. 1 – Hypothetic scheme for the advantageous arrangement of strain during heavy exercise (according to[13]).

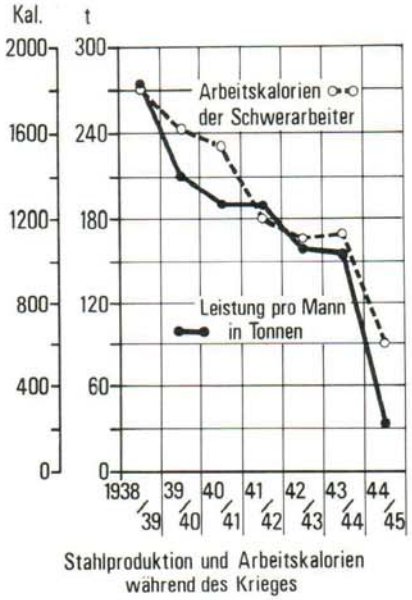

FIG. 2 – Relation between decreasing caloric intake ("Arbeitskalorien") and steel production per worker ("Leistung pro Mann") during World War II (according to[8]).

reduction of caloric intake led to a well adjusted, decreased intensity of work (Fig. 2), in most cases without symptoms of self-overloading. In a critical experiment he demonstrated that a special motivation such as offering cigarettes increased the intensity of work at the expense of diminution of the body weight (Fig. 3). In our experiments (Fig. 4) 4 cyclists pedalled on an ergometer with the task to set the intensity of effort by themselves so as to reach a maximum during one hour. In these experiments oscillations in the performance could be observed, typical of regulating systems. With the increasing pedalling rate the degree of physiological strain increased (Fig. 5). By means of the increased strains the negative effect of pedalling rate on efficiency was partially compensated so that the same mean loads resulted from the 60 and 90 rpm experiments.

The experiments with Borg's RPE-scale for ratings of perceived exertion yielded information about some perceptual mechanisms[1,2,4]. This scale (Fig. 6) consists of 15 numerals with items between "very, very light" and "very, very hard". Using this scale our subjects had no difficulties in scoring their perceived exertion, even in the very first experiments[12]. The intraindividual reproducibility (Fig. 7) was within $\pm$ 1 score, described by ten-fold repeated experiments with 10 subjects, working on a bicycle ergometer with loads corresponding to stress categories of 50, 100, 150 and 200 watt or strain categories with loads, depending

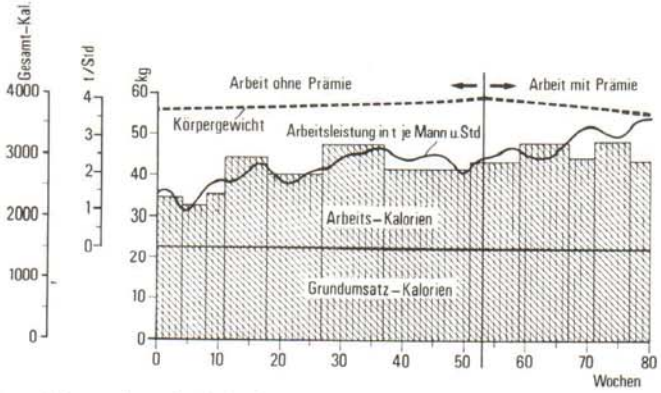

FIG. 3 – Effect of increasing caloric intake ("Arbeit ohne Prämie") or motivation (by offering cigarettes "Arbeit mit Prämie") on self-setting of performance ("Arbeitsleistung in t je Mann und Stunde") during heavy exercise (loading goods wagons, according to[9]).

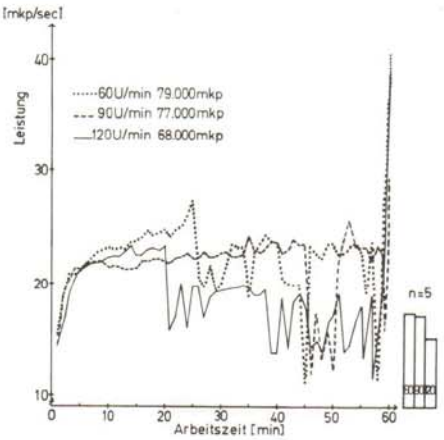

FIG. 4 – Behaviour during self-setting of load in 1-hour-experiments with racing cyclists. Aim: maximum of 1-hour-performance at 60, 90 and 120 rpm on an ergometer. Curves: examples of 1 subject. Bars: mean load of 5 experiments with 4 cyclists each (according to[11]).

on the state of fitness: 20, 40, 60, 80, 100 and 120% of individual W_{170}. In these experiments not only the reproducibility was good, but also the linearity (Fig. 8).

For an inverse experimental situation the RPE-scores were given to the subjects and they had to arrange loads on a bicycle ergometer by themselves. During the work period of 15 minutes two types of behaviour could be observed[13]. For low RPE-scores the self-setting of load increased continuously reaching a plateau, whereas in high RPE-scores an increasing-decreasing behaviour was observed (Fig. 9). The heart rate, however, showed a similar course in all cases, only at different levels.

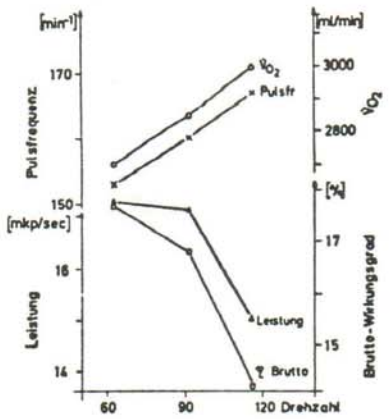

FIG. 5 – Mean strain values (heart rate, $\dot{V}_{O_2}$), load and efficiency in the experiments in Figure 4.

6
7 Very, very light
8
9 Very light
10
11 Fairly light
12
13 Somewhat hard
14
15 Hard
16
17 Very hard
18
19 Very, very hard
20

FIG. 6 – Borg's scale for ratings of perceived exertion (RPE;[1,2]).

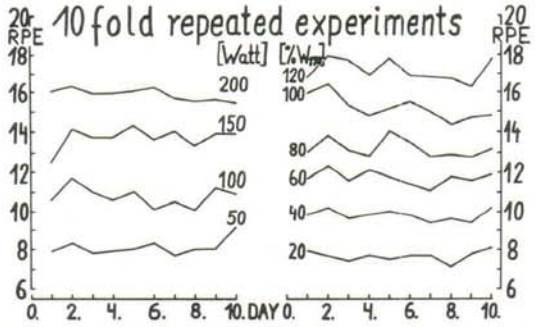

FIG. 7 – Reproducibility of the RPE-scores in repeated experiments with 10 subjects (according to[12]).

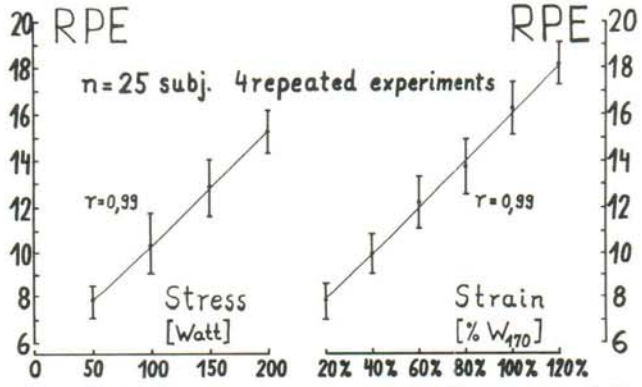

FIG. 8 – Linearity of RPE-scores, related to steps of stress (Watt) or strain ($\%W_{170}$); (according to[12]).

In further experiments it could be demonstrated, that the perceived exertion depends on the speed of movement[6,10]. With increasing pedalling rates from 40 to 100 rpm the perceived exertion decreased for equal loads. The influence of the state of fitness on scoring, however, was very small. Only in higher RPE-values the subjects with higher degrees of fitness scored for the same loads lower RPE--values than those with low fitness.

Finally in four-fold repeated experiments on children we observed the precision of scoring RPE-values[7]. Young girls, active in sports, between 7 and 11 years of age, were loaded on a bicycle ergometer with five different degrees of strain (percentages of W_{170}). The mean intraindividual standard deviation for the repeated experiments is shown in Figure 10. The intraindividual reproducibility decreased distinctly from the 7 to the 11 years group with increasing age, the s_d of the 11-year-old girls was half that of the 7-year-old.

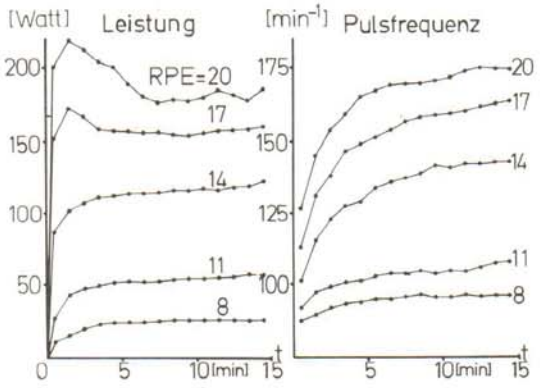

FIG. 9 – Mean behaviour of 5 subjects in experiments with given RPE-scores and self-setting of performance. Left side: setting of load, right side: reaction of heart rate (according to[13]).

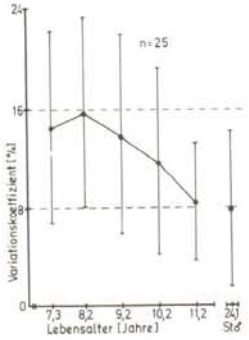

FIG. 10 – Mean intraindividual reproducibility of perceived exertion in experiments with girls between 7 and 11 years old. For comparison: male students, 24.1 years of age (according to[7]).

CONCLUSION

All experiments concerning perceived exertion during heavy exercise confirm a mechanism, which is obviously learned in the course of everyday experience. This learning effect was seen in the girls aged between 7 and 11 years and is confirmed by the fact, that in male adults we found no difficulties in scoring perceived exertion, even in the very first experiment.

With the RPE-scores it is possible to describe the intensity of work as well as to determine a certain degree of exertion in the self-setting experiments. Therefore we see the perceived exertion and other mechanisms[3] as part of a feedback system which enables human beings to arrange their degree of exertion in an advantageous way. An influence on perceived exertion must influence the self-set exertion too. Indeed, this effect could be demonstrated in the cyclist's

experiments of 1 hour. The increasing pedalling rate effects a smaller perceived exertion for the same loads, which consequently leads to higher self-set exertions. Therefore it remains to discuss, whether the curious effect, that perceived exertion is more dependent on stress (load) than on strain, could handicap those, who have to set the exertion during heavy work by themselves. Summarizing, the experiments with perceived exertion confirm the assumption, that the heavy working human being is comparable to a complicated cybernetic machine and not only to a simple engine.

REFERENCES

1. *Borg, G.* Perceived exertion as an indicator of somatic stress. Scand. J. Rehabil. Med., **2** (1970) 92–98.
2. *Borg, G., ed.* Physical work and effort. Wenner-Gren Center, Int. Symp. Series, vol. 28; Oxford–New York–Toronto–Sidney–Paris–Frankfurt, Pergamon Press 1977.
3. *Cafarelli, E.* Peripheral and central inputs to the effort sense during cycling exercise. Eur. J. Appl. Physiol., **37** (1977) 181–189.
4. *Edwards, R.H.T., Melcher, A., Hesser, C.M., Wigertz, O. and Ekelund, L.-G.* Physiological correlates of perceived exertion in continuous and intermittent exercise with the same average power output. Eur. J. Clin. Invest., **2** (1970) 108–114.
5. *Graf, O.* Arbeitsablauf und Arbeitsrhythmus. In: Lehmann, G., ed. Handbuch der gesamten Arbeitsmedizin. Bd. 1: Arbeitsphysiologie. Berlin – München – Wien, Urban und Schwarzenberg, 1961.
6. *Gross, R., Wilbert, G., Löllgen, H. und Ulmer, H.-V.* Der Einfluß von Tretgeschwindigkeit und Schwungmasse auf das Leistungsempfinden bei Fahrradergometerarbeit. Pflügers Arch., **347,** Suppl. (1074) R 25.
7. *Kable, C., Ulmer, H.-V. and Rummel, L.* The reproducibility of Borg's RPE-scale of female pupils from 7 to 11 years of age. Eur. J. Physiol., **368,** Suppl. (1977) R 101.
8. *Kraut, H.* Die ernährungsphysiologischen Grundlagen der Arbeitsleistung. Zentralbl. Arbeitswiss., **1** (1947) 121–126.
9. *Kraut, H.* Der Nahrungsbedarf des körperlich Arbeitenden. Ärztl. Wochenschr., **3** (1948) 499–504.
10. *Löllgen, H., Ulmer, H.-V., Gross, R., Wilbert, G. and v. Nieding, G.* Methodical aspects of perceived exertion rating and its relation to pedalling rate and rotating mass. Eur. J. Appl. Physiol., **34** (1975) 205–215.
11. *Ulmer, H.-V.* Zur Methodik, Standardisierung und Auswertung von Tests für die Prüfung der körperlichen Leistungsfähigkeit. Köln-Lövenich: Deutscher Ärzte-Verlag 1975.
12. *Ulmer, H.-V., Görtz, W., Janz, U. and Stein, H.-P.* Borg's RPE-scale, a method for estimating physical performance in field experiments. In NATO, ed.: Proc. (Res. Study Group) Seminar on Symposium Physical Fitness with Special Reference to Military Forces, 1. – 5. April 1978, Toronto/Canada. pp. 127–130. Published by Defence and Civil Institute of Environmental Medicine, Toronto/Canada 1978.
13. *Ulmer, H.-V. und Wiesberg, K.* Einteilung des Leistungseinsatzes bei vorgegebenen Anstrengungsgraden (Borg-Skala) verschiedener Intensität im Verlauf einer 15-minutigen Ergometerarbeit. Z. Arb. Wiss., **32** (4 NF) (1978) 77–80.