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Acid-Base Balance and Subjective Feelings of Fatigue during Physical Exercise

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Abstract. Six trained male subjects performed exercise on a bicycle ergometer. The external load was increased every minute by 10 watt until exhaustion. The subjects quantified their subjective feeling of fatigue by means of a rating scale.

Parameters of acid-base balance (pH, p_{CO_2}) were determined in arterial blood from the a. brachialis.

Correction of the acidaemia by infusion of $NaHCO_3$ (8 %) during exercise had no effect upon the subjective feeling of fatigue, and except for carbon dioxide output no effect upon some important physiological functions (heart rate, blood pressure, ventilation, and oxygen consumption) during submaximal and maximal exercise.

Key words: Acid-Base Balance — Fatigue — Subjective Assessment — Exercise.

Introduction

Fatigue may be defined as a reversible state of decreased physical and mental work capacity, resulting from preceeding work (Schmidtke, 1965; Nitsch, 1970; Simonsen, 1971). This state of decreased capacity is accompanied by a number of physiological and biochemical changes and by subjective feelings. Some of these physiological and biochemical changes are functionally and causally related to the decrement of the work capacity, as for example the muscle glycogen content (Hermansen *et al.*, 1976; Bergström *et al.*, 1967; Karlsson and Saltin, 1971) and some others are only related to the work output (ventilation).

The subjective feelings of fatigue can be operationalized and measured in angle degrees as described by Hueting (1964, 1968) and Hueting and Sarphati (1966). Significant intercorrelations were found between systematically varied dynamic work loads and physiological and psychological responses to these loads. It was also shown that the assessment of subjective feelings of fatigue during exercise provides a greater discriminating power between non-trained and trained subjects than measurement of heart rate (Hueting *et al.*, 1969), as was likewise the case for the discriminative power between different static muscle loads (Janssen and Docter, 1973).

Depending upon intensity and duration of exercise performance there exists a disturbance of acid-base balance. A decrease of pH of arterial blood during work has been found by many investigators (Bouhuys *et al.*, 1966; Doll and Keul, 1968; Keul *et al.*, 1966; Roth *et al.*, 1969; Scherrer, 1969). In the literature a number of effects of acid-base changes due to physical exercise on various physiological functions are mentioned.

The excitability behaviour, the contractile apparatus and the energy-yielding processes of the muscle cell may be affected (Kayser, 1970; Piiper, 1971; Hirche *et al.*, 1973; Haralambie, 1973; Jung and Gadermann, 1973). In addition to these intracellular changes the function of the nervous system and of the heart may be altered (Piiper, 1971; Haralambie, 1973).

It is not clear whether the chemical change of blood buffer capacity will have any effect on physical performance. The effect of ingestion of Na-bicarbonate upon maximum performance and maximum lactic acid concentration has been investigated by Dennig *et al.* (1931, 1940), Dorow *et al.* (1940) and Margaria *et al.* (1971). Dennig and Dorow observed an improvement in performance in swimmers and runners, Margaria did not find any effect of bicarbonate-induced alkalosis neither on the maximal performance of subjects performing a supramaximal exercise nor on the total amount of lactic acid or its rate of appearance in blood.

A few attempts have been made to affect maximal performance by ingestion of tris-hydroxymethyl-aminomethane (THAM). Rummler and Brummer (1966) found in addition to an effect on the acid-base status of the blood an increase in swimming performance time of rats. On the other hand Staib *et al.* (1964) who did a comparable investigation could not confirm Rummlers' data.

It is generally accepted that the subjective feelings of fatigue are based upon metabolic, circulatory, physicochemical and other measurable changes; however the correlation may not be close. Disturbance of acid-base balance may be one of the underlying physiological processes. It may be as well one of the factors determining the decrement of maximal performance due to a disturbance of functions, not only decreasing supply of anaerobic but also of aerobic energy.

To verify this hypothesis it will be necessary to manipulate some of these physiological processes experimentally. In this framework we studied by means of infusion of $NaHCO_3$ the effect of correction of acid-base disturbance during physical exercise upon the rating of the subjective feelings of fatigue and upon some physiological parameters closely related to work-output.

Methods and Materials

Six trained male subjects, aged 18 to 25 years, performed exercise at a bicycle ergometer. The external load was increased every minute by 10 watt until exhaustion. This test was repeated four times with intervals of one week each on the same day of the week and at the same time of the day.

Day I and IV served as control experiments. At day II a small catheter was inserted in a superficial vene of the arm through which NaCl (0.9%) was infused at a low speed. Another catheter in the a. brachialis of the other arm was used to sample blood for biochemical analysis and for continuously direct bloodpressure measurements. This experiment served as blanco. At day III the course of the experiment was the same as at day II, except that the NaCl was replaced by a $NaHCO_3$ (8%) infusion in order to correct a change in acid-base balance. The total amount of $NaHCO_3$ needed was calculated from the results of the test on day II, according to the formula of Mellemgaard and Åstrup (1960): bicarb. mEq. needed = body weight (kg) × 0.3 BD (BD = base deficit, the excess of fixed acid in mEq per liter blood, compared with blood with a pH of 7.4 and a p_{CO_2} of 40 mm Hg). The $NaHCO_3$ infusions started at the beginning of the experiments and depending on the observed changes in base-deficit in test II the rate of administration was increased.

The average total amount of $NaHCO_3$ infused in these experiments was 270 ml (sd 60). The subjects were unaware which of the fluids was used and they were not informed about the purpose of the experiment.

Subjective feelings of fatigue, heart rate, blood-pressure, ventilation, oxygen consumption were measured every 10th minute and at exhaustion just before the subject had to give up. Every 5th minute and at exhaustion a sample of arterial blood was taken in which pH and p_{CO_2} were determined.

The subjects indicated their subjective feeling of fatigue using a display (volt meter) with a scale divided into 90 degrees (method according to Hueting, 1968). By pressing a push button they were able to move a pointer on the scale. The zero position indicates "no subjective feeling of fatigue", the 90 degrees position indicates "maximal feeling of fatigue", i.e. the subject is unable to sustain the load any longer.

Heart rate was measured by means of a cardiotachometer; blood pressure was measured using an Elema-Schönander transducer EMT-35 and electromanometer EM-31. For the determinations of $\dot{V}_{O_2}$ and $\dot{V}_{CO_2}$ expired air was collected in Douglas bags and analyzed by a paramagnetic O_2 analyzer and an infrared absorption CO_2 analyzer.

The expired air volume was measured with a gasometer and corrected to STPD, pH and p_{CO_2} were measured in arterial blood according to the micro Astrup method.

The data were treated as paired observations using Wilcoxon's symmetry test. The null hypothesis was rejected at the 5% level.

Results

The mean and standard deviations of maximum performance at different days were: day I 335.0 watt (37.6), day II 340.4 watt (26.2), day III 338.8 watt (33.1), day IV 340.2 watt (32.4).

The differences in these maximum performances were not significant. The effects of the infusion of $NaHCO_3$ upon H-ion concentration, p_{CO_2} and base excess are plotted against percentages of maximal work load of experiment II (Table 1). The bottom line in the table shows statistical significance of differences between the values of experiment II and III. From these results it can be seen that in experiment III it was possible to keep the H-ion concentration during work practically at rest levels.

Table 1. Means (m) and standard deviations (s.d.) of H-ions concentration, p_{CO_2} and base excess in arterial blood at rest and during work without (day II) and with (day III) infusion of $NaHCO_3$

			Rest	Work (% of maximum work-load of day II)					
				30	45	60	75	90	100
H-ions conc. (art.)	day II	m	41.8	41.7	42.7	43.8	46.2	50.2	60.2
(nmol/l)		s.d.	1.6	2.3	2.6	2.5	1.9	2.1	7.5
	day III	m	40.8	41.7	42.0	41.7	39.2	40.5	45.0
		s.d.	2.8	1.5	1.8	1.8	2.4	2.5	4.3
significance of difference II—III			–	–	–	+	+	+	+
p_{CO_2} (art.)	day II	m	40.3	40.4	41.1	40.3	39.4	32.8	29.7
(mm Hg)		s.d.	2.4	2.8	3.8	2.8	5.5	3.7	4.5
	day III	m	39.2	40.2	40.7	41.2	39.0	36.3	34.4
		s.d.	3.3	3.9	4.2	2.7	3.2	3.0	2.1
significance of difference II—III			–	–	–	–	–	+	+
Base excess (art.)	day II	m	– 1.2	– 1.2	– 1.5	– 2.7	– 4.6	– 9.5	– 15.5
(mmol/l)		s.d.	1.4	1.7	1.8	1.1	1.5	1.6	3.7
	day III	m	– 1.1	– 1.1	– 1.1	– 0.8	– 0.1	– 2.0	– 5.8
		s.d.	2.4	2.1	1.6	1.3	1.0	2.6	2.9
significance of difference II—III			–	–	–	+	+	+	+

A linear regression equation between the rating of the subjective feelings of fatigue and work load was calculated for each trial; from these equations the external load (watt) at respectively 0, 30, 50, 70 and 90 degrees on the rating scale was calculated. There were no significant differences in external load at the different degrees of fatigue between the test days.

Heart rate increased during the work period up to 194.0 beats/min on day II and to 191.2 beats/min on day III respectively without significant differences; as was the case for the observed changes in submaximal and maximum systolic and diastolic blood pressure. The maximum values for systolic and diastolic blood pressure at day II were respectively 180.8 mm Hg and 99.3 mm Hg and at day III 182.1 mm Hg and 95.0 mm Hg.

There were no significant differences in submaximal values obtained for O_2-consumption, CO_2-output and ventilation; of the maximum values only the CO_2-output at day III (5390 ml/min) was significantly higher in comparison to the value at day II (4690 ml/min); the mean values for O_2 consumption at day II and day III were respectively 5250 ml/min and 5420 ml/min and for ventilation 152.3 l/min and 149.2 l/min.

Discussion

The results presented in Table 1 demonstrate that under these experimental conditions $NaHCO_3$ infusion was effective in correcting the acidaemia caused by physical activity. The increase in CO_2 production from the reaction between HCO_3 and H-ions results in an increase in p_{CO_2} and in an increase in CO_2-output.

The infusion of $NaHCO_3$ (8%) had no effect upon the subjective feelings of fatigue during exercise, based upon these results we can say that the change of the acid-base state of the arterial blood is not one of the mechanisms underlying the feelings of fatigue.

Data on heart-rate and blood-pressure in our experiments suggest that pH changes during exercise do not affect cardiovascular function in normal trained healthy subjects as measured by these parameters. This is in agreement with the investigations of Downing *et al.* (1965), Opie *et al.* (1963), Khazei *et al.* (1969), who did not find any effect of acidosis or alkalosis upon cardiovascular function.

We did not find any effect upon submaximal and maximal ventilation, and oxygen consumption and upon maximal performance of the subjects. It is known from experiments of Relman *et al.* (1963) and Adler *et al.* (1965a, b) that at rest changes in acid-base status of the blood are not directly followed by the same changes in the cell. The possibility exists that correction of the blood pH in our experiments had no effect upon the biochemical composition of the muscle cell and thereby no effect upon oxygen consumption and performance.

Although the results of our study suggest that the change of pH in the arterial blood during physical exercise is not an underlying factor for the subjective feelings of fatigue and that it is of no influence on some important physiological functions related to submaximal and maximal exercise, it may be possible that $NaHCO_3$ infusions might have an effect if H-ion concentration would increase to values found by Hermansen and Osnes (1972), Osnes and Hermansen (1972) and Kindermann *et al.* (1973a, b), during different types of exercises.

References

Adler, S., Roy, A., Relman, A. S.: Intracellular acid-base regulation. I. The response of muscle cells to changes in CO_2-tension or extra-cellular bicarbonate concentration. J. clin. Invest. **44**, 8—20 (1965a)

Adler, S., Roy, A., Relman, A. S.: Intracellular acid-base regulation II. The interaction between CO_2 tension and extracellular bicarbonate in the determination of muscle cell pH. J. clin. Invest. **44**, 21—30 (1965b)

Bergström, J., Hermansen, L., Hultman, E., Saltin, B.: Diet, muscle glycogen and physical performance. Acta physiol. scand. **71**, 140—150 (1967)

Bouhuys, A., Pool, J., Binkhorst, R. A., van Leeuwen, P.: Metabolic acidosis of exercise in healthy males. J. appl. Physiol. **21**, 1040—1046 (1966)

Dennig, H., Becker-Freyseng, H., Rendenbach, H., Schostak, G.: Leistungssteigerung in künstlicher Alkalose bei wiederholter Arbeit. Naunyn-Schmiedebergs Arch. exp. Path. Pharmak. **195**, 261—263 (1940)

Dennig, H., Talbot, J. T., Edwards, H. T., Dill, D. B.: Effect of acidosis and alkalosis upon capacity for work. J. clin. Invest. **9**, 609—613 (1931)

Doll, E., Keul, J.: Zum Stoffwechsel des Skeletmuskels. II. Sauerstoffdruck, Kohlensäuredruck, pH, Standardbicarbonat und Base-Excess im venösen Blut der arbeitenden Muskulatur. Pflügers Arch. ges. Physiol. **301**, 214—229 (1968)

Dorow, H., Galuba, B., Hellwig, H., Becker-Freyseng, H.: Der Einfluß künstlicher Alkalose auf die sportliche Leistung von Läufern und Schwimmern. Naunyn-Schmiedebergs Arch. exp. Path. Pharmak. **195**, 264—266 (1940)

Downing, S. E., Talner, N. S., Gardner, T. H.: Cardiovascular responses to metabolic acidosis. Amer. J. Physiol. **208**, 237—243 (1965)

Haralambie, G.: Importance of humoral changes to physical performance. In: Limiting factors in physical performance, J. Keul, Ed., pp. 189—201. Stuttgart: Thieme 1973

Hermansen, L., Hultman, E., Saltin, B.: Muscle glycogen during prolonged severe exercise. Acta physiol. scand. **71**, 129—139 (1967)

Hermansen, L., Osnes, J. B.: Blood and muscle pH after maximal exercises in man. J. appl. Physiol. **32**, 304—308 (1972)

Hirche, H., Langohr, H. D., Wacker, U.: Lactic acid accumulation in working skeletal muscle. In: Limiting factors in physical performance, J. Keul, Ed., pp. 166—171. Stuttgart: Thieme 1973

Hueting, J. E.: Relationship between some physiological and psychological variables with regard to physical exercise. Acta physiol. pharmacol. neerl. **13**, 198—199 (1964)

Hueting, J. E.: Psychofysiologisch onderzoek van lichamelijke arbeid. Thesis, University of Amsterdam (1968)

Hueting, J. E., Coffeng, A. M., van Leeuwen, M., Poulus, A. J.: A comparison of physiological and psychological responses during physical exercise in non-trained and trained male subjects. Acta physiol. pharmacol. neerl. **15**, 82—84 (1969)

Hueting, J. E., Sarphati, H. R.: Measuring fatigue. J. appl. Psychol. **50**, 535—538 (1966)

Janssen, C. G. C., Docter, H. J.: Quantitative subjective assessment of fatigue in static muscle effect. Europ. J. appl. Physiol. **32**, 81—86 (1973)

Jung, K., Gadermann, E.: Veränderungen im Säure-Basen-Status während und nach maximaler Fahrradergometerarbeit im Liegen. Sportarzt u. Sportmedizin **9**, 210—219 (1973); **10**, 235—241 (1973)

Kaijser, L.: Limiting factors for aerobic muscle performance. Acta physiol. scand. Suppl. **346** (1970)

Karlsson, J., Saltin, B.: Diet, muscle glycogen and endurance performance. J. appl. Physiol. **31**, 203—206 (1971)

Keul, J., Doll, E., Keppler, D., Reindell, H.: Die Veränderungen arterieller Substratspiegel unter dem Einfluß körperlicher Arbeit. Int. Z. angew. Physiol. **22**, 356—385 (1966)

Khazei, A. H., McLaughlin, J. S., Suddhimondala, C., Attar, S., Cowley, R. A.: The effects of acidosis and alkalosis on cardiac output and peripheral resistance in humans. Amer. Surg. **35**, 600—605 (1969)

Kindermann, W., Haralambie, G., Kock, J., Keul, J.: Säure-Basen-Haushalt und Lactatspiegel im arteriellen Blut bei Ruderern nach olympischen Wettkämpfen. Med. Welt **24**, 1176—1178 (1973a)

Kindermann, W., Huber, G., Keul, J.: Säure-Basen-Haushalt und Lactatspiegel im arteriellen Blut sowie Herzfrequenz bei jugendlichen Schwimmern. Med. Welt **24**, 1959—1963 (1973 b)

Margaria, R., Aghemo, P., Sassi, G.: Effect of alkalosis on performance and lactate formation in supramaximal exercise. Int. Z. angew. Physiol. **29**, 215—223 (1971)

Mellemgaard, K., Astrup, P.: The quantitative determination of surplus amounts of acid or base in the human body. Scand. J. clin. Lab. Invest. **12**, 187—199 (1960)

Nitsch, J.: Theorie und Skalierung der Ermüdung. Dissertation, Deutsche Sporthochschule, Köln 1970

Opie, L. H., Kaders, T., Gevers, W.: Effects of pH on the function and glucose metabolism of the heart. Lancet **1963 II**, 551—553

Osnes, J. B., Hermansen, L.: Acid-base balance after maximal exercise of short duration. J. appl. Physiol. **32**, 59—63 (1972)

Piiper, J.: Buffering of lactic acid produced in exercising muscle. Symp. Onset of Exercise, A. Gilbert, P. Guille, Eds. Purpan-Toulouse: Centre d'Hémotypologie C.H.U. 1971

Relman, A. S., Adler, S., Roy, A.: Intracellular acid-base equilibrium: the reaction of muscle cells to "metabolic" and "respiratory" changes in extracellular acidity. Trans. Ass. Amer. Phycns **76**, 176—183 (1963)

Roth, W., Wuscheck, H., Schneider, W.: Probleme des Säuren-Basen-Gleichgewichts in der Sportphysiologie. Sport **6**, 161—173 (1969)

Rumler, W., Brümmer, H.: Über die Steigerung der körperlichen Leistungsfähigkeit durch THAM-Salze. Acta biol. med. germ. **17**, 432—437 (1966)

Scherrer, M.: Acid-base imbalance and gas exchange during heavy work. In: Biochemistry of exercise, J. R. Poortmans, Ed., pp. 2—14. Basel: Karger 1969

Schmidtke, H.: Die Ermüdung. Bern: Huber 1965

Simonson, E.: Physiology of work capacity and fatigue. Springfield, Ill.: Thomas 1971

Staib, A. H., Feller, K., Andreas, K.: Beobachtungen über pharmakologische Beeinflussungsmöglichkeiten des Blut-pH. Med. Sport **3**, 181—182 (1964)

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