Original Paper DOI: 10.5604/20831862.1086735 Biol. Sport 2014;31:69-72

NIGARI (DEEP SEAWATER CONCENTRATE) ENHANCES THE TREADMILL EXERCISE PERFORMANCE OF GERBILS

Accepted for publication 02.10.2013

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ABSTRACT: The beneficial effect of magnesium supplementation on exercise performance has been reported by many researchers. In the present study, the effect of nigari, a concentrate of deep seawater containing high magnesium levels, on exercise performance, was examined. Gerbils were given double-distilled water or nigari (18 mg · kg^{-1}, po) orally 30 min before exercise. All animals were subjected to forced exercise on a treadmill for 90 min at three successive speeds of 10, 15, and 20 m · min^{-1}. The retention numbers were recorded. The retention numbers were 85.0 ± 21.0, 46.0 ± 9.7, and 48.0 ± 14.2 in the control group, and 44.0 ± 10.9, 23.0 ± 8.4, and 13.0 ± 4.8 in the nigari-treated group at the three speeds, respectively. The retention numbers were significantly reduced at higher speeds (by 50% at 15 and 73% at 20 m · min^{-1}, respectively) in the nigari-treated group when compared to those of the control group, respectively. Thus, nigari administration appeared to reduce retention numbers and enhance exercise performance in gerbils.

KEY WORDS: Nigari, concentrated deep seawater, Mg^{2+}, retention number, treadmill exercise

INTRODUCTION

Exercise utilizes oxygen and nutrients to produce energy. The energy systems used during exercise include the ATP-PCr, glycolytic and oxidative systems. All three of these energy systems contribute to energy production, but exercise intensity, duration, and frequency determine which of these energy systems will predominate. The higher the energy output, the more energy is needed to maintain energy balance. Therefore, the availability and the efficiency of the energy consumed may relate to exercise performance. Depending on the exercise being performed, there are numerous methods for evaluating exercise performance, such as measuring duration in swimming exercise, determining the maximum oxygen uptake ($\dot{V}O_2$max) during sub-maximal work, and evaluating the number of elbow flexion repetitions during resistance exercise [1]. However, relatively few studies have investigated retention numbers [2-3]. The present study was therefore conducted to examine the effect of nigari administration on the retention number of gerbils subjected to treadmill exercise.

Magnesium (Mg) is the second most abundant intracellular divalent cation in all living cells and acts as a cofactor in more than 300 enzymatic reactions [4]. Mg is also involved in cellular energy production, glycogen breakdown, cardiac excitability, muscular contraction, and physiological regulation of neuromuscular functions [5]. Therefore, Mg is widely thought to be one of the most important factors in exercise and physical performance. Mg depletion during exercise may lead to changes in neuromuscular function and reduce physical performance [5].

Several studies have demonstrated the beneficial effects of Mg supplementation on exercise performance [3,6-7]. The effects of a Mg supplement on strength development for knee extension were examined, and the results showed that strength measured by isokinetic torque was significantly increased in the Mg supplement group [6]. Moreover, Mg supplementation was shown to have beneficial effects in our previous two studies [3,7].

Deep seawater (DSW) has been found to be far richer in minerals such as Mg, Ca and K compared to surface seawater, and thus its utilization and application in the fields of agriculture, medical treatment, and the food industry has become the focus of considerable research [8]. The administration of desalinated DSW appears to have positive effects against atherosclerosis progression, platelet aggregation,

and cardiovascular haemodynamics in animal model studies [9-11]. Nigari is refined from deep seawater (DSW) through the process of electrolysis and reverse osmosis to remove calcium sulfate and sodium chloride as well as to retain the high concentration of magnesium chloride and other important trace minerals [12]. Given the importance of the numerous micronutrients present in nigari, the effects of nigari on exercise performance warrant further study. In the present study, nigari was administered to gerbils subjected to treadmill exercise, and the effect on treadmill exercise performance was investigated.

MATERIALS AND METHODS

Adult female gerbils (n = 12) weighing 70-80 g were obtained from the Laboratory Animal Center of Taichung Veterans General Hospital. All animals were housed at a temperature of 25°C in a light-controlled room (12:12 h light-dark cycle) with free access to rat chow and tap water. Animal care and experimental procedures (# La-101992, TCVGH, Taiwan) were in accordance with the Guide for the Care and Use of Laboratory Animals published by the U.S. Department of Health and Human Services.

The gerbils were randomly divided into the control group (double-distilled water) and the nigari-treated group. Nigari liquid was diluted by mixing with double-distilled water. The composition of the nigari is shown in Table 1. Each gerbil was habituated to the treadmill apparatus (Model T306, Diagnostic and Research Instruments Co., Taoyuan, Taiwan) used in the experiment. The treadmill was equipped with wire loops and retention sensors at one end of the belt through which a mild electric shock could be delivered, as shown in Figure 1. Electric shocks were used sparingly to motivate the animals to run, as described in our previous study [3]. The gerbils were stimulated at the lowest level (a current of 0.6 μA with an inter-pulse interval of less than 2 s). The experimental animals used in the present study were unfamiliar with motorized treadmills and had not previously experienced electric shock. The retention bar to the rear of the treadmill track administered a shock to a gerbil's tail if it failed to run at the required speed. The retention number was recorded during treadmill exercise and was used to represent exercise performance, i.e., a low retention number indicated better performance. Retention was defined as the number of animals approaching the defined electrified grid area at the rear and was counted during the exercise periods [3].

Five hundred μl of diluted nigari (containing Mg^{2+}, 18 mg kg^{-1}) or double-distilled water was administered orally 30 min before the forced treadmill task. All animals ran for 90 min at three successive velocities: 10, 15, and 20 m·min^{-1}, 30 min at each velocity, and the retention numbers were recorded.

Statistical analysis

All data were expressed as means ± SEM. The Mann-Whitney U test was used to analyse statistically significant differences between the two groups. Differences were considered statistically significant at $p < 0.05$.

TABLE 1. COMPOSITION OF MAJOR MINERALS AND TRACE ELEMENTS IN NIGARI

Mineral	Nigari (mg·L^{-1})
Mg	96.2
K	10.8
Na	9.01
Ca	0.039
Li	0.017
B	0.28
Cl^{-1}	267.0
SO_4^{-2}	30.6

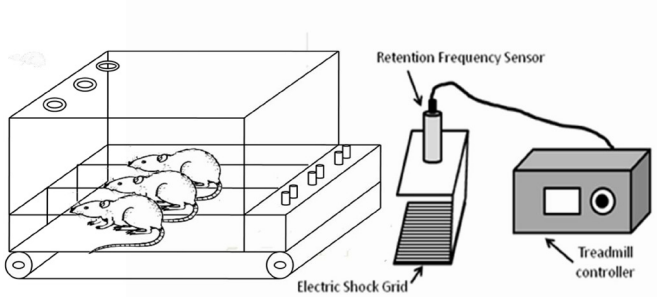

FIG. 1. SCHEMATIC VIEW OF THE EXPERIMENTAL TREADMILL

RESULTS

The average retention numbers in the treadmill exercise were 85.0 ± 21.0, 46.0 ± 9.7, and 48.0 ± 14.2 in the control group (Figure 2), and 44.1 ± 10.9, 23.0 ± 8.4, and 13.0 ± 4.8 in the nigari-treated group, at speeds of 10, 15, and 20 m·min^{-1}, respectively (Figure 2). Lower retention numbers indicate better exercise performance. Significantly lower retention numbers were observed at speeds of 15 and 20 m·min^{-1} in the nigari-treated group when compared to those of the control group at the same speeds. In addition, the retention numbers were also lower in the nigari-treated group at 10 m·min^{-1} than in the control group, but the difference was not significant.

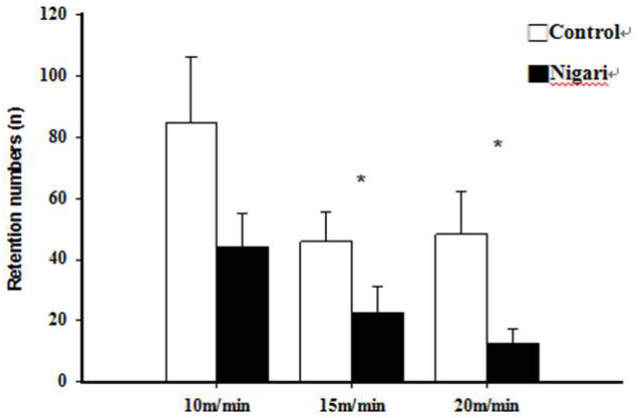

FIG. 2. THE RETENTION NUMBERS AT DIFFERENT SPEEDS IN THE CONTROL GROUP AND THE NIGARI-TREATED GROUP.
Note: Data are presented as means ± SEM (n=6). *, $p<0.05$ compared with the 15 and 20 m·min^{-1} speeds in the same group, respectively.

DISCUSSION

In the present study, our results indicate that nigari enhanced exercise performance in gerbils. Accumulating evidence has demonstrated the antidepressant and anxiolytic activity of various NMDA antagonists [13-14]. Mg inhibits the NMDA receptor ion channel in a voltage-dependent manner. Moreover, administration of Mg resulted in a significant reduction in the immobility time in forced swimming exercise in mice [13]. In the present study, retention numbers were higher at the speed of 10 $m \cdot min^{-1}$ in the control group and the nigari-treated group when compared with those at the higher speeds of 15 and 20 $m \cdot min^{-1}$. These results may be due to some unknown aspects of gerbil behaviour which could not be adjusted in the investigation. Gerbils are known, for instance, to be easily startled [15-17] , and perhaps their improved performance at the higher speeds was due to the additional practice and/or learning gained at the lower speed. Furthermore, the higher retention numbers at 10 $m \cdot min^{-1}$ may have been induced in part by the stress caused by the moving belt and also by the stimulation resulting from the gerbil's awareness of the forced exercise. In this study, the retention number was lower at the speed of 10 $m \cdot min^{-1}$ in the nigari-treated group compared with that of the control group. Additionally, nigari treatment significantly reduced the retention numbers at the higher speeds of 15 and 20 $m \cdot min^{-1}$ compared with the lowest speed. Similar results were observed in our previous study [3]. Nigari containing a high level of Mg may also reduce anxiety, thereby enhancing exercise performance. The anti-anxiolytic effect of Mg may explain, at least in part, the abovementioned effects.

Mg is regarded as one of the most important elements in exercise as well as physical performance. There is also evidence that Mg deficiency can result in a significant reduction in exercise performance, and a decline in optimal sport performance [5,18]. These results have been demonstrated in terms of associations of Mg with variables such as heart rate, maximal oxygen uptake, time to exhaustion, and other parameters in athletes [5]. Deep seawater is a pure source of various minerals and is far richer in nutrients such as Mg compared to that of surface seawater; and thus it has been the focus of considerable research, particularly with regard to its putative nutraceutical effects. In addition to its use in health food products, cosmetics, beverages, and agriculture, the administration of deep seawater has been shown to be effective in the prevention of atherosclerosis and osteoporosis in animal model studies [9,19-20] and appears to improve atopic eczema/dermatitis and postprandial hyperlipidaemia in humans [21-22]. Nigari is refined from deep seawater containing a variety of minerals (mainly Mg) and small amounts of other trace elements. Previous studies have evaluated the effect of oral nigari supplementation on postprandial serum lipid and paw oedema in various experimental models [22-23]. However, to the best of our knowledge, the effect of nigari supplementation on exercise performance in an animal model has not been previously reported. In this study, we examined the effect of nigari on exercise performance as measured by retention numbers in gerbils. The retention number at the speed of 10 $m \cdot min^{-1}$ in the nigari-treated group was lower than that of the control group, but the difference was not significant. However, the retention numbers in the nigari-treated group were lower at the speeds of 15 and 20 $m \cdot min^{-1}$ (50% and 73% lower, respectively) compared to those of the control group, and hence the exercise performance was apparently significantly enhanced at these higher speeds in the nigari-treated group.

Numerous investigators have demonstrated that a reduction in serum or plasma magnesium concentration occurs with prolonged endurance exercise. Some studies have reported that hypomagnesaemia during exercise may be accounted for by a redistribution of Mg in the body compartments, such as erythrocytes, adipose tissue, and exercising muscle. Furthermore, strenuous exercise may also induce an apparent increase in sweat and urinary excretion of Mg. All of these factors contribute to Mg deficiency, which can reduce muscular efficiency and exercise performance and may, in turn, increase Mg requirements by 10-20% [24]. We have previously demonstrated that pre treatment with magnesium sulfate enhanced exercise performance and elevated both plasma Mg and glucose levels in gerbils during forced swimming exercise [3,7]. Furthermore, in a previous study, we showed that pre treatment with magnesium sulfate increased glucose and magnesium levels in the cortex, and also resulted in increased GLUT-3 protein expression [25]. These data suggest that the magnesium sulfate-elevated cerebral glucose concentrations may be enhanced by GLUT-3 expression, and the peripheral and central glucose levels may be elevated via the regulation of both the glycolysis pathway and oxidative phosphorylation. In addition, magnesium serves as a cofactor in many rate-limiting enzymes including hexokinase, pyruvate dehydrogenase, and creatine kinase [25-26]. Mg supplementation seems to have a potentially beneficial effect on muscle energy metabolism and work efficiency.

In the present study, the lack of a significant difference in retention numbers between the nigari-treated group and the control group at the treadmill speed of 10 $m \cdot min^{-1}$ may have been due to the low intensity of the exercise. It is possible that Mg supplementation may result in a rise in glucose and Mg concentrations at high intensity or prolonged endurance treadmill exercise. With respect to the influence of Mg supplementation on exercise performance, many studies have demonstrated its beneficial effects [3-4, 6-7, 25], whereas a few researchers have reported no improvement with Mg supplementation 27-28]. Possible reasons for the different effects of Mg supplementation on exercise performance include varying dosages, salt forms, and experimental models used in the studies. It is well known that Mg is involved in numerous processes that affect muscle function, including oxygen uptake, energy metabolism, and electrolyte balance. These phenomena suggest that the Mg in nigari may be responsible for the improvement of exercise performance.

CONCLUSIONS

In summary, the present study demonstrated that nigari supplementation was associated with significantly improved exercise performance

in gerbils subjected to treadmill exercise. The application of nigari in exercise performance studies involving other animal species, such as rats or mice, is warranted. Furthermore, the effects of nigari supplementation on athletes' exercise performance is also worthy of further investigation.

Acknowledgements

This study was supported by grants from Taichung Veterans General Hospital and Hung Kuang University (TCVGH-HK1008005), Taiwan.

Conflict of interest: non declared.

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