Fall 1981

DIETARY OBESITY, EXERCISE TRAINING, AND THERMOGENESIS IN RATS

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University of New Hampshire PH.D. 1981

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Dietary Obesity, Exercise Training, and Thermogenesis in Rats

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A Dissertation

Submitted to the University of New Hampshire

in Partial Fulfillment of

the Requirements for the Degree of

Doctor of Philosophy

in

Psychology

September, 1981

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ACKNOWLEDGMENT

I wish to thank my dissertation chairman, Jim Davis, for his support throughout my career at UNH. He, more than anyone else, taught me what quality research is all about. I appreciate the confidence he had in my ability to carry out this project, and the long hours he spent reading what I wrote and giving constructive criticism. I am pleased to call him advisor and friend.

I also want to express my thanks to Carolyn Mebert. She was always willing to provide assistance and she gave me encouragement when it seemed that the work would never end. Without her help, this dissertation would have been much more difficult to complete.

The rest of my committee members, Jim Holter, Earl Hagstrom, Tony Tagliaferro, and Bob Kertzer, provided valuable assistance. Their help greatly improved the quality of this manuscript.

Many others also made it easier for me to complete this project. Jack Colborne devoted much time and energy into the manuscript preparation. Gail Dahlstrom and Mae Arnold helped make Conant Hall a better place to work. I want to thank them all.

A grant from the Central University Fund (s189) of the University of New Hampshire greatly helped in the completion of this work.

Finally I want to give special thanks to Dina who shared both the good times and the bad.

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ABSTRACT

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The exact contributions of changes in thermogenesis to the energy balance of either rats or humans is not known. There is some evidence that differences in post-prandial heat production (dietary-induced thermogenesis), can explain why some individuals gain weight easily when overeating and other do not. There is also evidence that exercise enhances dietary-induced thermogenesis. However, it may be the effects of exercise training rather than the exercise itelf which enhances dietary-induced thermogenesis. Aerobic exercise training may produce increases in dietary-induced thermogenesis and allow more calories to be expended as heat when overeating.

In these three experiments, the effects of diet and exercise training on food intake, body weights, body composition, and thermogenesis was studied in male and female Sprague-Dawley weanling and adult rats.

Overeating and obesity was produced by giving rats a supermarket diet, and aerobic training was accomplished by forcing some of the animals to swim 2 hours/day.

Thermogenesis was measured by indirect calorimetry while animals were in chambers connected to a closed-loop system. Changes in aerobic capacity were not measured directly but were inferred from changes in an enzyme in muscles known to increase with aerobic training, citrate synthase. The resulting changes in body weight with the supermarket diet and daily exercise could not be explained by changes in food intake. Both early diet and exercise affected thermogenesis and changes in heat production were found to be important in explaining the body weight changes.

I. INTRODUCTION

The constancy of adult body weight of most species is quite remarkable and not fully explained under all circumstances given the present state of knowledge about energy intake and expenditure. Adult animals demonstrate an impressive ability to maintain a constant body weight despite changing food supplies and variable levels of energy expenditure.

If a stable body weight is the result of a balance between energy intake and expenditure, adjustments in one or both of those factors must account for why body weight remains relatively stable throughout most of the adult life of animals of many species. Traditionally, a more important role had been given to food intake. However, there is a growing body of experimental evidence which suggests that energy expenditure adjustments must also be considered. With more sensitive equipment, it has become possible to detect small changes in heat production which can be important factors in energy balance when considered over 24 hours, or longer time periods. The circumstances under which systematic changes in heat production occur are not fully understood. Also the large variability between subjects that is seen in measurements of heat production has

not been explained. In the case of obese humans, it is known that changes in basal metabolic rate (BMR) oppose changes in body weight (Miller, 1975). Thus the overweight person is faced with opposition from his or her own metabolic rate when trying to reduce. Such changes in BMR may substantially hamper efforts to lose weight. It is likely that a similar metabolic opposition to body weight increases occurs.

In this review of some of the relevant literature, studies using both rats and humans as subjects will be considered. It is accepted by many that the rat balances energy intake with energy expenditure on a daily basis, and that adjustment of food intake is the most important factor in that balance (Adolph, 1947; Jacobs and Sharma, 1969; Janowitz and Grossman, 1949; Kanarek, 1976). Because man's ability to regulate energy balance on a daily basis has been thought to be poor in comparison to the rat, the usefulness of the rat as a model for studying human obesity has been questioned. However, the rat's outstanding ability to regulate energy balance and maintain a stable body body weight quickly disappears when the rat is given a high fat diet (Schemmel et al., 1970), a high carbohydrate diet (Kanarek and Hirsch, 1977), or a diet consisting of a variety of very palatable foods (Sclafani and Springer, 1976). When given such diets, rats respond very similarly to humans, and become obese. The resulting dietary obesity could be very comparable in the two species and the rat may

be a very good model for studying such obesity. It is important to realize that not all strains of rat respond to obesity-producing diets in the same way (Schemmel et al., 1972a), suggesting a strong genetic component in susceptibility to obesity. Caution should be used in comparing results across species of rats, and in noting similarities between rats and humans.

Forcing rats to exercise also seems to disrupt the energy balance regulation of rats. Changes in body weight which result from exercise cannot be explained by changes in food intake. There are similarities in the effects of exercise in rats and in humans. However, it must be remembered that humans are never forced to exercise in the same sense that rats are. This may be an important factor in how each species responds to the stress involved in the exercise.

In summary, some strains of rats can provide a good model for studying how energy balance is regulated in humans, and how that regulation changes with a very palatable diet and with exercise.

II. STABIILIITY CF BCDY WEIGHT

In most species, adult body weights are surprisingly stable, even when challenges tc the diet are given. Many times the resulting change in body weight is far less than expected. The initial explanation is that changes in food intake compensate to allow for body weight stability. However, it is nct clear that changes in food intake can always explain the stability of body weight. Some early studies (Cowgill, 1928; Adolph, 1947; Janowitz and Grossman, 1949) indicated that animals cculd increase or decrease the amount of food eaten to compensate for increased cr decreased calcric density, but not cn a short-term basis. There were delays ranging from 4 days in rats (Adolph, 1947) to 8 days in dcgs (Cowgill, 1928) before the animals adjusted their intakes to the new diets. Janowitz and Grossman (1949) diluted diets to as much as 25% of the caloric ccntent a control diet for rats. The animals took approximately a week to adjust their food intakes tc a new diet. It seems that animals have the ability to adjust their intakes to variations in caloric density but the adjustment is not immediate.

This suggests that if you deprive animals of food or force them to eat more than normal, they should adjust their subsequent intake in order to maintain their previous body weight. Levitsky et al. (1976) fasted rats up to 96 hours and observed food intake during recovery. They found that the animals regained the lost body weight without increasing food intake subsequent to the fast. Collier (1970) produced body weight losses (and lowered food intakes) through water deprivation. He found that his rats also recovered the lost body weight without overeating when given ad lib. access to food. Boyle et al. (1977), in following up on the results of Levitsky et al. (1976), found that refeeding rats which previously had been food restricted to either 81 or 92% of their normal body weights, resulted in a greater efficiency of utilzation of food in those animals. They found that the food restricted groups gained more weight on the same intake than did controls, and concluded that a metabolic adaptation to the undernutrition must have occurred. However, they did express food intake as grams eaten, instead of grams eaten/body weight. From their results it appears that a substantial increase in efficiency would be seen even if the correction for body weight were made.

Studies in which animals ate an excess of calories compared to normal intakes also reveal a surprising constancy of body weight. Grafe and Graham (reported in Miller and Payne, 1962), fed a 20-kg dog a diet containing about 20% protein. The dog was able to maintain a stable

body weight on intakes of both 1,120 and 2,580 kcal/day. Miller and Payne (1962) using rats and pigs fed either a high calorie or a low calorie diet. They found that differences in body weight between animals on the diets were much lower than would be expected given the difference in calories ingested. For rats, the caloric difference between the high calorie and low calorie diets was about 30%. The observed differences in weight were far less than expected. In pigs, there was more than a 37,000 calorie total difference between the diets, but the body weight remained constant between pigs on each diet. The caloric difference should have resulted in a difference of about 4 kg in body weight. Moreover, the difference in intake while keeping body weight constant could not be explained by differences in physical activity, digestibility, fat storage, or losses in the urine.

Stirling and Stock (1968) fed rats either a high protein or low protein diet. The rats on the low protein diet (high calorie) took in 72% more calories during a 20-day period than did animals on the high protein (low calorie) diet. The small change in body weight which resulted was far less than expected given the caloric intake difference.

Garrow (1979), fed monkeys a mixed diet supplying 100 kcal/day for 12 weeks. For the next 8 weeks he fed the same monkeys a mixed diet supplying 175 kcal/day. An analysis of the rate of weight gain showed no differences on either

diet. Thus, the animals were consuming 75% more energy while adding body weight at the same rate.

It is hard to explain all of these results by just considering food intakes. Clearly, some other control than food intake is involved in the regulation of body weight.

In humans, a similar body weight stability is seen. First Neumann (1902, see Miller, 1979), and then Gulick (1922), monitoring their own food intakes and body weight changes, found that their body weight remained very stable despite large differences in their food intakes over long periods of time.

Miller and Mumford (1967), using first themselves as subjects, and then student volunteers, found that an increase in caloric intake does not necessarily have to create an increase in body weight in man. Most researchers agree that in the normal adult, lean-body mass remains relatively constant (Brozek, 1963). If a normal adult deliberately overeats, then the only effect on weight should be due to increased fat storage. It has been accepted by nutritionists that 1 gram of fat is deposited for every 9 excess calories (Miller and Mumford, 1967). However, Miller and Mumford (1967) found that changes in body weight due to overeating were not as great as would be predicted if the excess calories were being stored as fat. In their study one group consumed a high protein diet and another group consumed a low protein diet. For both groups energy loss in urine and feces, body composition, nitrogen status and

activity were measured. It was found that in both groups the excess calories could not have been converted to fat according to the formula previously given. Subjects eating the high protein diet ate an excess of approximately 39,000 kilocalories and were found to gain an average of 3.7 kg rather than 5.9 kg they would have gained if the excess were converted to fat. In subjects on a low protein diet the discrepancy was even more apparent. Subjects overate approximately 35,230 excess kilocalories and only put on an average of 0.9 kg in body weight. On the assumption that adipose tissue contains 66% fat, each person should have gained 5.9 kg. Obviously the excess calories were going someplace other than into extra body weight. The overeating occurred over a period of four weeks. Miller and Mumford suggested four possibilities to explain the discrepancy between amount eaten and relative stability of body weight. The discrepancy could have been due to increased activity, reduced digestibility, changes in body composition or increased heat production. Their measurements of the first three variables elimirated them as explanations of the results. Therefore they concluded that increased heat production probably accounted for the excess calories expended.

Ashworth (1962) gave either 1000 or 2000 calorie suppliments to 5 young adult men and women. Over periods ranging from 7 to 35 days, it was found that the calorie suppliments did not reduce voluntary food intake. Also the

weight gain was much less than was expected given the subject's caloric intakes. Measures of oxygen consumption were not taken but it is reasonable to postulate an increase in dietary-induced thermogenesis as the mechanism to explain the fate of the excess calories. There are other reports (Durnin and Morgan, 1969), which also failed to find the predicted gain in body weight with overfeeding. However there are reports that in overfeeding the excess calories are all converted to body fat (Passmore et al., 1955).

Sims and his colleagues (Sims et al., 1968; Sims et al., 1968b; Sims et al., 1973) performed an impressive series of human overfeeding experiments in which it was found that the amount of food eaten was not a good indication of the magnitude of weight gained. In one study, (Sims et al., 1973), inmates at a Vermont prison voluntarily overate for extended periods of time. Some volunteers ate 7,000 to 10,000 kcal/day for periods of more than 200 days, which was an excess of about 50%, even for these individuals who were performing strenous work daily. Of the 9 subjects, one failed to reach the goal of a 25% increase, and six reached the goal only with great difficulty. It was reported that some of the subjects who failed to gain weight readily were eating more than some subjects who readily gained weight. Clearly the variability in body weight increases was not fully explained by intake changes. Also, it was found (Sims et al., 1973), that the caloric cost of maintaining elevated body weights in individuals who

deliberately overate was very high. Subjects who maintained body weight or 1800 kcal/kg during a baseline period, required 2700 kcal/kg to maintain their elevated body weights.

Rose and Williams (1961) studied humans who were either large or small meal eaters. The subjects' caloric intakes varied from 1,600 to 7,400 kcal/day and they had body weights which varied very little over a long period of time. They identified pairs of individuals whose weights and activity levels were the same, where one individual was eating twice as many calories as the other. Clearly individuals differ in the manner they dispose of excess calories.

These results, along with those of the animal studies previously reviewed, demonstrate that in many cases, body weight stability cannot be due to adjustments in food intake. It seems that in order to understand the stability of body weight, energy expenditure changes must be considered. It could be the case that heat production, or thermogenesis, accounts for some or all of the excess calories during overeating. Such an adjustment could explain the body weight stability. Also, it could explain why some individuals seem to be able to overeat frequently without gaining weight.

III. THERMOGENESIS

Jansky (1973) divided thermogenesis, or heat production, into an "obligatory" and a "regulatory" component. The "obligatory" component often is referred to as the basal metabolic rate (BMR) or the fasting heat production (FHP), and is a measure taken in an animal which is in a fasted state and is awake but resting. The "regulatory" component consists of energy used to digest food and convert it into a usable form, maintain body temperature in a cold environment, produce physical movement, create new tissue (growth or repair), form offspring, and nurse the young. Thermogenesis is measured either directly by measuring the heat produced by an animal or indirectly by measuring the oxygen consumed by an animal and then calculating the equivalent heat production (assuming a known RQ).

Basal metabolic rate is very difficult to measure accurately, since it is defined as the energy output of a subject under very exact conditions, such as 12-18 hours after a meal (in monogastric animals) when the subject is physically and mentally at rest, in a thermal neutral environment and taking into account conditions with respect

tc circadian rhythms (Garrow, 1978). Many investigators find it easier to measure resting metabolic rate. Resting metabolic rate, as used in this dissertation will refer to the metabolic rate of a subject that has been fasted 12 tc 19 hours, and is at rest in a thermal neutral environment.

It is well-known that an increase in metabolic rate cccurs after a meal. Initially, this was thought tc be due to the energy required to utilize protein and was called specific dynamic action (SDA). There still exists some confusion between "specific dynamic actien" and "luxuskonsumption". Neumann (see Miller, 1975) ccined the term "luxuskcrsumpticr" tc describe the phencmenon in which excess calories are expended as heat rather than converted into fat. His work (and that of Gulik, 1922) demcnstrated that only a small prcpcrtion of excess calories went into bcdy weight changes when he overate for periods up to one year. He suggested that the cther excess calories were dissipated as heat. Since Neumann, there have beer many other reports cf luxuskcnsumptien in man (Miller et al., 1967b; Swindells, 1972; Clough and Durnin 1970; Brey et al., 1974; Strong, 1967). Both SDA and luxuskonsumptien are measured as heat prcdtced in respcnse tc fcod, but some feel that SDA is related to the composition of the fccd and luxuskonsumptien is related to nutritiernal status of the subject (Miller and Mumford, 1973). Also, it is suggested that SDA is rct observed immediately after eating, but is seen to peak after apprcximately 2 tc 2.5 hours following a

meal. Recently investigators have argued that a distinction between the terms is not useful and have suggested that both phenomena should be regarded as dietary-induced thermogenesis (DIT; Miller and Mumford, 1973). It is important to understand that a change in BMR would not be expected after eating an excess of calories and in fact some investigators have demonstrated this (Miller et al., 1967; Gulick, 1922; Strang et al., 1935). DIT could be an adaptive mechanism which develops independently of BMR. Variables which affect DIT should not necessarily be expected to affect BMR.

IV. THERMOGENESIS IN ANIMALS

Lowered metabolism is known to contribute to the obesity seen in genetically obese rats (Festing, 1979; Cleary et al., 1980), and mice (Vander Tuig et al., 1980). However, the question of whether changes in metabolism are important factors in determining body weight of more "normal" rats and mice is still unanswered.

Forbes and Kriss, working in the field of animal husbandry, conducted a series of experiments showing that total heat production was a good measurement of feeding efficiency in livestock. They reported (Forbes et al., 1928) that heat production for cattle showed an exponential increase as a function of the caloric size of the meal. They later (Forbes, Kriss, and Miller, 1934) demonstrated the same effect with laboratory rats. When the size of the animal's daily meal was increased from 4 to 6 g to 6 to 8 g, heat production was increased about 160%. Thus, it was shown that excess calories in a meal were expended as heat when they were not needed to maintain a constant body weight. A later experiment (Forbes et al., 1946) showed that rats on low fat diets as opposed to diets of 1 and 30% fat had greater heat productions and a lower feed

efficiency. Heat production was shown to be affected by both the size and the composition of the diet.

Miller and Payne (1962) observed that rats and pigs could maintain a stable body weight while taking in an excess of calories. Differences in activity between groups of rats eating a high calorie and a low calorie diet could not explain why animals on the high calorie diet consumed 30% more calories and maintained the same body weight as low calorie diet animals. When the experiment was repeated with pigs, the high calorie group ate 3 to 5 times as many calories as the low calorie group without showing weight differences. Since activity was ruled out as the cause of the caloric differences the experimenters hypothesized that metabolic changes accounted for the differences. Using pigs as subjects they found that the major part of the excess calories was expended as heat through post-prandial metabolic increases, thus demonstrating the role of DIT in maintaining weight in those animals.

Stirling and Stock (1968) confirmed the finding of Miller and Payne using rats. Animals were fed either a high protein (normal stock diet) or a low protein diet (the normal stock diet diluted with fat). The animals on the low protein diet ate much more than the high protein animals but maintained a constant body weight. There was a caloric intake difference of 920 kilocalories over a 20-day period but the average body weight of the low protein group was only one gram higher than that of the high protein group.

Much of the excess energy was acccunted fcr in terms of increased heat production of the low protein grcup. Over the 20-day period they expended 690 more kilocalories in heat than did the high prctein grcup.

Rothwell and Stock (1978, 1979a, 1979b,) produced overeating in adult rats by presenting them with a variety of highly palatable foods ("cafeteria" diet). Animals on this diet tcck in 80% more energy cver a 21-day period than animals on a stcck diet, but had an average weight gain of cnly 27% more than controls. They found that much cf the difference cculd be acccunted fcr by higher heat production of the rats cn the ""cafeteria" diet". Measurements of resting oxygen consumptien were taken at 4 times during the 21-day period (days 5,11,13,16). It was found that DIT consistently was higher in the animals on the "cafeteria" diet. These results cffer mcre support fcr the argument that dietary induced thermogenesis plays a major rcle in the maintenance of a stable bcdy weight.

Gurr et al. (1979, 1980) replicated the experiment of Miller and Payne (1962). Using 4 castrate, male pigs they ccnfirmed the original findings of Miller and Payne that animals fed a low protein diet consumed three times as much energy as arimals on a high prctein diet. There was no difference in body weight between the twc groups, but there was a significantly greater heat production in the low protein group. The body fat content of the lcw prctein group (determined by carcass analysis) was significantly

greater than for the high protein group. Activity was not a factor since all animals were restrained in metabolic crates.

Current research concerning thermogenesis in animals is involved with more closely documenting the thermogenic responses to overfeeding, and trying to explain the mechanisms by which changes in thermogenesis occur. Of particular interest to these investigators are diets which produce voluntary overeating in experimental animals. The use of such diets will be explained in the next section.

V. DIETARY OBESITY

High fat diets

Several methods of producing dietary obesity have been used in rats. High fat diets were found to produce obesity first in mice (Fenton and Carr, 1951) and then in rats (Mickelson, et al., 1955). The explanation of the resulting obesity was that it was due to a combination of overeating (Corbit and Stellar, 1964; Schemmel et al., 1970; Hamilton, 1964) and of the animals becoming more efficient in converting the energy eaten into body fat (Schemmel et al., 1972b).

It is interesting to note that there was a great deal of variability in the magnitude of the body weight increases when a high fat diet was given (Schemmel et al., 1970; DeLacy, 1975), and that some animals were reported to have become obese without increasing food intake (Herberg et al., 1974; Lemonnier, 1973). Females also were reported to be less efficient in depositing the energy taken in as body fat than were males (Schemmel and Mickelson, 1974).

When given to weanling rats, a high fat diet produced obesity, but only after a delay of approximately 60 days (Schemmel et al., 1969; Peckham et al., 1962; Lemonnier,

1972). The reason for such a delay is unknown, but rats given the diet at weaning reach higher levels of body weight than animals given the diet only during adulthood (Peckham et al., 1962). Peckham et al. (1962), also have found that young rats given a high fat diet are predisposed to obesity even if the diet is withdrawn a short time later. DeCastro and Balagura (1976) found that rats given a high fat diet increased the size and duration of meals and decreased meal frequency.

High carbohydrate diets

High carbohydrate diets also have been found to increase body weight and body fat in rats (Allen and Leahy, 1966). Kanarek and Hirsch (1977), found that rats given ad lib. access to a 32% sucrose solution in addition to ad lib. access to chow and water became obese. Overeating was seen consistently in animals given a high carbohydrate diet (Kanarek and Hirsch, 1977).

As with a high fat diet, giving a high carbohydrate diet to weanling rats resulted in a delay in onset of obesity. This delay was reported to be about 50 days (Kanarek and Hirsch, 1977). Kanarek and Hirsch also found that at 70 days of age, rats given ad lib. access to the 32% sucrose solution in addition to ad lib. access to chow and water were not heavier than controls, but had significantly more body fat. Heggeness (1961), found a similar delay in body weight increases in weanling rats given a 60% carbohydrate diet. Oxygen consumption

measurments were taken in that study and the results suggested that there was an upper limit in body weight increase during that period and that the excess calcries were expended as heat.

Supermarket diets

A particularly good way of producing dietary obesity was introduced by Sclafani and Springer (1976). Referred to as a supermarket diet, cafeteria diet, snack food diet, and occasionally junk-food diet, it consists of presenting the animal with a variety of palatable foods. Usually the foods are changed frequently. Some foods commonly used are cookies, peanut butter, candy, bananas, cat food, marshmallows, and sweetened condensed milk. Exposure to this diet has been reported to produce dietary obesity in adult rats (Rothwell and Stock, 1979b; Sclafani and Springer, 1976; Sclafani and Gorman, 1977), and weanling rats (Rothwell and Stock, 1980; Simpson et al., 1980).

Body weight. Adult rats consistently increase their body weights when given access to a supermarket diet. The increase in body weight is quite rapid and occurs in both males and females. Several studies have demonstrated that, compared to controls eating a standard laboratory diet, supermarket diet animals demonstrate rapid body weight shifts. Male rats given a supermarket diet were reported to be 15% heavier than controls after 15 days (Rothwell and Stock, 1979b), and 27% heavier than controls after 21-days (Rothwell and Stock, 1979a). Female rats were reported to

be 35% heavier after 60 days (Sclafani and Springer, 1976). Sclafani and Gorman (1977) compared the weight gains of male and female animals given a supermarket diet for 60 days. Male animals gainsed 33% more weight than male controls and female animals gainsed 171% more weight than female controls. Thus, females gained more weight as compared to controls than did males. There are, however, consistent reports of very large variability in the amount of weight increase seen in animals on the supermarket diet (Sclafani and Springer, 1976; Sclafani and Gorman, 1977; Rothwell and Stock, 1979b). The amount of weight increase experienced by supermarket diet animals probably depends to a large extent on the exact composition of the diet, but seems also to depend on some other factor within the animals.

Food intakes. The most obvious explanation of the body weight increases is that animals overeat the palatable foods, producing dietary obesity. When the palatable foods are withdrawn, animals decrease their caloric intakes to return to lower body weights. The foods in the supermarket diet are usually just put on the floor of the cage or put in individual food dishes. The spillage and mixing of foods involved makes accurate measures of caloric intake difficult. However, in those cases where food intakes were measured, supermarket diet animals were definitely hyperphagic (Rothwell and Stock, 1979a, 1979b, 1980). The degree of overeating varied from 75% over 22 days (Rothwell and Stock, 1979b) to 80% over 21 days (Rothwell and Stock,

1979a). In the other studies using a supermarket diet, investigators have reported that it seemed apparent that supermarket diet animals were overeating as compared to controls. Rothwell and Stock (1979a, 1979b), found that the degree of hyperphagia was such that greater weight increases should have occurred in the supermarket diet animals. They argued that energy expenditure must have been increased in those animals.

Body fat. There is good agreement that much of the weight gain seen in animals eating a supermarket diet represents increases in body fat (Stephens, 1980; Rothwell and Stock, 1979a, 1979b; Sclafani and Gorman, 1977). Rothwell and Stock (1979a) reported that 93% of the excess weight gain in their animals fed supermarket diets, was fat. Sclafani and Gorman (1977) reported than males eating the supermarket diet became as obese as females when body fat was extimated using the Lee Index.

Thermogenesis. Rothwell and Stock (1979a) argue that differences in heat production account for the large variability of weight gain seen in animals given a supermarket diet. They argue that since all animals were hyperphagic and there were large differences in body weight increases, that there must also be differences in energy expenditure. The most reasonable explanation of the weight increase differences seems to be that heat productions varied for the animals causing variability in weight increases. This, according to Rothwell and Stock, explained

why the animals fed supermarket diets, consumed 80% more energy than controls and yet gained only 27% more weight. Garrow and Stalley (1975) have argued that energy expenditure through heat production increases or decreases in order to maintain a stable body weight.

Rothwell and Stock (1979a) found a consistent 20 to 30% difference in resting oxygen consumption throughout the period of weight gain, with the animals fed supermarket diets, having a higher consumption. Resting oxygen consumption was measured for two hours on days 5, 11, 13, and 16 of the diet availability. No information was reported concerning when measurements of oxygen consumption occured relative to meal times. In a second study, Rothwell and Stock (1979b), found no difference in the resting oxygen consumption of animals fed supermarket diets, as compared to controls during the time the animals were eating the supermarket diet (22 days).

Withdrawal of supermarket diets. The dietary obesity produced by supermarket diets also has been reported to be reversible. Many investigators have reported that body weight in animals fed supermarket diets, returns to levels of control animals when the supermarket diet is withdrawn. The return to the lower body weight levels seems also to occur very rapidly. Sclafani and his co-workers found animals fed supermarket diets, lost the excess weight gained on the diet by 25 to 30 days after withdrawal of the supermarket diet (Sclafani and Springer, 1976; Sclafani and

Gorman, 1977). Rothwell and Stock (1979b) found that the excess weight was lost by 14 days after withdrawal of the supermarket diet, and Stephens (1980) reported the excess weight lost by 100 days after the diet withdrawal. However, there were exceptions (Rolls and Rowe, 1977, 1979, 1980). In one study Rolls and Rowe (1977) reported that weights of animals fed supermarket diets, did not return to levels of controls, even by 18 weeks after diet withdrawal. These animals also defended their new higher body weights if challenged by food deprivation. One problem in comparing this study with the others mentioned is that Rolls and Rowe used male hooded rats rather than Sprague-Dawley rats. It is well known that there are strain differences in weight gained on high fat diets (Schemmel et al., 1970), and it is likely that there are strain differences in effects of a supermarket diet on body weight.

Some studies have examined the effects of repeated bouts of access to a supermarket diet followed by a period of access to only lab chow on subsequent weight gains when the supermarket was reinstituted. Sclafani and Springer (1976) reported that animals fed supermarket diets, which were food deprived to 80% of the ad lib. body weights experienced greater weight gains than their original increases, when returned to the supermarket diet. Scalfani and Gorman (1977) reported that older (174 days of age) adult male and female rats gained more weight over the same time period on the supermarket diet than did younger (84

days of age) adults. In fact, for animals 174 days of age, the weight gain was not any different for animals which had had one previous period of supermarket diet feeding (from 84 to 144 days of age) than for animals without previous access to the supermarket diet. Rothwell and Stock (1979a), also reported that repeated periods of access to the supermarket diet did not affect the animals' weight loss when the diet subsequently was withdrawn.

When caloric intakes were measured after animals were taken off of the supermarket diet, Rothwell and Stock (1979b) found no difference between supermarket diet and control animals over the first 12 days after diet withdrawal. However, during these 12 days the body weights of the animals fed supermarket diets, returned to control levels. It was concluded that reduced caloric intakes could not account entirely for the reduced body weights of animals fed supermarket diets, after the diet withdrawal. In a second study, Rothwell and Stock (1979b) reported that although the animals became hypophagic after withdrawal of the supermarket diet, it was not enough of a reduction to explain the weight loss.

Also, there are reports that when the supermarket diet is withdrawn, animals become less obese. Rothwell and Stock (1979b) found that animals with access to the supermarket diet for 22 days were significantly fatter than controls. However, 15 days after the diet was withdrawn, the animals were not fatter than controls. Stephens (1980) measured

body fat 100 days after supermarket diet withdrawal in rats which had beer eating the diet for 100 to 130 days and reported they were significantly leaner than controls.

Rothwell and Stock (1979a, 1979b, 1978) have consistently reported that animals which have become obese on the supermarket diet had higher resting oxygen consumption rates than controls over the first few days of supermarket diet withdrawal. In one study (Rothwell and Stock, 1978) they found that animals fed supermarket diets, had a significantly higher rate of oxygen consumption over the first 3 days after diet withdrawal as compared to controls. During those 3 days, the animals fed supermarket diets, lost 40% of their excess body weight even though food intake was slightly, though non-significantly higher than controls. In a second study, (Rothwell and Stock, 1979b) they reported that resting oxygen consumption increased 24% over control rates during the first 3 days of supermarket diet withdrawal. But, 7 days after diet withdrawal, consumption rates were no different from controls. In fact, consumption rate for the animals fed supermarket diets, was even lower than during the period of access to the supermarket diet. In a third study (Rothwell and Stock, 1979a), they reported that animals eating the supermarket diet had a higher DIT than controls and this higher DIT remained higher after the supermarket diet was withdrawn. However, DIT was not measured prior to group formation and the supermarket diet group could have had signficantly

higher oxygen consumption rates to begin with. This possibility is not unlikely in view of the great individual variability in DIT. Thus their argument than DIT is independent of the immediate energy intake is not conclusive.

The rapid increase in body weight that occurs when a supermarket diet is given, and the equally rapid decrease that occurs when it is withdrawn provides a good model for studying the changes in energy intake and expenditure in this type of dietary obesity.

Supermarket diets in weanling rats. Few studies have examined the effects of a supermarket diet in weanling rats. Rothwell and Stock (1980a), gave 33-day old male Sprague-Dawley rats a supermarket diet for 14 days. Animals with access to the supermarket diet did not gain more weight than controls during this pericd despite consuming 50% more energy. However, expenditure, as measured by resting oxygen consumption, was significantly higher for the animals on the supermarket diet than for controls.

Simpson et al., (1980, 1981) reported that there was a delay in the obesity produced by giving a supermarket diet to weanling rats. Female Sprague-Dawley rats were weaned at 21 days of age and given access to a supermarket diet. There was no difference between body weights of the animals fed supermarket diets, and controls until 57 days of age, at which time the animals fed supermarket diets, were significantly heavier.

Meal patterning. Laboratory rats normally eat 8 to 14 small meals per day when food is always available (Sclafani, 1979), and there is some evidence that the gain in body fat is greater on the same food intake if large, rather than small meals are eaten (Fabry, 1967). Pocknee and Beaton (1976), also provided evidence that other changes may occur with differing meal patterns. They studied the effects of large versus small meals in male weanling Wistar rats. Although the total amount of food consumed over periods of 24 to 75 days did not differ between groups, animals eating one large meal had heavier livers, kidneys, femurs, small intestines, and stomachs that animals eating smaller, frequent meals. The differences were found to be permanent and persisted into adulthood in the animals. Such differences suggest that the pattern of food intake may have effects on metabolism of the animals. Giving the obesity-producing diets may alter meal patterning in the animals. This could be evident in the supermarket diet which the animals obviously find very palatable and begin eating as soon as it is put into the cage. Such measurements of meal patterning in these animals need to be performed.

VI. EXERCISE IN RATS

Studies of overfeeding appear to illuminate situations in which body weight stability cannot be explained by examining food intake. Studies of the effects of exercise on body weight and on energy intake and expenditure may illuminate other situations in which changes in energy expenditure are very important factors in energy balance.

Several studies have examined the effects of exercise on body weights, food intakes, and body composition in rats. There is much more agreement about the effects of exercise on body weights and body composition than about the effects on food intakes. The effects of voluntary exercise have been examined by giving rats access to a running wheel. Levitsky et al. (1970) found that there was an initial weight loss when male albino rats were given access to a running wheel, but that the weight loss was recovered entirely within 2 days. Food intake decreased and remained lower for several days, after which it returned to levels of control animals. Over a period of 18 days, food intakes of the exercising animals were not significantly different from control animals.

Premack and Premack (1963) found that daily food intake of female Sprague-Dawley rats was reduced when given access to a running wheel. When access to the wheels was denied, daily intakes increased. They interpreted the results as suggesting that the animals were increasing eating to compensate for being deprived of another activity, running.

The situation seems somewhat different for forced exercise. Mayer et al. (1954) observed that rats forced to exercise 1 to 6 hours per day, increased their food intakes proportional to their increase in exercise. Less than 1 hour/day of exercise resulted in depressed intakes and decreased body weights. Collier (1970), suggested that when the execise (either forced or voluntary) was within the animal's normal range of daily energy expenditure that energy intakes did not balance energy expenditure.

The consistency of reports that exercise suppressed appetite in male rats and enharced appetite in female rats led many investigators to conclude that the issue was resolved. However, when studying how an animal regulates energy balance, one is not so much interested in whether the absolute level of food intake increases or decreases with exercise, as in how the energy consumption and expenditure per unit of body mass changes with exercise. It is essential to correct the amount of food eaten for the body weight of the animal when expressing food intakes if one is trying to study how the rat regulates energy balance. This correction has not been done.

For example, Hanson et al. (1967) swam male Wistar rats for 30 minutes twice daily. They reported that exercise led to lower body weights regardless of whether animals were maintained on high or low fat diets and regardless of whether animals on each of those diets were fed ad lib. or were restricted to 65% of ad lib. intake. They reported no difference in caloric intake between exercised and sedentary animals. However, they expressed caloric intakes as total kcal eaten, without adjusting the intake for the body weight of the animal. Since there was an difference of approximately 80 g in body weights of exercised vs sedentary animals, this could reflect a higher overall intake for the exercised animals when intake was expressed as kcal/kg of body weight.

Stevenson et al. (1966) swam male Sprague-Dawey rats for either 1, 2, or 4 hours/day. Body weight increased significantly more over a 4-week period for controls than for exercised animals. Body weights did not differ for animals swimming 2 vs 4 hours/day, but weights of both of these groups were lower than those of animals swimming only 1 hour/day. It was reported that food intakes were significantly lower than controls for animals swimming 1 or 2 hours/day and were no different from controls for animals swimming 4 hours/day. All food intakes were expressed as gram/day and were not adjusted for body weights of the animals. Only mean group intakes and mean group body weights at the beginning and end of the 4-week period were

reported. But, if the mean intakes are adjusted with the mean body weights and expressed as grams of food/kg of body weight, then food intake increased with length of exercise, at least during the last five days of the experiment. Sedentary animals had the lowest food intakes during this period. It is impossible to evaluate whether the differences were significat form the data reported in the paper, but it is likely that at least for the group swimming 4 hours/day that food intakes were significantly higher than for controls. It does not seem to be the case that food intakes were reduced in any of the exercised groups.

Oscai et al. (1969) swam male Wistar rats for 2 hours/day and found that exercise produced lowered body weights. They reported that exercised animals ate significantly less than sedentary animals, but again, intakes were not adjusted for the body weights of the animals. If intakes are adjusted for body weight, using the group means reported for each, exercised animals ate considerably more than either sedentary free-eating controls or sedentary animals pair-fed with exercised animals.

Oscai et al. (1971a) swam male Wistar rats for 6 hours/day. They reported that the exercised rats gained weight more slowly than controls and that intakes of exercised animals were not different from controls. Again, intakes were not adjusted for body weight and, if so adjusted, would result in exercised animals eating considerably more than sedentary animals.

Swimming in female rats has been consistently reported not to result in body weight decreases. The reason why exercised females do not have reduced body weights has been reported to be because they increase their food intakes to prevent body weight losses or slowed growth (Oscai et al., 1971a).

Oscai and his co-workers have examined the effects of 6 hour/day of swimming in female Wistar rats. They reported that female exercised animals gained weight at the same rate as females sedentary animals and that the increased caloric intakes of these animals accounted for this observation (Oscai et al., 1971a). In a second study, female Wisar rats were swam for 6 hours/day for 21 weeks. Again, body weights did not differ from those of controls and caloric intakes were significantly higher for exercised animals. Adjusting intakes for body weight should not make any difference in the results of these studies since body weights of the groups did not differ.

Crews et al. (1967) swam female Wistar rats for 2 hours daily. No difference was seen between the body weights of those animals and controls.

Forced running has been reported to have effects similar to forced swimming in male rats. Thomas and Miller (1958) studied the effects of long-term daily treadmill running of up to one mile per day on male Sprague-Dawley rats. They found that body weight and food intake were reduced when the rats were exercised, but that food intake

became higher than that of controls on the days the animals were not exercised. The overall weekly food consumption was not different for exercised and sedentary males. If the food intakes had been expressed as grams of food/kg of body weight, it is likely that intakes of exercised animals would have been significantly higher.

Dohm et al. (1977) forced male albino (Holtzman) rats to run on a treadmill at one of three intensities: 20 m/min, 27 m/min, or 35 m/min. All running was done for 1 hour/day for 6 weeks. There were no body weight differences among any of the groups in the second week, but in the fourth and sixth weeks body weights of all exercised animals were significantly lower than body weights of a sedentary control group. There were no body weight differences among the exercised groups. Also, it was reported that food intake was significantly reduced in all exercised groups during the second, fourth and sixth weeks of the study, and that there was no difference in intake due to intensity of exercise. However, when intakes are expressed as g/kg of body weight, using the mean values for intakes and body weights reported, a different pattern is seen. During week 2, intakes of control animals are higher than for the three exercised groups. The largest difference was between the control group and the group which ran at the highest intensity (35 m/min). During the fourth week, the highest intakes were in the group running at the medium intensity (27 m/min). The intakes of the control group and the group running at the

highest intensity virtually were identical. The lowest intakes were in the group running at the lowest intensity. During week 6, the intakes of the animals running at the highest intensity were 3% higher than controls and intakes of animals running at the medium intensity were 1% higher than controls. Intakes of animals running at the lowest intensity were 4% lower than controls. In summary, animals running at the lowest intensity consistently ate less than controls in all three periods of measurement, while animals exercised at the medium and highest intensity ate as much or more than controls during the last two periods of measurement.

In a second experiment, Dohm et al. (1977) compared body weights and food intakes of the group running 35 m/min with those of sedentary controls and with those of a group of sedentary animals which were pair-fed with the exercised group. They found that the body weight difference between the pair-fed animals and the sedentary control animals was greater than the difference between the exercised and sedentary control animals. They argued that the depressed food intake could have played only a minor role in the lowered body weights of the exercised animals. However, the pair-fed animals probably were fed the same food in grams rather than in g/kg as compared to exercised animals, so the argument of the authors does not seem justifiable.

Katch et al. (1979) using male Sprague-Dawley rats forced one group to run on a treadmill at 5 m/min (low intensity group) and one group to run at 16 m/min (high intensity group). The experiment was divided into 5 periods of five days. Animals exercised only during the second and fourth 5-day periods. It was found that gain in body weight over the 5 periods was significantly greater for the sedentary than for either exercised group. The weight gains did not differ for the two exercised groups. They also reported that food intakes (even when expressed as kcal/gram of body weight) did not differ among the three groups during any of the three periods of no exercise. During both periods of exercise, both groups ate significantly less than controls. In addition, the low intensity group ate significantly more than the high intensity group during both exercise periods.

Crews et al. (1969) forced male Wistar rats to run on a treadmill for 12 weeks. The intensity began at 22 m/min for 20 minutes/day and gradually was increased over the course of the experiment. During the final 3 weeks, the rats were running at 31 m/min for 2 hours/day. Rats were given either daily exercise, pair-fed with the exercised group, or put into the sedentary control group with ad lib. feeding. In addition, one-half of the animals in each group ate a normal diet and one-half ate a protein-deficient diet. Exercised animals on both diets gained weight slower than sedentary controls. It was reported than food intakes were

significantly lower for exercised animals on either diet than for sedentary contols. But, intakes were not adjusted for body weights. Not enough information was given in the paper to estimate what difference such an adjustment would make.

Nance et al. (1977) forced male and female Sprague-Dawley rats to run on a treadmill for up to 1 hr/day for seven days. They concluded that body weight and food intakes were reduced for males, but not for females. They expressed food intake as change from a baseline period of measurement, and also in comparison to sedentary controls. However, during this baseline period body weights were identical for exercised and sedentary animals. This was not true after the exercise began. Thus, expressing food intakes in grams only did not give an accurate picture of the effect of exercise on food intake in the lighter exercised males.

Certainly the studies just summarized have failed to consider the effect of exercise on food intake from an energy balance viewpoint. It would be a mistake to accept as truth their reports that exercise suppresses appetite in male rats. In fact, it is very likely that exercise has just the opposite effects on food intake in males.

There have been many more studies of exercise in male rats than in female rats. This is due in part to the accepted finding that females, unlike males, are able to increase their food intake to meet the excess energy

expenditure of exercise. Body weights in females have not been reduced by exercise of short duration (Crews et al., 1967) or of longer duration (Oscai et al., 1971; Oscai et al., 1973). In these studies, the intakes of the exercised animals were higher than those of sedentary controls.

Swimming consistently has led to reduced amounts of body fat deposition and seems to be very effective in reducing the increase in body fat associated with aging (Hansen et al., 1967; Oscai et al., 1971; Oscai and Holloszy, 1969).

In addition, Kral et al. (1974) reported that physical training could increase fat cell metabolism in the rat. Using male Sprague-Dawley rats, they found that animals which swam for 1 hour/day had lower body weights than either sedentary controls or animals which were given one exhaustion swim. This decrease was due in part to a decreased fat cell size. Such a decrease was not seen in either the sedentary group or the group given one exhaustive swim. Moreover, it was found that the size, rather than the number of fat cells changed, resulting in a 3% reduction in fat pad weight. The authors suggested that the decreased fat cellsize indicated enhanced lipolysis in the smaller fat cells. Thus, long-term training may have prolonged effects on fat metabolism which is not seen insedentary animals exposed to temporary bouts of exercise.

Penpargkul and Scheur (1970) observed changes in metabolic performance in the hearts of male Sprague-Dawley rats during forced exercise. They concluded that rats conditioned by daily swimming had increased coronary flow, as compared to sedentary controls. This resulted in increased oxygen consumption during stress in the conditioned animals, giving them an increased maximum aerobic capacity.

The effects of forced running on body composition have been reported to be similar to those of forced swimming (Pitts and Bull, 1977). The question of whether the body weight reduction seen in males includes lean body mass along with fat is unclear. There are some reports that lean body mass decreased with exercise (Pitts and Bull, 1977; Oscai and Holloszy, 1969) but others reported a relative increase of lean body mass with exercise (Crews et al., 1969; Oscai et al., 1973).

VII. THERMOGENESIS IN MAN

A growing group of investigators are of the opinion that changes in metabolic rate are an important factor in the energy balance of man, and that they serve to keep body weight stable. The exact nature of the metabolic changes that occur, the mechanisms by which they occur, and the instances in which they occur are not fully understood. Even among people who believe that thermogenic changes are important in energy balance in man, there is disagreement about how much thermogenesis can change and what precipitates the changes. Also, almost every study of thermogenesis in man has found large individual differences in the magnitude of thermogenic changes with differing levels of nutrition. Until the reasons for this high variability is understood the full importance of metabolic changes in man will not be known.

The experiments summarized in this section examined the importance of changes in metabolic rates in achieving energy balance in man. Three major hypotheses will be examined. First, some people believe that dietary-induced thermogenesis increases in some orderly fashion with the caloric size of the meal. Second, many feel that over or

undereating for extended periods of time induces a metabolic adaptation. Third, there are those who believe that thermogenic differences can be found between individuals of normal body weight and those who are obese. This difference in thermogenesis could explain the ease with which some people gain weight.

One suggestion of the role of dietary-induced thermogenesis in energy balance is that it increases in some orderly fashion as more excess calories are consumed during a meal. Miller and Mumford (1967) overfed a group of 16 young adult men and women for periods of 4 to 8 weeks. One-half of the subjects consumed a low-protein diet (15%) and one-half consumed a high protein diet (28%). Subjects took in approximately 1,400 kcal/day more than normal. The subjects on the high protein diet gained an average of 3.7 kg of body weight as compared with a theoretical gain of 5.4 kg. For subjects on the low-protein diet the gain was 1.1 kg as compared to a projected 5.0 kg if the extra calories were converted to adipose tissue. The experimenters could not explain their results by increased activity, reduced digestibility, or changes in body temperature. This suggested that the extra calories were expended as heat.

In a follow up experiment using some of the same subjects, Miller et al. (1967) demonstrated an increased heat production in their subjects after they ate meals of varying caloric size. Using 11 adult men and women, they found the thermic response to the meal increased

exponentially as the caloric content of the meal increased. Moreover, the increase in heat production was greater when the subjects exercised 30 minutes before and after the meal. Meal size ranged from 370 to 3,200 kcal and the range of daily caloric intakes was 3,450 to 4,450 kcal. These results support the notion of dietary-induced thermogenesis as an important mechanism in maintenance of a stable body weight and in energy balance in general.

Swindells (1972) conducted a series of experiments which measured the oxygen consumption of ten women after consuming meals of 230 to 1200 kcal. In one experiment, she found the thermic response to a meal was unrelated to the caloric size of the meal. Meals for each subject were 1/9, 1/3, or 1/2 of the daily allowance of calories, and oxygen consumption was measured for 3 hours after the meal. In a second experiment, two women weighing 56.4 and 47.2 kg respectively, were given meals of first 600 and then 900 kcal. Two additional women (weighing 76.6 and 66.7 kg) were given meals of first 800 and then 1200 Kal. Daily allowances for the two lighter subjects were 1800 kcal, and 2400 kcal for the two heavier subjects. The results showed that for each individual there was a greater thermic response to the larger meal. Bray et al. (1974) varied the caloric size of a breakfast given to 6 adult men, and measured the post-prandial thermic response. Oxygen consumption varied in all subjects after the various meals but the caloric size of the meal had no effect on the

increase. When the subjects exercised for 30 minutes following breakfast the thermic response was higher than following the same breakfast without exercise. For subjects eating breakfasts of greater than 1,000 kcal, exercise approximately doubled the thermic response. However, one subject ingested only 350 kcal and in this case no additional increase in thermic response was seen with exercise. This study demonstrated an increased thermic response after eating, but did not show that the magnitude of that response was related to caloric size of the meal.

The studies summarized above all provide support for the notion of an increased heat production after eating. However, there is no agreement as to whether the magnitude of that response is related directly to the size of the meal. In comparing the results of Miller et al. (1967), where the increase in heat production was related directly to size of the meal with the studies of Swindells (1972) and Bray et al. (1974), where there was no relationship, some methodological differences can be seen. First the meals used by Miller et al., were a higher proportion of normal caloric intake than those in the other two studies. In fact, in Swindell's study, the meal with the highest caloric content was about 50% of normal daily intake. DIT, as a mechanism to maintain a stable body weight, would be expected to be most evident as more excess calories were eaten. In the study of Bray et al., there were only 3 different size meals even though it would be expected that

more of an increase in thermogenesis would occur in the larger (3000 kcal) meal.

Another difference among the experiments is the measurement of oxygen consumption. Miller et al., divided the day into 5 periods (beginning at 0800 hr), of 5,6,5,4, and 4 hours. During the first 3 periods an integrating motor pneumotachograph (IMP) was worn for approximately one-half of the period. During the final 2 periods, oxygen consumption was measured using a Beredict-Roth apparatus. Bray et al., collected small samples of air in a meterological balloon. The air was mixed and the oxygen and carbon dioxide concentrations were measured. Swindells used a Douglas Bag to make her measurements of resting oxygen consumption. Measurements were taken for 3 hours after meals. Thus some of the variability in results could have been due to different methods being used to analyze oxygen consumption.

It is not clear exactly what the relationship is between magnitude of overeating and thermic response in normal or obese individuals. The only thorough data were those of Miller et al. (1967), which indicated an exponential relationship. Certainly more studies are necessary in order to completely understand such a relationship. Such studies should be relatively easy to conduct in both normal weight and obese individals. It is surprising that little is known about such a relationship in animals. A supermarket diet which can induce overeating in

experimental animals should provide a good means for examining the relationship between size of a meal and metabolic rate. The composition of the meal could also be varied to examine differences in the magnitude of the thermic response with different nutrients.

Miller and Parsonage (1975) suggested that changes in metabolic rate act to resist changes in body weight. Apfelbaum et al. (1971) found a 20% reduction in BMR with restricted diets. This reduction in BMR serves to resist any lowering of body weight and also serves to frustrate overweight individuals who are dieting. Likewise, there seems to be a metabolic adaptation to a state of overnutrition. Sims et al. (1973) demonstrated that the energy required to maintain body weight in obese subjects was 35% below normal. There is a growing body of literature which suggests that metabolic adaptations to overfeeding and underfeeding do occur in humans. An unresolved question concerns the exact nature of the adaptations and whether they are immediate.

A great many studies have examined the role of DIT in getting rid of excess calories during extended periods of overfeeding. Many of the studies described in an earlier section concluded that the body weight change in man during periods of overeating was much less-than-expected given the calories ingested. Many of the same investigators then examined energy output of their subjects to see if changes there could explain the less-than-expected variations in

body weight. Passmore and his colleagues performed a series of experiments (Passmore et al., 1955; Passmore et al., 1963; Strong et al., 1967) in which energy expenditure was measured in both lean and obese subjects who were either over- or under-eating. In one experiment, (Passmore et al., 1955) it was found than when thin men were fed an excess of approximately 1500 kcal/day for 2 weeks, they gained weight slower than expected. In a second experiment (Passmore et al., 1963), two obese women were subjected to periods of over-eating and under-eating for 9 and 5 days respectively. A complete energy balance was performed for each subject, beginning with a 9-day baseline period of data collection before varying diets. It was found that the obese subjects put on weight much more readily than the thin subjects in the previous experiment. The experimenter concluded that variations in weight gain probably were due to variations in water retention of the subjects. The results of oxygen consumption measurement showed that there was an increase in respiratory quotient (RQ) after about 8 days of overfeeding. The RQ's were not above 1.0 until this point. The explanation was that the excess dietary carbohydrate was stored first as glycogen in the muscles and then converted to fat when the stores were full. The experimenters agreed that the increases in oxygen utilization were insignificant and were attributable to SDA. Thus, they argue that their data do not support the existence of a luxuskonsumption mechanism in humans. In a third experiment (Strong et al.,

1967), 16 subjects of varying degrees of obesity were used. One subject was underweight, 7 were of normal body weight and 8 were obese. Again, all subjects underwent a complete energy balance during a 4 day period of overeating. Diets provided an excess of 2960 to 7880 kcal over a 4 day period. The experimenters concluded that variations in weight gained during the 4 day period were due to differences in amount of water retained. They found that no excess calories were lost in the feces during overfeeding, so there seems to be no evidence that the body adapts to excess calories by excreting them through feces. Measurement of oxygen consumption were made in an attempt to correlate heat production with intake. Measurements were made at approximately 2-hour intervals throughout the night. The results show that energy expenditure increased with overfeeding. Statistical analysis showed an 8.5% increase overall as compared to a control period. The metabolic rate also was higher in the early part of the night (20% higher). This was attributed to SDA for the last meal of the day. The results were interpreted as evidence against luxuskonsumption playing an important role in energy balance. Excess energy intake of all subjects was calculated to be about 1530 kcal/day, while the increased metabolic rate was calculated to be 300 kcal/day, or about 20% of the excess energy. These results were not analyzed separately for obese and non-obese subjects. Also, the oxygen measurements were not taken at the right times to

measure the maximum luxuskonsumption effect if it was present. The maximum amount of increase in utilization should have occurred in the few hours after each meal. Measurements taken later in the night should not necessarily be expected to show as great an increase.

In a study cited earlier (Miller et al., 1967), it was shown that the increase in DIT as directlty related to the caloric size of the meals. The study also provides evidence for DIT as a mechanism for getting rid of excess calories during overfeeding. Their subjects were 11 adult men and women who overate for periods of 3 to 8 weeks. It was concluded that the surprising stablity of body weights was due to an increase in heat production. The average duration of the thermic response to meals of excess caloric content was 3 hours. BMR also was measured before and after the meals and was not found to change significantly. The magnitude of the increased heat production was found to be about 25% of BMR. In this study, the measurements of oxygen consumption were taken for about 50% of the day, much longer than in the studies of Passmore and colleagues.

Durnin and Morgan (1969), performed an experiment to determine how much of the excess calories would be expended as heat during a period of overfeeding. In their experiment, 6 young men consumed an average of 70,000 kcal each, over a 42-day period. Measurements of oxygen consumption were made while the subjects were both resting and exercising. It was found that throughout a 24-hour

period during overfeeding, metabolic rates were increased 10 to 12% as compared to measurement taken during a control period. The mean increase in body weight was 6 kg per subject, or about 10% of initial weight. They concluded that increased metabolic rate could account for at most, 12% of the excess calories or about 300 of the daily excess of 1700 kcal.

Apfelbaum et al. (1971) conducted a series of studies in which they concluded that with a restricted diet the amount of weight loss is less than expected due to a decrease in energy expenditure. They also found ar increase in energy expenditure with overfeeding. Three groups of subjects had their oxygen consumption measured for a 15-day period. One group (n=9), was a control and recieved a normal diet. A second group (n=8), had their diets supplimented with 1500 kcal/day and a third group (n=41), consisted of these subjects and received a restricted diet. This diet (220 kcal/day) was 55 g of casein, potassium chloride, vitamins, and water. Both of the experimental groups had their normal intakes measured for a 15-day period before the diet manipulations began. Energy expenditure did not differ for the control groups during the 15-days in which they consumed a normal diet. For the group receiving a restricted diet, it was estimated that the average caloric decrease was 2,100 kcal/day. Since it was found that fat loss did not account for the major part of this caloric decrease it was concluded that energy expenditure must have

been reduced. Oxygen measurements showed a decrease in energy expenditure of 12 to 17%. For the overeating group, the results are in agreement with Miller et al. (1967). The total caloric excess was 22,500 kcal of which only 10,000 kcal could be accounted for in adipose store increases. This leaves 12,500 calories unaccounted for or, 800 kcal/day. The increase in energy expenditure measred by oxygen consumption could account for about one-half of the excess, leaving the other one-half unexplained. The authors speculated that changes in spontaneous activity could explain the other 400 kcal. This study, then, demonstrates that changes in energy expenditure could be important in maintaining a constant body weight in the face of a deficit or abundance of calories eaten.

Goldman et al. (1976) reported a series of experiments in which they attempted to see if excess calories could be accounted for in overfeeding experiments. One group of 4 subjects (body weights from 62 to 83 kg) was placed on a high fat diet supplying an average of 860 kcal/day over baseline for 83 days. Body weights increased by ar average of 15% (11.4 to 19.1%) or 11 kg (8.1 to 14.6 kg). Measurement of body fat showed that the average amount of fat gained was 7.6 kg or 70% of total weight gain. Energy expenditure was measured before and after the 83-day period. Expenditure of energy increased for every subject during the period of overfeeding. The increase in BMR was higher after overfeeding but when corrected per unit of surface area, was

slightly lcwer after cvereating. When energy expenditure was measured during various forms of exercise, an 18% increase in energy expenditure was seen. Morecver, only about one-half of the increase cculd be explained by the increased body weight.

A seccnd experiment used 4 subjects (body weights from 59 to 118 kg) who were overfed a carbohydrate diet fcr 18 days. The diet supplied an excess cf 2000 kcal/day. The average body weight ircrease was 4.5 kg (3.3 to 5.6 kg) or 5%. It was estimated that 75% of the increase was fat. measurement cf energy expenditure shcwed an elevation in BMR and in the cost of various activities. When post-prandial measurement of energy expenditure was made it was fcund that metabolic rate (even ccrrected fcr bcdy surface) was elevated. This effect was most pronounced immediately after the meal.

A third experiment used 5 subjects (ranging ir body weight from 65 to 75 kg). These subjects were fed a high carbchydrate diet for 18 days, supplying, as before, an excesss of 2000 kcal/day. The average weight increase was 4.3 kg or 6%. The average amcurt of fat gained was 56% of the total increase. Again, energy expenditure increased significantly after cverfeeding. BMR showed a 17% increase and metabolic rate increased 12% after meals. The energy cost of exercise was 12%, almcst the same as in the provious grcup. RQs, measured cn the last day cf cverfeeding, showed increases of about 15% after dinner.

In summarizing the experiments, an excess of carbohydrate calories increased the thermic response of the subjects beyond expected values. This was true even when metabolic rates were adjusted for the increased body surface area. The greatest increase in heat production was found to be immediately after meals and was an increase over BMR which also was found to be elevated. No such increases were seen when the excess calories were fat. There also were large individual variations in the results of different subjects in these experiments. Classifying the subjects as either obese or non-obese, or as either "easy-going" or "hard gainers" did not result in eliminating all of the variations in the results.

Glick et al. (1977) found no difference in oxygen consumption between obese and normal weight women either during a 5-day period of overfeeding or after a 5-day period of restricted eating. Also, they reported that exercise did not increase the thermic effect of a meal. Their argument was that there was not a short-term adaptation to overfeeding, though they do not discount some adaptation after a longer period of time.

Bradfield et al. (1973) gave either a high protein diet or a diet containing no protein to a group of obese women for 10 days each. It was found that the post-prandial rise in metabolism was not different for the two diets and that the rise was not greater in a group of normal weight women.

Dauncey (1980) examined the effect on energy expenditure of 1 day of overfeeding on 4 men of normal weight. It was found that there was an increase in oxygen consumption with overfeeding. Dauncey reported that there was very high variability in both intake and expenditure between and within the subjects.

Danforth and colleagues (Danforth et al., 1979) have suggested that an adaptation to overfeeding occurs in man, but that it may not be evident until after about 2 weeks of overfeeding. Garrow (1978) has suggested that in most of the studies in which metabolic changes have been seen in response to overfeeding, the excess energy consumed was in excess of 23 mcal. Thus the argument of whether there is a threshold and what kind of threshold there is remains undecided. Certainly not all of the data can be explained with either a duration, or an amount of excess, threshold.

A decrease in resting metabolic rate consistently has been reported with underfeeding. This result is seen in lean (Benedict et al., 1919; Keys et al., 1950) as well as obese (Apfelbaum et al., 1971, 1977; Jung and James, 1980; Garrow, 1978) individuals.

The effect of overfeeding on resting metabolic rate is less clear. There are many reports of an increase in RMR with overfeeding (Grafe and Kock, 1912; Apfelbaum et al., 1971) but there also are reports of no change (Munro, 1950; Stang et al., 1935; Miller et al., 1967b; Strong et al., 1967). It is unclear whether these individuals have RMR

that are different from normal weight individuals. Miller and Parsonage (1975) confirmed findings of Martineaud and Tremolieres (1964) who found that some, but not all, of the obese subjects they studied had lower than normal resting metabolic rates. Others (Kaplan et al., 1976; York et al., 1980) reported no difference and still others (Zahorska-Markiewicz, 1980) reported that RMR was higher in obese individuals.

The evidence indicates that in humans, metabolic adaptations occur in response to over and under eating. It is widely reported that there are large individual differences in the magnitude of these adaptations the cause of which is not understood.

In the case of overeating, an increase in thermogenesis often is seen. It is seen most often in cases of long-term overeating but also may occur in response to short-term overeating. Also, the amount of the excess may be important in determining the magnitude of the thermogenic response. There is still much debate about whether the adaptation to overeating is lacking in obesity. The high variability in the data suggests that weight gains in all individuals are due to this lack of adaptation.

It is possible that at least some forms of obesity are due to a thermic defect. Jung et al. (1979b), found that normal weight females showed a greater thermic response to a dose of norepinephrine than did either obese females or females who formerly were obese. This could suggest that an

inherent thermic defect contributes to obesity in some individuals and is not due to developmental or environmental factors.

There have been several other reports of a difference in the thermic response to a meal between normal weight and obese individuals. Kaplan et al. (1976) tested the calorigenic response to a high-protein meal in obese and nonobese women. The meal consisted of 823 kcal and was a semisynthetic high-protein meal. In this study, both RMR and post-prandial heat production were measured. It was found that there was no difference in BMR between the groups, but the thermic response to the meal was significantly greater in the nonobese group. This study suggests that failure to get rid of excess calories could be a factor in development of obesity. If these obese individuals are accumulating extra calories during each meal, the result could be a higher body weight. However, it can be argued that the decreased thermogenesis is an adaption to the obesity rather than a cause.

Pittet et al. (1976) administered a 50-g load of glucose to obese and nonobese females and measured heat productions using direct and indirect calorimetry simultaneously. Metabolic rate increased significantly more in the nonobese subjects than in the obese subjects after administration of glucose. In the nonobese group, the increase was 13% of the fasting value, and in the obese group the increase was 5.2% of fasting value. Heat loss

measured by direct calorimetry showed no changes in either group after the glucose, but losses were higher to begin with in the nonobese group, and remained higher after the glucose. Similar results were found by Shetty et al. (1979). They fed obese and lean subjects a test meal (Carnation 'Build up' in milk). The lean subjects had a greater rise in metabolic rate following the meal than either the obese or post-obese group. When subjects were given an acaloric drink, there were no changes in metabolic rate.

York et al. (1980) examined males with stable body weights who maintained that body weight on either high or low daily intakes. They found that there was no difference in BMR, but that DIT was higher in the group maintaining body weight on high intakes.

There also are several reports that there is no difference in the thermic response to a meal in normal weight versus obese people. Zahorska-Markiewicz (1980) found that the thermic response to a 4200 kj mixed meal was no greater for individuals of normal body weight than for obese individuals.

Glick et al. (1977) have reported that they found no difference in the response to overfeeding between obese and nonobese women. The subjects ate an average of 2,300 excess calories daily on top of their normal daily intake. They found no differences in metabolic rates between groups either at rest or exercising. These results suggest that

DIT does not play an important role in short-term energy balance.

Clough and Durnin (1970) measured the metabolic rates of subjects classified as either "thin" or "average". They found no difference in the metabolic rates of the two groups. This was true whether oxygen consumption was measured at rest or during exercise following a standard meal.

Irsigler et al. (1979) reported a study in which they measured energy expenditure via direct calorimetry in individuals classified (according to the Broca Index) as "normal","overweight", or "obese". Overweight and obese subjects showed a greater total heat production than did normal subjects. There also was more variability among subjects in the overweight and obese groups. When output was examined in relation to energy intake there was a close relationship between intake and output in normal subjects. For subjects in the other groups, there did not seem to be a relationship between intake and expenditure. Food intakes were held constant and were representative of normal intakes.

The evidence is strong that there are metabolic differences between normal weight individuls and obese individuals. However, the conclusion of Pittet et al. (1976) that there is an inherent thermogenic defect in the obese which is not caused by developmental or environmental factors is premature. There have been no thorough studies

to suggest that this difference is ertirely due to genetic factcrs. Undoubtedly scme cf it is due to genetic factors (Griffiths and Payne, 1976) but experiential factcrs may have a role alsc. Sirce many regtlatcry ccntrols develop early in life for many species, including man, it may be that contrcls cf metabclic rate alsc develop during the first years of life.

It may be that some forms cf cbesity in humans are caused metabolically and cannot be treated sucessfully by dietary restriction. Miller (1979) suggested that this may be the case and that suitable ways to stimulate metabolism in those individuals should be researched.

VIII. EXERCISE IN MAN

The beneficial effects of exercise in humans are many and varied and a review of all of these effects is beyond the scope of this review. In this section the effects of exercise on energy balance and on those factors influencing body weight will be discussed. Durnin (1979) made the argument that if, for no other reason, exercise is helpful in increasing energy expenditure and helps create a negative energy balance. Nelson (1973) warned that all adults should be considered at-risk to develop obesity. His argument is that the known metabolic decrease with age (Nelson, 1973; Tzankoff and Norris, 1977, 1978) will not always be compensated for by decreases in appetite. Thus, exercise as an increaser of energy expenditure can help resist body weight increases, even in non-obese people.

There is a frequent speculation that lack of physical activity is a contributing factor to obesity (Bjorntorp, 1975). Mayer et al. (1956) studied workers in West Bengal and found that body weight was inversely proportional to level of activity in the person's job. They also found that the highest caloric intakes were in the most active and the most sedentary groups. Other investigators have noted that

obese adults were less active than non-obese adults (Bloom and Eidex, 1967; Marr et al., 1970; Curtis and Bradfield, 1971). Others have noted that adolescent obese girls were less active than non-obese adolescent girls (Buller et al., 1969; Johnson et al., 1959). However, from none of these or similar studies is it clear that lack of physical activity is a cause rather than a result of obesity.

Garrow (1978) has concluded that a low level of physical activity is not an important factor in perpetuating the excess weight in obese individuals. His argument is that such expenditure comprised such a low total amount of energy as to be insignificant in shedding body weight. Durnin (1979) pointed out that even a low level of physical activity helps create a negative energy balance in the obese and ignoring any increase in expenditure is a mistake. Besides, every bit of energy expenditure means more calories can be eaten without increasing body weight. Lutwak and Coulston (1975) suggested that there are two questions about the benefits of exercise in reducing body weight. The first question is whether the energy expenditure due to exercise is additive to any caloric deficit due to dietary restriction in producing more efficient weight loss. The second question is whether exercise directly affects body composition to produce a more desirable distribution of lean body mass and body fat. Some researchers are asking a third question. That is whether aerobic exercise training has an effect on the way in which excess calories in a meal are

used, or not used (Kertzer et al., 1981). Thus, it may be that having a high maximum aerobic capacity (due to some combination of heredity and exercise history) allows more of the excess calories to be expended as heat when overeating. A study by Weltman et al. (1980) provides support for an affirmative answer to the first question. Using sedentary men with a mean age of 42 years, they examined subjects in 4 groups. One group was placed on a diet which restricted normal daily intake by 500 kcal. A second group performed brisk walking 4 times/week beginning at 15 min/session and increasing 5 min/session to 45 min/session. This was considered mild exercise and was continued over a 10 week period. A third group experienced both caloric restriction and mild exercise. A fourth group served as controls and received neither caloric restriction nor exercise. It was found that caloric restriction alone resulted in the greatest percentage of body weight loss, but that the combination of caloric restriction and mild exercise resulted in the greatest loss of body fat. Caloric restriction resulted in more loss of fat than exercise alone and all 3 groups lost significantly more body fat than the sedentary group. It appears that the combination of exercise and dietary restriction is most effective at reducing body fat, while sparing lean body mass. It should be mentioned that individuals in the exercise-only group were not particularly interested in losing body weight and their weights were sigrificantly lower than those of the men

in the other groups initially. The most valid comparisons can be made among the 3 other groups in which initial body weight differed only slightly.

In dealing with the second question, about the effects of exercise on body composition, it is usually reported that body fat decreases with exercise (Pollock, 1973; Pollock and Jackson, 1977; Ellestad et al., 1975; Bjorntorp, 1976; Johnson et al., 1972). However, it is not clear if body weight reductions always occur. There are some reports that there may not be a decrease in body weight initially with exercise because the increase in lean body mass compensates for the decrease in body fat (Bjorntorp, 1976; Johnson et al., 1972). If exercise were continued the increase in lean body mass would eventually decline and the decrease in fat would lead to body weight reductions (Bjorntorp, 1976). There are other reports of a total decrease in body mass and a decrease in body fat (Pollock and Jackson, 1977) and no change in lean body mass with exercise (Pollock, 1973; Kenrick et al., 1972). There are some indications that the decrease in fat represents a decrease in the size of fat cells rather that in the number of such cells.

The effects of exercise may be much different in severely obese humans. Bjorntop et al. (1970, 1975) found that exercise in severely obese people produced no decreases in body weight and body fat, or only slight decreases in body fat over periods of up to one year of an exercise program. Bjorntorp et al. (1975) found that obese patients

with difficulty in losing weight either by exercising or dieting were likely to have hyperplastic adipose tissue. Since Brook et al. (1972) have found that the first years of life in humans are paraticularly important for development of hyperplasticity, it is possible that very poor eating habits can be permanently disabling to later efforts to reduce body weight. Citing a study by Chirico and Stunkard (1960) Nelson (1979) suggested that lack of exercise was a more important factor in obesity for women than for men. Chirico and Stunkard found that there was more difference in the daily activity of obese versus non-obese women than between obese versus non-obese men.

Sex differences in the effects of exercise on body weight and body composition have not been adequately studied, particularly in obese individuals. Women have more fat cells than men (Sjostrom et al., 1972) and Bjorntorp (1976) found that the remaining adipose tissue mass after physical training is primarily dependent on the number of fat cells. Parizkova (1963) found that women athletes lost weight when training, but the intensity of the training was much greater than is usually performed by non-athletes. Bjorntorp (1976) also pointed out that female rats do not show a decrease in body weight with forced exercise and a similar failure may be found in human females and with moderate levels of exercise.

Intensities of exercise may be important in assessing the effects of exercise on body weight and body fat. Bjorntorp et al. (1972) have suggested that body fat loss may be greater in a program of moderate exercise for longer duration than in a program of intense exercise for shorter periods. In those studies, giving patients who had experienced myocardial infarction three 30-minute periods of exercise/week for 9 months resulted in significantly more body fat loss than when the period of exercise was 1 hour/day 3 times weekly for 6 months.

Measurement of effects of exercise on food intake consistently demonstrated that the caloric expenditure due to exercise is not always made up by an increase in caloric intake (Mayer et al., 1956; Bjorntorp, 1976; Johnson, 1972). There is some evidence that the amount or intensity of exercise affects caloric intake in man as in animals, so that light or moderate exercise leads to a decrease in caloric intake and more intense exercise results in increases (or less of a decrease) in intake (Horton, 1976). Bjorntorp (1976) suggested that humans exposed to an exercise program initially decrease food intake and body weight but then maintain a balance between intake and expenditure.

Bjorntorp (1976) in attempting to explain the effects of exercise on body fat, concluded the increased energy expenditure of exercise was not enough by itself to explain the loss of body fat. Estimates of intake, rather than

actual intake measurements, were used in the studies described, but it seems unlikely that the increase in energy expenditure can account for all of the fat loss. Bjorntorp suggested that increased activity between training sessions and effects on appetite regulation may help account for the fat decreases. Also it is possible that increased heat production can help explain the fat loss.

Thus, in returning to the third question asked about the effects of exercise, it may be that having a high maximum aerobic capacity reflects the ability to expend a large amount of exess energy as heat when overeating. Increases in that ability to expend excess calories as heat would accompany increases in maximum aerobic capacity. Thus an individual with a naturally high aerobic capacity or an individual who has increased his or her maximum aerobic capacity through exercise training would be better able to resist adding body fat when overeating. Temporary bouts of exercise, or exercise which does not increase maximum aerobic capacity would not be as useful in increasing DIT.

IX. EXERCISE AND THERMOGENESIS

In a frequently-cited study, Miller et al. (1967) reported that when their subjects exercised for 30 minutes before and after a meal, the magnitude of the dietary-induced thermogenesis was increased. Since this report, several investigators have examined the effects of exercise on thermogenesis, and in particular on DIT. A frequently-asked question is whether the increase in metabolic rate due to food and exercise together is greater than the sum of each alone.

Bradfield et al. (1968) tested the effect of 45 minutes of walking on DIT in 6 obese females. The shape of the curve describing the rise and decline of metabolic rate after a meal of 750 kcal did not differ whether the subjects had exercised or not. However, the magnitude of the rise was greater after the exercise, suggesting that the exercise had effects on DIT which were longer lasting than the exercise itself.

Bray et al. (1974) using 6 lean males, studied the effects of a meal of either 1,000 or 3,000 kcal on DIT before and during exercise. They found that the thermic effects of the meal did not differ for either meal, but that exercise almost doubled DIT after either meal. This finding is in agreement with that of Miller et al. (1967) in which a thermic response of 28% above BMR was increased to

56% the execise. Bray et al., found that the enhancement of DIT by exercise occurred even when the subjects overate by 4,000 kcal/day for 28 days. The effect alsc was seen when subjects were eating both a high and a low-protein diet for 2 weeks prior to measurements.

A third study, which supports results of Miller et al. (1967) was reported by Zahorska-Markiewicz (1980). Using 14 obese women, it was found that exercise on a cycle ergometer potentiated DIT after a 4,200 kj mixed meal in normal weight controls, but not in obese subjects. Thus, in normal weight subjects, exercise after a meal resulted in a greater energy expenditure than the same amount of exercise in a fasted state. In these subjects, expenditure was no different after a meal than before.

Whipp et al. (1976) found that work (cycle ergometry) increased the thermic effect of a meal by a constant factor, independent of rate of work. Subjects in that study were 6 lean males, 1 obese male, and 2 obese females. Apfelbaum et al. (1971) earlier had reported that the efficiency of work increased with underfeeding and was reduced with overfeeding. Whipp et al. did not find a reduced efficiency of work with overfeeding in their subjects.

Many workers in the area have failed to find any effect of exercise on the thermic effect of a meal. Starg and McClugage (1931) reported no effect on SDA of exercise. Swindells (1972) failed to find an increase in the thermic effect of a meal ranging in size between 600 and 1200 kcal

after a 30 min walk before and after a meal. Also, it was found, in an additional experiment reported in the same paper, that VO2 measurements made during exercise before and after a meal were no different in the females in this study. These results are contrary to those reported by Zahorska-Markiewicz (1980).

Hanson (1973) found that weight gain on a high-fat diet in 4 males did not change efficiency of work when that work consisted of pedalling a cycle ergometer. However, when the work consisted of walking and carrying a pack, there was a predicted increase in O2 utilization per unit work up to the point of 19% weight gain (maximum attained). Warnold et al. (1978) also failed to find that exercise potentiated the thermic effect of meals in 4 obese females on a reducing diet.

Returning to the original question of whether the metabolic response to exercise and a meal is greater than the metabolic response to each alone, there is no obvious conclusion to be drawn. The studies just described had different methods to produce exercise and had many different intensities of exercise. They did not consider the maximum aerobic capacities of the subjects used. The last criticism is perhaps the most interesting one. Investigators report that their subjects are either lean, normal, or obese, but give no information about their work capacity. Since there is a wide range of work capacity, or maximum aerobic capacity even among individuals all classified as lean, it

would be helpful to know the maximum aerobic capacity of each subject. It could be that the potentiating effects of exercise on DIT are not due to the brief period of exercise before or after a meal, but are due to an increased maximum aerobic capacity due to exercise training. It would also be expected that sedentary individuals with high maximum aerobic capacities would show high DIT regardless of whether they exercised before or after a meal. This could explain the discrepant findings summarized above. Miller could have used subjects with high maximum aerobic capacities while Swindells did not.

The luxuskonsumption idea has sometimes been criticized because it seems to place the animal at a disadvantage from an evolutionary point of view. A mechanism which wastes excess calories could have a very high energy cost. Bennett and Rubin (1979) presented a theory which might explain both the variability of luxuskonsumption and how it relates to survival. They argued that mammals' selective advantage was their capacity for sustained high aerobic capacity which would permit longer sustained activity. An animal with greater stamina could maintain higher levels of pursuit or flight, depending on the circumstances. This would seem to have obvious survival advantages.

Since maximum aerobic capacity varies with the physical conditoning of an organism, it is possible that dietary induced thermogenesis varies directly with maximum aerobic capacity. Anything which would affect aerobic capacity then

could alsc affect dietary induced thermcgenesis. Since training effects due tc ccnditicnirg can be acquired or deteriorate, it is reasonable to expect that DIT can change in the same individual. The thermcgenic capacity increase may be due to an increased dynamic range for the sympathetic nervous system. In summary, physical ccndtioning leads to increases in maximum aerobic capacity, which cculd then, through an increase in sympathetic nervcus system activity lead to an increase in capacity for DIT. This issue has nct been explcred adequately in either the human or the animal literature on energy balance. If the relationship between DIT and aerchic capacity exists, it should be possible to explain discrepancies in positive or negative findirgs cf DIT. The prchlem is that physical conditicn cf subjects has nct been reliably reported. Subjects are classified as either lean, rcrmal, cr obeses. Beirg in gcod physical ccndition is not the same as being a lean individual. Perhaps the relationship between physical conditon and capacity for thermogenesis should be further investigated.

Effects cf physical activity on the thermic respcnse to food have been studied even less in animals than in man. A series of studies by Gleeson and colleagues (Gleescn et al., 1978, 1979, 1980) provides the only indication that exercise, cr exercise training affects DIT in rats. In one study (Gleeson et al., 1978) male Wistar rats were fed either a corn starch-based cr a ccrr cil-based diet. All animals either swam 1 hcur/day cr remained sedentary. No

differences were seen in RMR among the 4 groups, but the exercised animals eating the corn starch diet showed a greater increase in DIT than any other group. In a second experiment (Gleeson et al., 1979) 10 weeks of forced running on a treadmill produced a significantly higher RMR, and a significantly higher postprandial response to intubation of a glucose meal than was evident in sedentary controls. In the third experiment (Gleeson et al., 1980) it was found that rats trained on a treadmill showed a 50% increase in metabolic rate after either a high or low fat meal. This increase was significantly higher than seen in sedentary animals. The size of the meal was not reported. These studies demonstrate that exercise training by either swimming or forced running can have an effect on metabolic rate, and particularly on DIT.

X. EXPERIMENT 1

The importance of luxuskonsumption in the regulation of energy balance and the maintanence of a stable body weight is still unclear. The inconsistent data obtained thus far suggest that there are great individual differences, but the source of these differences is largely unknown (a number of possible variables were reviewed in earlier chapters). For example, it seems likely that there are metabolic differences between lean and obese individuals. Some of these differences no doubt are due to genetic factors. Early environment also seems to be important. It is reasonable to believe that early diet could affect whatever mechanisms are involved in luxuskonsumption.

Simpson et al. (1980, 1981) have reported that weanling rats given a supermarket diet do not become heavier than controls until approximately 56 days of age. This delay in the onset of increased body weight could be due to changes in metabolic rate at approximately 56 days of age, such as a reduction in an animal's ability to expend excess calories as heat during periods of overeating. If such a shift does occur, it could be be due to maturation, or it could be due in part to the animal's previous diet regime.

Rothwell and Stock (1980a) reported that 33-day old male Sprague-Dawley rats given a supermarket diet for 14 days did not gain more weight than chow-fed controls, even though they were consuming 50% more energy. They found that resting oxygen consumption was higher in the animals on the supermarket diet, reflecting a higher energy output. However, Rothwell and Stock did not measure energy expenditure after 47 days of age. A decrease in the energy expenditure in the supermarket diet animals could have occurred after this time, allowing for more calories to be converted to body fat.

Exercise training has long-lasting effects on metabolism and could account for some of the variability seen in studies of energy metabolism. Studies reviewed in earlier chapters examined the effects of brief periods of exercise before and after a meal on metabolic rate. However, the physical conditioning (reflected by exercise history) of the subjects was not considered. One possible way in which physical conditioning could affect a luxuskonsumption mechanism is by increasing aerobic capacity. The increased ability to transport and use oxygen could lead to an increased ability to expend excess calories as heat. The rationale for this hypothesis is based on the idea that luxuskonsumption could have evolved secondary to selection for a high physical working capacity. The cost of locomotion increases rapidly as body mass increases, especially if the body mass is fat (Bennett and Rubin,

1979). Thus a mechanism to limit fat storage could have survival value in the face of an abundant food supply since it would help maintain a high working capacity.

Working capacity can best be expressed as maximum capacity for consuming oxygen, referred to as maximum aerobic capacity or VO2 max. The ability to expend excess calories as heat during periods of overeating could be directly related to VO2 max. Thus, large differences in VO2 max due to genetic and experiential factors in both humans and other animals could be associated with large differences in ability to expend excess calories as heat, or luxuskonsumption. According to this hypothesis, an exercise program which increased VO2 max should also increase luxuskonsumption.

Weanling rats would seem to be particularly good subjects for a study of the effects of diet and exercise on energy intake and expenditure. High fat diets have been reported to produce a greater degree of obesity when given to juvenile animals (Peckham et al., 1962) than to adults, and exercise has been reported to have more effects on lean body mass in young animals (Pitts and Bull, 1977) than in older animals. It is likely that the effects of diet and exercise on energy intake and expenditure are more pronounced in weanling rather than older rats.

In experiment 1, the effects of a highly palatable, obesity-producing diet, and the effects of daily aerobic exercise on energy intake and expenditure were examined in

male and female weanling rats. The obesity-producing diet consisted of a variety of highly palatable foods blended together, and the aerobic exercise was swimming.

METHODS

Subjects

Thirty-two male and 32 female Charles River (Sprague-Dawley descended) CD outbred albino rats were used as subjects. All animals were from litters which were reduced to 10 animals immediately after birth. After weaning animals were housed individually throughout the experiment in a vivarium with a 12:12 hr. light/dark cycle, an average temperature of 20 degrees centigrade (-1 degree), and a relative humidity of 50% (+10%).

Diet

At weaning, 16 males and 16 females were given ad libitum access to a supermarket diet (Sclafani and Springer, 1976), in addition to Purina Rat Chow. The supermarket diet consisted of a mixture (blended in an electric blender) of a variety of highly palatable foods (as determined by pretesting) such as marshmallows, bananas, candy, peanut butter, and sweetened condensed milk (with vitamins and minerals added). The supermarket diet was changed every second day and a different combination of foods was used (with the exception of the condensed milk which was always a part of the diet). Remaining animals were maintained on ad libitum Purina Rat Chow and water.

The relative compositions of both diets was obtained. The lab chow diet consisted of 22% protein, 4% fat, and 58% carbohydrate. The supermarket varied from day to day, but on the average it consisted of 13% protein, 18% fat, and 53% carbohydrate.

Exercise

Beginning at weaning, half of the animals in each dietary condition were forced to swim for 2 hours, 5 days/week. Animals began by swimming 15 minutes each day. The swimming time was increased by 15 minutes on each successive day until they were swimming two hours per day. Animals swam one hour in the morning and one hour in the afternoon. All swimming took place in heated tanks (33 degrees centigrade, + 1 degree) with an average water depth of three feet. Animals swam in groups of 3 or 4. Several animals drowned during the study and were not included in the analyses of the dependent variables. The actual number of subjects completing each condition is given in Figure 1. Only six subjects from each condition were used as subjects in the oxygen consumption measurements. This was because of the enormous amount of time required to measure oxygen consumption.

Figure 1
Design for Experiment 1

Between-Subjects Variables

Diet History

Exercise History	Lab chow (LC)		Supermarket diet (SD)	
	Male	Female	Male	Female
Sedentary (S)	n=8	n=8	n=8	n=7
Exercised (E)	n=5	n=7	n=7	n=8

Within-Subjects Variables

1. Age (2 levels which varied with the different dependent variables)

2. Meal (3 levels: RMR, DIT1, DIT2). Used with ANOVA for Oxygen Consumption only

The 8 groups of animals in experiment 1 were designated as follows:

1) Male (or Female) SD-E. These animals had access to a supermarket diet and began exercising at weaning.
2) Male (or Female) SD-S. These animals had access to a supermarket diet and remained sedentary throughout the experiment.
3) Male (or Female) LC-E. These animals received only standard lab chow throughout the experiment, but began daily exercise at weaning.
4) Male (or Female) LC-S. These animals received only standard lab chow throughout the experiment and remained sedentary throughout.

Dependent Variables

Caloric intakes. Food intakes were recorded every second day for each animal throughout the study. The caloric content of each diet was determined by bomb calorimetry. All intakes were recorded as kilocalories per kilogram of body weight.

Body weight Body weights were recorded every second day for all animals throughout the study.

Body Fat Estimates of body fat were made at 56 days of age and again at 103 days of age. The estimates were made using the Lee Index (the cubed root of body weight divided by naso-anal length). The animals were lightly anesthetized with ethyl ether while the length measures were taken.

Energy Expenditure. Heat production was measured using a closed-loop indirect respiration calorimeter. Each animal was tested individually in a 5.4 liter cylindrical plexiglass chamber housed in a sound-proof box. Animals were restrained by a screen that was lowered into the chamber so that they could creep around slightly but do little more.

Two animals were tested simultaneously by alternating back and forth between two chambers. Electromagnetic valves controlled this switching. One chamber was closed to room air and connected to Beckman analyzers (OM-11 and IR-2, O2 and CO2 respectively). The chamber air was circulated through the two analyzers using the pump and flow meter in the OM-11. Flow rate was regulated at 0.5 liters/minute. During this time the other chamber was flushed with room air by a Cole-Palmer tubing pump operating at 1.8 liters/minute. A one minute delay occurred between switching to the other chamber so that the analyzers could be recalibrated to room air. At the beginning of a day's run analyzers were balanced using pure nitrogen and then calibrated to room air and to a span gas. The analyzers were recalibrated to the span gas between pairs of animals.

The outputs of the two analyzers were recorded continuously on a MFE four-channel recorder. Oxygen and carbon dioxide measurements were taken during 15-minute trials while the animal was in the chamber. Data also were recorded by hand at precisely five minute intervals by

recording the meter readings on the front panels. Each animal was tested for two trials following a 15-hour fast (RMR), with the first trial always discarded to make certain that the equipment had stabilized. Two more 15 minute trials were run following a standard meal of 30 kcal (DIT1 and DIT2, respectively). These measures of fasting and post-prandial heat production were taken twice and averaged during the period when the animals were 46 to 56 days of age and taken twice and averaged during the period when the animals were 87 to 103 days of age.

Statistical Analysis. All dependent measurements except energy expenditure were analyzed using a 2x2x2x2 factorial design with 3 between subjects factors (sex, diet, exercise), and 1 within subjects factor (age). Total caloric intakes also were analyzed as a 2x2x2 factorial design without the within subjects factor. The energy expenditure data were analyzed by analysis of variance using three separate designs. The first design (referred to as the full design) was a 2x2x2x2x2 factorial design using 3 between-subject factors (sex, diet, exercise) and two within-subject factors (age: 2 levels; meal: 3 levels- RMR, DIT1, DIT2). The second design was a 2x2x2x2 factorial design on RMR only, using the same 3 between-subjects factors as in design 1 and age as a within-subjects factor. The third design was a 2x2x2x2 factorial design with the same four factors as in design 2 on overall DIT. Overall DIT was defined as the percentage increase above RMR for the

first hour following the meal [30(DIT1 + DIT2) - 60(RMR)]/60(RMR). All post hoc tests were performed using the Neuman-Keuls method. Complete ANOVA tables for Experiment 1, along with cell means and standard deviations for the highest order interactions, are reported in Appendix A.

RESULTS

Energy Expenditure

When O2 consumption rates were analyzed using the full design, it was found that females had overall O2 consumption rates that were significantly higher than those of males (mean O2 consumption for females was 26.28 ml/min/kg versus 23.51 ml/min/kg for males, $p<.01$). However, some of the difference is due to a higher RMR in females. Results of the RMR ANCVA showed that males and females did not differ in RMR at 46 to 56 days of age, but they were different at the second measurement (86 to 103 days of age). By the second measurement, the RMR of males had dropped significantly below that of the females, which did not change from the first measurement (Table 1).

The high RMR seen in females also was a function of diet. Females eating the lab chow diet had significantly higher RMR than either of the supermarket diet groups (males or females), and higher than that of the male lab chow group (Table 2). Even when RMR was expressed as a function of metabolic mass (ml/min/body weight to the three quarters power), the female lab chow group remained the highest and the rank order of the groups did not change.

Table 1

Resting metabolic rate (O2 consumption in ml/min/kg)

	Males	Females
46-56 days	23.47	24.45
86-103 days	18.08 [1]	22.04
	(n=20)	(n=23)

[1] different from all other values, p=.01

Table 2

Resting metabolic rate (O2 consumption in ml/min/kg)

	Males	Females
Lab chow	19.97 (n=9)	24.52[1] (n=12)
Supermarket diet	21.43 (n=11)	22.07 (n=11)

[1] different from all other values, p=.01

The absolute values for DIT1 and DIT2 were higher for females, but when DIT was expressed as a percentage of RMR (overall DIT), males and females did not differ (Table 3). However, overall DIT varied with age as a function of sex. While the overall DIT of the females at 46 to 56 days of age was higher than that of the males (Table 4), it dropped significantly over the next four weeks. There was no change in DIT as the males aged.

DIT was also a function of diet. Results of the full design ANOVA showed that animals eating only lab chow had higher overall O2 consumption rates than animals which had access to the supermarket diet (25.99 ml/min/kg vs 24.08 ml/min/kg, $p<.01$). While some of the difference was due to the higher RMR of the lab chow females (Table 2), the lab chow animals also had significantly higher dietary-induced thermogenesis (Table 5). DIT1 and overall DIT both were significantly higher in the lab chow animals. The pattern of results was not changed when metabolic measures were expressed as a function of metabolic mass.

Results of the full design ANOVA showed that exercised animals had overall O2 consumption rates that were higher than those of sedentary animals (24.16 vs 20.04 ml/min/kg, $p<.01$). Exercise did not interact significantly with the meal variable or the age variable Appendix A). Furthermore, neither RMR nor DIT showed any significant effects due to

Table 3

O2 consumption

	n	RMR (ml/min/kg)	DIT1 (ml/min/kg)	DIT2 (ml/min/kg)	Overall DIT
Males	20	20.77	26.98[1]	22.79[2]	20.66%
Females	23	23.24[2]	31.42[1]	24.14	21.03%

[1] different from all other values, p=.01
[2] different from 20.77, p=.01

Table 4

Overall DIT (%increase above RMR during 1 hour after meal)

	Males	Females
46-56 days	20.49	26.44[1]
86-103 days	20.83	15.62
	(n=20)	(n=23)

[1] different from 15.62, p=.01

Table 5

O2 consumption

	n	RMR (ml/min/kg)	DIT1 (ml/min/kg)	DIT2 (ml/min/kg)	Overall DIT
Lab chow	20	22.47[1]	33.35	24.16	25.38%[2]
SD	23	21.77[1]	27.44	22.98	16.74%

[1] different from all other values, p=.01
[2] different from 16.74%

exercise.

The age main effect in all three ANOVAs was statistically significant. All aspects of metabolic rate decreased with age. However, there was no significant interaction of the age variable with diet in any analysis. The pattern of RMR and DIT results were the same for lab chow and supermarket diet animals at both ages. There was no major change in the pattern of metabolic rates between 46 to 56 days of age and 86 to 103 days of age.

Caloric Intakes Supermarket diet animals ate more than lab chow animals (12913.77 vs 10690.35 kcal/kg, $p<.01$), and exercised animals ate more than sedentary animals (29253.27 vs 26955.51 kcal/kg, $p<.01$). Surprisingly, overall intakes between males and females were not significantly different (Appendix A).

However, the three-way interaction among sex, diet, and exercise was significant for total caloric intake (Table 6). Exercise significantly increased caloric intake only in males eating the lab chow diet. The increase was large enough so that the intake of the male LC-E group was not significantly different from that of the male SD-E group. Exercise did not increase the intake of any other group when compared to the sedentary group of the same sex which was eating the same diet. However, with the exception of the exercised male animals, the supermarket diet groups all ate

Table 6

Total caloric intakes (kcal/kg)

	Males		Females	
	Sedentary	Exercised	Sedentary	Exercised
Supermarket diet	27628.55[5]	30138.96[2]	29988.45[3]	31347.82[1]
	(n=8)	(n=7)	(n=7)	(n=8)
Lab chow	24169.35	29031.38[4]	26414.80	26132.31
	(n=8)	(n=5)	(n=8)	(n=7)

[1] different from 27628.55 and all lower values, p=.01
[2] different from 26414.80 and all lower values, p=.01
[3] different from 27628.55 and all lower values, p=.01
[4] different from 26414.80 and 26132.31, p=.05; different from 24169.35, p=.01
[5] different from 24169.35, p=.05

significantly more than the comparable lab chow groups. Both male and female sedentary animals eating the supermarket diet overate by 14% as compared to the same sex lab chow sedentary groups. Supermarket diet exercised males ate 4% more than lab chow exercised males over the course of the experiment, while supermarket diet exercised females ate 20% more than lab chow exercised females (Table 6).

Caloric intakes also were examined over two different age spans. Period 1 was from weaning to the beginning of the first measurement of energy expenditure (22 to 46 days of age). Period 2 was from the end of the first energy expenditure measurement until the beginning of the second (56 to 86 days of age). The ANCVA performed on these data used the three between-subjects factors and age as a within-subjects factor.

There was a significant three-way interaction among age, sex, and diet (Table 7). During the first period of measurement, supermarket diet males and females did not differ in amount eaten, but lab chow males ate more than lab chow females so that relatively speaking, the supermarket diet males were overeating to a greater extent than the supermarket diet females. During the second period, for both supermarket diet and lab chow groups, the females ate more than either comparable male group. At both ages male and female supermarket diet animals ate more than lab chow

Table 7

Total caloric intakes (kcal/kg)

	Males		Females	
	SD diet	Lab chow	SD diet	Lab chow
21-46 days	15949.83[2]	14420.59[3]	16347.70[1]	13077.61[3]
56-86 days	8400.95[5]	7606.08	9796.54[4]	8860.85[5]
	(n=15)	(n=13)	(n=15)	(n=15)

[1] different from all values except 15949.83, p=.01
[2] different from all values except 16347.70, p=.01
[3] different from all lower values
[4] different from 8400.95 and 7606.08, p=.01; different from 8860.85, p=.05
[5] different from 7606.08, p=.01

animals.

There also was a significant three-way interaction among age, sex, and exercise (Table 8). During the first period of measurement, exercised males ate more than sedentary males and more than females in either exercise condition. Exercise significantly increased the food intake of the males and that only during the 21 to 46 days period. The food intake of all 4 groups decreased with age, with the males decreasing more than the females. The exercised males had the greatest decrease, so that they were not significantly different from the sedentary males at 56 to 86 days of age. The decrease for females was not as great as that in the males, so that females were eating significantly more than their respective male groups during the second period.

In order to determine if the young, growing animals were protein deficient, protein intakes were calculated for each group during the period from 44 to 45 days of age. There did not seem to be any major differences in protein intake per kg of body weight among the groups at this time (Table 9). Thus, the supermarket diet animals were not severely protein deficient at this time.

Table 8

Total caloric intakes (kcal/kg)

	Males		Females	
	Sedentary	Exercised	Sedentary	Exercised
21-46 days	13908.92[2]	17014.36[1]	14790.75[2]	14634.55[2]
56-86 days	7812.90	8323.91	8978.24[4]	9679.15[3]
	(n=16)	(n=12)	(n=15)	(n=15)

[1] different from all other values, p=.01
[2] different from all values below 13908.92, p=.01
[3] different from 8323.91 and 7812.90, p=.01
[4] different from 7812.90, p=.05

TABLE 9

Protein intake at 44-45 days of age (g/kg body weight)

	SD-E	SD-S	LC-E	LC-S
Males	37.27	34.11	39.90	32.51
	(n=7)	(n=8)	(n=5)	(n=8)
Females	32.44	31.48	35.60	34.09
	(n=8)	(n=7)	(n=7)	(n=8)

Body Weight

Male animals weighed significantly more than female animals both at the beginning of the first energy expenditure measurement (46 days of age) and at the beginning of the second energy expenditure measurement (86 days of age). Figure 2 presents the body weight curves for all eight groups. It can be seen that the rank ordering of the various groups showed a different pattern for males and females.

Supermarket diet animals were not significantly heavier than lab chow animals at 46 days of age. However, at 86 days of age, supermarket diet animals significantly outweighed lab chow animals (Table 10).

There was no difference between exercised and sedentary groups of either sex at 46 days of age (Table 11). By 86 days of age, both exercised groups weighed less than their comparable sedentary group with the greatest difference between the male sedentary and exercised groups.

Body Fat

The Lee Index values showed significant main effects for sex, diet, and exercise. Males were fatter than females (.2975 vs .2890, $p<.01$), supermarket diet animals were fatter than lab chow animals (.2980 vs .2879, $p<.01$), and

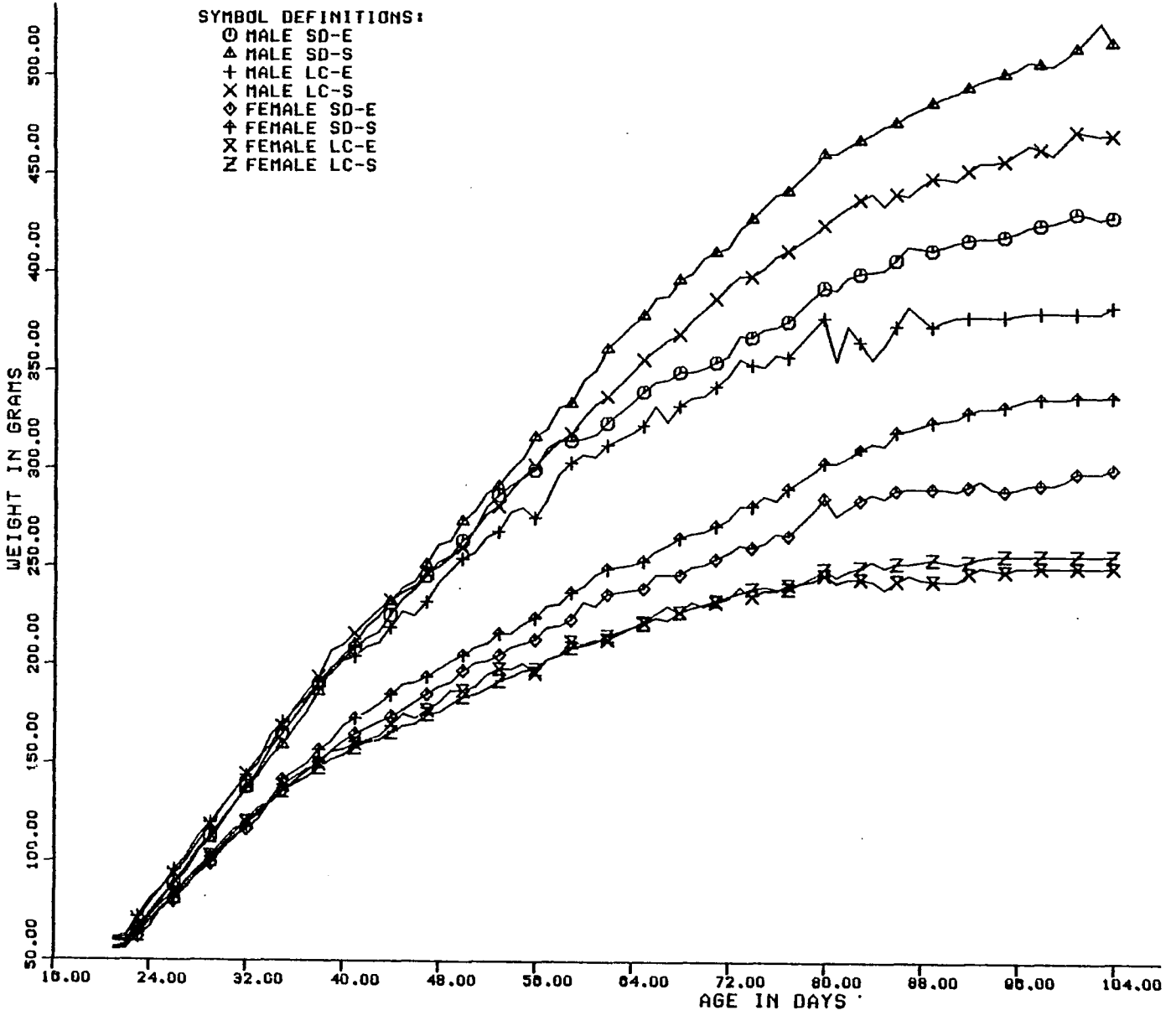

SYMBOL DEFINITIONS:
MALE SD-E
MALE SD-S
MALE LC-E
MALE LC-S
FEMALE SD-E
FEMALE SD-S
FEMALE LC-E
FEMALE LC-S
WEIGHT IN GRAMS
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
450.00
500.00
16.00
24.00
32.00
40.00
48.00
56.00
64.00
72.00
80.00
88.00
96.00
104.00
AGE IN DAYS

FIGURE 2

TABLE 10

Body weight (grams)

	Lab chow	Supermarket diet
46 days	192.52	200.47
86 days	320.79[1] (n=28)	369.87[1] (n=30)

[1] different from all other values, p=.01

Table 11

Average body weights

	Males		Females	
	Sedentary	Exercised	Sedentary	Exercised
46 days	228.50[2]	218.75[2]	174.14	169.29
86 days	455.25[1]	388.58[1]	285.14[1]	262.35[1]
	(n=16)	(n=12)	(n=15)	(n=15)

[1] different from all other values, p=.01
[2] different from all values below 218.75, p=.01

sedentary animals were fatter than exercised animals (.2955 vs .2903, $p<.01$).

Independent of diet and sex, exercised animals were leaner than sedentary animals at both 56 and 103 days of age (Table 12). Also the sedentary animals got fatter as they got older, but the exercised animals did not.

The three-way interaction among age, sex, and diet was significant (Table 13). At both 56 and 103 days of age, supermarket diet animals were fatter than lab chow animals. This was true for both males and females. Males in both diet conditions were fatter than females in the comparable diet condition at both ages, and both males and females eating the supermarket diet got significantly fatter from age 56 days to age 103 days. However, the lab chow animals did not get fatter during the same time period, and female lab chow animals became significantly leaner.

Table 12

Lee Index

	Sedentary	Exercised
56 days	.2932[1]	.2907
103 days	.2977[1] (n=31)	.2900 (n=27)

[1] different from all other values, p=.01

Table 13

Lee Index

	Males		Females	
	Lab chow	SD	Lab chow	SD
56 days	.2919[3]	.3000[2]	.2847[4]	.2915[3]
103 days	.2941[3]	.3027[1]	.2821	.2977[2]
	(n=13)	(n=15)	(n=15)	(n=15)

[1] different from .3000, p=.05; different from all other values, p=.01

[2] different from all values below .2977, p=.01

[3] different from all values below .2915, p=.01

[4] different from .2821, p=.05

Discussion

Daily forced swimming led to overall O2 consumption rates that were significantly higher than those of sedentary animals. The increase was a combination of an increase in RMR and in DIT, since neither alone significantly increased. This suggests that exercise had effects on energy expenditure which outlasted the exercise itself. While changes in aerobic capacity were not measured in this study, the exercise program was similar to that used by Penpargkul and Scheur (1970), which significantly increased aerobic capacity. Therefore, it seems reasonable to assume that exercised animals in this study had enhanced aerobic capacities along with increased O2 consumption rates. The results in this experiment showed that the effect of exercise was on overall metabolic rate, not specifically on RMR or DIT. Since the metabolic measures in this experiment were taken over such short periods of time, longer monitoring of oxygen consumption rates could more accurately identify the specific effects of exercise. Thus, while some effect of exercise on metabolism was detected in this study, the increase found could be very important over the course of a day, or a week.

In both males and females, exercise reduced the body weights of the animals on the supermarket diet. Thus, animals in good physical condtion were better able to deal with the excess calories in the supermarket diet without becoming obese. Both the caloric cost of the exercise and

the increased energy expenditure thrcugh heat prodtction may have been imprtant variables acccunting for the fact that exercised animals were leaner than sedentary animals. Therefore, individual differences ir physical conditioning might accc:nt for the great variability reported amcng subjects in bcth luxuskcnsumptic:n and body weight gain upon cvereating.

There were clear sex differences in the way in which diet and exercise produced body weight and food intake changes. Exercise had a greater effect cn body weight in males than did diet. The weight decreases in both supermarket diet and lab chow arimals in response to exercise were large in comparison to the increase produced by the supermarket diet. The increase in food intake produced by exercise in lab chow animals was greater than the increase produced by giving sedentary animals a supermarket diet. However, exercise did not affect food intakes of supermarket diet animals.

A different pattern was seen in females. Diet affected body weight and food intakes much more than did exercise. The supermarket diet produced significant increases in both body weight and food intakes for both exercise conditons, while exercise produced no changes in food intakes in either diet conditicr, and only a decrease in body weight for animals eating a supermarket diet. The finding that the food intakes of lab chow exercised animals did not differ from those of sedentary lab chow animals should have

resulted in a greater reduction in body weight than was seen in the male lab chow exercised group, which did increase food intakes. It appears that the exercised lab chow females partially compensated by lowering their DIT.

Some of these results are in agreement with a previous report (Rolls and Rowe, 1979), which found that adult male and female hooded rats given a supermarket diet and access to a running wheel responded differently. In that study, as in this one, exercised male animals given a supermarket diet did not become heavier than lab chow sedentary animals and exercised female supermarket diet animals did become heavier than female lab chow sedentary animals. However, in that study the body weights of the exercised supermarket diet animals were not significantly lower than those of the supermarket diet animals after 9 weeks of the diet. In this study, weights of the supermarket diet exercised females remained lower than those of the supermarket diet sedentary animals.

One of the most interesting results was that male lab chow animals increased their food intake in response to exercise and female lab chow animals did not. There are reports (Nance et al., 1977; Oscai et al., 1973) that the opposite is true. The discrepancy can be explained in males because most investigators have failed to take body weight differences into account when expressing food intake and when corrected for body weight would probably show increased intakes for exercised males (see Chapter VI for a review).

The discrepancy is not easily explained for females. There have been few studies which have examined the effect of swimming on intakes in females, but some investigators found that exercised females did increase food intake in response to 2 hours/day (Crews et al., 1967) or 6 hours/day (Oscai et al., 1973) of swimming.

Averaged across sex, the magnitude of the increase in body fat produced by the supermarket diet was greater than the magnitude of the decrease produced by exercise, although both effects were substantial. It is interesting that although the exercised lab chow females did not differ in body weight from the lab chow sedentary group, they were leaner.

Early exposure to the supermarket diet led to C2 consumption rates that were significantly lower than those of animals eating only a standard laboratory diet. This difference was most clearly seen in the post-prandial increase in metabolic rate immediately after a meal (DIT1). RMR and DIT2 were also lower for supermarket diet animals, but not significantly so.

Rothwell and Stock (1980a), reported that weanling rats given a highly palatable diet for 14 days, similar to the present one, overate by 50%. While the rats overate on the palatable diet, they did not become heavier than controls. However, they did expend significantly more energy as heat.

In the present study, supermarket diet animals overate by 21% over the entire experiment. They were not significantly heavier than controls at 46 days of age, but were at 86 days of age. Both their RMR and DIT were lower, not higher than controls. Animals in this study had access to the palatable diet for a larger period of time beginning at a younger age. They also overate this diet to a lesser extent than the animals in the Rothwell and Stock study. It is possible that one or both of these factors account for the differences.

All animals were given a 30 kcal meal after the RMR test and before DIT was measured. The intent was to provide each animal with a larger than normal meal. Most animals ate all or nearly all of the meal. When the amount eaten was expressed as a percentage of normal daily intake, values ranged from 20 to 35% of normal. Supermarket diet animals tended to be in the lower part of that range. This difference might account for some of the differences in DIT between lab chow and supermarket diet animals. However, all animals ate a meal of sufficient size to constitute overeating. Still, if there is a linear relationship between the amount of overeating and the amount of energy expended through heat, perhaps some of the reduced DIT with the supermarket diet could be explained.

The animals given a supermarket diet at 21 days of age did not immediately gain weight despite their overeating. Simpson et al. (1980) reported a similar delay in weight

gain when weanling female rats were given a supermarket diet, and they reported that the weight gain began at about 56 days of age. An inspection of the body weight curves for the eight groups (Figure 2) shows that there is no single point at which the supermarket diet animals suddenly began to increase their body weight in relation to the lab chow animals. The body weight of the supermarket diet animals gradually increased throughout the experiment. However, all of the supermarket diet animals were fatter than lab chow animals at 56 days of age.

The early failure to increase body weight in the animals eating the supermarket diet did not appear to be due to protein deficiency. At 46 days of age neither growth rates nor protein intakes differed differentially by diet or exercise. Even though the protein content was lower in the supermarket diet, the animals eating that diet ate comparable amounts of protein to animals eating lab chow. This was due to the increased intakes of the animals eating the supermarket diet and to the fact that those animals obtained a portion of their daily intake from lab chow.

It is possible that a metabolic shift occurred at some point in the early life of the supermarket diet animals so that calories which were previously expended as heat were put into body weight. No shift in metabolism at 56 days of age was detected in this study. The results showed no major changes in the O2 consumption rates of either the supermarket diet or the lab chow animals from 46 to 56 days

of age to 86 to 103 days of age, but the metabolism of the supermarket diet animals already was significantly below that of the lab chow animals at 46 days of age. Changes in eating patterns also do not seem to be an adequate explanation for the delay in weight gain. Animals eating the supermarket diet clearly were overeating before 56 days of age and, if anything, ate less during the latter time period. A shift in metabolic rate already had occurred earlier than 46 days of age. And, the supermarket diet animals were, in fact, fatter at 56 days of age than the lab chow animals.

Supermarket diet animals were not heavier than lab chow animals at 46 days of age, but they were significantly fatter. During the period from 22 to 46 days of age, it seems that they were adding body fat at the expense of lean body mass. Kanarek and Hirsch (1977) found the same effect in weanling rats given access to a 32% sucrose solution in addition to ad lib. access to chow.

Springer and Gorman (1977) reported that in adult rats, females gained more weight on the supermarket diet as compared to female controls than males as compared to male controls. In this study the weight gain of sedentary animals supported these results. Female SD-S animals gained more weight than male SD-S when each was compared with the same sex controls. However, for exercised animals, the weight gain was approximately equal for male and female supermarket diet animals as compared to controls.

XI. EXPERIMENT 2

The obesity produced by a supermarket diet in adult rats is reversible when the diet is withdrawn (Sclafani and Gorman, 1977; Rothwell and Stock, 1979b; Stephens, 1980). The loss of body weight when supermarket diet animals are returned to chow has been attributed to both a reduced caloric intake and an increase in metabolic rate (Rothwell and Stock, 1979a,1979b). The reversibility of obesity produced in weanling rats has not been studied. In this experiment, animals which had been given access to a supermarket diet for 82 days, were studied for approximately 60 days following diet withdrawal. Energy intakes and expenditures were measured along with body weight and body composition.

Methods

Subjects were 19 male and 22 female Charles River CD outbred albino rats. All of the animals on the supermarket diet in Experiment 1 were used, as well as additional littermates which had been raised on a diet of Purina Rat Chow and water. One-half of these littermates had been forced to swim for 2 hours daily since weaning. The remaining one-half were sedentary.

Animals which had received the supermarket diet since weaning were taken off that diet at 104 days of age and given only Purina Rat Chow and water ad libitum. The exercise conditions were not changed for any of the animals. The resulting eight groups were as follows:

1) Male (Female) SD-E. These animals had access to the supermarket diet from weaning until 104 days of age at which time they were switched to lab chow only. They swam 2 hours daily, beginning at weaning and continuing throughout this experiment.
2) Male (Female) SD-S. These animals had access to the supermarket diet from weaning until 104 days of age at which time they were switched to a lab chow only diet. These animals did not exercise at any time.
3) Male (Female) LC-E. These animals were raised on Purina Rat Chow only and continued to eat only lab chow. They swam 2 hours daily, beginning at weaning and continuing throughout this experiment.
4) Male (Female) LC-S. These animals were raised on Puria Rat Chow only and continued to eat only lab chow. These animals did not exercise at any time.

Dependent Variables

Energy Expenditure. All animals had energy expenditure measurement taken before the diet change took place (86 to 103 days of age), and again at 147 to 171 days of age. The testing procedures were the same as in Experiment 1 (RMR, DIT1, and DIT2 were determined). Separate analyses of

variance were performed for RMR and overall DIT.

Caloric Intakes. Intakes were recorded 3 times weekly for each animal and expressed as kcal/kg of body weight.

Body Weights. Analyses of body weights were performed at 103 and 171 days of age. At each age, the "body weight" for each animal was taken to be the mean of a 5-day period centering on day 103 and 171.

Body Fat. Estimates of body fat were made using the Lee Index, at 103 and 171 days of age.

Citrate Synthase.

Changes in maximum aerobic capacity were not directly measured in this study. However, a number of muscle enzymes, including citrate synthase, are known to increase with a training program which also increases maximum aerobic capacity (Winder, 1974; Holloszy et al., 1970; Holloszy and Booth, 1976). At the end of this experiment, animals were anaethesized with Nembutol (sodium pentobarbitol). The gastrocnemius muscle was removed from the right leg of each animal, weighed and stored frozen. The muscles were thawed and immediately homogenized in 10 volumes (vol.wt) of 0.1 M Tris-HCL, pH 8.0, in a Polyton homogenizer (Brinkmann Instruments, Inc.). The samples were centrifuged at 12,000 x g for 15 minutes at 2 degrees Centigrade. The supernatant fraction was retained for enzyme assay. The pellet was resuspended by homogenization in the original volume of buffer used for the initial homogenization. Both the supernatant fraction (diluted 1:2) and the resuspended

pellet fraction (diluted 1:3) were assayed for total activity of citrate synthase in the tissue, using the procedure of Shepherd and Garland (1969). The assays were initiated by the addition of enzyme and the absorbance at 412 nm was recorded for 2 minutes. Activity was linear for this time and linearly related to the amount of enzyme. Virtually no activity was detected without the addition of oxaloacetate.

Statistical Analysis

measurement of energy experditure was analyzed as in Experiment 1. The design of the experiment is shown in Figure 3. A full design analysis of variance was performed using 3 between-subject factors (sex, diet, and exercise) and 2 within-subjects factors (age and meal). Separate analyses of variance were performed for RMR and for overall DIT (percentage of metabolic increase over RMR for the first hour after the meal).

measurement of total caloric intakes and of citrate synthase activity was analyzed using a 2x2x2 factorial between-subjects design. measurement of body weight and body fat were analyzed as a between-subjects 2x2x2 with age as a within-subjects factor. All post hoc tests were performed using the Neuman-Keuls method. All ANOVA tables, along with cell means for the highest order interaction are in Appendix E.

Figure 3

Design for Experiment 2

Between-Subjects Variables

Diet History

Exercise History	Lab chow (LC)		Supermarket diet (SD)	
	Male	Female	Male	Female
Sedentary (S)	n=7	n=7	n=6	n=6
Exercised (E)	n=3	n=4	n=3	n=5

Within-Subjects Variables

1. Age. (2 levels which varied with the different dependent variables)

2. Meal. (3 levels: RMR, DIT1, DIT2). Used in ANOVA for Oxygen Consumption only

Results

Energy Expenditure

Results of the full design ANOVA showed that there was a significant main effect due to sex. Females had higher overall metabolic rates than males (23.47 vs 19.90 ml/min/kg, $p<.01$). Main effects for diet and exercise just missed significance. Main effects for diet and exercise also were not significant in either the RMR or overall DIT ANOVA. An inspection of the cell means for these analyses (Appendix B), shows that the differences due to diet and exercise, although not significant, were in the same direction as in Experiment 1. The number of subjects was less in this experiment and, in addition, animals were used that were not used in Experiment 1. The pattern of the individual cell means for overall DIT (Appendix B) was much the same, except for the female LC-E group. However, an inspection of the cell means in the full design ANOVA (Appendix B) shows that the RMR of those animals was exceptionally high. Thus, the values for DIT1 and DIT2 at both ages were higher than for any of the other groups (except for DIT2 at age 1, which was the second highest value at that age), but the overall DIT were high because of the high resting metabolic rate. Measurement of oxygen consumption at 86 to 103 and 147 to 171 days of age failed to show any significant differences (Appendix B).

Caloric Intakes

From the time of withdrawal of the supermarket diet until the beginning of the second measure of energy expenditure, females ate signficantly more calories than males (13007.06 vs 10507.90 kcal.kg, $p<.01$). Animals which previously had access to the supermarket diet ate significantly less when given only lab chow than did animals never having had access to the supermarket diet (LC animals=12197.56 kcal/kg, SD animals=10816.32 kcal/kg, $p<.01$). There was no overall sex difference in intakes for SD animals, but for SD-LC animals, females ate significantly more than males (Table 14).

From the individual cell means (Appendix B), it can be seen that over the course of the experiment, male SD-S animals ate 5% less than male LC-S animals, while female SD-S animals ate 26% less than female LC-S animals. For exercised animals, male supermarket diet animals ate 11% less than male lab chow animals and female supermarket diet animals ate 21% less than female lab chow animals.

Intakes also were calculated over 6-day periods, beginning when the supermarket diet was withdrawn. An ANCVA with 6 levels of age was performed on the intake values during these periods. During six 6-day periods the pattern of caloric intakes did not change. Within each 6-day period, animals with previous access to the supermarket diet ate significantly less than animals which ate only lab chow.

Table 14

Total caloric intakes (kcal/kg)

	Males	Females
Supermarket diet	10129.71	11378.09
Lab chow	10848.28	14636.03[1]
	(n=19)	(n=22)

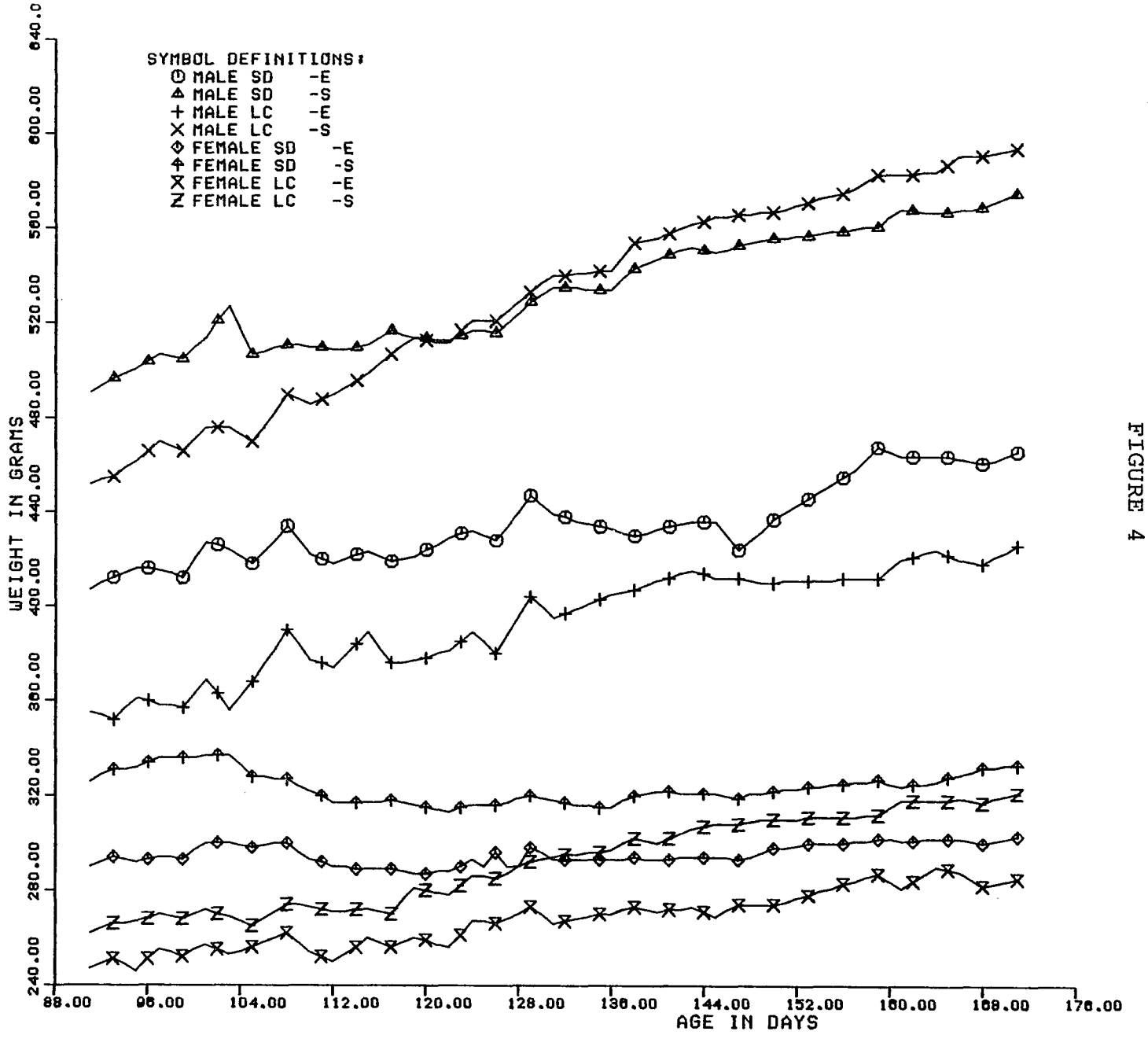
[1] different from all values, p=.01

Females ate significantly more than males and exercised animals ate significantly more than sedentary animals during each 6-day period. Also, there was a significant overall sex-diet interaction, but this interaction already has been reported in the previous ANOVA (Table 14).

Body Weights

Figure 4 presents the body weight curves for all groups of animals. Results of the ANOVA showed significant main effects for sex, diet, and exercise. Males were heavier than females (499.30 vs 311.45 g, $p<.01$), animals previously eating the supermarket diet were heavier than animals eating only chow (420.21 vs 381.60 g, $p<.05$), and sedentary animals were heavier than exercised animals (427.80 vs 352.50 g, $p<.01$). Also, there was a significant sex-exercise interaction (Table 15). Among males, but not among females, exercise led to lower body weights. When a separate ANOVA was performed on body weight at 171 days of age, the pattern of results was the same except that the main effect of diet was not significant (Appendix B).

Also, there was a significant 3 way interaction among age, diet and exercise (Table 16). At the end of the experiment (day 171), sedentary animals did not differ from lab chow animals in body weight, although they were significantly heavier at the beginning (day 103). The pattern was different with exercised animals. Supermarket diet animals weighed more at the end as well as at the beginning of the experiment. All groups significantly


SYMBOL DEFINITIONS:
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MALE SD -S
MALE LC -E
MALE LC -S
FEMALE SD -E
FEMALE SD -S
FEMALE LC -E
FEMALE LC -S
WEIGHT IN GRAMS
640.00
600.00
560.00
520.00
480.00
440.00
400.00
360.00
320.00
280.00
240.00
88.00
96.00
104.00
112.00
120.00
128.00
136.00
144.00
152.00
160.00
168.00
176.00
AGE IN DAYS

FIGURE 4

Table 15

Average body weights (grams)

	Males	Females
Exercised	418.00[2]	308.83
	(n=6)	(n=9)
Sedentary	534.14[1]	313.27
	(n=13)	(n=13)

[1] different from all other values, p=.01

[2] different from 308.83, p=.01; different from 313.27, p=.05

Table 16

Average body weight (grams)

	Exercised		Sedentary	
	SD	Lab chow	SD	Lab chow
103 days	365.88	301.43	435.77	373.00[1]
171 days	392.38	342.71	455.23	449.71 [2]
	(n=8)	(n=7)	(n=12)	(n=14)

all values differ, p=.01 except:

[1] not different from 365.88
[2] not different from 455.23 or 435.77

increased their body weight from age 103 to 171 days with the lab chow animals gaining at a faster rate than the supermarket diet groups.

The 3 way interaction among age, sex, and diet was also signficant (Table 17). At 103 days of age the two supermarket diet groups (male and female) weighed more than their same sex lab chow controls, but the difference was greater for the female supermarket group. However, following withdrawal of the supermarket diet, the weight increase for the supermarket diet males was less than that of the lab chow males, so that at 171 days of age the lab chow males weighed the same as the supermarket diet males. A similar pattern occurred with the females. The supermarket diet females gained no weight following the diet removal while the lab chow females gained a significant amount of weight, but not enough to equal the weights of the supermarket group.

Body Fat

Lee Index values showed significant main effects for sex, diet and exercise. Males were fatter overall than females (.2972 vs .2893, $p<.01$), animals previouly eating the supermarket diet were fatter overall than lab chow only animals (.2976 vs .2885, $p<.01$), and sedentary animals were fatter than exercised animals (.2957 vs .2875, $p<.01$).

The only significant interaction was for age and diet (Table 18). There was a significant decrease in fatness for

Table 17

Average body weight (grams)

	Males		Females	
	SD	Lab chow	SD	Lab chow
103 days	488.50	442.20	337.00	264.55
171 days	532.70	533.80[2]	339.09[1]	305.18
	(n=9)	(n=10)	(n=11)	(n=11)

all values differ, p=.01, except:

[1] not different from 337.00
[2] not different from 532.70

Table 18

Lee Index

	Supermarket diet	Lab chow
day 103	.3009[1]	.2877
day 171	.2943[1]	.2894
	(n=19)	(n=21)

[1] different from all other values, p=.01

the supermarket diet animals over the course of the experiment, but at 171 days of age they were still significantly fatter than lab chow only animals. There were no significant interactions with exercise.

Citrate Synthase

Only the main effect of exercise training condition was significant. Muscles of exercised animals had significantly higher levels of citrate synthase activity than those of sedentary animals (20.55 vs 16.35 u moles/min/g tissue). Neither diet nor sex had any effects on citrate syrthase activity.

Discussion

Obesity after early exposure to the supermarket diet was found to be reversible, as with adult exposure (Sclafani and Springer, 1976; Sclafani and Gorman, 1977; Rothwell and Stock, 1979b). The reversal essentially was complete in sedentary animals of both sexes, but not in exercised animals. Reductions in food intake, but not changes in metabolic rates, were found to be important factors in the reversibility.

The pattern of food intake gives no clue as to why body weights of the supermarket diet, exercised animals remained high after diet removal. It was very surprising that there was not a significant diet-exercise interaction on food intake. This means that there was no difference in the intakes of execised and sedentary supermarket diet animals after diet withdrawal. It would be expected that if the intakes were the same, the weight reduction would be greater in the exercised animals due to increased energy cost of the exercise. It is difficult to explain why the opposite result was found.

Rolls and Rowe (1979) also reported that body weights of exercised supermarket diet animals remained significantly higher than body weights of exercised controls when the supermarket diet was removed. However, they also found the same lack of reversibility in body weights of sedentary animals when the diet was withdrawn.

The pattern of food intakes seen in this study was very different from previous reports. Rothwell and Stock (1979b) found no difference in intakes between animals previously eating a supermarket diet and control animals during the first 12 days after supermarket diet withdrawal. But, during those 12 days, the body weights of supermarket diet animals returned to control levels. In a second study reported in the same paper, Rothwell and Stock found that the animals became hyperphagic when the supermarket diet was withdrawn, but that the reduced intake was not sufficient to explain the reduced body weights. Rolls and Rowe (1979) found a temporary reduction in food intakes of male and female hooded rats after removal of the supermarket diet, which subsequently became signficantly higher than the intakes of controls.

In this experiment, food intakes of all supermarket diet animals decreased significantly when the diet was withdrawn, and remained below control levels throughout the experiment. Even when the intakes were examined over subsequent 6-day periods after supermarket diet withdrawal, the same reduction was seen in each period. For every 6-day period, rank order of mean caloric intake was the same.

In examining the pattern of food intake after supermarket diet withdrawal, it appears that a reduction in food intake played a larger role in reducing the obesity in females than in males. This is particularly true of sedentary animals. For both male and female sedentary

supermarket diet groups, the rate of weight gain slowed so that the sedentary lab chow groups caught up. But the reduction in total intake compared to the same sex sedentary controls was 26% for females, and only 5% for males. It is possible that the methods by which obesity reversal occurred were different for the two groups.

Neither overall metabolic rate nor overall DIT was higher initially in the supermarket diet animals in this study. Since many of the animals in the study were used in Experiment 1, it was expected that there would be such a difference. Lack of such difference primarily was due to the low DIT of the lab chow, exercised group. These animals had a very low DIT, and there was a trend toward a lowering DIT with time even in Experiment 1. It is not surprising that these animals would be conserving rather than wasting energy. They were the leanest and the lightest of all the groups and were expending energy daily in swimming. Under such circumstances, it would be not be expected that a high DIT would have survival advantages.

Some animals which were not used in Experiment 1 were used in this experiment. Although these animals were littermates, it is possible that the amount of individual variability in DIT, even in such a population was high. This could account partially for the failure to find a significant difference.

However, the reports (Rothwell and Stock, 1979a, 1979b) that energy expenditure increased with supermarket diet removal were not substantiated by this study. Rothwell and Stock found that the increase in energy expenditure after supermarket diet withdrawal was the major cause of the reversibility of body weight increases. In this study there were no significant metabolic changes associated with changing from a supermarket diet to a lab chow diet, but the weight reversibility occurred, at least in sedentary animals.

The increase in body fat, as estimated by the Lee Index, was significantly greater for the IC animals than for the SD animals. The latter group actually became relatively leaner over the course of the experiment, but none of the SD groups became relatively leaner than the comparable LC groups. This finding is not in agreement with that reported by Stephens (1980) who found that in male hooded rats, animals became leaner (as determined by carcass analysis) than controls when the supermarket diet was withdrawn. However, he measured body fat 100 days after discontinuing the supermarket diet, compared to less than 50 days in the present study. Thus it remains possible that the supermarket diet animals in this study may have continued to become leaner with time.

The higher citrate synthase activities in exercised animals support the argument that the exercise program used in this experiment, and, in the previous one, increased

aerobic capacity since it is an excellent marker enzyme for the effects of training (Holloszy and Booth, 1976).

XII. EXPERIMENT 3

The first experiment assessed the effects of early exposure to a supermarket diet and the effects of early aerobic exercise on energy intake and expenditure in weanling rats. In order to compare these results with the changes in food intake and energy expenditure seen in adult rats, a third experiment was conducted. The supermarket diet used in Experiment 1 was given to adult animals, some of which had received daily aerobic exercise since weaning and some of which had received no exercise. Again, the effects of diet and exercise on energy intake and expenditure were measured.

Few other studies using a supermarket diet have attempted to measure caloric intake, and the ones which did used only sedentary rats and failed to report all relevant values (Rothwell and Stock, 1979a, 1979b; Rolls and Rowe, 1979). Accurate measures of caloric intakes in adult rats were taken in this experiment.

According to the hypothesis that heat production is related to degree of physical fitness, animals which have been exercised since weaning should be able to expend more of the excess calories consumed from a supermarket diet as

heat. This would allow these animals to better resist body weight changes, since less energy would be available to be converted into body fat.

Method

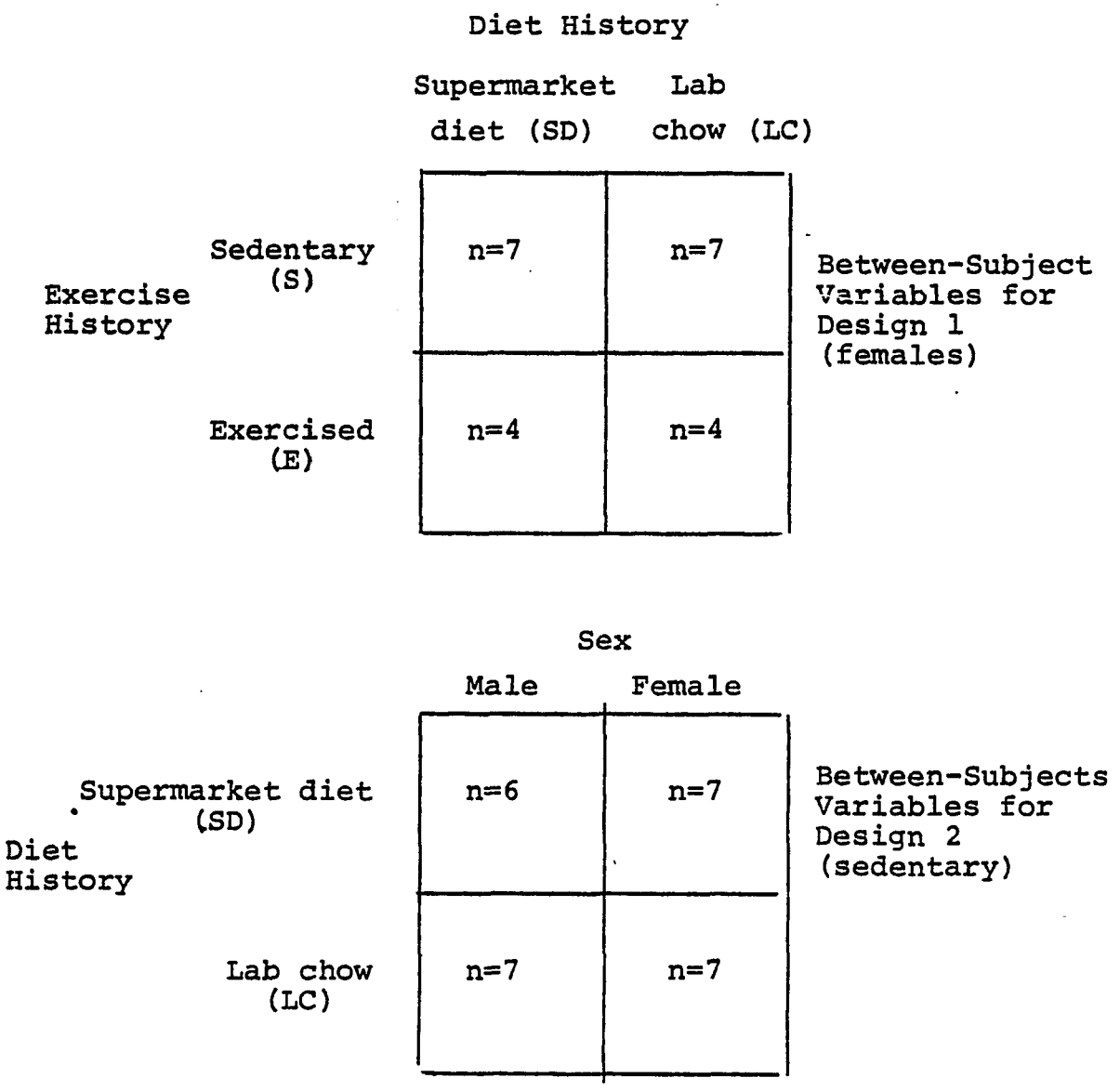
Subjects were 22 female and 13 male Charles River CD outbred albino rats. All animals were weaned at 21 days of age and received only Purina Rat Chow and water ad libitum until they were 108 days of age.

The design of the experiment originally was a 2x2x2 factorial . However, by 108 days of age there were only 2 male exercised animals surviving. The other 8 of the 10 animals that originally were designated to be used in this experiment drowned before they were 108 days of age. In addition, 2 exercised females drowned before the beginning of the experiment and 1 male died early in the experiment. Considering the two empty cells in the original design, it was decided to analyze the experiment as two, 5x5 factorial designs (Figure 5). Design 1 included only females. Animals were in one of 2 diet conditions (lab chow or supermarket diet), and were in one of 2 exercise conditions (exercised or sedentary). Design 2 included only sedentary animals. Animals were in one of 2 diet conditions lab chow or supermarket diet.

Beginning at 108 days of age, one-half of the exercised females, one-half of the sedentary females, and 6 of the 13 sedentary males were given access to the supermarket diet described in Experiment 1 along with ad libitum access to chow and water. The exercising animals continued to exercise for 2 hr/day, 5 days/week.

Figure 5

Design for Experiment 1



Within-Subjects Variables

1. Age. (2 levels which varied with the different dependent variables)

2. Meal. (3 levels: RMR, DIT1, DIT2). Used only with the ANOVA for Oxygen Consumption.

The dependent variables were the same as in Experiment 2. Measures of oxygen consumption were taken twice, at 86 to 103 and 147 to 171 days of age. Procedures were the same as in Experiments 1 and 2. Caloric intakes (kcal/kg) and body weight were recorded 3 times weekly. Estimates of body fat, using the Lee Index, were made at 103 and 172 days of age. Citrate synthase activity in the gastrocnemius muscle was determined at the end of the experiment using the procedure described in Experiment 2.

Oxygen consumption was analyzed for each design, using 2 between-subjects (diet and exercise for design 1, sex and diet for design 2), and 2 within-subjects factors (age and meal). This analysis will be referred to as the full design ANOVA. Separate analyses of variance were performed for RMR and overall DIT, using the appropriate two between-subject factors for each design and using two levels of age as a within-subjects factor. A 2x2 ANOVA was performed to analyze total caloric intakes and citrate synthase for each design. For body weight and Lee Index values, a 2x2 between-subjects with one within-subjects factor (age) ANOVA was used for each design.

Results

Energy Expenditure

Design 1 (females). The full design showed significant main effects for diet (lab chow animals had a higher O2 consumption), and for exercise (exercised animals had a higher O2 consumption). However, the age-diet interaction also was significant (Table 19), independent of exercise. The overall metabolic rates of the supermarket diet animals dropped significantly more than those of the lab chow animals from the beginning to the end of the experiment. Lab chow animals had significantly higher RMR overall than supermarket diet animals (23.40 vs 20.47 ml/min/kg, $p<.05$). This pattern did not change when grams to the .75 power was used instead of kg when expressing O2 consumption. The age-diet interaction was not significant for RMR.

DIT showed no significant differences due to diet, but across both ages was higher for supermarket diet animals; the difference approached significance (20.97 vs 13.47 ml/min/kg, $p<.059$). The diet-exercise interaction, averaged across age was significant for overall DIT (Table 20). No difference in overall DIT existed between sedentary supermarket diet animals and sedentary chow animals. However, exercise had opposite effects on supermarket diet and lab chow animals. It increased DIT in the supermarket diet animals and lowered it in the lab chow animals so that the two were significantly different. The finding that

TABLE 19

Oxygen consumption (ml/min/kg) Design 1 (females)

	Supermarket diet	Lab chow
86-103 days	25.50	26.06
147-171 days	20.61[1]	24.09
	(n=11)	(n=11)

[1] different from 26.06 p=.05; different from all other values, p=.01

TABLE 20

Design 1 (females)
Overall DIT (%increase above RMR in one hour after meal)

	Supermarket diet	Lab chow
Sedentary	16.08	17.76
	(n=7)	(n=7)
Exercised	29.50[1]	5.98
	(n=4)	(n=4)

[1] different from 5.98, p=.05

metabolic rate was higher in the exercised animals was due to the high DIT of the exercised supermarket diet animals, since RMR was lower in the exercised animals eating the supermarket diet (see Table 21). There was no significant difference in RMR due to exercise, though overall RMR was slightly higher for exercised animals (see Appendix C).

The meal-diet-exercise interaction in the full design ANCVA (still using females only) also was significant (Table 21). RMR did not differ between sedentary and exercised supermarket diet animals nor between sedentary and exercised lab chow animals. The RMR of the lab chow exercised animals was higher than that of either sedentary group. Also, from Table 21 it can be seen that the only group in which DIT1 was not significantly above RMR was the lab chow exercised group. There were no differences in DIT1 or DIT2 among any of the groups.

Design 2 (sedentary animals). The only significant main effect from the full design ANCVA, using sedentary animals only, was sex, with females having higher overall metabolic rates than males. However, the age-sex difference also was significant (Table 22). Metabolic rates of females were only significantly higher than males at 87-103 days of age and not at 147-171 days of age. The RMR ANCVA showed that some of the difference was due to the higher RMR of females (21.01 vs 16.80 ml/min/kg, $p<.01$). The opposite pattern in sex differences was found in overall DIT. The main effect of sex, according to the DIT ANCVA, was significant only at

TABLE 21

Oxygen consumption (ml/min/kg)

	Exercised		Sedentary	
	SD	Lab chow	SD	Lab chow
RMR	20.78	26.33[1]	20.29	21.73
DIT1	28.84[3]	31.45	26.87[4]	28.27[5]
DIT2	23.88	23.16	19.52	21.95
	(n=4)	(n=4)	(n=7)	(n=7)

[1] different from all values except 21.73, p=.05
[2] different from all other values in the row
[3] different from 20.78, p=.01
[4] different from 20.29, p=.01
[5] different from 21.73, p=.01

TABLE 22

Oxygen consumption (ml/min/kg) Design 2 (sedentary)

	Males	Females
86-103 days	20.10	25.08[1]
147-171 days	18.81	21.14
	(n=13)	(n=14)

[1] different from all other values, p=.01

p<.052, with males having the higher DIT (25.29% vs 16.92%).

There also was a significant meal-sex interaction in the full design (Table 23). It can be seen that DIT1 for both males and females was higher than the respective RMR. However, only DIT2 for males was still significantly above RMR.

Caloric Intakes

Design 1 (females). Both the main effect of diet and of exercise were significant, but their interaction was not. Supermarket diet animals ate 13% more total calories than lab chow animals during the 40 days from the beginning of the diet until the beginning of the final measurement of energy expenditure (11464.53 vs 10156.28, p<05). Exercised animals ate 12% more than sedentary animals during the same period (11615.43 vs 10350.40 kcal/kg, p<.05). There was no significant diet-esercise interaction.

Design 2 (sedentary animals). Both sex and diet significantly affected caloric intakes but the interaction was not significant. Females ate 40% more than males (10278.98 vs 7351.62 kcal/kg, p<.01), and supermarket diet animals ate 15% more than lab chow animals (9518.27 vs 8267.08 kcal/kg, p<.01).

Body Weight

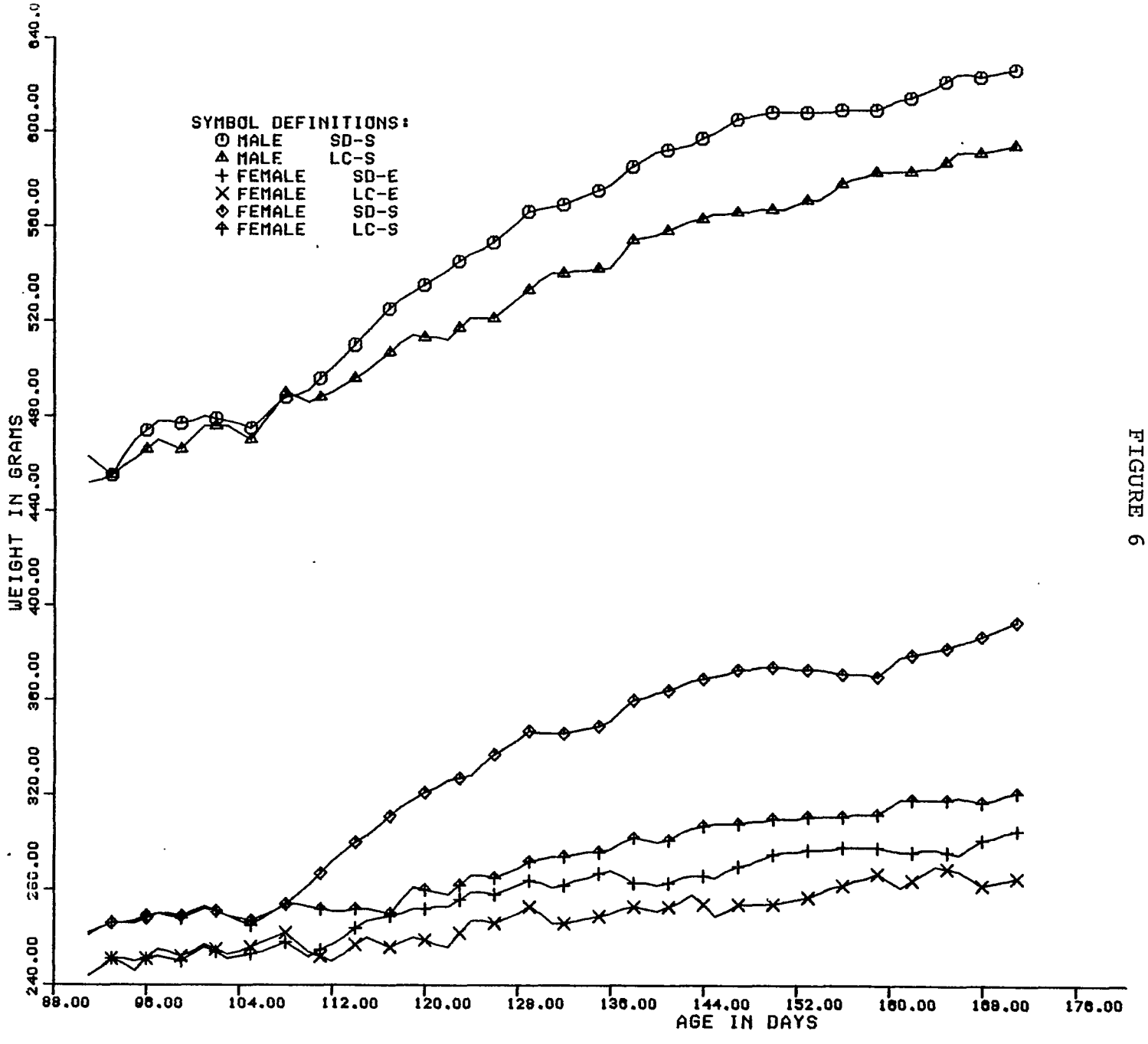
Design 1 (females). Figure 6 presents body weight curves for all groups in Experiment 3. The only significant main effect in the design was due to exercise, with sedentary animals weighing the most. However, the

TABLE 23

Oxygen consumption Design 2 (sedentary)

	Males	Females
RMR (ml/min/kg)	16.80	21.01[3]
DIT1 (ml/min/kg)	22.46[2]	27.57[1]
DIT2 (ml/min/kg)	19.12[3]	20.74
Overall DIT	25.29%	16.92%
	(n=13)	(n=14)

[1] different from all other values, p=.01
[2] different from all other values below 20.74, p=.01
[3] different from 16.80, p=.05


SYMBOL DEFINITIONS:
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MALE LC-S
FEMALE SD-E
FEMALE LC-E
FEMALE SD-S
FEMALE LC-S
WEIGHT IN GRAMS
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400.00
440.00
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520.00
560.00
600.00
640.0
88.00
96.00
104.00
112.00
120.00
128.00
136.00
144.00
152.00
160.00
168.00
176.00
AGE IN DAYS

FIGURE 6

age-exercise interaction also was significant (Table 24). At the beginning of the experiment, exercised animals did not differ in weight from sedentary animals, but at the end of the experiment, the sedentary animals weighed significantly more, having gained twice as much weight as the exercised groups.

The diet-exercise interaction was significant (Table 25). The body weight of the exercised supermarket diet and exercised lab chow animals were almost identical. The largest differences were between the sedentary supermarket diet animals and the sedentary lab chow animals, with the former group being heavier, and between the lab chow sedentary and lab chow exercised animals, with the former group again being heavier.

The age-diet interaction also was significant (Table 26). Although supermarket diet and lab chow animals did not differ in weight at the beginning of the experiment, supermarket diet animals were significantly heavier by the end.

Design 2 (sedentary animals). As was seen with females, supermarket diet animals weighed more at the end, but not at the beginning of the experiment (Table 27). This shows that the body weight increase was significantly higher in the supermarket diet sedentary females than in the lab chow females, since there was not a significant diet-exercise interaction and since the increase in body weight with supermarket diet access was greater for females.

TABLE 24

Average body weights design 1 (females)

	Exercised	Sedentary
103 days	253.88	270.07
171 days	291.13[1]	353.71[1]
	(n=8)	(n=14)

[1] different from all other values, p=.01

TABLE 25

Average body weights Design 1 (females)

	Exercised	Sedentary
Supermarket diet	272.63	323.71
	(n=4)	(n=7)
Lab chow	272.38	300.07
	(n=4)	(n=7)

TABLE 26

Average body weights Design 1 (females)

	Supermarket diet	Lab chow
103 days	262.64	265.73
171 days	347.64[1] (n=11)	314.27[1] (n=11)

[1] different from all other values, p=.01

TABLE 27

Average body weights Design 2 (sedentary)

	Supermarket diet	Lab chow
103 days	368.00	375.00
171 days	486.08[1]	456.86[1]
	(n=13)	(n=14)

[1] different from all other values, p=.01

The overall effect for sex was significant with males weighing more than females, but the age-sex interaction was not significant (see Appendix C).

Body Fat

Design 1 (females). An ANCVA on Lee Index values showed significant main effects for only exercise. Exercised animals were leaner overall than sedentary animals (.2812 vs .2903, $p<.01$). The age-exercise interaction was not significant but the age-diet interaction was (Table 28). Supermarket diet animals became signficantly fatter by 172 days of age, while there was no significant change in fatness in the lab chow groups.

Design 2 (sedentary animals). An ANCVA on Lee Index values showed significant main effects for sex, with males being the fatter, and for diet with supermarket diet animals being the fatter. However, the 3-way interaction among age, diet and sex also was significant (Table 29). At the beginning of the experiment, there were no differences in body fat between supermarket diet and lab chow groups for either males or females. Males were fatter than the comparable female animals for both diet conditions. At the end of the experiment, the female supermarket diet group was significantly fatter than the female lab chow group, but neither male groups differed significantly. The increase in fatness of supermarket diet males was not significant, and was less than that of the females consuming the supermarket diet.

TABLE 28

Lee Index — Design 1 (females)

	Supermarket diet	Lab chow
103 days	.2829	.2830
172 days	.2977[1]	.2842
	(n=11)	(n=11)

[1] different from all other values, p=.01

TABLE 29

Lee Index Design 2 (sedentary)

	Males		Females	
	SD	Lab chow	SD	Lab chow
103 days	.3007[2]	.2963[3]	.2864	.2843
172 days	.3057[1]	.2989[2]	.3046[2]	.2857
	(n=6)	(n=7)	(n=7)	(n=7)

[1] different from all values below .2989, p=.01
[2] different from all values below .2963, p=.01
[3] different from all lower values, p=.01

Citrate Synthase

Design 1 (females). Levels of citrate synthase activity were higher in exercised animals but the difference was not significant (19.06 vs 17.76 u moles/min/gram of tissue). There was no significant diet effect.

Design 2 (sedentary animals). There was not a significant effect of sex or diet on citrate synthase activity.

Discussion

The change from lab chow to a supermarket diet increased body weight, caloric intakes, and body fat in sedentary adult animals. These results were expected (Sclafani and Springer, 1976; Sclafani and Gorman, 1977; Rolls and Rowe, 1978; Rothwell and Stock, 1979a, 1979b). The change did not increase body weight in exercised females. This result is not in agreement with a previous report (Rolls and Rowe, 1979).

The failure of the supermarket diet exercised females to increase body weight in response to the supermarket diet was due, at least in part, to an increase in DIT. Caloric intakes of these animals were not significantly different from those of supermarket diet sedentary females which did increase body weight in response to the supermarket diet.

It was obvious from results of oxygen consumption measurements in this study that the effects of exercise on DIT varied with diet. The higher DIT of the exercised supermarket diet females was predicted from the hypothesis that aerobic exercise training leads to an increased ability to expend excess calories as heat during overeating. The finding that DIT was very low in exercised lab chow females seems, on first glance, to contradict that hypothesis. However, it is not clear that these animals were, in fact, overeating. Their body weight and their body fat content were very low, while their caloric intakes and RMR were very

high. It may be that their caloric intake was at the upper limit of their ability to process the food. If that were the case, they may not have been meeting their energy needs, even on the high intakes. Thus, they may not have wasted energy because they did not have excess energy to waste. Such adaptaive changes in metabolism have been reported repeatedly in starved humans (Miller, 1975). Similar results have been seen in DIT of human marathon runners (Kertzer et al., 1981).

Increases in DIT probably serve to limit fat storage in the face of abundant food supplies to maintain a high working capacity. When an excess of food is not available, excess body fat usually is not a problem, and increases in DIT would not be advantageous to the animal. The exercised lab chow females had been exercising for 2 hours/day, 5 days/week for 21 weeks. Their energy demands obviously were high, and may not have been met by their caloric intakes. Under such circumstances a mechanism to limit body fat would not be adaptive and it may not be surprising to see low DIT.

In design 2, with only sedentary animals, there was no indication that increases in DIT occurred with the supermarket diet.

The increase in body weight seen in sedentary animals when the supermarket diet was given was less than previously has been reported (Sclafani and Gorman, 1977; Rothwell and Stock, 1979a,1979b). Caloric intakes were elevated in all animals eating the supermarket diet. Females ate more than

males when averaged across diet. This higher intake probably explains why that when compared to same sex lab chow sedentary animals, female supermarket diet animals gained more weight than male supermarket diet animals. This difference in increase in weight has been reported previously (Sclafani and Gorman, 1977).

Body fat increased in all animals given the supermarket diet. However, the increase for males on this diet, although twice as much as was seen in male lab chow animals, was not significant. Increase in body fat was less for exercised animals than for sedentary animalss.

Citrate synthase activity was higher in exercised animals, but not significantly so. Sample size was small and only female animals were exercised. There was no diet effect on citrate synthase activity. It is likely that exercised animals had higher aerobic capacities than sedentary animals.

The supermarket diet led to increased body weight, increased food intakes and increased body fat in male and expecially in female, adult rats. Exercise led to decreased growth, increased food intakes and decreased body fat.

In conclusion, a history of aerobic exercise did increase dietary-induced thermogenesis in female rats during overeating and allowed them to resist body weight changes even though they were overeating the palatable supermarket diet.

XIII. GENERAL DISCUSSION

Exercise

The effects of exrcise were consistent in both weanling and adults. Daily exercise led to lower body weight, leaner body composition, increased food intake and higher rates of oxygen consumption.

The effects of exercise also interacted with sex, diet, and age. Exercise affected males and females differently depending on the nature of the diet they were eating. When eating only lab chow, exercise had no immediate effects on body weight, relative amount of body fat or food intake in females, but exercise significantly increased food intake in males. From weaning until 103 days of age, male animals which were exercised ate more than any other lab chow group and even ate as much as exercised supermarket diet males. However, their body weights did not increase as rapidly as the sedentary male animals.

The effects of exercise on body weights and body fat in the female lab chow-fed exercised group were not evident until 171 days of age. At that time the difference in body weights was noticable, but not significant, and the female lab chow-fed exercised group had significantly less total

body fat than the female lab chow-fed sedentary group. Thus, long-term exercise may have effects in females which are not seen in studies of short-term periods of exercise, especially if the animals are on a "normal" diet.

There was no difference in long and short term exercise in males. The body weight difference between the male lab chow-fed exercised group and lab chow-fed sedentary animals in Experiment 2 continued to increase right up until 171 days of age. Intakes of exercised animals in general were higher than those of sedentary animals, but the sex-diet-exercise interaction was not significant, as it was in weanlings.

The lack of significant sex-diet-exercise interaction on food intakes and body fat was surprising considering the difference in the effects of exercise on body weights of male and female lab chow animals. This suggested that there should be sex differences in the effects of exercise on energy expenditure. Such a simple explanation was not supported by the results of the oxygen consumption measurements. There were, however, some general differences between males and females. For example, females had higher RMR than males throughout the study. Dietary-induced thermogenesis was higher for females than for males at 46 to 56 days of age, but it declined rapidly so that at 86 to 103 days of age there was no difference. At 147 to 171 days of age, dietary-induced thermogenesis of females was somewhat less than that of males. Although the same animals were not

included in all 3 measurements, there seemed to be a consistent pattern of decrease in DIT with age in females.

The effects of exercise training were different for males and females on the supermarket diet. Although exercise did not affect body weight of females eating lab chow, it reduced body weight in the female supermarket diet, exercised group. However, the effect of exercise on body weight was still greater in males than in females. The rank order of body weights of various groups at 104 days of age was different for males and females (Figure 1). Exercise significantly reduced body weight of males fed the supermarket diet below those of the male lab chow sedentary animals. There was no difference between the respective female groups. The different effects of exercise in the male and female lab chow groups apparently was not due to differences in food intake. The exercised female animals did not overeat to a greater extent than exercised male animals. Also, there was no difference in the extent of overeating of either group when each was compared with the same sex lab chow sedentary group. However, after the females had been exercised for a longer period of time (day 171), the body weight of the female supermarket diet exercised animals were below that of female lab chow sedentary animals, although they had overeaten as much as the female supermarket diet sedentary animals.

Even though the exercise-induced reduction in body weight of the supermarket diet animals was greater in males, exercise did not affect food intake in either sex. However, in Experiment 1, female supermarket diet exercised animals ate more than to female lab chow exercised animals, while male supermarket diet exercised animals did not overeat as compared to male lab chow exercised animals.

Body fat estimates showed that both male and female supermarket diet animals were fatter than the same sex sedentary animals at all measurements, but there was no significant sex-diet-exercise interaction on body fat.

Given the pattern of body weight differences between males and females eating the supermarket diet and the lack of significant sex-diet-exercise interactions on food intake and body fat, energy expenditure differences could be expected. However, there were no significant sex-diet-exercise interactions in oxygen consumption either.

Thus, the reduced body weights of male exercised supermarket diet animals and the lack of change in the body weights of female exercised supermarket diet animals can not be explained by changes in metabolism; however, neither was it due to differences in food intakes.

As mentioned previously, adult female exercised animals did increase dietary-induced thermogenesis significantly when given a suermarket diet. This helps explain the fact that while they were overeating compared to the lab chow group (and in fact were eating as much as the sedentary

supermarket diet females) they did rct increase body weight. In this instance, luxuskonsumption apparently was enhanced in the animals with a history cf daily aerobic exercise.

Withdrawing the supermarket diet in Experiment 2 produced anctber instance in which the changes in body weight could not be explained by changes in fcod irtake. Comparable reductiors ir fcod irtake occurred fcr both exercised and sedentary supermarket diet animals after diet withdrawal, but the previcus bcdy weight increases were eliminated only in sedentary animals. It would have been expected that the reversal alsc wculd have been seen in exercised supermarket diet animals, considering that they alsc were expending energy thrcugh daily swimming. It could be that wher the diet was withdrawn, DIT also decreased, resulting in essentially no changes in bcdy weight. No strong evidence to supprt such an hypcthesis was found. Hcwever, it car be seer that there was a reduction in DIT in exercised males but not exercised females when the diet was withdrawn.

Supermarket diet

The supermarket diet, indeperdent of exercise, consistently increased body weights, fccd intakes and body fat in weanling and adult animals. These results all were expected (Sclafani and Gorman, 1977; Rothwell and Stock, 1979a). The delay in weight gain previously reported with weanling animals on a supermarket diet (Simpscn et al., 1980, 1981) was found in Experiment 1. At 46 days of age,

supermarket diet animals of both sexes were no heavier than the same sex lab chow group, in spite of 25 days of overeating. However, they were fatter than lab chow animals. The early exposure to the supermarket diet did have the effect of producing more body fat at the expense of lean body mass in the animals. By 86 days of age, supermarket diet animals weighed more, as well as having more body fat relatively. The diet resulted in energy expenditure changes only in weanling rats, in which there was a decrease in DIT in animals eating a supermarket diet. This decrease was significant both at 46 to 56 days of age and at 86 to 103 days of age. However, metabolism was unchanged when adults ate the supermarket diet. It could be that regulatory controls of metabolic rate are particularly susceptible to experiential factors at an early age in the rat. It has been reported that the regulatory controls for number of fat cells (Knittle and Hirsch, 1968) and for upper limit of lean body mass (Pitts and Bull, 1977) are not fully developed at weaning.

These results did not support those of Rothwell and Stock (1978, 1979a, 1979b, 1980) who found elevations in DIT with the supermarket diet. Unfortunately, in the reports cited above, full descriptions of the methods used to measure oxygen consumption were not reported. In one study (Rothwell and Stock, 1979a) they reported that measurement of oxygen consumption were taken for 2 hours on days 5, 11, 13, and 16. However, they did not report when in

relation tc a meal, the measurements were taken, or the size cr the composition of the meals. This lack of reporting of methcds makes their results very difficult tc ccmpare with the results cf this study.

There was some evidence in these studies that early access to the supermarket diet could have had long-lasting effects on body weight. Access to the supermarket diet alone prodtced reduced cxygen ccnsumpticn rates in weanling rats but not in adults. Though body weights of sedentary weanling arimals returned tc ncrmal body weight levels when the supermarket diet was withdrawn, they did not experience any changes ir energy expenditure. In Experiment 2, metabolic rates of animals with previous access to the supermarket diet were still scmewhat below those of lab chow animals. It could be the case that such a differerce cculd have made the animals previously eating the supermarket diet mcre susceptible to obesity later in life.

In both weanlirg and adult rats given the supermarket diet variability in body weight increases was very high. This result has been previously repcrted with body weight increases in animals given a high fat diet (Schemmel et al., 1970) as well as in arimals given a supermarket diet (Sclafani and Gorman, 1977). Such variability would be expected if varying degrees of luxuskonsumptic ar€ associated with varyirg maximum aercbic capacities, since VC2 max is highly variable.

One problem encountered in determining metabolism by measuring O2 consumption was determining the most accurate units in which to express metabolism. Traditionally, O2 consumption has been expressed as volume of oxygen consumed per unit time per unit of body weight to the .75 power. Supposedly that unit of body weight takes into account lean body mass and also makes comparisons across species possible (Kleiber, 1975). However, there are number of problems raised by using this method. First, the appropriate unit would have to be grams to the .75 power, because kilograms to the .75 power would yield an estimated metabolic mass greater than the total mass for any animal below 1 kilogram. Second, there is not good evidence that this measure of metabolic mass does in fact correctly estimate lean body mass. Third, any measure which reflected lean body mass would ignore the metabolic properties of adipose tissue (Miller, 1975). The problem of the correct unit of body weight to use in expressing metabolism has not been given much attention when the comparisons are within a species. Most investigators have not questioned the validity of the traditional method. I feel that the problem deserves more consideration. If a unit of measurement which expressed metabolism as units of lean body mass is desirable, then more accuracy can possible be obtained with other methods, such as the Lee Index. Throughout this study, the unit of body used in expressing metabolism was kilograms. This is not to suggest that it is the best unit to use, but to

suggest that it is just as accurate in comparing animals within a species. More importantly, the pattern of results obtained in the present study was the same whether the unit was kg or grams to the .75 power (although some changes in significance level occurred).

In future studies, it seems obvious that it would be desirable to make longer, or even continuous 24 hour measurements of oxygen consumption. The intent in this study was to examine metabolic rates in a large number of animals, to find changes with diet and exercise training that could be more closely examined in future studies. Many of the manipulations in this study produced changes in body weight that could not be adequately explained by changes in food intake. In some instances, changes in metabolism were found to occur and could possible explain some of the results. In other cases, neither measure seemed adequate. The study has made a valuable contribution simply by identifying which kinds of diet and exercise manipulations are worth further study.

Using citrate synthase as an indication of changes in VO2 max is a useful technique. In both Experiments 2 and 3, the exercised animals had higher levels of citrate synthase in the gastrocnemius muscle than did sedentary animals, although the difference was significant only in Experiment 2. The nonsignificant difference in Experiment 3 may have been due to either the small sample size or to the fact that only females were exercised (although I know of no reports

of a sex difference in citrate synthase activity due to exercise). When all of the animals in Experiments 2 and 3 were pooled, citrate synthase was significantly higher in exercised animals. Thus, it seems that when tests of VO2 max cannot be made directly, measurement of citrate synthase activity can be used to assess changes in aerobic capactiy. However, since differences in VO2 max may explain some of the high variability in thermogenesis, direct or indirect measurements of it should be a part of future energy balance studies.

It is not clear that daily energy balance can be demonstrated for exercising rats. The reduced body weights seen in exercising males have not been adequately explained by changes in food consumption. In fact, the failure of most investigators to adjust food consumption for the body weight of the animals has led to a great misunderstanding of the role of food intake in accounting for the reduced body weights. The argument that exercise suppresses appetite in male rats has been made frequently (Stevenson et al., 1966;Katch et al., 1979; Dohm et al., 1977; Oscai and Holloszy 1969). The data used to suport that argument are very misleading. The belief that a rat weighing 200 grams and eating 20 grams/day of chow ard a rat weighing 400 grams and eating 20 grams/day of chow do not differ in food intake is erroneous. If one is attempting to accurately assess whether energy intake balances energy expenditure of a rat it seems critical to take into consideration the weight of

an animal when expressing both. A more accurate way of expressing both would involve a formula for weighting both intake and expenditure by both the lean body mass and adipose tissue of the animal. It is difficult to obtain accurate body composition measures for living animals and better techniques for estimation of lean body mass and body fat need to be developed. Even if is not possible to obtain good estimations of the body composition of each of the animals, it is more accurate to adjust intake for total body weight than to simply express it as total weight of food or calories eaten.

This error in interpreting data applies more to males than females, since most studies show that exercise does not reduce body weights of female rats (Oscai et al., 1971a; Oscai et al., 1973; Crews et al., 1967). Thus, in females, expressing intake as total amount eaten would not be unreasonable.

The effects of exercise on body weight and body composition found in these experiments were no different than reported by others using forced exercise (Dohm et al., 1977; Hanson et al., 1967; Oscai and Holloszy, 1979; Oscai et al., 1971a). The effects on food intake were different from those reported by most others. But, when these other studies are examined, none adjusted food intake for body weight of the animals. It is impossible to make accurate predictions of the significance of the values when adjusted for body weights of the animals, since not enought data is

reported in the papers. However, in many cases it is very likely that the pattern of results would be interpreted quite differently from the way it was originally interpreted.

In all three experiments in this study, exercise consistently resulted in an increase in food consumption when expressed as kcal of food/kg of body weight. This was true regardless of diet and sex.

Hanson et al., (1967) swam male Wistar rats for 30 minutes twice daily. They reported that exercise led to lower body weights regardless of whether animals were maintained on high or low fat diets and regardless of whether animals on each of those diets was fed ad lib or was restricted to 65% of ad lib intake. They reported no difference in caloric intakes between exercised and sedentary animals. However, they expressed caloric intakes as total kcal eaten, without adjusting the intake for the body weight of the animal. Since there was an approximate difference of 80 grams between body weights of exercised vs sedentary animals, this could reflect a higher overall intake for the exercised animals when intake was expressed as kcal/kg of body weight.

There are many other reports of the appetite suppressing effects of exercise on male rats. This result has been reported for forced swimming of 1 or 2 hours/day in male Sprague-Dawley rats (Stevenson et al., 1966), and for forced swimming of 2 hours/day in male Wistar rats (Oscai et

al., 1969). There was no appetite suppression in males which were forced to swim for 4 hours/day (Stevenson et al., 1966) or for 6 hours/day (Oscai et al., 1971a). In none of these studies was the body weights of the animals taken into consideration when expressing food intakes. From the mean food intakes and body weights for each of the groups it seems that if food intake were corrected for body weight that exercise would have increased food intake in each study. In females, exercise has been reported to increase food intakes. This is true of forced swimming of either 2 hours/day (Crews et al., 1967), or of 6 hours/day (Oscai et al., 1971a).

Forced exercise has been reported to have similar appetite suppressing effects on male rats (Thomas and Miller, 1958; Dohm et al., 1977; Katch et al., 1979; Crews et al., 1969; Nance et al., 1977). Again in all of these studies, intake was expressed only as total amount eaten, even though body weight was consistently reduced with the exercise. Again, from mean values reported for intakes and weights for the groups, it is likely that if corrected for body weight, food intake would have been found to increase with exercise. Certainly, the view that exercise has appetite suppressing effects in male rats is not accurate. With a goal in mind of explaining how the rat regulates energy balance, the effect of exercise on food intakes needs to be reexamined.

In summary, decreases in metabolic rate were found to be contributing factors to the obesity produced by giving male and female weanling rats and adult female rats a supermarket diet. Exercise was consistently found to increase metabolic rates and help prevent obesity. Male weanling rats which exercised daily did not become heavier than sedentary controls, though they were fatter, when given an obesity-producing diet. Also, when given a supermarket diet as adults, female rats which had been exercised from weaning were better able to resist body weight increases ordinarily caused by the diet.

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APPENDIX A

Analysis of Variance - Oxygen consumption (full design)

Source	df	MS	F	Prob.
Mean	1	2875.97	3932.39	0.000
Sex	1	8.17	11.18	0.002
Diet	1	4.42	6.04	0.019
Exercise	1	3.65	4.99	0.032
SD	1	3.61	4.94	0.033
SE	1	0.01	0.01	0.928
DE	1	0.00	0.01	0.942
SDE	1	0.01	0.08	0.778
Error	35	0.73		
Age	1	32.75	116.14	0.000
AS	1	0.90	3.20	0.082
AD	1	0.30	1.06	0.310
AE	1	0.23	0.80	0.377
ASD	1	0.06	0.22	0.640
ASE	1	0.00	0.00	0.969
ADE	1	0.02	0.08	0.780
ASDE	1	0.02	0.07	0.799
Error	35	0.28		
Meal	2	23.12	132.21	0.000
MS	2	0.86	4.92	0.010
MD	2	1.26	7.22	0.001
ME	2	0.03	1.68	0.193
MSD	2	0.02	1.01	0.369
MSE	2	0.04	0.26	0.776
MDE	2	0.03	0.17	0.847
MSDE	2	0.01	0.34	0.716
Error	70	0.18		
AM	2	0.65	8.47	0.001
AMS	2	0.18	2.40	0.099
AM	2	0.06	0.78	0.462
AME	2	0.03	0.45	0.640
AMSD	2	0.08	1.01	0.370
AMSE	2	0.03	0.34	0.711
AMDE	2	0.02	0.32	0.730
AMSDE	2	0.02	0.21	0.809
Error	70	0.08		

Cell means for oxygen consumption (full design) ANOVA

		Male SD-E	Male SD-S	Male LC-E	Male LC-S	Female SD-E	Female SD-S	Female LC-E	Female LC-S
46-56 Days	RMR	24.70	23.82	24.08	21.77	24.78	23.16	25.88	24.20
	DIT1	31.91	28.21	33.63	30.23	33.17	29.32	38.77	35.90
	DIT2	27.50	25.18	26.19	24.88	26.90	25.43	28.65	27.33
86-103 Days	RMR	19.02	18.33	18.64	16.76	21.02	19.33	24.83	23.46
	DIT1	23.44	22.53	25.55	23.17	27.30	23.71	33.08	31.63
	DIT2	19.92	18.99	21.25	19.06	19.62	20.56	23.01	22.42

Cell standard deviations for oxygen consumption (full design) ANOVA

46-56 Days	RMR	4.09	2.54	1.97	2.22	2.69	2.67	3.71	4.28
	DIT1	6.18	3.90	2.29	2.29	5.03	5.14	2.97	5.25
	DIT2	3.81	3.03	1.02	2.09	2.68	4.90	2.90	2.53
86-103 Days	RMR	1.44	5.30	1.15	2.12	2.00	2.55	3.68	4.08
	DIT1	1.55	4.72	1.13	2.21	4.30	5.66	3.34	6.51
	DIT2	1.45	5.25	1.72	2.15	2.39	4.64	2.66	3.92

Analysis of variance - Overall DIT

Source	df	MS	F	Prob. F exed.
Mean	1	35521.91	104.90	0.000
Sex	1	0.00	0.00	1.000
Diet	1	1408.77	4.16	0.049
Exercise	1	4.13	0.01	0.913
SD	1	116.89	0.35	0.561
SE	1	3.48	0.01	0.920
DE	1	121.17	0.36	0.554
SDE	1	0.33	0.00	0.975
Error	35	338.64		
Age	1	569.87	4.99	0.032
AS	1	622.17	5.45	0.026
AD	1	98.37	0.86	0.360
AE	1	50.38	0.44	0.511
ASD	1	204.57	1.79	0.190
ASE	1	5.57	0.05	0.827
ADE	1	34.30	0.30	0.587
ASDE	1	17.47	0.15	0.698
Error	35	114.15		

Cell means for Overall DIT ANOVA

	Male SD-E	Male SD-S	Male LC-E	Male LC-S	Female SD-E	Female SD-S	Female LC-E	Female LC-S
46-56 days	19.53	12.55	24.53	27.21	23.15	18.51	31.84	32.61
86-103 days	14.43	16.16	25.88	28.30	16.22	14.45	14.82	16.97

Cell standard deviations for Overall DIT ANOVA

	Male SD-E	Male SD-S	Male LC-E	Male LC-S	Female SD-E	Female SD-S	Female LC-E	Female LC-S
46-56 days	15.86	12.07	8.50	8.17	12.48	16.95	16.27	16.19
86-103 days	8.51	19.72	9.23	6.37	21.04	17.52	19.34	16.40

Analysis of variance - RMR

Source	df	MS	F	Prob. F exed.
Mean	1	39949.13	2912.17	0.000
Sex	1	121.75	8.87	0.005
Diet	1	9.56	0.70	0.409
Exercise	1	47.08	3.43	0.072
SD	1	68.93	5.02	0.031
SE	1	0.11	0.01	0.927
DE	1	1.76	0.13	0.722
SDE	1	2.64	0.19	0.664
Error	35	13.72		
Age	1	306.96	45.14	0.000
AS	1	47.77	7.02	0.012
AD	1	13.59	2.00	0.166
AE	1	0.25	0.04	0.850
ASD	1	8.29	1.22	0.277
ASE	1	0.04	0.01	0.936
ADE	1	0.11	0.02	0.899
ASDE	1	0.01	0.00	0.977
Error	35	6.80		

Cell means for RMR ANOVA

	Male SD-E	Male SD-S	Male LC-E	Male LC-S	Female SD-E	Female SD-S	Female LC-E	Female LC-S
46-56 days	24.71	23.82	24.08	21.77	24.79	23.16	25.88	24.20
86-103 days	19.02	18.33	18.64	16.76	21.02	19.33	24.83	23.46

Cell standard deviations for RMR ANOVA

	Male SD-E	Male SD-S	Male LC-E	Male LC-S	Female SD-E	Female SD-S	Female LC-E	Female LC-S
46-56 days	4.09	2.54	1.96	2.22	2.69	2.67	3.71	4.38
86-103 days	1.44	5.30	1.15	2.12	2.00	2.55	3.68	4.08

Analysis of variance- Total Caloric Intake

Source	df	MS	F	Prob.
Mean	1	44798454000.00	13514.47	0.000
Sex	1	7529906.00	2.27	0.138
Diet	1	158059150.00	47.68	0.000
Exercise	1	63257894.00	19.08	0.000
SD	1	15797506.00	4.77	0.034
SE	1	35118830.00	10.59	0.002
DE	1	446366.00	0.13	0.715
ASD	1	14130980.00	4.26	0.044
Error	50	3314850.00		

Cell means for total caloric intake ANOVA

	SD-E	SD-S	LC-E	LC-S
Male	30138.96	27628.55	29031.38	24169.35
Female	31347.82	29988.45	26132.31	26414.80

Cell standard deviations for caloric intake ANOVA

	SD-E	SD-S	LC-E	LC-S
Male	2018.42	3241.84	1069.99	1230.52
Female	1339.51	1288.17	558.39	2005.91

Analysis of variance- Caloric Intakes at 2 ages

Source	df	MS	F	Prob. F exed.
Mean	1	15996353000.00	11043.08	0.000
Sex	1	1935183.00	1.34	0.253
Diet	1	65525317.00	45.24	0.000
Exercise	1	25634772.00	17.70	0.000
SD	1	9337507.00	6.45	0.014
SE	1	18976594.00	13.10	0.001
DE	1	19947.00	0.01	0.907
SDE	1	5694944,00	3.93	0.053
Error	50	1448541.10		
Age	1	1152508300.00	1055.05	0.000
AS	1	29598224.00	27.10	0.000
AD	1	14328134.00	13.12	0.001
AE	1	4452167.00	4.08	0.049
ASD	1	6814884.00	6.24	0.016
ASE	1	23216915.00	21.25	0.000
ADE	1	243156.50	0.22	0.639
ASDE	1	3680871.50	3.37	0.072
Error	50	1092370.00		

Cell means for 2 levels of caloric intakes ANOVA

	Male SD-E	Male SD-S	Male LC-E	Male LC-S	Female SD-E	Female SD-S	Female LC-E	Female LC-S
46-56 days	17191.3	14863.6	16766.7	12954.3	16580.4	16081.7	12410.7	13661.1
86-103 days	8540.0	8279.3	8021.3	7346.6	10081.3	9471.1	9219.6	8547.0

Cell standard deviations for 2 levels of caloric intakes ANOVA

	Male SD-E	Male SD-S	Male LC-E	Male LC-S	Female SD-E	Female SD-S	Female LC-E	Female LC-S
46-56 days	1610.8	2950.2	1095.1	787.3	1118.7	592.7	508.9	1242.1
86-103 days	255.4	451.9	481.0	647.2	624.4	763.5	330.8	896.9

Analysis of variance - Body Weights

Source	df	MS	F	Prob. F exed.
Mean	1	8529396.40	6178.53	0.000
Sex	1	280609.31	203.27	0.000
Diet	1	17390.57	12.60	0.001
Exercise	1	20066.52	14.54	0.000
SD	1	1348.48	0.98	0.328
SE	1	5127.93	3.71	0.060
DE	1	159.97	0.12	0.735
SDE	1	402.53	0.29	0.592
Error	50	1380.49		
Age	1	644999.74	1854.35	0.000
AS	1	64102.02	184.29	0.000
AD	1	10068.76	28.95	0.000
AE	1	10344.23	29.74	0.000
ASD	1	167.98	0.48	0.490
ASE	1	3238.53	9.31	0.004
ADE	1	64.19	0.18	0.669
ASDE	1	32.91	0.09	0.760
Error	50	347.83		

Cell means for Body weight ANOVA

	Male SD-E	Male SD-S	Male LC-E	Male LC-S	Female SD-E	Female SD-S	Female LC-E	Female LC-S
46-56 days	221.00	227.25	215.60	229.75	171.75	182.14	167.11	166.14
86-103 days	402.29	472.88	369.40	437.63	286.75	314.71	240.67	255.57

Cell standard deviations for Body weight ANOVA

	Male SD-E	Male SD-S	Male LC-E	Male LC-S	Female SD-E	Female SD-S	Female LC-E	Female LC-S
46-56 days	12.79	36.58	15.42	14.61	20.62	21.09	7.62	14.10
86-103 days	25.46	62.83	32.45	38.34	25.91	42.72	15.43	27.26

Analysis of variance - LEE INDEX

Source	df	MS	F	Prob. F exed.
Mean	1	9.72618	184168.82	0.000
Sex	1	0.00160	30.32	0.000
Diet	1	0.00300	56.83	0.000
Exercise	1	0.00084	15.94	0.000
SD	1	0.00004	0.75	0.391
SE	1	0.00006	1.08	0.304
DE	1	0.00001	0.15	0.700
SDE	1	0.00011	2.04	0.159
Error	50	0.00005		
Age	1	0.00010	6.85	0.012
AS	1	0.00000	0.00	0.975
AD	1	0.00019	13.77	0.001
AE	1	0.00023	16.01	0.000
ASD	1	0.00011	7.88	0.007
ASE	1	0.00002	1.24	0.271
ADE	1	0.00000	0.12	0.734
ASDE	1	0.00002	1.34	0.253
Error	50	0.00001		

Cell means for Lee Index ANOVA

	Male SD-E	Male SD-S	Male LC-E	Male LC-S	Female SD-E	Female SD-S	Female LC-E	Female LC-S
46-56 days	.29871	.30113	.28940	.29350	.28988	.29329	.28443	.28500
86-103 days	.29814	.30663	.28640	.29888	.29325	.30286	.28071	.28325

Cell standard deviations for Lee Index ANOVA

	Male SD-E	Male SD-S	Male LC-E	Male LC-S	Female SD-E	Female SD-S	Female LC-E	Female LC-S
46-56 days	.00320	.00694	.00288	.00428	.00380	.00754	.00399	.00466
86-103 days	.00422	.00537	.00607	.00889	.00602	.01011	.00304	.00489

APPENDIX B

Analysis of Variance- Oxygen consumption (full design)

Source	df	MS	F	Prob.
Mean	1	106560.90	1881.39	0.000
Sex	1	684.68	12.09	0.001
Diet	1	208.96	3.69	0.063
Exercise	1	192.10	3.39	0.075
SD	1	142.88	2.52	0.122
SE	1	8.25	0.15	0.705
DE	1	37.66	0.66	0.421
SDE	1	0.36	0.01	0.937
Error	33	56.64		
Age	1	52.01	9.75	0.004
AS	1	0.27	0.05	0.822
AD	1	14.55	2.73	0.108
AE	1	4.94	0.93	0.343
ASD	1	2.57	0.48	0.492
ASE	1	4.02	0.75	0.392
ADE	1	14.74	2.76	0.106
ASDE	1	1.75	0.33	0.571
Error	33	5.33		
Meal	2	676.09	89.66	0.000
MS	2	31.98	4.24	0.018
MD	2	12.44	1.65	0.200
ME	2	18.22	2.42	0.097
MSD	2	13.19	1.75	0.182
MSE	2	1.20	0.16	0.853
MDE	2	0.93	0.12	0.884
MSDE	2	7.70	1.02	0.366
Error	66	7.54		
AM	1	6.43	1.33	0.270
AMS	1	0.75	0.16	0.856
AMD	1	2.50	0.52	0.597
AME	1	2.33	0.49	0.618
AMSD	1	0.22	0.05	0.955
AMSE	1	14.94	3.10	0.052
AMDE	1	2.67	0.55	0.577
AMSDE	1	1.35	0.28	0.757
Error	66	4.82		

Cell means for oxygen consumption (full design) ANOVA

	Male SD-E	Male SD-S	Male LC-E	Male LC-S	Female SD-E	Female SD-S	Female LC-E	Female LC-S
RMR	19.21	18.33	18.79	17.41	20.76	19.33	20.59	22.75
DIT1	23.66	22.53	25.51	23.64	27.92	23.71	32.11	30.19
DIT2	19.62	18.99	21.80	19.00	19.82	20.56	22.79	23.35
RMR	18.87	16.06	18.75	15.17	20.02	18.69	26.06	20.71
DIT1	22.26	21.81	24.57	21.38	25.68	24.57	30.79	26.35
DIT2	18.20	20.69	19.87	18.39	21.91	20.20	23.54	20.55

Cell standard deviations for oxygen consumption (full design) ANOVA

	Male SD-E	Male SD-S	Male LC-E	Male LC-S	Female SD-E	Female SD-S	Female LC-E	Female LC-S
RMR	0.54	5.30	1.20	2.70	2.12	2.55	2.75	3.08
DIT1	2.15	4.73	1.12	3.10	4.50	5.66	1.89	1.94
DIT2	1.51	5.25	1.47	1.80	2.62	4.65	3.16	5.80
RMR	1.59	4.89	2.63	2.55	4.03	3.52	5.62	4.65
DIT1	4.59	3.64	3.32	3.05	2.55	6.52	5.09	2.49
DIT2	1.33	4.00	2.24	3.61	0.85	6.84	2.28	3.19

Analysis of variance - Overall DIT

Source	df	MS	F	Prob. F exed.
Mean	1	25313.72	72.41	0.000
Sex	1	767.50	2.20	0.148
Diet	1	31.02	0.09	0.768
Exercise	1	770.99	2.21	0.147
SD	1	656.07	1.88	0.180
SE	1	306.64	0.88	0.356
DE	1	7.91	0.02	0.881
SDE	1	788.74	2.26	0.143
Error	33	349.58		
Age	1	400.09	1.68	0.204
AS	1	9.83	0.04	0.840
AD	1	120.43	0.51	0.482
AE	1	224.88	0.95	0.338
ASD	1	13.42	0.06	0.814
ASE	1	785.54	3.30	0.078
ADE	1	138.15	0.58	0.451
ASDE	1	1.18	0.00	0.944
Error	33	237.93		

Cell means for overall DIT ANOVA

	Male SD-E	Male SD-S	Male LC-E	Male LC-S	Female SD-E	Female SD-S	Female LC-E	Female LC-S
86-103 days	12.74	16.16	26.31	23.94	16.22	11.96	3.57	18.68
147-171 days	7.07	36.51	19.80	31.48	23.86	18.50	12.78	16.84

Cell standard deviations for overall DIT ANOVA

	Male SD-E	Male SD-S	Male LC-E	Male LC-S	Female SD-E	Female SD-S	Female LC-E	Female LC-S
86-103 days	7.68	19.72	9.05	14.04	21.04	13.42	5.51	14.68
147-171 days	7.89	19.62	19.03	10.74	32.41	14.18	10.97	21.94

Analysis of variance-RMR

Source	df	MS	F	Prob. F exed.
Mean	1	26657.41	772.55	0.000
Sex	1	599.17	17.36	0.000
Diet	1	230.01	6.67	0.014
Exercise	1	15.38	0.45	0.509
SD	1	11.79	0.34	0.563
SE	1	79.10	2.29	0.140
DE	1	126.75	3.67	0.060
SDE	1	18.97	0.55	0.464
Error	33	34.51		
Age	1	24.99	5.00	0.032
AS	1	0.59	0.12	0.734
AD	1	0.04	0.01	0.931
AE	1	7.44	1.49	0.231
ASD	1	1.15	0.23	0.634
ASE	1	1.44	0.29	0.595
ADE	1	1.61	0.32	0.574
ASDE	1	0.22	0.04	0.837
Error	33	5.00		

Cell means for RMR ANOVA

	Male SD-E	Male SD-S	Male LC-E	Male LC-S	Female SD-E	Female SD-S	Female LC-E	Female LC-S
86-103 days	12.81	18.33	18.79	17.41	20.76	19.33	26.59	22.75
147-171 days	11.99	16.06	18.75	15.17	20.02	18.69	26.06	20.71

Cell standard deviations for RMR ANOVA

	Male SD-E	Male SD-S	Male LC-E	Male LC-S	Female SD-E	Female SD-S	Female LC-E	Female LC-S
86-103 days	11.11	5.30	1.20	2.70	2.12	2.55	2.73	3.08
147-171 days	10.39	4.89	2.63	2.55	4.03	3.52	5.52	4.65

Analysis of variance - Caloric intakes

Source	df	MS	F	Prob.
Mean	1	5385879700.00	3183.33	0.000
Sex	1	55096862.00	32.73	0.000
Diet	1	45798321.00	27.21	0.000
Exercise	1	53219758.00	31.62	0.000
SD	1	15625459.00	9.28	0.005
SE	1	2932469.00	1.74	0.196
DE	1	405169.50	0.24	0.627
SDE	1	338638.00	0.20	0.657
Error	33	1683323.00		

Cell means for total caloric intakes ANOVA

	SD-E	SD-S	LC-E	LC-S
Male	11088.00	9650.56	12416.34	10176.25
Female	12986.53	10037.72	16535.45	13550.65

Cell standard deviations for total caloric intakes ANOVA

	SD-E	SD-S	LC-E	LC-S
Male	201.53	949.78	227.04	228.16
Female	2524.01	1513.57	136.65	1502.76

Analysis of variance - Body weights

Source	df	MS	F	Prob.
Mean	1	11549631.00	1583.54	0.000
Sex	1	515685.30	70.70	0.000
Diet	1	36228.11	4.97	0.033
Exercise	1	74303.25	10.19	0.003
SD	1	2854.35	0.39	0.536
SE	1	52696.47	7.23	0.011
DE	1	5818.46	0.80	0.378
SDE	1	471.78	0.06	0.801
Error	33	7293.53		
Age	1	32381.13	144.65	0.000
AS	1	8000.86	35.74	0.000
AD	1	6244.92	27.90	0.000
AE	1	540.88	2.42	0.129
ASD	1	10.40	0.05	0.831
ASE	1	1381.55	6.17	0.018
ADE	1	2444.79	10.92	0.002
ASDE	1	1.21	0.01	0.942
Error	33	223.85		

Cell means for Body weights ANOVA

	Male SD-E	Male SD-S	Male LC-E	Male LC-S	Female SD-E	Female SD-S	Female LC-E	Female LC-S
86-103 days	424.67	515.86	363.00	476.14	330.60	342.33	255.25	269.86
147-171 days	465.67	561.43	418.67	583.14	348.40	331.33	285.75	316.29

Cell standard deviations for Body weights ANOVA

	Male SD-E	Male SD-S	Male LC-E	Male LC-S	Female SD-E	Female SD-S	Female LC-E	Female LC-S
86-103 days	22.19	72.67	25.24	38.17	110.51	48.22	24.72	28.77
147-171 days	12.86	87.12	11.06	53.54	128.26	34.36	31.63	35.59

Analysis of variance - Lee Index

Source	df	MS	F	Prob. F exed.
Mean	1	5.73960	67414.29	0.000
Sex	1	0.00068	7.99	0.008
Diet	1	0.00150	17.66	0.000
Exercise	1	0.00109	12.85	0.001
SD	1	0.00008	0.96	0.336
SE	1	0.00011	1.25	0.273
DE	1	0.00000	0.01	0.938
SDE	1	0.00004	0.45	0.509
Error	32	0.00009		
Age	1	0.00010	5.90	0.021
AS	1	0.00000	0.06	0.806
AD	1	0.00029	16.64	0.000
AE	1	0.00000	0.12	0.736
ASD	1	0.00000	0.11	0.738
ASE	1	0.00001	0.72	0.404
ADE	1	0.00001	0.42	0.523
ASDE	1	0.00001	0.76	0.389
Error	32	0.00002		

Cell means for Lee Index ANOVA

	Male SD-E	Male SD-S	Male LC-E	Male LC-S	Female SD-E	Female SD-S	Female LC-E	Female LC-S
86-103 days	.29800	.30650	.28467	.29629	.29300	.30300	.28075	.28429
147-171 days	.29050	.30050	.28667	.29886	.28920	.29367	.28150	.28571

Cell standard deviations for Lee Index ANOVA

	Male SD-E	Male SD-S	Male LC-E	Male LC-S	Female SD-E	Female SD-S	Female LC-E	Female LC-S
86-103 days	.00424	.00509	.00513	.00774	.00851	.01106	.00427	.00522
147-171 days	.00071	.00493	.00513	.00590	.01207	.00745	.00507	.00692

Analysis of variance - Citrate synthase

Source	df	MS	F	Prob.
Mean	1	8255.65	724.69	0.000
Sex	1	10.95	0.96	0.335
Diet	1	22.80	2.00	0.168
Exercise	1	107.85	9.47	0.005
SD	1	0.44	0.04	0.846
SE	1	3.92	0.34	0.562
DE	1	2.16	0.19	0.667
SDE	1	38.01	3.34	0.078
Error	29	11.39		

Cell means for citrate synthase ANOVA

	SD-E	SD-S	LC-E	LC-S
Male	18.70	17.20	22.80	17.50
Female	20.93	12.83	19.50	17.59

Cell standard deviations for citrate synthase ANOVA

	SD-E	SD-S	LC-E	LC-S
Male	.00	5.80	2.40	1.42
Female	4.48	3.19	0.84	2.28

APPENDIX C

Analysis of variance - Oxygen consumption (females)

Source	df	MS	F	Prob.
Mean	1	72877.23	2353.96	0.000
Diet	1	137.01	4.43	0.050
Exercise	1	211.61	6.84	0.018
DE	1	4.00	0.13	0.723
Error	18	30.96		
Age	1	320.19	36.67	0.000
AD	1	79.15	9.06	0.008
AE	1	14.96	1.71	0.207
ADE	1	9.66	1.11	0.307
Error	18	8.73		
Meal	2	601.35	68.38	0.000
MD	2	17.84	2.03	0.146
ME	2	0.17	0.02	0.980
MDE	2	33.85	3.85	0.031
Error	36	8.79		
AM	2	12.77	1.40	0.260
AMD	2	0.84	0.09	0.912
AME	2	0.46	0.05	0.951
AMDE	2	1.93	0.21	0.811
Error	36	9.14		

Cell means for oxygen consumption- full design (females)

		SD Exercised	SD Sedentary	Lab chow Exercised	Lab chow Sedentary
87-103 days	RMR	22.79	22.50	26.59	22.75
	DIT1	31.79	30.38	32.11	30.19
	DIT2	25.98	21.28	22.79	23.35
141-171 days	RMR	18.77	18.07	26.06	20.71
	DIT1	25.89	23.37	30.79	26.35
	DIT2	21.77	17.77	23.54	20.55

Cell standard deviations for oxygen consumption- full design (females)

		SD Exercised	SD Sedentary	Lab chow Exercised	Lab chow Sedentary
87-103 days	RMR	5.50	3.51	2.75	3.08
	DIT1	0.72	6.43	1.89	1.94
	DIT2	1.50	2.12	3.16	5.80
141-171 days	RMR	1.43	3.40	5.62	4.65
	DIT1	2.63	1.87	5.09	2.49
	DIT2	1.57	2.09	2.28	3.19

Analysis of variance - Overall DIT (females)

Source	df	MS	F	Prob.
Mean	1	12237.31	40.83	0.000
Diet	1	1217.23	4.06	0.059
Exercise	1	6.98	0.02	0.880
DE	1	1619.65	5.40	0.032
Error	18	299.70		
Age	1	1.37	0.00	0.947
AD	1	34.98	0.11	0.739
AE	1	1.40	0.00	0.947
ADE	1	88.47	0.29	0.597
Error	18	305.41		

Cell means for Overall DIT (females)

	SD Exercised	SD Sedentary	Lab chow Exercised	Lab chow Sedentary
104 days	31.92	15.90	3.57	18.68
171 days	27.12	16.26	8.38	16.84

Cell standard deviations for Overall DIT (females)

	SD Exercised	SD Sedentary	Lab chow Exercised	Lab chow Sedentary
104 days	28.96	13.24	5.52	14.68
171 days	7.28	17.56	18.65	21.94

Analysis of variance - RMR (females)

Source	df	MS	F	Prob.
Mean	1	20219.28	1003.62	0.000
Diet	1	124.41	6.18	0.023
Exercise	1	65.78	3.27	0.088
DE	1	42.81	2.12	0.162
Error	18	20.15		
Age	1	77.06	7.61	0.013
AD	1	21.98	2.17	0.158
AE	1	2.38	0.23	0.634
ADE	1	0.78	0.08	0.785
Error	18	10.12		

Cell means for RMR (females)

	SD Exercised	SD Sedentary	Lab chow Exercised	Lab chow Sedentary
104 days	22.79	22.50	26.59	22.75
171 days	18.77	18.07	26.06	20.71

Cell standard deviations for RMR (females)

	SD Exercised	SD Sedentary	Lab chow Exercised	Lab chow Sedentary
104 days	5.50	3.51	2.75	3.08
171 days	1.43	3.40	5.62	4.65

Analysis of variance - Caloric intakes (females)

Source	df	MS	F	Prob.
Mean	1	2456351400.00	1568.80	0.000
Diet	1	7392278.50	4.72	0.043
Exercise	1	8147049.50	5.20	0.035
DE	1	729469.00	0.47	0.505
Error	18	1565748.90		

Cell means for total caloric intakes (females)

SD Exercised	SD Sedentary	Lab chow Exercised	Lab chow Sedentary
12028.67	11142.17	11202.19	9558.62

Cell standard deviations for total caloric intakes (females)

SD Exercised	SD Sedentary	Lab chow Exercised	Lab chow Sedentary
1778.81	1309.69	137.12	1179.19

Analysis of variance - Body weight (females)

Source	df	MS	F	Prob.
Mean	1	3477243.70	1441.64	0.000
Diet	1	1453.12	0.60	0.448
Exercise	1	15800.12	6.55	0.020
DE	1	1392.94	0.58	0.457
Error	18	2412.00		
Age	1	37202.03	58.36	0.000
AD	1	2796.05	4.39	0.050
AE	1	5478.57	8.59	0.009
ADE	1	375.32	0.59	0.453
Error	18	637.47		

Cell means for body weights (females)

	SD Exercised	SD Sedentary	Lab chow Exercised	Lab chow Sedentary
104 days	248.75	270.57	259.00	269.57
171 days	290.50	376.86	285.75	330.57

Cell standard deviations for body weights (females)

	SD Exercised	SD Sedentary	Lab chow Exercised	Lab chow Sedentary
104 days	21.93	23.00	24.62	27.41
171 days	30.65	60.57	31.63	51.83

Analysis of variance - Lee Index (females)

Source	df	MS	F	Prob.
Mean	1	3.32478	38316.78	0.000
Diet	1	0.00029	3.31	0.085
Exercise	1	0.00084	9.64	0.006
DE	1	0.00027	3.16	0.092
Error	18	0.00009		
Age	1	0.00055	31.80	0.000
AD	1	0.00040	23.05	0.000
AE	1	0.00006	3.57	0.075
ADE	1	0.00005	2.65	0.121
Error	18	0.00002		

Cell means for Lee Index (females)

	SD Exercised	SD Sedentary	Lab chow Exercised	Lab chow Sedentary
104 days	.27675	.28643	.28075	.28429
171 days	.28575	.30457	.28150	.28571

Cell standard deviations for Lee Index (females)

	SD Exercised	SD Sedentary	Lab chow Exercised	Lab chow Sedentary
104 days	.00785	.00500	.00427	.00522
171 days	.00395	.01230	.00507	.00692

Analysis of variance - Citrate synthase (females)

Source	df	MS	F	Prob.
Mean	1	6901.67	634.05	0.000
Diet	1	0.36	0.03	0.858
Exercise	1	8.67	0.80	0.384
DE	1	1.89	0.17	0.682
Error	18	10.89		

Cell means for Citrate synthase (females)

SD Exercised	SD Sedentary	Lab chow Exercised	Lab chow Sedentary
18.63	17.93	19.50	17.59

Cell standard deviations for citrate synthase (females)

SD Exercised	SD Sedentary	Lab chow Exercised	Lab chow Sedentary
4.13	4.31	0.84	2.28

Analysis of variance - Oxygen consumption (sedentary)

Source	df	MS	F	Prob.
Mean	1	73141.24	2232.82	0.000
Sex	1	528.94	16.15	0.001
Diet	1	12.52	0.38	0.542
SD	1	57.93	1.77	0.197
Error	23	32.76		
Age	1	270.42	24.07	0.000
AS	1	73.24	6.52	0.018
AD	1	3.44	0.31	0.585
ASD	1	23.00	2.05	0.166
Error	23	11.23		
Meal	2	571.56	111.39	0.000
MS	2	45.11	8.79	0.001
MD	2	1.49	0.29	0.749
MSD	2	3.65	0.71	0.496
Error	46	5.13		
AM	2	27.81	4.13	0.022
AMS	2	1.97	0.29	0.748
AMD	2	7.66	1.14	0.329
AMSD	2	1.56	0.23	0.794
Error	46	6.71		

Cell means for oxygen consumption-full design (sedentary)

		Male SD	Female SD	Male Lab chow	Female Lab chow
87-103 days	RMR	17.45	22.50	17.41	22.75
	DIT1	24.21	30.38	23.64	30.19
	DIT2	18.93	21.28	19.00	23.35
147-171 days	RMR	17.33	18.07	15.17	20.71
	DIT1	20.60	23.37	21.38	26.35
	DIT2	20.32	17.77	18.39	20.55

Standard deviations for oxygen consumption-full design (sedentary)

		Male SD	Female SD	Male Lab chow	Female Lab chow
87-103 days	RMR	3.24	3.51	2.70	3.08
	DIT1	2.03	6.43	3.10	1.94
	DIT2	1.69	2.12	1.80	5.80
147-171 days	RMR	3.37	3.40	2.55	4.65
	DIT1	4.24	1.87	3.05	2.48
	DIT2	3.31	2.09	3.61	3.19

Analysis of Variance - Overall DIT (sedentary)

Source	df	MS	F	Prob.
Mean	1	23722.81	110.69	0.000
Sex	1	987.76	4.19	0.052
Diet	1	160.95	0.75	0.395
SD	1	42.68	0.20	0.660
Error	23	214.32		
Age	1	0.76	0.00	0.958
AS	1	3.37	0.01	0.912
AD	1	128.81	0.48	0.494
ASD	1	235.97	0.88	0.397
Error	23	267.11		

Cell means for overall DIT (sedentary)

	Male SD	Male Lab chow	Female SD	Female Lab chow
87-103 days	25.98	23.94	15.90	18.68
147-171 days	18.96	31.49	16.26	16.84

Cell standard deviations for overall DIT (sedentary)

	Male SD	Male Lab chow	Female SD	Female Lab chow
87-103 days	16.75	14.04	13.24	14.67
147-171 days	11.93	10.74	17.56	21.94

Analysis of Variance - RMR - (sedentary)

Source	df	MS	F	Prob.
Mean	1	19254.23	1219.55	0.000
Sex	1	233.83	14.81	0.001
Doet	1	0.40	0.03	0.875
SD	1	21.77	1.38	0.252
Error	23	15.79		
Age	1	65.41	9.46	0.005
AS	1	14.20	2.05	0.165
AD	1	0.06	0.01	0.928
ASD	1	17.08	2.47	0.130
Error	23	6.91		

Cell means for RMR (sedentary)

	Male SD	Male Lab chow	Female SD	Female Lab chow
87-103 days	17.45	17.41	22.50	22.75
147-171 days	17.33	15.17	18.07	20.71

Cell standard deviations for RMR (sedentary)

	Male SD	Male Lab chow	Female SD	Female Lab chow
87-103 days	3.24	2.70	3.51	3.08
147-171 days	3.37	2.55	3.41	4.65

Analysis of variance - Caloric intakes (sedentary)

Source	df	MS	F	Prob.
Mean	1	2096261700.00	2344.08	0.000
Sex	1	56359700.00	63.02	0.000
Diet	1	8546929.00	9.56	0.005
SD	1	658016.30	0.74	0.400
Error	23	894277.38		

Cell means for total caloric intake (sedentary)

Male SD	Male Lab chow	Female SD	Female Lab chow
7790.39	6975.54	10999.31	9558.62

Cell standard deviations for total caloric intake (sedentary)

SD	Lab chow	SD	Lab chow
557.22	201.66	1318.39	1179.19

Analysis of variance - Body weights (sedentary)

Source	df	MS	F	Prob.
Mean	1	9746473.60	2604.33	0.000
Sex	1	697388.73	186.35	0.000
Diet	1	5226.65	1.40	0.249
SD	1	206.80	0.06	0.816
Error	23	3742.42		
Age	1	135634.83	196.67	0.000
AS	1	3800.30	5.51	0.028
AD	1	4650.30	6.74	0.016
ASD	1	219.54	0.32	0.578
Error	23	689.65		

Cell means for body weights (sedentary)

	Male SD	Male Lab chow	Female SD	Female Lab chow
104 days	481.67	480.43	270.57	269.57
171 days	613.50	583.14	376.86	330.57

Cell standard deviations for body weights (sedentary)

	Male SD	Male Lab chow	Female SD	Female Lab chow
104 days	43.23	36.53	23.00	27.41
171 days	65.69	53.54	60.57	51.83

Analysis of Variance - Lee Index (sedentary)

Source	df	MS	F	Prob.
Mean	1	4.68829	47024.04	0.000
Sex	1	0.00138	13.80	0.001
Diet	1	0.00087	8.73	0.007
SD	1	0.00008	0.81	0.377
Error	23	0.00010		
Age	1	0.00062	31.76	0.000
AS	1	0.00012	6.21	0.020
AD	1	0.00031	15.80	0.001
ASD	1	0.00017	8.80	0.007
Error	23	0.00002		

Cell means for Lee Index (sedentary)

	Male SD	Male Lab chow	Female SD	Female Lab chow
104 days	.30067	.29629	.28643	.28429
171 days	.30567	.29886	.30457	.28571

Cell standard deviations for Lee Index (sedentary)

	Male SD	Male Lab chow	Female SD	Female Lab chow
104 days	.00812	.00774	.00500	.00522
171 days	.00819	.00590	.01230	.00692

Analysis of variance - Citrate synthase (sedentary)

Source	df	MS	F	Prob.
Mean	1	8311.13	707.95	0.000
Sex	1	0.73	0.06	0.806
Diet	1	3.77	0.32	0.576
SD	1	1.23	0.10	0.750
Error	22	11.74		

Cell means for citrate synthase (sedentary)

Male SD	Male Lab chow	Female SD	Female Lab chow
18.70	17.50	17.93	17.60

Cell standard deviations for citrate synthase (sedentary)

SD	Lab chow	SD	Lab chow
4.55	1.42	4.30	2.50