

Familial Aggregation of 7-Year Changes in Musculoskeletal Fitness

Peter T. Katzmarzyk,¹ Norman Gledhill,¹ Louis Pérusse,² and Claude Bouchard³

¹School of Kinesiology and Health Science, York University, Toronto, Ontario, Canada.

²Division of Kinesiology, Department of Preventive Medicine, Laval University, Ste-Foy, Quebec, Canada.

³Pennington Biomedical Research Center, Louisiana State University, Baton Rouge.

The purpose of this study was to determine the degree of familial resemblance in baseline and 7-year changes in musculoskeletal fitness. Data from the 1981 Canada Fitness Survey and the Campbell's Survey 7-year follow-up were used. The sample consisted of 1264 people (635 males and 629 females) between the ages of 7 and 69 years for whom measurements of musculoskeletal fitness were available at baseline. A subsample of 834 people had measurements at both baseline and 7-year follow-up. Sit-and-reach trunk flexibility, number of push-ups without time limit, number of sit-ups in 60 seconds, and hand-grip strength were used as indicators of musculoskeletal fitness. The data were adjusted for the effects of age and body mass index (and baseline level of the variable for changes) by using regression procedures, and they were standardized to zero mean and unit variance within each of the four sex-by-generation groups (fathers, mothers, sons, and daughters). Familial correlation models were fitted to the data by using the computer software SEGPATH. The results indicate significant familial resemblance for all indicators of musculoskeletal fitness for baseline measures and 7-year changes. The heritabilities, or the percentages of the total variance attributable to heredity, were 64% for trunk flexibility, 37% for push-ups, 59% for sit-ups, and 48% for grip strength. Similarly, heritabilities for the change scores were 48% for trunk flexibility, 52% for push-ups, 41% for sit-ups, and 32% for grip strength. The results suggest that familial, and perhaps genetic, factors are important in explaining the variance in musculoskeletal fitness not only cross-sectionally but also for changes over time.

MUSCULOSKELETAL fitness refers to those components of fitness that are related to flexibility, muscular strength, muscular power, and muscular endurance. Musculoskeletal fitness is positively related to health status across the life span (1,2) and to functional ability in the elderly population (3,4). In general, levels of musculoskeletal fitness tend to decline over the life span (5,6); however, there is considerable individual variability in changes over time (5). Thus, it is important to understand the determinants of musculoskeletal fitness as well as the determinants of changes that occur with aging.

Most phenotypes, or traits, are influenced by both genetic and environmental factors to varying degrees. The total phenotypic variability (V_P) in a given trait can be modeled as having genetic (V_G), environmental (V_E), and genotype-environment interaction ($V_{G \times E}$) components, in addition (7) to unmeasured residual error (e): $V_P = V_G + V_E + V_{G \times E} + e$. The heritability of a trait is defined as the proportion of the total phenotypic variance that can be attributed to genetic factors (i.e., $h^2 = V_G/V_P$), and estimates are typically derived from studies of nuclear families, monozygotic (MZ) and dizygotic (DZ) twin pairs, and extended family pedigrees.

The results of several studies have suggested that indicators of musculoskeletal fitness, such as those used in the

present study (grip strength, push-ups, sit-ups, and sit-and-reach trunk flexibility) are influenced by genetic factors (8). Family studies (9–14), studies of twins (15–19), and mixed designs (20) have all shown that indicators of musculoskeletal fitness are inherited characteristics, although estimates of heritability vary from measurement to measurement.

The available evidence for a genetic component to musculoskeletal fitness comes from cross-sectional studies of families and twins. We know of no published studies related to the heritability of *changes* in musculoskeletal fitness over time. Given the dearth of information regarding the genetics of age-related changes in musculoskeletal fitness, the purpose of this study was to determine the degree of familial resemblance in baseline and 7-year changes in musculoskeletal fitness. The 1988 Campbell's Survey database, which was a longitudinal follow-up of the 1981 Canada Fitness Survey, was used to address the aims of the study.

METHODS

Sample

The Campbell's Survey was a 7-year longitudinal follow-up to the 1981 Canada Fitness Survey (CFS) and contains information on 4345 individuals ranging in age from 7 to 69

years. The original CFS sample was selected by Statistics Canada to be representative of the Canadian population and contains information on individuals from urban and rural areas of every province (21). Data collection revolved around households, and the first person to be contacted by the CFS team was designated as the reference person. All individuals in the household were then identified by their relationship to the reference person. Thus, the family structures of the entire sample could be reconstructed from this information.

The present sample is limited to nuclear families with at least two biologically related individuals (mothers, fathers, sons, or daughters), which yielded a total of 1264 people (635 males and 629 females) for whom measurements of musculoskeletal fitness in 1981 (baseline) were available in the Campbell's Survey database. The sample was distributed among 502 nuclear families, with an average family size of 2.75 people. A subsample of 834 people had measurements of musculoskeletal fitness at both baseline and follow-up, which was used for the longitudinal analyses. The smaller sample size for the longitudinal analyses resulted because many participants did not complete the musculoskeletal measurements at the second visit; rather they had only anthropometric or questionnaire data available. This may introduce some bias into the change scores if it was those people that decreased in fitness the most that did not complete the second fitness assessment. Although this question cannot be answered, there were no significant differences between the two groups at baseline.

Measurements

All measurements were made following the standardized procedures of the CFS (22). Stature and body mass were measured to the nearest millimeter and 0.1 kg, respectively, and the body mass index (BMI; kg/m^2) was calculated. Hand-grip strength was measured with a Stoelting adjustable dynamometer (C.H. Stoelting Co., Chicago, IL). Participants held the dynamometer at the level of the thigh in line with the forearm and were instructed to squeeze vigorously to exert maximum force. Maximal grip strengths of two trials for the left and right hands were summed to provide a single measure of grip strength (kg). The number of push-ups completed without time limit (n) and the number of sit-ups performed in 60 seconds (n/min) were used as indicators of muscular endurance. Participants performed sit-ups from the supine position, with their fingers behind their ears, their ankles held, and their knees flexed 90° . A complete sit-up required touching the knees to the elbows. For push-ups, males balanced from the toes, whereas females balanced from the knees. Each push-up required a cycle of straightening of the elbows to the chin touching the floor, with a straight back. Finally, a sit-and-reach test was used to assess trunk flexibility. Participants reached toward their toes, with their knees flat on the floor. The test was repeated twice, with the maximum value recorded to the nearest 0.5 cm. A trunk flexibility score of 25 cm is equivalent to touching the floor.

Data Adjustments

Baseline values and changes in the musculoskeletal fitness measures were adjusted for the effects of age and BMI in both the mean and variance by using SAS regression pro-

cedures (23), as explained in detail elsewhere (24). Briefly, each measure was regressed on BMI and up to a cubic polynomial in age (age, age^2 , age^3) by using forward stepwise regression (mean regression) retaining terms significant at the 5% level, within sex-by-generation groups (mothers, fathers, sons, and daughters). The change scores (Δ) were further adjusted for the effects of ΔBMI and the baseline level of the phenotype. The residuals from the mean regressions were retained and regressed on BMI and up to a cubic polynomial in age (variance regression) in a forward stepwise manner to test for heteroscedasticity. Heteroscedasticity was present if any of the predictor variables entered the variance regression at the 5% level of significance. In the presence of significant heteroscedasticity, the final phenotype was calculated as the residual from the mean regression divided by the square root of the predicted score from the variance regression. In the absence of heteroscedasticity, the residual from the mean regression was used as the final phenotype. The final phenotypes were standardized to a mean of zero and unit variance within sex-by-generation groups (mothers, fathers, sons, and daughters) prior to further analysis.

Familial Correlation Model

As a test of familial aggregation in the measures of musculoskeletal fitness, an analysis of variance (ANOVA) was used to compare the between-family to within-family variances, using the family identification number as the dependent variable. Hypotheses regarding familial resemblance in musculoskeletal fitness were then tested by using the computer program SEGPATH (25). Familial correlation models were fitted directly to the data under the assumption that the family data follow a multivariate normal distribution. The sex-specific correlation model was based on four types of relatives: fathers (F), mothers (M), sons (S), and daughters (D), giving rise to eight familial correlations (one spouse, FM; four parent-offspring, FS, MS, FD, and MD; and three sibling, SS, DD, SD). A series of nested (reduced) models were compared with a general model in which all parameters were estimated by using tests of the maximum-likelihood ratio, defined as the difference in minus twice the log likelihood ($-2 \ln L$). Asymptotically, the log-likelihood ratio follows a χ^2 distribution with degrees of freedom equal to the difference in the number of parameters estimated under the two hypotheses (26). Null hypotheses concerning the strength of the familial resemblance included no familial resemblance ($\text{FM} = \text{FS} = \text{FD} = \text{MS} = \text{MD} = \text{SD} = \text{SS} = \text{DD} = 0$), no sibling resemblance ($\text{SD} = \text{SS} = \text{DD} = 0$), no parent-offspring resemblance ($\text{FS} = \text{FD} = \text{MS} = \text{MD} = 0$), and no spousal resemblance ($\text{FM} = 0$). A series of null hypotheses, including no sex differences in offspring ($\text{FS} = \text{FD}$, $\text{MS} = \text{MD}$, $\text{SS} = \text{DD} = \text{SD}$), no sex differences in offspring or parents ($\text{FS} = \text{FD} = \text{MS} = \text{MD}$, $\text{SS} = \text{DD} = \text{SD}$), and no sex or generation differences ($\text{FS} = \text{FD} = \text{MS} = \text{MD} = \text{SS} = \text{DD} = \text{SD}$), and all correlations being equal ($\text{FM} = \text{FS} = \text{FD} = \text{MS} = \text{MD} = \text{SS} = \text{DD} = \text{SD}$) were also tested.

Akaike's information criterion (AIC), defined as $-2 \ln L$ plus twice the number of parameters estimated, was used to judge the fit of the models (27). The model with the lowest

Table 1. Descriptive Statistics for Fathers, Mothers, Sons, and Daughters for Baseline Measures and 7-year Changes (Δ)

| Parameter | <i>n</i> | Mean | <i>SD</i> | <i>n</i> | Mean | <i>SD</i> |
|--------------------------------------|----------|-------|-----------|----------|------|-----------|
| | | | Fathers | | | |
| Age (y) | 368 | 38.2 | 10.2 | 267 | 12.4 | 5.3 |
| Body mass index (kg/m ²) | 366 | 25.2 | 3.3 | 266 | 18.6 | 3.1 |
| Grip strength (kg) | 368 | 105.0 | 16.9 | 267 | 55.8 | 28.7 |
| Δ Grip strength (kg) | 224 | -7.9 | 12.0 | 200 | 36.5 | 22.1 |
| Trunk flexibility (cm) | 359 | 27.4 | 9.3 | 267 | 27.0 | 7.6 |
| Δ Trunk flexibility (cm) | 217 | -3.0 | 5.2 | 200 | 0.4 | 7.6 |
| Push-ups (<i>n</i>) | 353 | 17.9 | 10.3 | 257 | 15.7 | 11.1 |
| Δ Push-ups (<i>n</i>) | 214 | -3.8 | 8.0 | 193 | 7.9 | 14.5 |
| Sit-ups (<i>n</i>) | 351 | 26.2 | 9.7 | 263 | 33.8 | 11.1 |
| Δ Sit-ups (<i>n</i>) | 214 | -6.0 | 8.3 | 196 | 2.6 | 11.4 |
| | | | Mothers | | | |
| Age (y) | 401 | 36.2 | 9.5 | 228 | 12.1 | 5.7 |
| Body mass index (kg/m ²) | 401 | 22.9 | 3.6 | 228 | 18.7 | 3.7 |
| Grip strength (kg) | 401 | 61.7 | 10.7 | 228 | 40.6 | 14.4 |
| Δ Grip strength (kg) | 259 | -5.8 | 9.4 | 151 | 15.6 | 14.2 |
| Trunk flexibility (cm) | 391 | 31.2 | 7.9 | 228 | 31.3 | 6.8 |
| Δ Trunk flexibility (cm) | 251 | -2.3 | 6.0 | 150 | 1.7 | 6.3 |
| Push-ups (<i>n</i>) | 380 | 15.8 | 10.1 | 223 | 19.0 | 12.4 |
| Δ Push-ups (<i>n</i>) | 242 | -4.2 | 10.2 | 148 | -1.0 | 13.9 |
| Sit-ups (<i>n</i>) | 372 | 19.1 | 10.1 | 225 | 29.1 | 10.3 |
| Δ Sit-ups (<i>n</i>) | 233 | -3.8 | 8.2 | 150 | -0.6 | 11.3 |
| | | | Daughters | | | |

AIC is the best fitting, or most parsimonious. The best-fitting model for each phenotype was derived by combining all nonrejected hypotheses, and the combination with the lowest AIC was selected.

RESULTS

The descriptive characteristics of the sample are presented in Table 1. The mean ages of the fathers and mothers were 38.2 years and 36.2 years, respectively, and the mean ages of the sons and daughters were 12.4 years and 12.1 years, respectively. The parents, on average, had decreases in grip strength, trunk flexibility, push-ups, and sit-ups over the 7 years, whereas the sons had a mean increase in all measures. The daughters had mean increases in grip strength and trunk flexibility, and small decreases in push-ups and sit-ups. Table 2 presents the results of the data-adjustment procedures. Age, age², age³, and BMI accounted for up to 82% of the variability in the baseline measures, whereas age, age², age³, Δ BMI, and baseline values of the phenotype accounted for between 5.9% and 62.4% of the variance in the change scores. Heteroscedastic effects were minor, accounting for between 0.8% and 9.9% of the variance in 9 of the 32 regressions.

The ANOVA results (Table 3) indicate that there was ap-

Table 2. Results of Forward Stepwise Regression Data-Adjustment Procedures for Baseline Measures and 7-year Changes (Δ)

| Parameter | | Mean Regression | | Variance Regression | |
|----------------------------|-----------|---|------|-----------------------------|-----|
| | | Terms | % | Terms | % |
| Grip strength | Fathers | age ³ , BMI | 18.7 | none | — |
| | Mothers | age ³ , BMI | 10.1 | none | — |
| | Sons | age, age ² , BMI | 82.0 | age, age ² | 9.9 |
| | Daughters | age, age ² , age ³ , BMI | 76.3 | BMI | 3.9 |
| Δ Grip strength | Fathers | age ² , Δ BMI, grip strength | 21.4 | none | — |
| | Mothers | age, Δ BMI, grip strength | 15.1 | grip strength | 3.1 |
| | Sons | age, Δ BMI, grip strength | 52.1 | none | — |
| | Daughters | age, age ² , Δ BMI | 62.4 | none | — |
| Trunk flexibility | Fathers | age | 10.3 | none | — |
| | Mothers | age ³ | 1.7 | none | — |
| | Sons | none | — | none | — |
| | Daughters | none | — | none | — |
| Δ Trunk flexibility | Fathers | age ² , Δ BMI, flexibility | 17.7 | none | — |
| | Mothers | age, age ³ , Δ BMI, flexibility | 15.3 | flexibility | 1.5 |
| | Sons | flexibility | 11.3 | none | — |
| | Daughters | flexibility | 4.6 | Δ BMI, flexibility | — |
| Push-ups | Fathers | age, age ² , BMI | 26.5 | age | 0.8 |
| | Mothers | age, age ² | 8.5 | none | — |
| | Sons | age, age ² | 28.4 | age | 3.4 |
| | Daughters | age | 4.3 | none | — |
| Δ Push-ups | Fathers | age, Δ BMI, push-ups | 15.2 | age ³ , push-ups | 4.4 |
| | Mothers | age ² , push-ups | 44.0 | age ³ | 3.0 |
| | Sons | push-ups | 32.3 | none | — |
| | Daughters | age ³ , push-ups | 38.4 | none | — |
| Sit-ups | Fathers | age, BMI | 43.4 | age | 0.9 |
| | Mothers | age, BMI | 37.9 | none | — |
| | Sons | age, age ² , age ³ , BMI | 22.3 | none | — |
| | Daughters | none | — | none | — |
| Δ Sit-ups | Fathers | age ³ , Δ BMI, sit-ups | 5.9 | none | — |
| | Mothers | age, Δ BMI, sit-ups | 16.6 | none | — |
| | Sons | age, sit-ups | 40.1 | none | — |
| | Daughters | age ³ , Δ BMI, sit-ups | 34.0 | none | — |

Note: BMI = body mass index.

Table 3. Familial Aggregation of Baseline and 7-year Changes (Δ) in Musculoskeletal Fitness Measures, Demonstrated by ANOVA

| Parameter | <i>F</i> | <i>R</i> ² | <i>P</i> |
|----------------------------|----------|-----------------------|----------|
| Grip strength | 1.41 | 0.48 | <0.0001 |
| Δ Grip strength | 1.41 | 0.58 | <0.0001 |
| Trunk flexibility | 1.83 | 0.55 | <0.0001 |
| Δ Trunk flexibility | 1.68 | 0.63 | <0.0001 |
| Push-ups | 1.64 | 0.53 | <0.0001 |
| Δ Push-ups | 1.18 | 0.54 | 0.05 |
| Sit-ups | 2.08 | 0.59 | <0.0001 |
| Δ Sit-ups | 1.43 | 0.59 | 0.0002 |

Notes: *F* is the ratio of between-family to within-family variance. ANOVA = analysis of variance.

proximately 40–100% more variance between families than within families, based on an examination of the *F* ratios. The dependent variable, which in this case was family membership (family identification number), accounted for between 48% and 59% of the variance in adjusted baseline measures and between 54% and 63% of the adjusted 7-year changes. Thus, indicators of musculoskeletal fitness aggregate significantly within the families of the CFS.

The results of the familial correlation model fitting procedures are presented in Table 4 for the baseline measures and in Table 5 for the 7-year changes. The hypothesis of no familial resemblance is strongly rejected for all phenotypes, indicating that there is indeed familial resemblance in musculoskeletal fitness both cross-sectionally and longitudinally, confirming the ANOVA results. For grip strength, trunk flexibility, and somewhat for push-ups, the pattern of no spousal resemblance coupled with significant sibling and parent-offspring resemblance suggests the role of genes in explaining a portion of the familial resemblance. In contrast, the significant spousal resemblance in addition to sibling and parent-offspring resemblance for sit-ups suggests that shared environmental factors are important in explaining this familial resemblance.

The significant familial resemblance in 7-year changes in trunk flexibility and sit-ups could be explained partially by shared environmental effects, as there is significant spousal resemblance in addition to sibling or parent-offspring resemblance (Table 5). However, genetic factors may be more important in explaining changes in grip strength and push-ups, as the hypothesis of no spousal resemblance was not rejected, whereas hypotheses regarding no sibling and parent-offspring resemblance were strongly rejected.

Table 6 presents the estimates of the familial correlations under the most parsimonious models along with the heritability estimates. Heritabilities were 64% for trunk flexibility, 37% for push-ups, 59% for sit-ups, and 48% for grip strength. Similarly, heritabilities for the change scores were 48% for trunk flexibility, 52% for push-ups, 41% for sit-ups, and 32% for grip strength.

DISCUSSION

The present investigation distinguishes itself from previous studies of the familial resemblance in musculoskeletal fitness by its longitudinal design. Unfortunately, the apparent lack of previous longitudinal genetic analyses of musculoskeletal fitness prevents the comparison of our results with those of others. However, the cross-sectional heritability estimates obtained in the present study compare well with transmissibility estimates (from a tau path analysis) obtained by Pérusse and colleagues (13) for the original CFS sample ($n = 13,804$). Estimates of the transmissibility from parents to offspring through both biological and cultural paths for trunk flexibility, push-ups, sit-ups, and grip strength were 48%, 44%, 37%, and 37%, respectively (13). Thus, we have provided consistent evidence that musculoskeletal fitness aggregates within the families of the original CFS, a representative sample of the population.

Several studies have investigated familial resemblance in muscular strength and endurance cross-sectionally by using both family and twin-study designs. Twin studies generally produce higher estimates of heritability than family studies. An earlier twin study by Engström and Fischbein (16) dem-

Table 4. Summary of Results of Hypothesis Tests for Baseline Musculoskeletal Fitness Measures

| Parameter | Grip Strength | | Trunk Flexibility | | Push-ups | | Sit-ups | |
|---|---------------|-------|-------------------|-------|------------|-------|------------|--------|
| | <i>p</i> * | AIC† | <i>p</i> * | AIC† | <i>p</i> * | AIC† | <i>p</i> * | AIC† |
| 1. General model | | 24.00 | | 24.00 | | 24.00 | | 24.00 |
| 2. No sex differences in offspring | 0.28 | 21.03 | 0.94 | 16.81 | 0.02 | 27.31 | 0.59 | 18.84 |
| 3. No sex differences in offspring or parents | 0.41 | 19.04 | 0.96 | 15.04 | 0.001 | 34.22 | 0.13 | 22.52 |
| 4. No sex or generation differences | 0.54 | 17.05 | 0.98 | 13.08 | 0.001 | 33.94 | 0.06 | 24.30 |
| 5. All correlations equal (environmental model) | 0.003 | 31.68 | 0.003 | 31.57 | 0.0005 | 36.11 | 0.07 | 22.92 |
| 6. No sibling resemblance | 0.0009 | 34.49 | <0.0001 | 50.34 | <0.0001 | 44.60 | <0.0001 | 56.52 |
| 7. No parent-offspring resemblance | <0.0001 | 53.34 | <0.0001 | 66.67 | <0.0001 | 57.54 | <0.0001 | 45.36 |
| 8. No spouse resemblance | 0.78 | 22.08 | 0.17 | 23.86 | 0.04 | 26.13 | <0.0001 | 53.44 |
| 9. No familial resemblance | <0.0001 | 60.48 | <0.0001 | 89.20 | <0.0001 | 78.51 | <0.0001 | 102.57 |
| 10. Most parsimonious model | | | | | | | | |
| General model | | | | | —/— | 24.00 | | |
| Models 4 and 8 | 0.64 | 15.13 | 0.88 | 13.06 | | | | |
| Model 2 | | | | | | | 0.59 | 18.84 |

**p* from the likelihood ratio χ^2 test; a significant value ($p < .05$) indicates rejection of the hypothesis.

†AIC = Akaike's information criterion; the most parsimonious model is the one with the smallest AIC; we subtracted ($-2 \ln L$) under the general model from the AIC of all the submodels for easy comparison.

Table 5. Summary of Results of Hypothesis Tests for 7-year Changes (Δ) in Musculoskeletal Fitness Measures

| Parameter | Δ Grip Strength | | Δ Trunk Flexibility | | Δ Push-ups | | Δ Sit-ups | |
|---|------------------------|------------------|----------------------------|------------------|-------------------|------------------|------------------|------------------|
| | p^* | AIC [†] | p^* | AIC [†] | p^* | AIC [†] | p^* | AIC [†] |
| 1. General model | | 24.00 | | 24.00 | | 24.00 | | 24.00 |
| 2. No sex differences in offspring | 0.001 | 33.76 | 0.08 | 25.13 | 0.20 | 22.04 | 0.49 | 19.45 |
| 3. No sex differences in offspring or parents | 0.002 | 33.13 | 0.10 | 25.24 | 0.07 | 24.33 | 0.63 | 17.45 |
| 4. No sex or generation differences | 0.004 | 31.16 | 0.12 | 22.06 | 0.06 | 24.16 | 0.61 | 16.53 |
| 5. All correlations equal (environmental model) | 0.007 | 29.28 | 0.17 | 20.31 | <0.0001 | 51.81 | 0.72 | 14.55 |
| 6. No sibling resemblance | 0.0009 | 34.40 | 0.0001 | 39.11 | <0.0001 | 43.62 | 0.10 | 24.16 |
| 7. No parent-offspring resemblance | 0.03 | 26.64 | 0.0002 | 37.75 | <0.0001 | 44.20 | 0.002 | 32.62 |
| 8. No spouse resemblance | 0.07 | 25.35 | 0.0003 | 35.05 | 0.07 | 25.29 | 0.003 | 31.03 |
| 9. No familial resemblance | 0.0002 | 38.39 | <0.0001 | 56.38 | <0.0001 | 62.71 | <0.0001 | 41.07 |
| 10. Most parsimonious model | | | | | | | | |
| General model | —/— | 24.00 | | | | | | |
| Model 5 | | | 0.17 | 20.31 | | | 0.72 | 14.55 |
| Model 2 | | | | | 0.20 | 22.04 | | |

* p from the likelihood ratio χ^2 test; a significant value ($p < .05$) indicates rejection of the hypothesis.

[†]AIC = Akaike's information criterion; the most parsimonious model is the one with the smallest AIC; we subtracted ($-2 \ln L$) under the general model from the AIC of all the submodels for easy comparison.

onstrated an F ratio of 4.28 between DZ and MZ twins for an aggregate measure of muscular strength, adjusted for body height. A more recent analysis of 10-year-old twins estimated that 65% and 72% of the variance in trunk strength and static arm-pull strength, respectively, are attributable to genes (17). In contrast, estimates of genetic heritability from the Québec Family Study (in which it was possible to distinguish between the genetic and cultural transmission) were 30% for muscular strength and 21% for muscular endurance, whereas cultural inheritance accounted for an additional 31% and 33% of the variance, respectively (14).

Estimates of transmissibility from parents to offspring for both dominant grip strength and trunk flexibility in a sample of Mennonite families were 0% and 66%, respectively (12). There was, however, significant sibling resemblance in dominant hand-grip strength that was almost completely explained by shared environmental effects. The zero transmissibility for dominant hand-grip strength is difficult to explain, as it goes against uniformly high estimates of heritability in other studies (8,14). Indeed, in the present study

there was both significant sibling resemblance and parent-offspring resemblance in grip strength, coupled with no spousal resemblance (Table 4), which suggests that genes are responsible for explaining a portion of the familial resemblance in grip strength.

Flexibility is a joint-specific characteristic, and it is related to joint morphology. Indeed, the International Consensus Document on Physical Activity, Fitness and Health includes flexibility in the "morphological" component of health-related fitness (28). Thus, the relatively high estimates of heritability for sit-and-reach flexibility obtained in this study could partially be explained by the influence of genes on the morphology (bones, tendons, and ligaments) of the hip joint.

In summary, this study found significant familial resemblance for measures of musculoskeletal fitness, both cross-sectionally and longitudinally, in the Canadian population. The finding of significant heritability for changes in musculoskeletal fitness over time suggests that there may be a genetic susceptibility to the functional decline that is observed with age. In contrast, approximately 40–70% of the vari-

Table 6. Estimates of Familial Correlations and Maximal Heritabilities Under the Most Parsimonious Model for Baseline and 7-year Changes in Musculoskeletal Fitness Measures

| Parameter | Grip Strength | | Trunk Flexibility | | Push-ups | | Sit-ups | |
|-------------------|-------------------|------------------|-------------------|-------------------|------------------|------------------|-------------------|-------------------|
| | Baseline | 7-y Change | Baseline | 7-y Change | Baseline | 7-y Change | Baseline | 7-y Change |
| FM | [0.00] | 0.16 \pm 0.08 | [0.00] | 0.27 \pm 0.04 | 0.12 \pm 0.06 | [0.00] | 0.32 \pm 0.05 | 0.22 \pm 0.04 |
| FS | 0.24 \pm 0.03 | 0.04 \pm 0.13 | 0.32 \pm 0.03 | [0.27 \pm 0.04] | −0.03 \pm 0.11 | 0.07 \pm 0.31 | 0.37 \pm 0.06 | [0.22 \pm 0.04] |
| MS | [0.24 \pm 0.03] | −0.06 \pm 0.11 | [0.32 \pm 0.03] | [0.27 \pm 0.04] | 0.22 \pm 0.07 | 0.38 \pm 0.10 | 0.17 \pm 0.06 | [0.22 \pm 0.04] |
| FD | [0.24 \pm 0.03] | 0.39 \pm 0.12 | [0.32 \pm 0.03] | [0.27 \pm 0.04] | 0.18 \pm 0.09 | −0.34 \pm 0.21 | [0.37 \pm 0.06] | [0.22 \pm 0.04] |
| MD | [0.24 \pm 0.03] | 0.22 \pm 0.11 | [0.32 \pm 0.03] | [0.27 \pm 0.04] | 0.45 \pm 0.06 | 0.42 \pm 0.09 | [0.17 \pm 0.06] | [0.22 \pm 0.04] |
| SD | [0.24 \pm 0.03] | −0.11 \pm 0.11 | [0.32 \pm 0.03] | [0.27 \pm 0.04] | 0.34 \pm 0.07 | 0.54 \pm 0.10 | 0.40 \pm 0.06 | [0.22 \pm 0.04] |
| SS | [0.24 \pm 0.03] | 0.39 \pm 0.09 | [0.32 \pm 0.03] | [0.27 \pm 0.04] | 0.29 \pm 0.12 | 0.14 \pm 0.16 | [0.40 \pm 0.06] | [0.22 \pm 0.04] |
| DD | [0.24 \pm 0.03] | 0.25 \pm 0.25 | [0.32 \pm 0.03] | [0.27 \pm 0.04] | 0.17 \pm 0.13 | 0.48 \pm 0.15 | [0.40 \pm 0.06] | [0.22 \pm 0.04] |
| Max. Heritability | 48% | 32% | 64% | 48% | 37% | 52% | 59% | 41% |

Notes: Estimates of familial correlations are $\pm SE$; values in brackets are fixed or equal to a preceding value; the maximal heritability is computed as $(r_{\text{sub}} + r_{\text{p-o}})/(1 + r_{\text{spouse}} + 2r_{\text{spouse p-o}})$. FM = father–mother; FS = father–son; MS = mother–son; FD = father–daughter; MD = mother–daughter; SD = son–daughter; SS = son–son; DD = daughter–daughter.

ance was unaccounted for, depending on the particular phenotype, which indicates that measures of musculoskeletal fitness are not fixed but rather modifiable characteristics. Recent North American physical activity recommendations encourage strength-developing activities (resistance training) as a component of habitual physical activity (29,30). Taken together, these results and recommendations suggest that lifestyle factors such as physical activity are important in maintaining fitness levels over time, but they must be viewed against the background of genetic susceptibility.

Although we have shown strong evidence for familial resemblance in changes in musculoskeletal fitness in the Canadian population, these analyses should be replicated in other populations to demonstrate the robustness of the results. The finding of significant familial aggregation indicates the need for molecular genetic studies aimed at identifying specific genes that are related to changes in musculoskeletal fitness. Additionally, there is a need for more refined analyses of household characteristics that may influence the observed familial aggregation.

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Address correspondence to Dr. Peter T. Katzmarzyk, School of Kinesiology and Health Science, York University, 4700 Keele Street, North York, Ontario M3J 1P3, Canada. E-mail: katzmarz@yorku.ca

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