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The effects of strenuous maternal exercise during gestation on maternal body components in rats

M. F. MOTTOLA, K. M. BAGNALL, A. N. BELCASTRO*, J. FOSTER AND D. SECORD†.

*Department of Anatomy, * Department of Physical Education and Sports Studies and † Department of Surgery, The University of Alberta, Edmonton, Alberta, Canada T6G 2E3*

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INTRODUCTION

Society today emphasises the beneficial aspects of exercise and fitness. This attitude has progressively expanded to include the pregnant woman within its influential realm, with many magazines and books available to the general public promoting exercise during pregnancy. Unfortunately, advice concerning maternal exercise is usually limited to vague generalisations to avoid excessive fatigue, advice which substitutes for valid scientific observations (Cumming & Belcastro, 1982). Published work reveals little conclusive information about the effects of exercise on the pregnant woman and/or the developing fetus. To substantiate guidelines for women who wish to exercise during pregnancy, scientific observations are needed in human research as well as observations using animal models (Longo, 1985; Clapp, 1985).

This project was designed to examine the effects of strenuous maternal exercise during gestation on the gross anatomy of the maternal rat. The following parameters were selected to monitor these effects.

(1) Daily maternal weight gain during pregnancy.

(2) Maternal postpartum weight (within 20 hours after parturition).

(3) Maternal postpartum skin weight (including subcutaneous fat and mammary glands) and the remaining maternal body weight.

In addition, the weights and number of newborn (within 20 hours of birth) rat pups were noted to identify contributions to any maternal weight changes.

MATERIAL AND METHODS

Young female Sprague–Dawley rats (Biosciences – University of Alberta), approximately 50 days of age, were used for study (n = 30). The young female rats were weighed daily on an animal balance accurate to the nearest 0·1 g and randomly housed two per cage. Food and water were supplied *ad libitum*. Daylight was controlled and included twelve hours of light (7 pm–7 am) and twelve hours of darkness (7 am–7 pm). Room temperature was maintained at 72 ± 2 °F. Humidity was maintained between 45 and 55 %.

All the young female rats were conditioned to run on a motor driven treadmill by the use of a progressive running programme of two weeks duration. The protocol for progressive treadmill running was based on the progression schedules for rats used by Brooks & White (1978), Bedford *et al.* (1979), Davies, Parker & Brooks (1981),

and Brooks & Donovan (1983). At the end of the two week programme the rats were capable of running at 30 metres/minute, on a 10° incline, for 120 minutes/day, 5 days/week. Bedford *et al.* (1979) reported that in non-pregnant Sprague–Dawley rats this intensity of treadmill running elicited values greater than 80% maximum oxygen consumption. On this basis, the exercise level was defined as strenuous.

A record was kept of the running behaviour of each rat. If a rat required constant coaxing or was injured, it was removed from the study. The final attrition rate was 20% which eventually reduced the final number of rats to eight per group. The rats ran during their dark cycle, as rats are nocturnal animals and physically active at night.

At the end of the two weeks progressive exercise programme (as soon as the last exercise bout was completed), the rats were paired by weight. The paired non-pregnant female rats were randomly selected by ear code identification to fulfil one of two experimental conditions: (1) a pregnant group that continued the strenuous running programme throughout gestation (pregnant runner – PR), or (2) a pregnant group that did not continue the running programme during pregnancy (pregnant control – PC).

The remaining non-pregnant rats continued the same strenuous running programme as the PR group for the same length of time, but were not allowed to become pregnant (non-pregnant runner – NPR). The rats in the NPR group were randomly housed two per cage.

After identification of the appropriate groups, a male rat was introduced into the cages housing the paired female rats (PR and PC). The trios lived together until the females reached a weight of 300 g and exhibited definite abdominal swelling. The pregnant females were then housed separately to eliminate mixing of the forthcoming litters. The separations occurred at approximately Day 15, the beginning of the last third of pregnancy (gestation is about 21 days according to Baker, Lindsey & Weisbroth, 1979.)

Again, a rat running behaviour chart was kept for the two running groups (PR and NPR). The PC group was removed from food, water and the influence of the male during the PR and NPR daily 120 minutes run, 5 days/week. The additional 120 minutes of food and water available to the PC group may have influenced body weight gain during pregnancy. Therefore, this variable was eliminated.

As soon after birth as possible, within a maximum of 20 hours (depending upon when birth occurred), the number of newborn rats per litter and gross body weight of each pup was recorded. At this time the newborns were also examined for superficial gross abnormalities.

The postpartum weight values of the maternal rats (PC and PR) were recorded as soon after parturition as possible (again within 20 hours). After the postpartum weighing, the maternal rats were killed using an ether overdose. A midline ventral incision was made through the skin and subcutaneous tissue using sharp scissors. Care was taken not to disrupt the muscular tissue found deep to the subcutaneous tissue. The skin, subcutaneous fat and mammary tissue were then carefully dissected away from the muscle on the ventral aspect of the animal using a blunt 'close–open' scissor technique. Care was taken not to damage the large vessels in the neck region. A small amount of blood was lost when the vessels to the mammary glands were cut. A superficial incision was made around each limb immediately superior to the ankle joint. A longitudinal superficial cut through skin and subcutaneous tissue joined the incision to the ventral midline cut. Again, care was taken not to disturb any of the

underlying muscular tissue. A circular superficial cut was made around the base of the tail and around the urogenital and rectal region. The rat was then placed in a prone position and the same blunt dissection technique was used to remove the skin and subcutaneous tissue. The subscapular fat pad was included with the skin and subcutaneous tissue. In the head region, the ears were cut near the base and included with the skin portion. The skin was gently pulled over the head and removed from the body by a cut made at the end of the nose.

The skin (which included subcutaneous tissue and mammary gland) was then weighed immediately on a digital balance to the nearest 0·1 g. The scale was cleaned after each weighing and returned to zero. The remainder of the carcass (including the tail) was also weighed to the nearest 0·1 g and both weights were recorded. The same postmortem procedure was used to determine skin weight and carcass remainder weight values for the NPR group at this time. A one-way analysis of variance (ANOVA; Avner, 1980) was performed on each of the following sets of data.

(1) The weight of the female rats on the day of conception (PC andPR) and the NPR at this time.

(2) The cumulative weight gained each day during pregnancy for the PC and PR groups of rats, also including the NPR group at this time.

(3) The last recorded pregnancy weight values before giving birth in the PC and PR rats, as well as the NPR group at this time.

(4) The postpartum weight values for the PC and PR groups, also including the NPR group at this time.

(5) The skin component weight values of the PC, PR and NPR rats.

(6) The carcass remainder weight values of the PC, PR and NPR rats.

The average weight values of each litter, the average number of neonates per litter and average total litter weight values of the newborns born to the PC and PR rats were compared using a paired Student's t test (Avner, 1980). Significance for all statistical tests was accepted at the $P < 0{\cdot}05$ level. *Post hoc* analysis (Scheffé & Neumann–Keul Multiple Range test) was performed on significant ANOVA results.

RESULTS

Table 1 presents the neonatal data found for groups PC and PR. No significant differences were found between the two groups with regard to average neonatal weight (g), number per litter, or total litter weight (g; $P > 0{\cdot}05$). The PC group had an average of 2 pups more per litter than the PR group but this value was not sufficiently large to be significant.

Table 1. *The average newborn weight values, the average number of newborn animals per litter and the total litter weight values found for both the PC and PR groups. (Values in parentheses represent one standard deviation.)*

Group	Number per litter	Newborn weight (g)	Total litter weight (g)
PC	11·6 (2·5)	6·8 (0·6)	78·2 (16·4)
PR	9·7 (1·7)	6·9 (0·7)	65·9 (10·9)

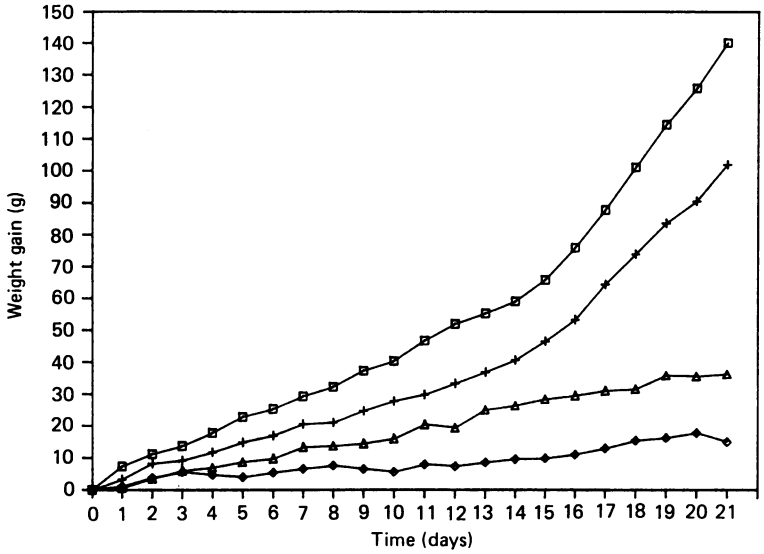

Fig. 1. The average cumulative weight gain values for PC, PR, NPR and C groups. See text for explanation. □, PC; +, PR; ◇, NPR; △, C.

The average cumulative amount of weight gained during pregnancy for both the PC and PR groups is plotted in Figure 1. A significant difference was found between these two groups on Day 5 of pregnancy ($P < 0{\cdot}05$). This significant difference in weight gained continued throughout the remainder of gestation. On the final day of pregnancy the PC group gained approximately 38·1 g more ($P < 0{\cdot}05$) than the PR group. Figure 1 also shows the weight gained during this same 21 day period for the non-pregnant (NPR) group of rats. The average weight gain values for normal non-pregnant Sprague–Dawley rats, from Biosciences – University of Alberta (labelled C, or control, in Fig. 1), are also included in Figure 1 for comparison. By Day 21, the C group gained 21·2 g more weight ($P < 0{\cdot}05$) than the NPR rats. A significant difference was found between the two non-pregnant groups on Day 11 of the 21 day period and this difference continued for the remainder of the experiment.

Table 2 shows the average postpartum weight values for the PC and PR groups and the average weight values for the NPR group on Day 22. Of particular interest is the fact that no significant difference was found between the average postpartum weight values for the PR group (257·6 g) and the average weight on Day 22 for the non-pregnant NPR group (252·2 g), even though the PR group had just given birth. By contrast, the PC group (282·7 g), which had also just given birth, had a significantly heavier average postpartum weight value when compared to both the PR (25·1 g) and the non-pregnant NPR (30·5 g) groups ($P < 0{\cdot}05$).

The results of the body component analysis (Table 2) indicated that the PC group had significantly more (10·5 g) skin, which included subcutaneous fat and mammary tissue, than the PR group ($P < 0{\cdot}05$). The average value for the remainder of the carcass was found to be significantly greater (15·7 g) in the PC group when compared to the PR group ($P < 0{\cdot}05$). In comparing the results with the NPR group, it can be seen (Table 2) that the PR group had an average of 6·1 g more skin component, but this difference was not sufficiently large to be significant ($P > 0{\cdot}05$). The PC group, however, had an average value of 16·6 g more skin component than the non-pregnant

Table 2. *Average body component analysis. (The values in parentheses represent one standard deviation.)*

Group	Postpartum (g)	Skin (g)	Remainder (g)
PC	282·7 (13·1)‖¶	53·6 (6·9)*‡	227·5 (08·9)†§
PR	257·6 (12·4)‖	43·1 (5·1)*	211·8 (10·0)†
NPR (22 days)	252·2 (11·5)¶	37·0 (3·7)‡	213·5 (08·2)§

Significance: * $P < 0{\cdot}05$; † $P < 0{\cdot}05$; ‡ $P < 0{\cdot}05$; ‖ $P < 0{\cdot}05$; § $P < 0{\cdot}05$; ¶ $P < 0{\cdot}05$.

NPR group and this was sufficiently large to be significant ($P < 0{\cdot}05$). The average weight found for the remainder of the carcass was almost identical in the PR (211.8 g) and NPR (213·5 g) groups, while the PC group (227·5 g) had an average significant value of 14·0 g more than the NPR group ($P < 0{\cdot}05$).

DISCUSSION

Maternal exercise of this intensity did not appear to affect newborn weight or number in Sprague–Dawley rats. These results agreed with other reports published from the authors' laboratory using mild and moderate exercise intensities (Bagnall, Mottola & McFadden, 1983; Mottola, Bagnall & McFadden, 1983) and also with other authors who have used rats (Parizkova, 1975; Wilson & Gisolfi, 1980), mice (Terada, 1974), ewes (Orr *et al.* 1972; Curet, Orr, Rankin & Ungerer, 1976; Clapp, 1978, 1980; Chandler & Bell, 1981; Lotgering, Gilbert & Longo, 1983*a*, *b*), goats (Hohimer, Bissonnette, Metcalfe & McKean, 1984) and guinea-pigs (Gilbert, Cummings, Juchau & Longo, 1979). These results are in contrast to those of some workers who have found effects on fetal development using guinea-pigs (Gilbert *et al.* 1981; Nelson, Gilbert & Longo, 1983), ewes (Emmanouilides, Hobel, Yashiro & Klyman, 1972; Longo, Hewitt, Lorijn & Gilbert, 1978) and goats (Dhindsa, Metcalfe & Hummels, 1978). These contrasting results on the effects of maternal exercise on the fetus are confusing but may have been due to differences in the intensity of the maternal exercise, whether the animal was familiarised to treadmill running before pregnancy, or to species differences.

The maternal results of the present study support similar research reporting on maternal effects of exercise. Wilson & Gisolfi (1980) reported a significant decrease in maternal weight gain values during pregnancy in their trained (seven weeks pre-pregnancy training) pregnant rats that ran throughout pregnancy. By the end of gestation these trained pregnant rats weighed 47 g less than the pregnant control group. Terada (1974) showed that pregnant mice exercised during pregnancy also weigh significantly less than controls. He attributed the decreased maternal body weight gain to a disturbance in caloric intake by diminished food and water consumption in the pregnant running group. This decrease in body weight gain may also be seen in the non-pregnant (NPR) group of the present study, when weight gain values are compared to normal growth curves for non-pregnant female Sprague–Dawley rats of the same age (Biosciences – University of Alberta). A significant decrease in weight gain is found by the eleventh day in the NPR group and this difference continues throughout the running programme.

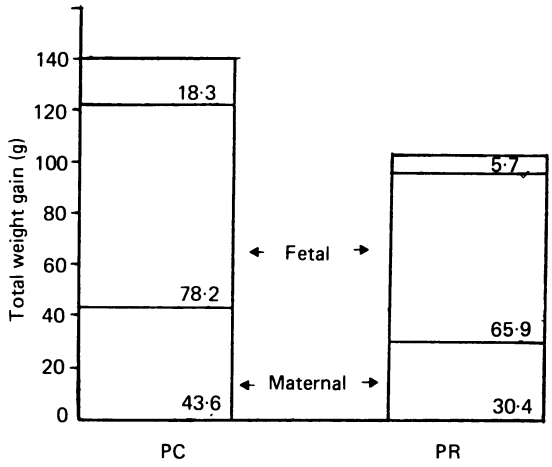

Fig. 2. The average maternal body component analysis of total pregnancy weight gain values.

The significant difference found in the latter stages of pregnancy between the PC and PR groups (38·1 g on the last day of pregnancy), with regard to the amount of weight gained during gestation, is important. This amount of weight gained during pregnancy by the maternal rats can be divided into the following components (Fig. 2).

(1) A *maternal* component (average postpartum weight minus average weight on the day of conception) which includes possible changes in the weight of the uterus, blood volume, extravascular and extracellular water, and an increased deposition of maternal fat (Martin, 1980). The placenta, amniotic membranes, and part of the umbilical cord would also be included in this component because the maternal rat ingests these tissues after giving birth.

(2) A *fetal* component represented by the average total litter weight value for each group. This component would also include a small (and probably insignificant) part of the umbilical cord which remains on the neonate at birth.

(3) A *remnant* component which would include those tissues expelled from the uterus with the conceptus but not ingested by the maternal rat, and/or maternal tissues lost at birth. This third component may include amniotic fluid from the conceptus and may also be composed of maternal blood and fluid loss that normally occurs during parturition.

By dividing the maternal data at the end of gestation into these three components, it can be seen from Figure 2 that proportionately the PR group had a significantly smaller maternal component (30·4 g) than the PC group (43·6 g; $P < 0·05$). In contrast, the fetal components were similar. From the data, it would appear that the fetuses are somehow spared from the effects of the maternal exercise at the expense of the maternal system. The rest of the discussion will therefore concentrate on these maternal alterations.

The difference in the maternal component (Fig. 2) between the PC and PR groups could be due to a number of factors which were not measured but might be considered in the future. Lederman & Rosso (1981) analysed the average carcass composition of pregnant (minus the conceptus) and non-pregnant rats on Day 21 of pregnancy. They reported that normally on Day 21, the major difference in the

maternal component is weight gained due to fat and water retention. It is entirely possible that the PR group of the present study may be deficient in either of these components.

To analyse the maternal component in this study, one step further, the postpartum body components are presented in Figure 3. The skin component included skin (plus fur), subcutaneous tissue, fat (including subscapular fat, an important large fat storage area in the rat: Galletti & Klopper, 1964) and mammary tissue. The subscapular fat depot is an important consideration as it has been shown to increase significantly during pregnancy in rats (*Nutrition Reviews*, 1981). The carcass remainder component consisted mainly of muscle tissue, bone tissue, abdominal contents, thoracic contents, internal fat deposits and tail.

In comparing the skin component values (Fig. 3), it is interesting to note that the PC group has 10·5 g more of the skin component (a significant difference; $P < 0{\cdot}05$) than the PR group, although both groups had just given birth. It seems reasonable to suggest that the PR group did not deposit as much fat subcutaneously as the PC group. Terada (1974) found similar results in mice and suggested that food and water ingestion may have been suppressed by the exercise. Another explanation may be a diminished deposit of maternal subcutaneous fat due to the maternal exercise, because training has been shown to enhance lipid oxidation (Divine-Patch & Brooks, 1980), which reduces body fat stores in female rats (Pitts, 1984). Another possible explanation for this significant difference may be due to an underdevelopment of the glandular tissue of the mammary gland in the PR group as the rate of lipid synthesis in the lactating mammary gland of the rat is very sensitive to the amount of food consumed and the amount of substrate available (Williamson, Munday & Jones, 1984). It has also been found that normal mammary epithelium is dependent upon an adequate mammary fat pad in mice (Shyamala & Ferenczy, 1984). If the reduction in the skin component found in the PR group is due to an insufficient storage of maternal adipose tissue or underdeveloped mammary glands, then perhaps an inadequate amount of milk production to feed the nursing neonates may eventually result. This might then explain the findings of Wilson & Gisolfi (1980) who reported a significantly higher number of neonatal deaths (in the 28 days following birth) attributable to maternal neglect and maternal cannibalism in their trained maternal rats, who also ran during pregnancy. In the present study, no maternal neglect was observed, but, had the neonates not been killed within 20 hours of birth, perhaps the maternal neglect and the cannibalism seen in Wilson & Gisolfi's (1980) study would also have been observed here. Maternal postpartum body component analysis in running animals and its effect on neonatal nutrition needs further investigation.

A significant difference of 15·7 g was also found between the PC and PR groups (Fig. 3) in the average carcass remainder weight values. This difference could be due to a number of factors. For example, the PC group had on average two more fetuses per litter than the PR group and this may constitute a heavier uterus in the PC group, although the difference (if any) would presumably be quite small. Another possibility centres on the fact that upon parturition maternal rats ingest the placenta of each fetus, and again on average, the PC group may have eaten two more placentas than the PR group. However, the actual difference would be small as the average placental weight is only in the region of 0·5 g (Petropoulos, 1973). It is possible that placental weights were smaller in the exercised groups as several authors have found smaller placental weights in their exercised groups than in control groups (Gilbert,

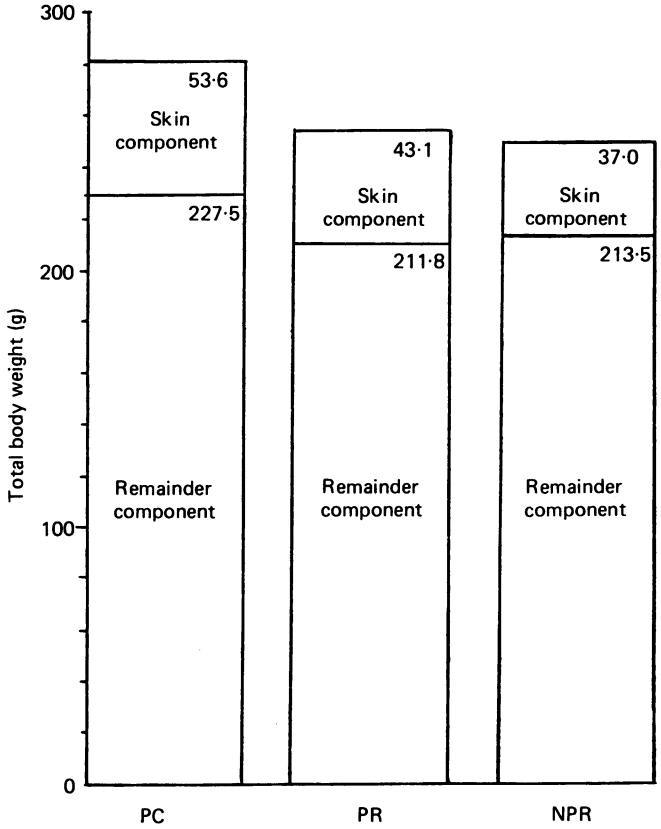

Fig. 3. The body component values for the maternal rats (PC and PR) compared to the NPR rats.

Nelson & Longo, 1981; Nelson *et al.* 1983). However, smaller placental weights were also found concomitantly with significantly smaller fetal body weights (Gilbert *et al.* 1981; Nelson *et al.* 1983). The PR group in the present study did not have smaller newborn body weight values than the PC group and consequently the possibility of smaller placental weight values seems unlikely. Even if the placentas were smaller in the PR group, the contribution to this large significant difference would seem to be minimal. Another factor to consider in the differences between the maternal carcass weight values is the amount of internal maternal body fat that is present. It seems that only fat depots located retroperitoneally are significantly increased during pregnancy in rats (*Nutrition Reviews*, 1981). Parametrial fat pads do not appear to be affected by pregnancy (*Nutrition Reviews*, 1981) nor do mesenteric or omental fat depots in rats (Galletti & Klopper, 1964). Unfortunately, the different fat components were not analysed further in the present study.

The suggestion of diminished fat deposition found in the PR group is further supported by the fact that the carcass remainder component values (Fig. 3) for the PR (211·8 g) and (213·5 g) NPR groups are almost identical even though the PR group had just given birth. This remainder component includes internal fat depots. It is suggested that running pregnant rats may not store extra fat internally but rather are more apt to store fat subcutaneously. If the extra 6·1 g gained by the PR group

in the skin component (Fig. 3) was due mainly to fat deposition required for lactation then the question arises as to the 'state' of the mammary tissue of the PR group and the ability of this group to nourish its young especially when this value is compared to the extra 16·6 g gained in the skin component by the PC group.

In Figure 2, an attempt is made to account for a fetal component and a maternal component based on the present results. If these components are subtracted from the amount of weight gained on the last day of gestation for both the PC and PR groups, there would be 18·3 g and 5·7 g, respectively, still unaccounted for. This seems to be composed of material which has been completely lost at parturition, and which has not been reingested by the maternal rat, such as amniotic fluid and maternal blood. This might be composed mainly of maternal blood volume because maternal blood volume increases substantially during pregnancy in the rat (Atherton *et al.* 1982), of which a certain percentage is lost during birth. Unfortunately, the exact amount is not known, but 18·3 g seems quite significant. If the third remnant component (Fig. 2) for each group is dealt with in terms of single fetal units by dividing this weight difference by the average number of fetuses/group, there would be approximately 1·58 g/fetus accounted for in the PC group and only 0·59 g/fetus in the PR group. With these values, it is possible that amniotic fluid volume could be a factor, but the normal range for the amount of amniotic fluid necessary for normal growth to occur in the rat is not known. However, a diminished amniotic fluid volume (oligohydramnios) can result in fetal abnormalities such as cleft palate and limb deformities in rat fetuses (Symchych & Winchester, 1978). As these problems are not observed in the pups born to either the PC or the PR groups, this suggests that the amniotic fluid volumes are within normal values. The difference in the third remnant component found between these two groups is therefore difficult to explain and warrants further investigation.

From the results of this study, it appears that fetuses are indeed spared from the effects of this intensity of exercise during gestation. However, questions are raised concerning the ability of the maternal rat to provide sufficient nutrients by lactation to her nursing pups through the adequacy of necessary fat deposition. These questions cannot be answered from the results of this study. More research is required in the area of maternal exercise during pregnancy and lactation with specific reference to body composition of the maternal rat and neonatal outcome.

SUMMARY

The effects of strenuous maternal exercise throughout gestation on the maternal rat were examined. The results indicated that maternal exercise of this nature (30 metres/minute, 10° incline, 120 minutes/day, 5 days/week) caused a significant decrease in the amount of weight gained by the running maternal rats when compared to controls. By analysing the maternal rat and various bodily components after parturition, it was suggested that subcutaneous tissue growth (fat deposits and mammary gland tissue) was significantly less in the running group. The carcass remainder component was also found to weigh less in the running group, even though the maternal running rats had just given birth to an equivalent (not significantly different) number of neonates of similar (not significantly different) weight to the control group.

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