The one-year morphometric and neurodevelopmental outcome of the offspring of women who continued to exercise regularly throughout pregnancy

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OBJECTIVE: Our purpose was to test the hypothesis that continuing regular exercise throughout pregnancy alters morphometric and neurodevelopmental outcome at 1 year.
STUDY DESIGN: The offspring of 52 women who exercised were compared with those of 52 control subjects who were similar in terms of multiple prenatal and postnatal variables known to influence outcome. All women were enrolled before pregnancy and had clinically normal antenatal and postnatal courses. Neurodevelopment was assessed by blinded examiners at 1 year of age, and morphometrics were obtained at birth and at 1 year of age.
RESULTS: At birth, the offspring of the exercising women weighed less (3.38 ± 0.06 kg vs 3.58 ± 0.07 kg) and had less body fat (9.5% ± 0.8% vs 12.6% ± 0.6%). However, at 1 year, all morphometric parameters were similar, and no clinically significant between-group differences were observed in performance on either the Bayley psychomotor (108 ± 1 vs 101 ± 2) or mental (120 ± 1 vs 118 ± 1) scales.
CONCLUSIONS: These data indicate that the offspring of exercising mothers have normal growth and development during the first year of life. (Am J Obstet Gynecol 1998;178:594-9.)

Key words: Pregnancy, exercise, postnatal growth, neurodevelopment

When fit women continue a vigorous regimen of sustained, antigravitational exercise (running, aerobics, stair-stepping, etc.) throughout pregnancy, it creates concern that the physiologic effects of the exercise on thermal equilibrium, placental bed blood flow, and fetal oxygen/substrate delivery may compromise both short-term and long-term growth and development of the offspring.[1] Nonetheless, 15% to 25% of women choose to continue these types of weight-bearing exercise throughout pregnancy at a frequency, duration, and intensity well above those recommended.[2]

Several years ago, the potential public health impact of 3 to 10 exercise sessions a week lasting ≥ 20 minutes at intensities in excess of 60% of maximum aerobic capacity on both short-term and long-term fetal and maternal outcome, coupled with a variety of theoretical medical concerns, stimulated our laboratory to begin a series of prospective studies that have examined multiple aspects of this question. To date, the results indicate that continuing to exercise at these levels does not impair fetal well-being and has multiple maternal benefits.[2] The explanation for these encouraging findings is twofold. First, the magnitude of multiple potentially harmful physiologic responses to exercise are markedly reduced by the maternal physiologic adaptations to pregnancy.[2-4] Second, regular exercise enhances many of the maternal physiologic adaptations to pregnancy[2, 5-7] in ways that are fetoprotective. As a result, biologically significant elevations in core temperature do not occur,[3] no evidence of tissue hypoxia in the fetal compartment (meconium staining, fetal bradycardia, erythropoietin levels) exists[2, 4, 8] and axial and circumferential growth are normal.[2, 9]

Although these findings are encouraging, they do not address the important issue of the impact of regular, sustained, antigravitational exercise on postnatal growth and neurodevelopment of the offspring. This study is the second that has been designed to examine this issue. In the initial study[10] detailed evaluation of 20 closely matched pairs was carried out at 5 years of age. The offspring of the women who exercised had experienced normal axial and circumferential growth but continued

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Table I. Maternal physical characteristics

Physical characteristic	*Exercise (mean ± SEM)*	*Control (mean ± SEM)*	*Significance*
Maternal age (yr)	31 ± 1	31 ± 1	NS
Weight (kg)	60.0 ± 1.1	60.4 ± 1.6	NS
Height (cm)	170.4 ± 2.1	169.6 ± 2.1	NS
Percent body fat	17.9 ± 0.7	21.0 ± 0.8	$p = 0.05$
VO_{2max} (ml/kg/min)	50.6 ± 2.0	48.2 ± 2.7	NS
Pregnancy weight gain (kg)	13.6 ± 1.4	17.5 ± 1.7	$p = 0.05$

NS, Not significant.

Table II. Morphometry of offspring at birth

Offspring characteristic	*Exercise (mean ± SEM)*	*Control (mean ± SEM)*	*Significance*
Birth weight (kg)	3.38 ± 0.06	3.58 ± 0.07	$p = 0.05$
Length (cm)	51.1 ± 0.3	51.1 ± 0.3	NS
Percent body fat	9.5 ± 0.4	12.6 ± 0.6	$p = 0.05$
Head circumference (cm)	34.6 ± 0.2	34.8 ± 0.3	NS
Calculated lean body mass (kg)	3.06 ± 0.05	3.13 ± 0.06	NS

NS, Not significant.

to weigh less and have less subcutaneous fat than the offspring of the matched controls. The exercise offspring also scored significantly higher on tests of general intelligence and oral language skills but were no different from the control offspring in the level of their preacademic learning skills, visual motor integration, and motor performance.

These differences were not expected and could not be explained by between-group differences in any of the usual postnatal factors that influence somatic growth and neurodevelopment. This suggested that other unrecognized postnatal events (subtle differences in parenting, independence, verbal exchange, physical activity, breast feeding, time with grandparents, etc.) and/or unrecognized errors in our selection and matching process may have played a role. To minimize or eliminate many of these potential confounders, we decided to evaluate a broader populace at an earlier age. Therefore in 1993 we began to evaluate a second, larger group of infants born to more diverse parents to test the hypothesis that continuing vigorous, sustained, antigravitational exercise on a regular basis throughout pregnancy alters postnatal growth and neurodevelopment in the first year of life.

Methods

Subject selection. A major problem in studies of this type is to isolate the effect of the independent variable of interest (in this case exercise during pregnancy) from multiple other prenatal and postnatal confounders. To accomplish this, a prospective, sequential, experimental design with exclusion criteria to eliminate known confounders was used. With this approach, our study sample was recruited from a larger group of regularly exercising and physically active control women who enrolled in our ongoing study of exercise during pregnancy after January 1992. To avoid multiple confounding variables all the women in the ongoing study are physically fit and meet specific age (25 to 38 years), morphometric (45 to 75 kg and 12% to 28% body fat), health (no chronic illness, tobacco, or drug abuse), fitness (active lifestyle, maximum aerobic capacity >32 ml · kg · min^{-1}), and sociodemographic criteria (family income >50th percentile, both parents with a high school education, stable family situation).[1, 9]

Beginning in 1992, every exercising or control woman from the larger study who experienced an uncomplicated pregnancy (both exercisers and controls) was offered the opportunity to have their offspring's postnatal growth and neurodevelopment evaluated at 1 year of age.[2] This study sample consists of the offspring of the women whose pregnancies met these criteria (124 of 145 of those delivered), who returned for follow-up, and who had a satisfactory evaluation at 1 year of age (±1 month) between then and November 1996. Eighty-four percent (104 of 124)of the eligible offspring (92% in the exercise group and 78% in the control group) returned and had a satisfactory evaluation performed. Three families moved out of the area, and in four cases (two in each group) the evaluation was judged unsatisfactory (uncooperative tired child or the parent coaching their child on one or more tasks). The remainder lacked either the interest or the time to return for follow-up. In accordance with University policies for human experimentation parental informed consent was obtained before the assessment.

Monitoring. All mothers in both groups had been followed closely throughout pregnancy, labor, and delivery by the study team. Their pregnancies had been accurately dated (sexual history, early pregnancy test, and ultrasound); maternal exercise performance (weekly exercise logs), dietary intake (24-hour dietary recalls), weight gain (every 4 to 8 weeks), and physiologic responses (every 8 weeks) had been serially monitored, and a single member of the study team had been present during labor and delivery to record events as they happened.[1, 2, 9]

Exclusion criteria. To avoid confounding the study sample with additional factors known to influence morphometric and neurodevelopmental outcome, cases in which the antenatal course was abnormal (premature labor, pregnancy-induced hypertension, abruptio placentae, intrauterine growth retardation) were excluded from this analysis as were cases with a variety of intrapartum complications (sepsis, fetal distress, Apgar score <7, etc.). However, 18 cases in which the intrapartum

Table III. Morphometry of the offspring at 1 year of age

Offspring characteristic	*Exercise (mean ± SEM)*	*Control (mean ± SEM)*	*Significance*
Weight (kg)	9.68 ± 0.15	9.75 ± 0.18	NS
Length (cm)	75.3 ± 0.5	75.4 ± 0.4	NS
Percent body fat	25.8 ± 0.7	26.0 ± 1.1	NS
Head circumference (cm)	46.9 ± 0.2	47.1 ± 0.2	NS
Chest circumference (cm)	47.1 ± 0.2	47.3 ± 0.3	NS
Abdominal circumference (cm)	46.8 ± 0.5	48.3 ± 0.5	NS

NS, Not significant.

Table IV. Neurodevelopmental characteristics at 1 year of age

Bayley scales	*Exercise (mean ± SEM)*	*Control (mean ± SEM)*	*Significance*
Mental score	120 ± 1	118 ± 1	NS
Percentile	88 ± 1	84 ± 2	NS
Psychomotor score	108 ± 1	101 ± 2	$p = 0.05$
Percentile	69 ± 3	53 ± 4	$p = 0.05$

NS, Not significant.

course was complicated solely by fetopelvic disproportion were included. The only postnatal exclusions were for diseases in infancy that might directly influence either morphometric or neurodevelopmental outcome (recurrent otitis media with serous effusion, feeding difficulties, surgery, and severe or protracted illness).

Exercise criteria. The mothers of the offspring included in the exercise group either ran, performed aerobics, or used one of several types of stair-climbing machines three or more times each week for more than 20 minutes a session at an intensity greater than 55% of their maximal capacity throughout pregnancy. Although all control women lead physically active lives, only 56% of them had exercised regularly before pregnancy. The remainder engaged in either intermittent activity (golf, tennis, hiking, etc.) or infrequent activity or did no recreational exercise at all (21%). The 56% who had exercised regularly before pregnancy were classified as control subjects because they voluntarily stopped or cut way back on all forms of sustained exercise (other than walking) during pregnancy.

Measurement techniques. All infants underwent morphometric assessment by one of three trained examiners within 24 hours of birth. All measurements were performed in duplicate and the average recorded. Weight was measured to the nearest 10 gm using an accurately calibrated balance beam or electronic scale. Length was measured to the nearest millimeter in a standardized fashion (coefficient of variation <1%) using a specially constructed measurement box and the tonic neck reflex.[11] Circumferential measurements of the head, chest, and abdomen were obtained to the nearest millimeter in a standardized fashion (coefficient of variation <3%) using a flexible plastic tape in midinspiration with the child quiet.[12] Triceps and subscapular skinfold thicknesses were measured to the nearest 0.1 mm using accurately calibrated Harpenden calipers (coefficient of variation between measurements and examiners <6%) and used to estimate fat mass.[9] In most cases (86 of 104) fat mass was also estimated using total body electrical conductivity and the average of the two estimates was used in data analysis.[13]

Within 1 month of the subjects' first birthday (average 361 ± 3 days of age), neurodevelopment was assessed by administering the original Bayley Scales of Infant Development[14] in a controlled, uniform environment with the mother present. To eliminate the possibility of bias, one of three blinded examiners with an interobserver scoring reliability of ±1% to 2% conducted the testing. The original scales were used throughout because the revised scales were not available at the start of the study, and the quoted correlations between the two ranged from 0.33 to 0.63.[15]

After the neurodevelopmental assessment, the morphometric measurements were repeated by one of two examiners. Weight was recorded to the nearest 10 gm (electronic scale), length to the nearest millimeter (measurement box), circumferences to the nearest millimeter (tape), and triceps and subscapular thicknesses were measured in a standardized fashion (Harpenden calipers).[12] In cooperative infants (78) the total body electrical conductivity estimate of fat was also repeated and the average of the two estimates of fat mass was used in the data analysis.

Maternal weight (to the nearest pound), height (to the nearest millimeter), and fitness (oxygen consumption [$\dot{V}O_{2max}$], percent body fat) were measured before pregnancy with conventional techniques.[2] Additional health and demographic data were obtained at the time of initial enrollment and updated at the time of the 1-year evaluation.

Statistical analysis. Between-group differences for the morphometric parameters and neurodevelopmental scores were sought with the Student's unpaired *t* test with the Bonferroni correction for multiple comparisons within each subset of related measurements. A *p* value less than 0.05 was considered significant. The sample size (*n* of 52 per group) and variance of the data provided the power to detect a 6% between-group difference in neurodevelopmental outcome and a 9% to 30% difference for various morphometric measures with a power >0.8. All data have been rounded off to the level of precision of the measurement and is expressed as the mean ± SEM.

Results

Maternal characteristics. The women in both groups were reasonably well matched for characteristics known to affect morphometric and neurodevelopmental outcome.[2, 9, 10] The physical data are detailed in Table I. The only significant difference was that preconceptional maternal fat mass and pregnancy weight gain were significantly less in the exercise populace. Paternal measurements were not obtained.

All couples were white with educational levels ranging from completing high school through postdoctoral training (range 12 to 22 years with a median of 17 years) and mean levels for both the women (18 ± 1 vs 17 ± 1 years) and their husbands (16 ± 1 vs 16 ± 1 years) were not significantly different between the two groups. However, parental intelligence was not objectively assessed. Family incomes were all in the upper 50% for the state and county of residence, and most women (91%) worked part time or full time. All ate a well-balanced diet with a caloric intake greater than 30 kcal · kg^{-1}. At the time of enrollment post partum, parity ranged from 1 to 4 with no significant between-group difference (mean 1.7 and median of 2 in both groups).

Because of the lower return rate in the physically active control women, the data obtained before and during pregnancy, labor, and delivery in the those who did not return was compared with those who did, and no significant differences were detected. Although the numbers were small (15 and 52), maternal age, prepregnancy weight, pregnancy weight gain, gestational age at delivery, and birth weight were virtually identical, whereas maternal education, parity, and family income tended to be slightly higher in those who chose not to return for follow-up (+1 year, +0.5, and +1 income bracket, respectively).

Exercise performance. In the exercise group 19 women were runners, 23 did aerobics, and 10 used stair machines. Before pregnancy the runners ran between 19 and 52 km a week at a pace ranging between 4.5 and 5.6 min · km^{-1} at an intensity ranging between 60% and 87% of their maximal aerobic capacity (VO_{2max}). The women who performed aerobics participated in between 3 and 10 sessions a week (median 5) at intensities that ranged between 62% and 90% of their VO_{2max} during the high-intensity portion of the workout. During pregnancy the women in both subgroups maintained their performance level above the minimum required (three 20-minute sessions a week) and actually averaged about 75% of their prepregnancy levels (range 62% to 113%) as measured by their duration-intensity index.[9] Six of the 10 women who used stair machines were part of a training study and exercised between three and five times a week at 55% of VO_{2max} throughout. The remainder maintained or increased their preconceptional level of performance (90% to 114%).

In the physically active control group more than 60% of the women did not engage in anything more than occasional (less than once a month) sustained recreational physical activity. In the remainder the maximum frequency of sustained recreational physical activity observed (other than an occasional after dinner walk) was once a week in early and once every 2 to 3 weeks later in the pregnancy.

Offspring characteristics. There were 24 boys and 28 girls in the exercise group and 29 boys and 23 girls in the control group. Gestational age at delivery was equivalent in the two groups (exercise, 277 ± 1 days; control, 279 ± 1 days). Morphometric characteristics at the time of birth are detailed in Table II. Note that the offspring of the exercising women were significantly lighter and leaner but that axial growth and growth of the cranial vault were similar to that of the control subjects. Also note that the offspring of the exercising women were not unduly small. The mean birth weight was at the 50th percentile for gestational age for the reference populace in North East Ohio,[16] whereas the mean birth weight for the control group was at the 66th percentile, and within both groups the boys were significantly ($p < 0.05$) heavier than the girls, indicating that the usual sex-specific differences in birth weight were present in both sets of offspring.[16]

The timing of the 1-year evaluation was similar in the two groups (mean 360 days for the exercise offspring, 362 days for the control offspring) and the same was true for the male and female offspring in the two groups. The morphometric measurements are detailed in Table III. Note that the between-group differences present at birth have entirely disappeared and that now the two populaces are quite similar. No significant within-group morphometric differences were observed between the males and females.

The scores and percentiles for the Bayley mental and psychomotor scales are listed in Table IV. Note that no significant between-group difference was observed in mental performance, and a statistically but not clinically significant between-group difference in the psychomotor score was noted. Within-group subdivision by sex revealed no significant difference in either parameter between the male and female offspring.

Comment

These data negate the initial hypothesis. In terms of morphometric outcome no evidence of poor postnatal growth during the first year of life in either group of offspring was found. When compared with either national statistics[17] or several other developmental cohorts,[18-22] height, weight, and subcutaneous fat mass (as assessed by individual skinfolds) are at or near the 50th percentile.

The morphometric findings are also compatible with those reported earlier for a smaller number of children at age 5.[10] The only exception is that the percent body fat was lower in both male and female exercise offspring in the earlier study, whereas it was unchanged in this series. The reason for this subtle difference is unclear, but we speculate that it may represent either a difference in the lifestyle and feeding practice of the urban versus the rural woman or simply in the timing of the evaluation. For example, it is well known that breast-fed babies are leaner than formula-fed infants after 3 months of age.[23] In this midwest urban populace, breast feeding for more than 3 months was unusual (only seven cases) whereas all the women breast fed for more than 6 months in the earlier Vermont populace–based study. Likewise, the minimal physical activity and high-caloric intake characteristic of infancy results in significant fat accretion that is not lost until the child becomes fully ambulatory at 12 to 15 months of age. Unfortunately, we have no detailed dietary data addressing this point. Perhaps if the offspring had been breast fed longer or we had waited until 18 months of age, the findings would have been more consistent. We hope we will be able to clarify this point at the time of the planned 5-year follow-up assessment.

Neurodevelopmentally, no evidence of a clinically significant deficit in either area in either group was observed. Both scored well above the mean on the mental scale and slightly above it in the area of motor performance. The between-group difference in the latter was primarily due to differences in ambulation skills rather than upper extremity coordination. The between-group differences in mental performance were nonexistent. This pattern requires explanation because it is quite different from our earlier report in which an in-depth evaluation at age 5 revealed no differences in motor performance and striking differences in the scores on both the Wechsler scales and multiple tests evaluating verbal language skills.[10] The most logical explanation is that the differences in mental performance at age 5 reflect unrecognized differences in childrearing practices, but the 5-year follow-up data from the current series will be needed to definitively resolve this issue.

The study design used in the current series has three inherent sets of limitations that warrant discussion. First, to isolate the independent variable of interest (exercise during pregnancy), only a select sample of women and their infants were studied. Because these women and infants are not representative of the population at large, the results obtained should only be applied to similar subjects and cannot be generalized at this time.

Second, the study design included multiple dependent outcome variables, and interactions between related variables with multiple comparisons increase the probability of finding one or more significant between-group differences by chance alone. Therefore a very conservative statistical approach to data analysis (the Bonferroni correction) is warranted. Practically this decreases statistical power but avoids overinterpretation of the data. Thus although it increases the confidence level that the differences identified are real, some additional between-group differences may not have been identified. However, the fact that the mean values in the two groups for the morphometric and the other neurodevelopmental variables at 1 year are very similar suggests that the latter should be of limited concern.

Third, the current data set does not allow us to completely exclude several possible confounders. These include sampling error and the sensitivity of one or more of the test instruments.

In studies of this type there is always the possibility that sampling error occurred. Although we tried to avoid this by using a prospective, sequential, sampling design with multiple exclusionary criteria, it can be argued that the two groups of women in the ongoing exercise study we sampled for this follow-up study were different in subtle ways that could influence the neurodevelopment of their offspring. For example, we have used years of education rather than a current objective test to assess parental intelligence in the two groups; income and marital stability, rather than a home visit and detailed interview, as basic indices of the quality of the home environment and interaction; and we have no index of parental motivation other than return for follow-up, which was different in the two groups. Thus it can be argued that the women who exercised might be inherently more intelligent and also possess greater motivation to do what is best both for themselves and, by inference, for their offspring's development (love, attention, and stimulation). If so, then their offspring should be expected to demonstrate superior ability on developmental tests and perhaps the fact that they did not do much better indicates that the exercise during pregnancy was harmful. Unfortunately, this possibility cannot be resolved with the database available. It will require another study in which the women are prospectively randomized to either regular exercise or no exercise throughout pregnancy, and a study using that design is currently under way.

Another problem is that the original Bayley mental scale may not have been sensitive enough to detect consistent between-group differences in the mental scales at 1 year at this relatively high level of performance (>80th percentile).[24, 25] Although the original Bayley scales worked well in differentiating functional differences between normal and high-risk infants, they were not designed to detect subtle differences between groups of normally functioning infants nor did they prove to have good long-term predictive value.[24, 25] Indeed, one reason for the revision was to improve the value of the test in areas such as language acquisition and its predictive value for later mental performance on tests like the Wechsler.[15]

Despite these limitations, the 1-year evaluation did not detect any specific deficits in any aspect of either the postnatal growth or the neurodevelopment of the offspring of the exercising women. This information should be reassuring for both active women who chose to continue vigorous exercise during pregnancy and those who care for them and their offspring. However, these findings should not be generalized to the population at large at this time.

Finally, the hypothesis that some stimulus associated with exercise (intermittent stress, vibration, sound, motion, fast heartbeat, etc.) alters neurodevelopment in utero in a beneficial way requires further evaluation. Full clarification will require more detailed evaluation of both the parents, the infant's environment, and the use of alternate test instruments. Additional studies in the neonate and fetus and sequential follow-up data from this cohort should also be of benefit in understanding the interaction.

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