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# DIETARY POTASSIUM AND SODIUM AS AFFECTING WORK OUTPUT AND OTHER PHYSICAL PERFORMANCE OF RATS

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## ABSTRACT

Young adult male Long-Evans rats, after a suitable training period, were tested principally for running endurance, with minimum intervals of one week, in order to determine the effect of different dietary K and Na levels. All nutrient levels exceeded the N.R.C. suggested requirement (A). In both of two experiments, the rats ran significantly longer when receiving a diet with a K level of 8 times A than with K levels of, respectively, 2.3 and 1.2 times A. In both of these experiments dietary Na level was 14 times A (15 g NaCl/ 2800 kcal). This relatively high Na level, as compared to levels respectively 1.6 and 5.6 times A, did not depress running times at a dietary K level of 1.2 A. When given a choice, the rats ate 9 times more of the low (1.6A) than of the high Na (14A) diet. The various implications have been discussed.

## INTRODUCTION

Potassium supplements given to a large group of elderly people have been reported to significantly improve their average hand grip strength, as well as their efficiency of mental recall and non-verbal intelligence (1). Burr et al., however, could not confirm these results (2). An increase in exercise endurance (3), and an improvement in human short-distance swimming performance (4) has been reported after the intake of an excess of baseforming minerals as Na and K. Johnson and Black found no significant effect of alkalizing supplements, predominantly containing Na, given 4 hours before each of a series of cross-country runs (5). Prior oral administration of KCl to rats was found to increase their swimming ability (6). Injection of KCl delayed muscle fatigue and restored the working capacity of a fatigued cat quadriceps muscle (7).

Potassium excretion in human subjects has been observed to be greater during the use of high than with low dietary sodium levels (8). Sodium salt given to dogs has been shown to lower the potassium level of plasma (9) and of muscle (10).

The experiments described in the following were conducted to determine the effect, if any, of dietary potassium level on, primarily, running endurance of rats. Dietary potassium levels used were higher than the N.R.C. suggested requirement (11). In addition, a possible interaction of dietary sodium level with the effect of potassium was tested.

## MATERIALS AND METHODS

In all experiments described in the following, young adult male Long-Evans rats[1] were housed individually in stainless steel cages at 21.1 ± 0.7° C (mean ± SD) and 50 ± 4% relative humidity. When received, they were 6 weeks old.

For the first 15 weeks after arrival they were fed a control diet, after that the experimental diets. The composition, in %, of the control diet was: casein[2], 10.0; wheat gluten, 10.0; sucrose, 14.0; dextrose, 9.7; cellulose, 3.0; corn oil, 3.6; vegetable shortening[3], 8.8; lard[4], 8.8; vitamin mixture, 0.34; mineral mixture, 3.6 to 6.6; and the remainder wheat starch. The mineral mixture contained per kg diet, in mg: Ca, 1940; P, 2050; Mg, 780; Fe (II), 53; Mn, 70; Zn, 15; Cu, 10; Cr (III), 4; Mo, 0.7; I, 0.3; Se, 0.08. Amounts of K and Na used will be detailed below. The pH of the mineral mixtures in a 2% suspension was kept at 5.6 by addition of citric acid to ensure thiamin stability in the diets (12). Vitamins were supplied in amounts 50% above the N.R.C. suggested requirements (11). In addition, the animals received per kg diet, in mg: inositol, 60; p-aminobenzoic acid, 30; folic acid, 0.5; biotin, 0.1; ascorbic acid, 60. The diets were stored refrigerated.

The treadmill, used to run the rats, was a slight modification of a design used by Kimeldorf (13) and employed a motor-driven, endless belt with ten ventilated cages, open at the bottom, just above the belt. After an initial training period prior to this, the rats during the 6 weeks preceding the actual experimental phase were run to exhaustion once a week, and with intervals of one week or more during the experimental phase. These runs took place at a speed of 24.4 meters/min. The incline of the belt in the first experiment described started at 7° and increased by 1° every 5 min., up to 11°. In the second experiment the incline was kept at 6°, in the third experiment it was kept at 7°, and in the fourth at 8°. Further details of the four experiments conducted follow.

<u>Experiment I:</u> Per kg, the control diet contained 1.1 g K as monophosphate, 8.9 g K as citrate, and 7.7 g Na as chloride. The experimental diets were the same as the control diet except for the K levels. The low K diet contained per kg 1.1 g K as monophosphate and 3.2 g K as citrate. The high K diets contained additionally to the low K diet 11.9gK either as citrate + 6.4 g citric acid, or as chloride without the citric acid addition.

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[1]Obtained in the first two experiments from Simonsen Labs., Inc., Gilroy CA, in the last two from The Charles River Breeding Labs., Inc., Wilmington, MA.

[2]Diet ingredients, unless stated otherwise, were obtained from ICN, Cleveland, OH.

[3]Commercial, general purpose, high stability (100 AOM) shortening.

[4]Armour Co., Chicago.

Experiment II: Per kg, the control diet contained 1.1 g K as monophosphate, 1.2 g K as citrate, 6.6 g K as chloride, and 7.7 g Na as chloride. The experimental diets differed from the control diet only in K level. In the low K diet the KCl in the control diet had been omitted. The high K diet consisted of the control diet with 6.6 g K as chloride per kg added.

Experiment III: Per kg, the control diet contained 1.1 g K as monophosphate, 1.2 g K as citrate, and 6.4 g Na as chloride. The experimental diets differed from the control diet only in Na level. The low Na diet contained per kg 0.9 g Na as chloride, the high Na diet 11.8 g Na as chloride.

In a separate experiment (IIIA), 14 rats of the same age and kind as in experiment III received both the high - and low Na diet in separate food bowls, in order to determine the difference in food intake from each diet.

Experiment IV: Per kg, the control diet contained 2.3 g K as monophosphate and 6.0 g Na as chloride. The experimental diets differed from the control diet only in Na level. The 'low' Na diet contained per kg 3.1 g Na as chloride, the high Na diet 11.8 g Na as chloride.

RESULTS

Experiments I & II (varying K levels). Running performance. The averages for the 3 running times to exhaustion just prior to the experimental phase in experiment I for the future initial low K, high K-citrate, and high KCl groups were, respectively, 99.9, 107.3 and 94.8 min. ($n = 9$ to 12). By adjusting throughout the experimental phase for these differences in preliminary values through the use of multiplication factors, the results shown in Figure 1 were obtained. On day 35 of the experimental phase, diets were switched in the manner indicated in the figure. According to analyses of covariance (14), the slopes of the values for the 'low' K and the high K-citrate group from days 3 through 31 are significantly different ($P < 0.01$). Further, the relative time values for the high K-citrate and high KCl groups from days 3 through 31 are significantly different ($P < 0.005$).

The averages for the 4 preliminary running to exhaustion times in experiment II for the future initial 'low' and high K groups were, respectively, 104.7 and 102.2 min. ($n = 16$ in both cases). By adjusting throughout the experimental phase for these differences in preliminary values, as described above, the results shown in Figure 2 were obtained. On day 35 of the experimental phase, diets, again, were switched between the groups. According to analyses of covariance, the slopes of the values for the 'low' and the high K group from days 4 through 32 are significantly different ($P < 0.005$). Further, the slopes of the values for the high and 'low' K group from days 32 through 78, as well as from days 39 through 78 are significantly different ($P < 0.025$).

Weights. Average weights just before the experimental phase for

Figure 1. Relative running times to exhaustion of young adult male Long-Evans rats receiving semipurified diets with different K levels. Experiment I. Average preliminary running time = 100.7 min. "Low" K=4.3 g K/kg diet. High K=16.2 g K/kg diet.

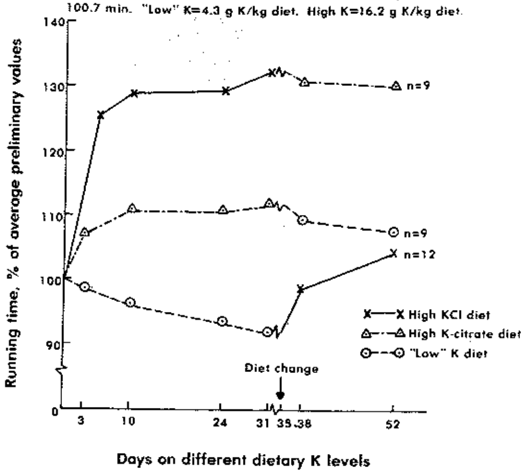
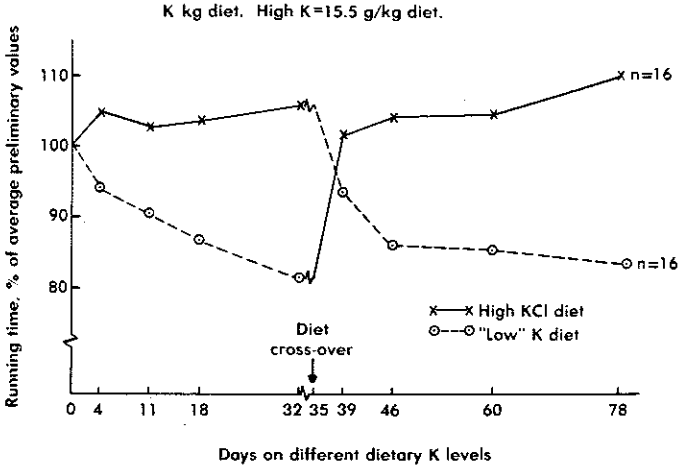



Figure 2. Running data as for figure 1. Experiment II. Average preliminary running time=103.5 min. "Low" K=2.3 g K kg diet. High K=15.5 g/kg diet.




the future initial 'low'-K, high-K-citrate and high-KCl groups of experiment I were, respectively, 370, 367, and 360 g. On day 31 of the experimental phase, weight increases, in above order, were 13.3, 10.6 and 11.5% from the time indicated above. No statistically significant differences existed between these rates or weight gains.

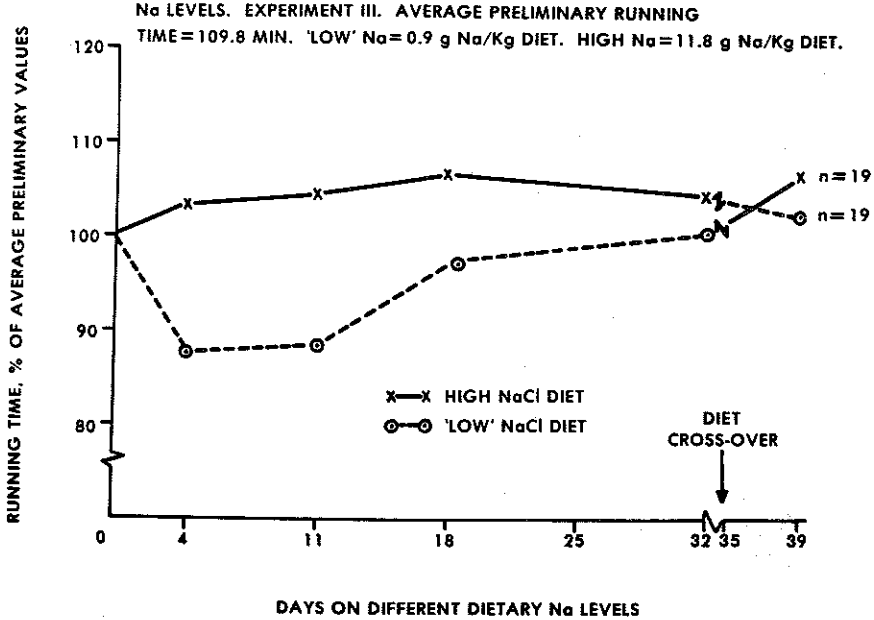
Average weights just before the experimental phase for the future initial 'low' and high K groups of experiment II were, respectively, 424 and 433 g. On day 32 of the experimental phase, weight increases, in above order, were 4.0 and 3.0% (no significant difference) from the time indicated above.

Food consumption. Average food consumption/rat, adjusted for differences during the two weeks preceding the experimental phase, was 18.2 g on the 'low' K diet, 18.5 g on the high K-citrate diet, and 18.3 on the high KCl diet in experiment I.

Water consumption. The high-K group in experiment II, on the average, drank 10.3% more water than the 'low'-K group. This difference was significant ($P < 0.01$), according to a paired t test.

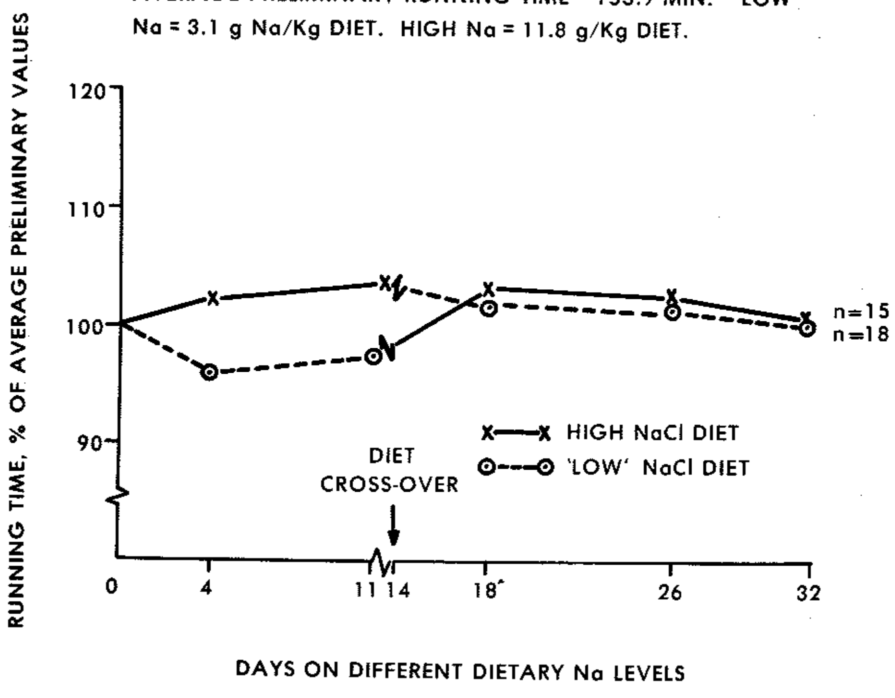
Experiments III & IV. (varying Na levels). Running performance. The averages for the 3 running times to exhaustion just prior to the experimental phase in experiment III for the future initial low-, and high Na groups were, respectively, 109.7 and 109.9 min. (n=19). On day 35 of the experimental phase, the diets for these groups, again, were switched. The average running time for the high Na group on day 4 of the experimental phase was 21.2% longer than for the low Na group (Figure 3). This difference gradually decreased with time to 4.0% on day 32. Four days after the diet switch, the only time determined after the switch, the average running time was 4.3% longer for the high - than for the low Na group. The difference in average running times between the two groups before the diet switch was significant ($P < 0.05$), according to Student's paired t test.

FIGURE 3. RELATIVE RUNNING TIMES TO EXHAUSTION OF YOUNG ADULT MALE LONG-EVANS RATS RECEIVING SEMIPURIFIED DIETS WITH DIFFERENT Na LEVELS. EXPERIMENT III. AVERAGE PRELIMINARY RUNNING TIME=109.8 MIN. 'LOW' Na=0.9 g Na/Kg DIET. HIGH Na=11.8 g Na/Kg DIET.



The averages for the 3 running times to exhaustion just prior to the experimental phase in experiment IV for the future initial low-, and high Na groups were, respectively, 155.1 (n = 15) and 152.7 (n = 18) min. On day 14 of the experimental phase, the diets for these groups, again, were switched. The average running times for the high Na group, adjusted for the difference in average preliminary time, on day 4 and day 11 of the experimental phase was 6.6% and 6.1% longer, respectively, than for the low Na group (Figure 4). On days 4, 12 and 18 after the diet switch, the high Na group ran 1.4, 1.5 and 0.5% longer, respectively, than the low Na group. These differences before and after the diet switch were not significant.

FIGURE 4. RUNNING DATA AS FOR FIGURE 3. EXPERIMENT IV. AVERAGE PRELIMINARY RUNNING TIME = 153.9 MIN. 'LOW' Na = 3.1 g Na/Kg DIET. HIGH Na = 11.8 g/Kg DIET.




Weights. Average weights just before the experimental phase for the future initial low - and high Na groups of experiment III were, respectively, 386 and 385 g. On day 32 of the experimental phase, weight increases, in above order, were 8.3 and 6.7% from the time indicated. This slightly higher weight gain for the low Na group occurred at all five times measured during the first 32 days of the experimental phase, averaging 1.4%, and is significant ($P < 0.01$) according to a paired t test.

In experimental IV, initial weights, under the same conditions as mentioned above, were 384 and 387 g, respectively. Weight increases on day 11 of the experimental phase were 1.2 and 0.8%, respectively, and not significantly different.

Water consumption. The high Na group in experiment III, on the average, drank 73.5% more than the low Na group during three 3-day periods between days 10 and 34 of the experimental phase. This was significant ($P < 0.001$). From 0 to 4 days after the diet switch, the high Na group drank 73.9% more.

During days 11 to 14 of the experimental phase in experiment IV the high Na group drank 45.0% more. From days 11 to 21 after the diet switch the high Na group drank an average of 64.3% more. Both differences were significant ($P < 0.01$).

Food consumption. The average food intake from the low Na diet in experiment IIIA from days 4 to 40 of the experimental phase (6 determinations, each over a 4-day period) was 14.7 g, that from the high Na diet was 1.6 g, a 9-fold difference. This difference was significant ($P < 0.001$).

## DISCUSSION

The 'low' K diets in experiments I and II contained, respectively, 2.3 and 1.2 times the N.R.C. suggested K requirement for the growing rat (11). Yet, under the circumstances employed, K doses respectively 8.5 and 8.2 times the N.R.C. suggested requirement produced average increases in running endurance, compared to the 'low' K diet, of 39% for the high KCl group during days 10 through 31 in experiment I and of 23% during days 11 through 32 and 46 through 78 of experiment II, with a tendency to increase with time in both experiments. An hypothesis that the K requirement might have been increased due to the relatively high Na levels in experiments I and II (namely, 14 times the N.R.C. suggested requirement), was not supported by the results of experiments III and IV. Rather, with the relatively 'low' K level of 1.2 times the N.R.C. suggested requirement in these latter two experiments, the rats receiving the high dietary Na level tended to run slightly longer than the 'low' Na group. Therefore, either another dietary factor than Na in the diets employed increases the K requirement of the rat, or the K requirement of the exercising rat is considerably higher than the N.R.C. suggested requirement. During the experimental phase, the rats were intensively exercised an average of slightly more than 1 hour per day, including the running to exhaustion. During this phase, they were on the average about 6 months old.

The reason that in experiment I the running improvement with K-citrate supplement was less than with KCl may be that rats in this respect react less favorably to strongly alkalizing dietary supplements.

The difference in quantitative response in experiments I and II can largely be explained by the higher K level of the 'low' K diet, and of the high K diet in experiment I, further probably also by the fact that the K in the control diet of experiment I was entirely in the form of citrate rather than mostly chloride as in experiment II. Similarly, the difference in quantitative response in experiments III and IV can be explained by the higher Na level of the 'low' Na diet in experiment IV.

The levels of dietary nutrients used simulated to a considerable degree those frequently used by the North American human. Dietary K concentrations such as occurring at the high levels in experiments I and II can be found in diets that contain liberal, but not exceptionally high, amounts of fruit, vegetables and potatoes. If the same holds true for the physically active young adult or middle aged human as has been reported here for the rat in regards to the effects of dietary K concentration, this will have important implications for the desirable dietary K intake of the human. At present, little more than two controversial reports are available regarding the benefits of increased K supply for elderly, sedentary people (1,2). The dietary Na level of 14 times the N.R.C. suggested requirement corresponds with 15 g of NaCl/2800 kcal in the diet according to bomb calorimeter determinations conducted previously (15).

During exercise and other stress, the increased secretion of ACTH and aldosterone causes intracellular K loss (16). Intracellular K concentration in skeletal and heart muscle increases when the extracellular K concentration is increased by external supplementation (16, 17). Cardiac output and stroke volume in the human and in the dog have been found to decrease progressively with increased degree of K depletion (16, 18). Increased plasma K concentration causes vasodilation whereas reduction of plasma K concentration produces vasoconstriction (19), with resultant changes in blood flow rate.

The tendency of the rats receiving the higher Na intake to run slightly longer than the 'low' Na groups is probably at least partially related to the slightly lower body weight increases of the former groups (15). These slightly smaller weight increases for the high Na groups may well have been caused (although not actually measured in these cases) by a relatively lower food intake.

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