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GENETIC AND ENVIRONMENTAL INFLUENCES ON LEVEL OF HABITUAL PHYSICAL ACTIVITY AND EXERCISE PARTICIPATION

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In order to quantify genetic and environmental determinants of physical activity level, 1,610 subjects from 375 families who lived in the greater Québec city area completed a three-day activity record in 1978–1981. Level of habitual physical activity, which includes all the usual activities of life, and exercise participation, which includes activities requiring at least five times the resting oxygen consumption and more, were derived from this record. Familial correlations were computed in several pairs of biologic relatives and relatives by adoption after adjustment for the effects of age, sex, physical fitness, body mass index, and socioeconomic status, and analyzed with a model of path analysis that allows the separation of the transmissible effect between generations (t^2) into genetic (h^2) and cultural (b^2) components of inheritance. The transmission was found to be statistically significant, but was accounted for by genetic factors for level of habitual physical activity ($t^2 = h^2 = 29\%$), and by cultural factors for exercise participation ($t^2 = b^2 = 12\%$). Although non-transmissible environmental factors remain the major determinants of these two physical activity indicators in this population, the results suggest that children can acquire from their parents certain customs regarding exercise behavior and that the propensity toward being spontaneously active could be partly influenced by the genotype.

activities of daily living; environment; genetics; leisure activities

A recent review of eight national surveys conducted between 1972 and 1983 in Canada and the United States has revealed that only 20 per cent of the North American population exercises with an intensity recommended for cardiovascular benefits, while an additional 40 per cent is active at a moderate level, perhaps sufficient to achieve some health benefits (1). These results indicate that about 40 per cent of the population is totally sedentary. On the other hand, there is evidence from epidemiologic studies that physical activity has beneficial effects on several morbid conditions such as coronary heart disease (2–4), obesity (5, 6), lipid profile (7), osteoporosis

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Abbreviations: METS, multiples of the resting metabolic rate; PWC_{150}, physical working capacity at heart rate of 150 beats/min.

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(8–10), cancer (11–13), and non-insulin dependent diabetes (14, 15). These findings have contributed to the promotion of physical activity as revealed by the fact that 11 of the United States 1990 health objectives focus on physical fitness and exercise (16). The recent report about the status of these objectives also revealed that substantial progress toward these goals had been achieved, even though much remained to be done (16).

The low prevalence of a high level of physical activity in United States and Canadian populations has contributed to an increased interest in the determinants of physical activity habits. However, so far, few studies have addressed this issue (17, 18), and none, to our knowledge, have attempted to establish whether genetic factors were involved, even though a recent study has shown the presence of familial resemblance in leisure-time energy expenditure and level of habitual physical activity (19). Therefore, the question addressed in the present study is whether or not genetic factors influence behaviors such as level of habitual physical activity and exercise participation. To answer the question, two indicators were derived from a three-day activity record completed by 1,610 subjects, and familial correlations computed from pairs of biologic and cultural relatives were used to quantify genetic and nongenetic sources of variation by the method of path analysis.

MATERIALS AND METHODS

Population of the study

The population of this study consisted of 1,610 subjects from 375 families of French descent who lived in the greater Québec city area. These families were initially recruited to participate in a study that dealt with the genetics of physical fitness and that included 717 parents and 893 biologic and adopted children with a mean age of 43.2 years (standard deviation (SD) = 5.2) and 14.6 years (SD = 3.3), respectively. All subjects were volunteers and gave their written consent to participate in this study, which was approved by the Ethics Committee of Laval University. From this cohort, it was possible to form the following pairs of relatives: spouses (maximum number of pairs, 344), parent-natural child (1,227), foster parent-adopted child (318), biologic siblings (365), dizygotic twins (60), monozygotic twins (62), siblings by adoption (119), uncle (aunt)-nephew (niece) (88), and first-degree cousins (95).

Physical activity assessment

A three-day activity record, including one weekend day, was used to determine the activity level of the subjects. This activity record was designed to be used in population studies in such a way that it could be filled out by children as well as adults. A complete description of this record has been given elsewhere (20). Briefly, each day was divided in 96 periods of 15 minutes, and for each 15-minute period the subjects were asked to note, on a scale from 1 to 9, the energy expenditure of the dominant activity of that period. Each category refers to activities of similar energy expenditure as established from several sources (21–24). The categories were explained and illustrated to the subjects and every subject received a list of activities corresponding to each category.

Two different indicators of physical activity were considered in this study. First, the categorical scores were summed over the 96 15-minute periods of each day and the mean sum of the three days was computed and used as an indicator of the level of habitual physical activity. Second, the number of periods corresponding to activities rated from 6 to 9 was counted for each day (number of 6, 7, 8, or 9 entries) and the average value was computed and used as the indicator of exercise participation. These categories were chosen because the corresponding activities have an energy cost equal to or greater than 1.2 kcal/kg/15 minutes, which is equivalent to about five times the resting metabolic rate (≥4.8 multiples of the resting metabolic rate (METS), one MET being the energy expenditure corresponding to the resting oxygen consumption). The following are examples of activities included in categories 6–9: category 6, leisure and sports activities in a recreational environment (baseball, golf without motor cart, etc.); category 7, moderate manual work (house building, snow shoveling, etc.); category 8, leisure and sports activities of higher intensity (fitness exercises, calisthenics, tennis, etc.); and category 9, intense manual work and high intensity sports activities or sports competition (tree cutting, carrying heavy loads, running, cross country skiing, football, etc.) For example, a value of 5 for this indicator would indicate that a subject is engaged in exercise or sports activities included in categories 6–9 for an average of 75 minutes a day.

Environmental influences

Information about environmental variables that could be associated with participation in physical activity was also obtained in these subjects. Body mass index (body weight (kg)/height (m^2)) was measured as an indicator of obesity. Moreover, the physical fitness level of the subjects was determined by computing the power output at a heart rate of 150 beats/minute (PWC_{150} = physical working capacity at a heart rate of 150 beats/minute (expressed in kpm/minute/kg body weight)) during a submaximal test on a cycle ergometer. Finally, socioeconomic status was obtained with the occupation of the father coded according to the procedures outlined in Blishen and McRoberts (25), utilizing data of the Canadian Census.

Statistical procedures

Physical activity variables were first adjusted for linear and nonlinear (interaction and quadratic) effects of age and sex by a multiple regression performed separately in parents and children (Y = age + sex + (age × sex) + age^2). A second multiple regression including body mass index (BMI), physical fitness (PWC_{150}/kg) and socioeconomic status (SES) was then performed to assess the importance of these covariables after adjustment for age and sex (Y = age + sex + (age × sex) + age^2 + BMI + PWC_{150}/kg + SES). The residuals were then normalized and used for the analyses. The normalized phenotypes were obtained by taking the inverse normal transformation of the ranked residuals (26).

Familial correlations in the various kinds of relatives were computed according to the pairwise method (27) in which the Pearson correlations are computed for each pair of a particular kind of relation and summed over all the pairs. These familial correlations were then analyzed by the method of path analysis.

Path analysis

Path analysis is a method initially devised by Wright (28, 29) to explain correlations between variables under a linear model. This method has been introduced and developed for human quantitative genetics by Morton (30) and Rao et al. (31, 32) and is commonly used in the field of genetic epidemiology to quantify genetic and environmental sources of variation in multifactorial phenotypes (26).

The model of path analysis used in the present study is called the BETA model and was described by Cloninger et al. (33). The particularity of this model is its ability to distinguish genetic and cultural components of inheritance from other environmental influences that are not transmitted between generations. In the model, genetic and nongenetic factors are assumed to be additive and departures from linearity (dominance, epistasis, and gene-environment interaction) are neglected (33). The model assumes that a quantitative trait P can be partitioned as $P = A + B + E$, where A and B denote additive genetic factors and cultural factors transmitted from parent to offspring, respectively, and E represents all other environmental factors that are not transmitted between generations. Transmission of cultural factors (cultural inheritance) may be learned or acquired when parents teach their children certain customs and preferences about diet, social environment, and other activities (33). Nontransmitted environmental factors (E) may be correlated within a generation because of environmental influences (relevant characteristics of the home, neighborhood, or school) shared by family members reared together; this correlation (denoted as c) may be different for different classes of relatives, such as twins and singletons. The model is determined by the following path equations:

$$P = hA + bB + eE \quad (1)$$

$$A_o = 1/2\ A_F + 1/2\ A_M + sS \quad (2)$$

$$B_o = \beta B_F + \beta B_M + r_1 R_1. \quad (3)$$

Here, h, b, and e are the path coefficients representing the extent to which additive genetic factors, transmissible cultural factors, and nontransmissible environmental factors, respectively, influence the phenotype. S denotes the segregation from midparent genic value and R_1 the fluctuation from parental cultural values (33). Equations 2 and 3 represent the transmission of genetic (A) and cultural (B) factors from parents (F, father, and M, mother) to offspring (o), respectively. The path coefficients from parents genic value A to child genic value A is taken as ½ from biologic considerations about the mechanism of diploid autosomal inheritance and beta (β) represents the path coefficient from parents' cultural value B to a child's cultural value B, representing the extent to which children inherit cultural values from parents. In the version of the BETA model used in this study, it was assumed that $\beta_F = \beta_M = \beta$ (34). The model allows for a correlation between phenotypes of mates (m) and between nontransmissible environment (E) of full siblings (c), dizygotic twins (c_{DZ}), and monozygotic twins (c_{MZ}). Thus, the complete BETA model has a total of seven parameters (m, β, h, b, c, c_{DZ}, c_{MZ}) and one derived parameter (w) which represents the correlation between genetic and cultural factors. Then, the phenotypic variance (V_P) is given by:

$$V_P = h^2 + b^2 + e^2 + 2whb = 1 = t^2 + e^2, \quad (4)$$

where total transmissible variance (t^2) equals $h^2 + b^2 + 2whb$ and the nontransmissible variance (e^2) equals $1 - t^2$. A Fortran program called BETA (34) was used to obtain the maximum likelihood estimates of the parameters from the observed correlations and to test linear constraints placed on the parameters. This program uses a subroutine program called MAXLIK (35) to maximize a likelihood function (36) which, asymptotically, has a chi-square distribution with degrees of freedom equal to the number of observed correlations minus the number of estimated parameters. The chi-square statistic for the differences between expected and observed correlations provides a goodness of fit test of the model to the data. Testing of hypotheses that involve linear constraints on the parameters is performed using the likelihood ratio test (37) by taking the difference between chi-square values of constrained and unconstrained models. Degrees of freedom for the likelihood ratio test are given by the number of constraints (36).

RESULTS

Descriptive statistics of the physical characteristics and physical activity indicators for the subjects are presented in table 1. Results indicate a higher score for level of habitual physical activity in parents compared with the children. When this difference across generations was compared within each sex (fathers vs. boys and mothers vs. girls), it reached significance only between mothers and girls ($p < 0.01$). On the other hand, results revealed that children exercised more than parents because they spent significantly ($p \leq 0.01$) more time on activities with high energy expen-

TABLE 1

Descriptive statistics (mean ± standard deviation) of physical characteristics and activity level indicators for parents and children: greater Québec city families who completed a three-day activity record, 1978–1981

Variable	Parents		Children	
	Fathers (n = 353)	Mothers (n = 364)	Boys (n = 477)	Girls (n = 416)
Age (years)	44.2 ± 5.1	42.1 ± 5.0	14.5 ± 3.3	14.8 ± 3.4
Weight (kg)	75.3 ± 11.1	59.2 ± 9.1	50.0 ± 15.0	46.7 ± 10.8
Height (cm)	171.9 ± 6.0	159.2 ± 5.6	159.2 ± 15.7	155.3 ± 10.6
Body mass index (kg/m²)	25.4 ± 3.2	23.4 ± 3.6	19.2 ± 2.8	19.1 ± 2.8
PWC_{150}* (kpm/kg body weight)	10.0 ± 2.9	6.8 ± 1.8	10.0 ± 2.3	7.1 ± 1.8
Level of habitual physical activity (sum of scores 1 to 9)†	237.5 ± 40.4	226.1 ± 25.9	233.7 ± 38.2	216.8 ± 31.4
Exercise participation‡ (number of 6, 7, 8, or 9 entries)	4.0 ± 5.9	1.5 ± 2.5	9.3 ± 7.3	6.0 ± 5.9

* PWC_{150}, physical working capacity at a heart rate of 150 beats/minute.

† Derived from a three-day activity record (20). There is a significant ($p \leq 0.01$) difference between male and female subjects (within each generation) and between mothers and girls.

‡ Derived from a three-day activity record (20). There is a significant ($p \leq 0.01$) difference between male and female subjects (within each generation) and between parents and children (within each sex).

diture (i.e., activities of 4.8 METS and over). The results also indicate that, within the same generation, male subjects tend to exercise more than their female counterparts ($p \leq 0.01$).

The effects of age and sex (results not shown) were found to account for 4 per cent and 7 per cent of the variance observed in level of habitual physical activity for parents and children, respectively. The corresponding values for the exercise participation indicator were 7 per cent and 12 per cent, respectively. However, when the levels of physical fitness, obesity, and socioeconomic status were included in the regression, in addition to age and sex, the percentage of variance in level of habitual physical activity accounted for by the independent variables increased from 4 to 12 per cent in parents and from 7 to 11 per cent in children. For exercise participation, the percentage of variance increased from 7 to 11 per cent in parents and from 12 to 13 per cent in children. The two indicators of physical activity were therefore adjusted for age, sex, and the environmental covariables by subtracting the scores predicted by the latter regression from the original scores. The residual scores were then normalized as described in the methods and used as the phenotypes for subsequent analyses. Before computing familial correlations, differences between means and variances of foster and biologic parents and unrelated and biologic siblings were tested for both phenotypes. No significant differences between means and variances in these subgroups of relatives were observed for both indicators of physical activity (results not shown).

Familial correlations computed in the various types of relatives are presented in table 2. The correlations observed in sibships of biologically related persons (full siblings, dizygotic twins, and monozygotic twins) and in unrelated siblings indicated a significant familial resemblance in the two indicators of physical activity. The data also revealed that persons of the same generation, whether genetically related or not, tend to be more similar in their physical activity habits than persons of two different generations. These results suggest that familial resemblance is probably associated with familial environmental factors shared by persons of the same generation.

The parameter estimates derived from the complete BETA model and from five specific hypotheses involving constraints

TABLE 2

Interclass correlations in different pairs of relatives for the indicators of physical activity†: greater Québec city families who completed a three-day activity record, 1978–1981

Type of relatives (no. of pairs)	Level of habitual physical activity	Exercise participation
Spouses (n = 272)	0.18**	0.16**
Parent-natural child (n = 1,039)	0.16**	0.09**
Foster parent-adopted child (n = 280)	0.08	0.12*
Full siblings (n = 347)	0.42**	0.34**
Dizygotic twins (n = 56)	0.62**	0.76**
Monozygotic twins (n = 55)	0.72**	0.74**
Unrelated siblings (n = 113)	0.17	0.37**
Uncle (aunt) - nephew (niece) (n = 76)	0.15	−0.11
First-degree cousins (n = 83)	0.22*	0.22*

* $p \leq 0.05$.

** $p \leq 0.01$.

† Computed on the normalized residual scores of age, sex, physical fitness, obesity, and socioeconomic status. There were no significant differences in means and variances between groups of biologic and foster parents and groups of biologic and unrelated siblings.

on the model (reduced models) are presented in tables 3 and 4 for level of habitual physical activity and exercise participation, respectively. The goodness of fit and likelihood ratio chi-square values are also given in these tables. For both indicators of physical activity, the full model provided a good fit to the data, as revealed by nonsignificant χ^2 values of 4.58 and 5.10, respectively. The hypothesis of no genetic effect ($h = 0$) was tested in the reduced model A, and was rejected ($p < 0.05$) for level of habitual physical activity and accepted for exercise participation. Reduced model B tested the hypothesis of no cultural inheritance ($\beta = b = 0$). This hypothesis was found acceptable for level of habitual physical activity but was rejected for the indicator of exercise participation ($p < 0.05$). The hypotheses of no transmission between generations ($h = \beta = b = 0$), no shared sibling environment ($c = c_{DZ} = c_{MZ} = 0$), and no spousal resemblance ($m = 0$) were tested in the reduced models C, D, and E, respectively, and were rejected ($p \leq 0.01$) for both indicators of physical activity.

The components of phenotypic variance computed (see equation 4 in Materials and Methods) from the results presented in the two preceding tables are shown in table 5. The table presents the results obtained from the complete model and from the most parsimonious solution, i.e., the solution with the fewest parameters that could fit the data. Results indicate a total transmissible variance of about 30 per cent for level of habitual physical activity, with a genetic effect of 20 per cent under the full model and 29 per cent under the most parsimonious solution ($\beta = b = 0$). On the other hand, no genetic effect was observed for the indicator of exercise participation, under both the full model and the most parsimonious solution, and the transmissible variance was entirely of cultural origin ($t^2 = b^2 = 12$ per cent). For both indicators, most of the phenotypic variance was accounted for by nontransmissible environmental factors (71 per cent $\leq e^2 \leq$ 88 per cent).

DISCUSSION

This study is the first to use a multivariate method of analysis derived from genetic epidemiology to quantify genetic and cultural components of inheritance in the inclination to be physically active. The results revealed that transmissible factors from one generation to another are involved in determining the level of habitual physical activity and exercise participation as assessed by a three-day activity record. With the BETA model of path analysis, we have shown that the level of habitual physical activity was significantly influenced by genetic factors, with an estimated heritability of 29 per cent under the most parsimonious solution. On the other hand, no

TABLE 3

Parameter estimates (± standard error) and chi-square values obtained for various hypotheses tested under the BETA model for level of habitual physical activity†: greater Québec city families who completed a three-day activity record, 1978–1981

Parameter of the model	Full model	Reduced models‡				
		A	*B*	*C*	*D*	*E*
m	0.18 ± 0.04	0.18 ± 0.04	0.18 ± 0.04	0.18 ± 0.04	0.10 ± 0.04	
β	0.70§	0.70§			0.70§	0.70§
h	0.44 ± 0.08		0.54 ± 0.03		0.49 ± 0.07	0.49 ± 0.0
b	0.25 ± 0.08	0.42 ± 0.03			0.40 ± 0.05	0.28 ± 0.0
c	0.30 ± 0.05	0.22 ± 0.04	0.35 ± 0.04	0.36 ± 0.03		0.29 ± 0.0
c_{DZ}	0.62 ± 0.09	0.54 ± 0.07	0.66 ± 0.08	0.62 ± 0.06		0.63 ± 0.1
c_{MZ}	0.61 ± 0.07	0.65 ± 0.06	0.60 ± 0.07	0.72 ± 0.05		0.59 ± 0.0
χ^2 (df‖) goodness of fit	4.58 (2)	9.31 (3)*	5.72 (4)	39.30 (5)**	44.02 (5)**	13.24 (3)*
χ^2 (df) contrast with the full model		4.73 (1)*	1.14 (2)	34.72 (3)**	39.44 (3)**	8.66 (1)*

* $p \leq 0.05$.

** $p \leq 0.01$.

† Data adjusted for age, sex, physical fitness, obesity, and socioeconomic status.

‡ *A*, no genetic effect ($h = 0$); *B*, no cultural inheritance ($\beta = b = 0$); *C*, no transmission between generations ($h = \beta = b = 0$); *D*, no shared sibling environment ($c = c_{DZ} = c_{MZ} = 0$); *E*, no spousal resemblance ($m = 0$).

§ Value fixed at the upper limit permitted by the model.

‖ df, degrees of freedom.

genetic effect ($h^2 = 0$) was observed for exercise participation, and the transmissible variance was found to be entirely cultural ($b^2 = 12$ per cent).

To better understand the meaning of these results, the two phenotypes under study must be well defined. The first phenotype, defined as the level of habitual physical activity, is essentially the total amount of activities (sum of scores 1 to 9) of a typical day. Therefore, activities such as resting in bed, sitting (writing, watching TV, etc.), standing (cooking, washing dishes, etc.), and light manual work (painting, gardening, etc.), in addition to low and high intensity recreational and sports activities, are included in this phenotype. On the other hand, the second phenotype refers to exercise and sports activities (scores 6 to 9), i.e., activities for which the average energy cost is at least about five times greater than the resting metabolic rate. These two indicators of physical activity are fairly similar to the definitions of physical activity and exercise recently presented at a workshop on epidemiologic and public health aspects of physical activity (38). Physical activity was defined as any bodily movement produced by skeletal muscles that results in energy expenditure, while exercise was defined as a subset of physical activity that is planned, structured, and repetitive, and with the objective of improvement or maintenance of physical fitness (39). Therefore, the fact that we found a genetic effect in level of habitual physical activity, but not in exercise participation, suggests that the activities categorized by the scores ranging from 1 to 5 are those probably influenced by heredity. These activities correspond to an important fraction of the total amount of daily physical activities. In a recent study (40), in which energy expenditure was measured in a respiratory chamber in 177 subjects, it was shown that a significant proportion of the variation observed in 24-hour energy expenditure, after adjustment for fat free mass, could be accounted for by spontaneous physical activity. The comparison of the results obtained for the two indicators of the present study leads one to speculate that the intrin-

TABLE 4

Parameter estimates (± standard error) and chi-square values obtained for various hypotheses tested under the BETA model for exercise participation†: greater Québec city families who completed a three-day activity record, 1978–1981

Parameter of the model	Full model	Reduced models‡				
		A	*B*	*C*	*D*	*E*
m	0.16 ± 0.04	0.16 ± 0.04	0.16 ± 0.04	0.16 ± 0.04	0.08 ± 0.05	
β	0.70§	0.66 ± 0.50			0.70§	0.66 ± 0.37
h	0§		0.38 ± 0.05		0.16 ± 0.20	0§
b	0.34 ± 0.03	0.35 ± 0.15			0.50 ± 0.04	0.38 ± 0.13
c	0.27 ± 0.04	0.27 ± 0.12	0.34 ± 0.03	0.35 ± 0.03		0.26 ± 0.11
c_{DZ}	0.73 ± 0.05	0.74 ± 0.18	0.80 ± 0.05	0.76 ± 0.04		0.74 ± 0.16
c_{MZ}	0.70 ± 0.05	0.71 ± 0.18	0.69 ± 0.05	0.74 ± 0.05		0.72 ± 0.15
χ^2 (df‖) goodness of fit	5.10 (2)	5.12 (3)	9.80 (4)*	17.44 (5)**	78.54 (5)**	12.30 (3)**
χ^2 (df) contrast with the full model		0.02 (1)	4.70 (2)	12.34 (3)**	73.44 (3)**	7.10 (1)**

* $p < 0.05$.
** $p \leq 0.01$.
† Data adjusted for age, sex, physical fitness, obesity, and socioeconomic status.
‡ *A*, no genetic effect ($h = 0$); *B*, no cultural inheritance ($\beta = b = 0$); *C*, no transmission between generations ($h = \beta = b = 0$); *D*, no shared sibling environment ($c = c_{DZ} = c_{MZ} = 0$); *E*, no spousal resemblance ($m = 0$).
§ Value fixed at the upper (or lower) limit permitted by the model.
‖ df, degrees of freedom.

TABLE 5

Components of the phenotypic variance in physical activity indicators: greater Québec city families who completed a three-day activity record, 1978–1981*

Variable	Transmissible variance			Environmental variance (e^2)
	Total (t^2)	Biologic (h^2)	Cultural (b^2)	
Level of habitual physical activity				
Full model	0.27	0.20	0.06	0.73
Most parsimonious solution ($\beta = b = 0$)	0.29	0.29	0	0.71
Exercise participation				
Full model	0.12	0	0.12	0.88
Most parsimonious solution ($h = 0$)	0.12	0	0.12	0.88

* Derived from the BETA model of path analysis. Data are adjusted for age, sex, physical fitness, obesity, and socioeconomic status.

sic drive to spontaneous physical activity could be partly influenced by the genotype. In other words, it seems that it is the propensity to be physically active that could be inherited.

The level of habitual physical activity has not been studied extensively in terms of its genetic component of variation, although results from some behavioral genetic studies (41, 42) suggest that persons with active temperaments (persons who are in a hurry, who are "on the go", and who lead fast-paced lives) and persons with vigorous temperaments (persons who like outdoors and sports activities and working with tools) may have partly inherited personality traits (41, 42), although in one study (43), no genetic effect was found for activity (active vs. lack of energy) measured by a self-reported questionnaire. Results from two different twin studies (44, 45) also suggested that activity level of children under 10 years of age was influenced by a significant genetic effect. Interestingly, in one of those studies (44), the genetic effect was significant for the number of activities in which the child was engaged, but not for the type of activity selected. This observation is consistent with our findings that the inclination toward being physically active rather than the type of activity performed is influenced by a genetic effect. The main evidence for a genetic component in the level of habitual physical activity of human subjects has come from a large twin study of data from the Finnish Twin Registry (46) in which physical activity was assessed in 1,537 monozygotic and 3,507 dizygotic male twin pairs aged over 18 years. The physical activity variables derived from the questionnaires (intensity and duration of activity, years of physical training, physical activity on the job, and the subject's own opinion of activity level) were factor analyzed to obtain a factor score of physical activity that was used to compute correlations in monozygotic and dizygotic twin pairs. By means of this procedure, the authors found a significant heritability estimate of 0.62 for general physical activity characteristics, which is an effect higher than the one we observed. However, the measured phenotype was not the same as the one used in this study and the estimated heritability was probably inflated by the limitations generally associated with the use of twin data alone (47).

Unlike the twin method, the technique of path analysis has the advantage of taking into account information from several kinds of relatives to estimate the genetic component of variation. Despite the fact that the hypothesis of no transmission between generations ($h = \beta = b = 0$) was rejected for both indicators of activity, our results (table 5) indicate that the phenotypic variance accounted for by this effect of transmission was relatively moderate (12 per cent $\leq t^2 \leq$ 29 per cent). The most parsimonious solution revealed that this effect of transmission is entirely genetic for the level of habitual physical activity (h^2 = 29 per cent), while it is entirely cultural for exercise participation (b^2 = 12 per cent). The presence of cultural inheritance in exercise participation suggests that children could acquire from their parents the behavior toward exercise, whereas the presence of biologic inheritance in level of habitual physical activity suggest, as mentioned earlier, that the intrinsic drive toward physical activity may be influenced by the genotype. These results also indicate that nontransmissible environmental factors, which were found to account for 71 to 88 per cent of the phenotypic variance (table 5), remained the major affectors of physical activity level. This strong contribution of environmental factors is an indication that changes in the activity level of the population could be achieved by appropriate interventions. Furthermore, the hypotheses of no shared sibling environmental effect and no spousal resemblance were both rejected for the two indicators, suggesting that common familial environment conditions contributed significantly to the variation in physical activity level. These results are in agreement with a recent study (19) in which the presence of a significant familial resemblance has been reported for the activity level assessed in 16,477 subjects who participated in the 1981 Canada Fitness Survey. These studies thus reveal that persons of the same family, whether genetically related or not, may influence each other in physical activity and exercise behaviors, which implies that education programs targeted at the family level would be useful in the promotion of physical activity in the population.

Among the numerous methods that are available to assess physical activity (48–51), activity questionnaires and diaries are probably the most practical ones for use in epidemiologic studies. However, accuracy remains a critical factor in the assessment of physical activity in population studies (50). Results from a recent study (52) that compares physical activity levels from three national surveys have shown that the amount of physical activity reported was dependent on how the question was asked and the type of responses offered as options. The three-day activity record used in this study is a semiquantitative diary (51) and has the advantage of using a simple coding system to determine activity patterns; this method was shown (20) to be as reliable in children ($r = 0.91$) as in adults ($r = 0.97$).

In summary, the use of the BETA model of path analysis has shown that physical activity level was influenced by a significant transmission effect from parents to offspring. For the level of habitual physical activity, a genetic effect of 29 per cent was found, while for exercise participation, a cultural component of inheritance that accounted for 12 per cent of the phenotypic variance was found. The genetic effect observed in level of habitual physical activity was interpreted as an indication of a possible genetic predisposition toward being physically active, while the cultural transmission of exercise participation suggested that children can acquire from their parents the behavior toward exercise. However, nontransmissible environmental factors accounted for most of the variation, with values ranging from 71 per cent to 88 per cent, depending on the model retained. Familial environmental conditions shared by family members were also found to contribute significantly, which suggests that the promotion of physical activity at the family level could be considered a useful strategy for the promotion of participation in physical activity in the population. Further research will be needed to better characterize the determinants of physical activity, but the results presented in this study provide evidence that genetic factors may be involved in a person's intrinsic drive toward being physically active.

References

1. Stephens T, Jacobs DR Jr, White CC. A descriptive epidemiology of leisure-time physical activity. Public Health Rep 1985;100:147–58.
2. Paffenbarger RS Jr, Hyde RT. Exercise in the prevention of coronary heart disease. Prev Med 1984;13:3–22.
3. Powell KE, Thompson PD, Caspersen CJ, et al. Physical activity and the incidence of coronary heart disease. Annu Rev Public Health 1987;253–87.
4. Salonen JT, Slater JS, Tuomilehto J, et al. Leisure time and occupational physical activity: risk of death from ischemic heart disease. Am J Epidemiol 1988;127:87–94.
5. Garrow JS. Effect of exercise on obesity. Acta Med Scand [Suppl] 1986;711:67–73.
6. Tremblay A, Després J-P, Bouchard C. The effects of exercise-training on energy balance and adipose tissue morphology and metabolism. Sports Med 1985;2:223–33.
7. Haskell WL. Exercise-induced changes in plasma lipids and lipoproteins. Prev Med 1984;13:23–36.
8. Aisenbrey JA. Exercise in the prevention and management of osteoporosis. Phys Ther 1987;67:1100–4.
9. Martin AD, Houston CS. Osteoporosis, calcium and physical activity. Can Med Assoc J 1987;136:587–93.
10. Santora II AC. Role of nutrition and exercise in osteoporosis. Am J Med [Suppl] 1982;1B:73–9.
11. Paffenbarger RS Jr, Hyde RT, Wing AL. Physical activity and incidence of cancer in diverse populations: a preliminary report. Am J Clin Nutr 1987;45:312–17.
12. Vena JE, Graham S, Zielezny M, et al. Occupational exercise and risk of cancer. Am J Clin Nutr 1987;45:318–27.
13. Bernstein L, Ross RK, Lobo R, et al. The effects of moderate physical activity on menstrual cycle patterns in adolescence: implications for breast cancer prevention. Br J Cancer 1987;55:681–5.
14. Vranic M, Berger M. Exercise and diabetes mellitus. Diabetes 1979;28:147–67.
15. Zinnman B, Vranic M. Diabetes and exercise. Med Clin North Am 1985;69:145–57.
16. Powell KE, Spain KG, Christenson GM, et al. The status of the 1990 objectives for physical fitness and exercise. Public Health Rep 1986;101:15–21.
17. Dishman RK, Sallis JF, Orenstein DR. The determinants of physical activity and exercise. Public Health Rep 1985;100:158–72.
18. Sallis JF, Haskell WL, Fortmann SP, et al. Predictors of adoption and maintenance of physical activity in a community sample. Prev Med 1986;15:331–41.
19. Pérusse L, Leblanc C, Bouchard C. Familial resemblance in lifestyle components: results from the Canada Fitness Survey. Can J Public Health 1988;79:201–5.
20. Bouchard C, Tremblay A, Leblanc C, et al. A method to assess energy expenditure in children and adults. Am J Clin Nutr 1983;37:461–7.
21. Passmore R, Durnin JVGA. Human energy expenditure. Physiol Rev 1955;35:801–40.
22. Consolazio CF, Johnson RE, Pecora LJ. Physiological measurements of metabolic functions in man. New York: McGraw-Hill, 1963.
23. Durnin JVGA, Passmore R. Energy work and

leisure. London: Heinemann Educational Books, 1967.
24. Groupe d'étude de Kino-Québec sur le système de quantification de la dépense énergétique (GSQ): rapport final. Québec: Gouvernement du Québec, Ministère du Loisir de la Chasse et de la Pêche, 1979.
25. Blishen BR, McRoberts HA. A revised socioeconomic index for occupations in Canada. Can Rev Soc Anthropol 1976;13:71-9.
26. Rao DC, McGue M, Wette R, et al. Path analysis in genetic epidemiology. In: Chakravarti A, ed. Human population genetics: the Pittsburgh Symposium. New York: Van Nostrand Reinhold, 1984:35-81.
27. Donner A. The use of correlations and regression in analysis of family resemblance. Am J Epidemiol 1979;110:335-42.
28. Wright S. Correlation and causation. J Agr Res 1921;20:557-85.
29. Wright S. The method of path coefficients. Ann Math St 1934;5:161-215.
30. Morton NE. Analysis of family resemblance. I. Introduction. Am J Hum Genet 1974;26:318-30.
31. Rao DC, Morton NE, Yee S. Analysis of family resemblance. II. A linear model for familial correlation. Am J Hum Genet 1974;26:331-59.
32. Rao DC, Morton NE, Yee S. Resolution of cultural and biological inheritance by path analysis. Am J Hum Genet 1976;28:228-42.
33. Cloninger CR, Rice J, Reich T. Multifactorial inheritance with cultural transmission and assortative mating. II. A general model of combined polygenic and cultural inheritance. Am J Hum Genet 1979;31:176-98.
34. Rice J. GENLIB: a library of computer programs for the genetic analysis of family data. St. Louis, MO: Washington University, 1981.
35. Kaplan EB, Elston RC. A subroutine package for maximum likelihood estimation (MAXLIK). Institute of Statistics, mimeo series no. 823. Chapel Hill, NC: University of North Carolina, 1972.
36. Rice JC, Cloninger CR, Reich T. Multifactorial inheritance with cultural transmission and assortative mating. I. Description and basic properties of the unitary models. Am J Hum Genet 1978;30:618-43.
37. Kendall MG, Stuart A. The advanced theory of statistics. Vol. 2. Inference and relationship. 3rd ed. New York: Hafner, 1973.
38. Powell KE, Paffenbarger RS Jr. Workshop on epidemiologic and public health aspects of physical activity and exercise: a summary. Public Health Rep 1985;100:118-26.
39. Caspersen CJ, Powell KE, Christensen GM. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. Public Health Rep 1985;100:126-30.
40. Ravussin E, Lillioja S, Anderson TE, et al. Determinants of 24-hour energy expenditure in man. Methods and results using a respiratory chamber. J Clin Invest 1986;78:1568-78.
41. Vandenberg SG. The hereditary abilities study: hereditary components in a psychological test battery. Am J Hum Genet 1962;14:220-37.
42. Loehlin JC. Heredity, environment and the Thurstone temperament schedule. Behav Genet 1986;16:61-73.
43. Price RA, Vandenberg SG, Iyer H, et al. Components of variation in normal personality. J Pers Soc Psychol 1982;43:328-40.
44. Scarr S. Genetic factors in activity motivation. Child Dev 1966;37:663-71.
45. Willerman L. Activity level and hyperactivity in twins. Child Dev 1973;44:288-93.
46. Kaprio J, Koskenvuo M, Sarna S. Cigarette smoking, use of alcohol, and leisure-time physical activity among same-sexed adult male twins. In: Gedda L, Parisi P, Nance WE, eds. Progress in clinical and biological research. Twin research 3: epidemiological and clinical studies. New York: Alan R. Liss, 1981:37-46.
47. Bouchard C, Malina RM. Genetics for the sport scientist: selected methodological considerations. Exerc Sport Sci Rev 1983;11:275-305.
48. Montoye HJ, Taylor HL. Measurement of physical activity in population studies: a review. Hum Biol 1984;56:195-216.
49. Saris WHM. The assessment and evaluation of daily physical activity in children. A review. Acta Paediatr Scand [Suppl] 1985;318:37-48.
50. LaPorte RE, Montoye HJ, Caspersen CJ. Assessment of physical activity in epidemiologic research: problems and prospects. Public Health Rep 1985;100:131-46.
51. Tremblay A, Bouchard C. Assessment of energy expenditure and physical activity pattern in population studies. In: Johnston FE, ed. Nutritional anthropology. New York: Alan R. Liss, 1987:101-16.
52. Slater CH, Green LW, Vernon SW, et al. Problems in estimating the prevalence of physical activity from national surveys. Prev Med 1987;16:107-18.