Effects of Dietary Restriction on Physical Performance in Mice

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Abstract Dietary restriction is known to prolong life in laboratory animals. However, little is known about the effects of dietary restriction on physical performance. To evaluate physical performance, we measured four item indices: time to climb out of obstacles, time to escape restraint by gummed tape, time hanging from a bar, and ability to resist slipping every week. The diets of ICR mice were restricted from the age of 7 weeks through 24 weeks. Body weight of the diet-restricted mice decreased during the 7th to 9th weeks of age. After the 10th week, weight gain resumed. In response to assigned tasks, the diet-restricted mice performed better in all activities: they climbed out of obstacles faster, freed themselves sooner from restraint by gummed tape, hung from a bar longer, and better resisted slipping down a slope. These results suggest that diet-restricted mice have superior physical abilities, such as those required to overcome or avoid risks to life, than do ad-libitum-fed mice. J Physiol Anthropol Appl Human Sci 24(3): 209–213, 2005 http://www.jstage.jst.go.jp/browse/jpa

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Introduction

Historically, Homo sapiens experienced periods of food shortage and famine, and adapted to restrictions in their food supply (Baker, 1988). In contrast, most people living in the modern technological society can obtain more than enough food. As a result, the prevalence of obesity and related diseases is increasing in the world; indeed, overnutrition has been recognized as a form of malnutrition (World Health Organization, 1997).

Dietary restriction (DR) without malnutrition affects physiological functions (Frame et al., 1998; Kouda et al., 2004) and prolongs lifespan (Yu, 1996; Weindruch and Sohal, 1997) in laboratory animals. Preliminary data indicate that these findings are applicable to humans. A study of humans produced observations like those of the animal studies, although life prolongation has not yet been shown (Walford et al., 2002). In laboratory animals, DR has also been reported to prevent cerebrovascular and cardiovascular diseases (Kemi et al., 2000), malignancy (Yoshida et al., 1997; Birt et al., 1999), autoimmune diseases (Kubo et al., 1992; Uran et al., 1995), and allergic diseases (Dong et al., 2000; Kouda et al., 2000; Fan et al., 2001; Nakamura et al., 2004).

Whereas there are numerous reports about disease prevention by dietary restriction, there are few reports about the effects of dietary restriction on physical performance. Concerning dietary restriction and physical activity, it has been shown that DR animals have higher activity levels, as demonstrated through their exercise in voluntary running wheels (Goodrick et al., 1983; Holloszy et al., 1991; Giles et al., 1992; McCarter et al., 1997). Recently, Horská et al. (1999) reported that the combination of caloric restriction and free exercise acts synergistically to decrease muscle fatigue and to improve muscle bioenergetics. However, little is yet known about the effects of dietary restriction on physical performance.

In the present study, we measured several reactions during assigned tasks and attempted to estimate physical performance in the kinds of activity involved in averting risks to life.

Materials and Methods

All experiments were approved by the Animal Experimentation Committee of the Hamamatsu University School of Medicine. Male ICR mice (age, 6 weeks; weight, 30–34 g) purchased from Japan SLC (Hamamatsu, Japan) were housed at the animal facility in the Institute for Experimental Animals at Hamamatsu University School of Medicine. The mice were maintained individually in plastic cages (20×30×13 cm) in an environmentally controlled room (temperature, 23 to 25°C; relative humidity, 50 to 60%; light: dark cycle, 12:12 h). The mice were randomly divided into an ad libitum (AL) group (n=6) and a dietary restriction (DR)
group \((n=7)\). All mice were given a standard rodent diet (Lab Diet \textsuperscript{®} 5002 PMI Nutrition International, Brentwood, MO) containing 201 g protein, 45 g fat, 46 g fiber, and 58 g ash per kilogram of diet. The total metabolizable energy was 13.0 MJ per kilogram of diet. The DR mice were fed at 16:00 daily. The amount of food supplied to the DR mice was 70\% of the amount actually consumed by the AL mice. The DR mice on Monday, Tuesday, Wednesday, and Thursday were fed with 70\% of the amount consumed by the AL mice, 210\% of food was given on Friday, and 0\% of that was given on Saturday and Sunday. Both AL and DR mice had free access to water throughout the study. The regimen was initiated at 7 weeks of age and terminated after 24 weeks of age. From 7 through 24 weeks of age, we measured four item indices every week: time to climb out of obstacles, time to escape restraint by gummied tape, time hanging from a bar, and ability to resist slipping.

To measure the time to climb out of obstacles, a stainless steel can (diameter, 17 cm; height, 22 cm) and 20000 tubular resin chips (diameter, 0.5 cm; length, 0.5 cm; weight, 25 mg) were used. After placing the mouse at the bottom of the can, the can was filled with the resin chips immediately. The time it took the mouse to climb out of the chips was measured. To measure the time to escape restraint by gummied tape, the abdomen of a mouse had a 5 cm wide, 15 cm length of tape attached. The time it took for the mouse to remove the tape was measured. To measure the bar-hanging time, the mouse was lifted to a horizontal bar with a diameter of 2 mm and a length of 60 cm; the mouse grasped the bar with its front paws. The time in which the mouse was able to hang from the bar was measured. To evaluate the ability of mice to resist slipping, an aluminum board 40 cm long and 30 cm wide with an angle protractor was used. We put the palms and plantae of a mouse on the board so that its head was toward the bottom. As the board was tilted at a sharper and sharper angle, the mouse resisted slipping off it. When the mouse started slipping, the angle of the board was recorded.

Statistical analysis was performed using SPSS \textsuperscript{*} 11.5J for Windows (SPSS Inc., Chicago, IL). An unpaired \(t\)-test was used to compare the DR group and AL group. Differences with values of \(p<0.05\) were considered significant.

Results

Figure 1 shows the body weight of AL mice and DR mice from 7 through 24 weeks of age. The mean body weight of the DR mice decreased from the 7th through 9th weeks of age due to the induction of the restricted diet. Body weight began to increase after the 10th week under the DR regimen.

Figure 2 shows changes in the time required to climb out of the obstacles. Just after DR mice were placed in the can, they began their climbing actions, whereas AL mice did not immediately show such actions. As a result, after 11 weeks of age the DR mice escaped from the obstacles in significantly less time than did the AL mice.

Figure 3 shows changes in the time required to escape from the tape restraint. The DR mice were significantly faster than the AL mice from 13 through 17 weeks of age, and again from 20 through 24 weeks. At 18 weeks of age, 2 AL mice took considerable time for escape behavior. As a result, there were no significant differences between AL mice and DR mice at 18 weeks of age.
Changes in time required to escape restraint by gummed tape. Open circles with vertical bars indicate the mean and SD of times required to escape restraint by gummed tape of the ad libitum (AL) mice (n=6), and closed circles of the dietary-restriction (DR) mice (n=7). There are significant differences between DR mice and AL mice from 13 through 17 weeks of age, and from 20 through 24 weeks.

Changes in duration of hanging from a bar. Open circles with vertical bars indicate the mean and SD of chinning times of the ad libitum (AL) mice (n=6), and closed circles with vertical bars (n=7). There are significant differences between DR mice and AL mice after 11 weeks of age.

Figure 4 shows changes in duration of hanging from a bar. The DR mice showed various motions to maintain a balanced posture while hanging, whereas the AL mice seldom moved. After 11 weeks of age, the DR mice held onto the bar significantly longer than the AL mice did.

Figure 5 shows changes in the ability to resist slipping. Open circles with vertical bars indicate the mean and SD of board angles of the ad libitum (AL) mice (n=6), and closed circles of the dietary-restriction (DR) mice (n=7). There are significant differences between DR mice and AL mice from 11 through 17 weeks of age, from 19 through 21 weeks, and at 24 weeks.

Discussion

It has been reported that a DR regimen consisting of a 30 to 50% reduction from the average food intake of AL mice results in a limited period of weight loss, after which the animals maintain their body weight or gradually regain some of the weight originally lost, despite continued dietary restriction (Weindruch et al., 1988; Fan et al., 2001). Our results were consistent with these previous observations.

The present study is the first report about dietary restriction and reactions to assigned tasks in animal study. In the results, DR mice had the advantage over AL mice in their reactions to tasks: climbing out of obstacles, escaping from restraint by gummed tape, hanging from a bar, and resisting slippage. Previously, experimental data demonstrated retrogression with age in nerve-muscle interaction, excitation-contraction coupling, mechanical properties, and muscle energies (McCarten, 1990). The DR regimen is believed to delay these age-related changes. In addition, Horkšá et al. (1999) demonstrated that the combination of caloric restriction and free exercise acted synergistically to decrease muscle fatigue.
and to improve muscle force. Therefore, the advantage in their reactions to tasks might be caused by these beneficial effects of the DR regimen.

On the other hand, motor action arises from complex phenomena, involving learning and the integration of past experiences with the prediction of future conditions. It is not the result merely of muscle force and endurance. In addition, lighter weight in DR mice than that in AL mice might relate to their advantage in reactions of climbing and hanging. However, DR mice also showed advantages in the time to escape restraint by gummed tape and in the ability to resist slipping, and these items were not influenced by body weight. Furthermore, in comparing with AL mice of 8 to 9 weeks of age and DR mice of after 18 weeks, DR mice showed an advantage in the time to escape restraint by gummed tape, the time hanging from a bar, and the ability to resist slipping, and both groups showed the same body weight. Therefore, the influence of body weight might be insignificant. It can then be considered that physical performance is affected by not only body weight but also numerous other factors.

It is difficult to investigate these behavioral phenomena and to explain the advantage of DR mice by using reductionistic analysis, in which each of the phenomena presented by the system under consideration would be divided into as many parts as possible and analyzed separately. Therefore, in the present study, we attempted to measure several reactions to assigned tasks and to estimate physical performance as a total system. However, further methodological improvement is needed before we can analyze these reactions within specific tasks.

In summary, we measured several reactions of mice to assigned tasks and attempted to estimate their physical performance. The results of the present study suggest that mice on a restricted diet have higher physical abilities, such as those required to avert risks to life, than ad-libitum-fed mice.

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References


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