Genetic Effects on Physical Activity: Results from the Swedish Twin Registry

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ABSTRACT

CARLSSON, S., T. ANDERSSON, P. LICHTENSTEIN, K. MICHAËLSSON, and A. AHLBOM. Genetic Effects on Physical Activity: Results from the Swedish Twin Registry. *Med. Sci. Sports Exerc.*, Vol. 38, No. 8, pp. 1396–1401, 2006. **Purpose:** The aim of this study was to investigate the genetic effects on leisure-time physical activity using data from the Swedish Twin Registry. **Methods:** We investigated 13,362 twin pairs (5334 monozygotic and 8028 dizygotic pairs) aged 14–46 yr. Information on leisure-time physical activity was obtained by questionnaire. Correlations and odds ratios of physical activity were calculated for males, females, and monozygotic and dizygotic twins, respectively. Structural equation modeling was used to estimate the contribution of genetic effects as well as common and nonshared environmental factors on leisure-time physical activity. **Results:** About one third of the twins reported that they exercised regularly (26% in females and 39% in males). The correlations of physical activity were twice as high in monozygotic compared with dizygotic twins, suggesting the presence of genetic effects. The variation in physical activity due to heritage was 57% (95% confidence interval (CI) = 0.49–0.63) in males and 50% (95% CI = 0.49–0.55) in females. The common environmental influence on physical activity was very small compared with the influence from environmental factors unique to the individual. **Conclusions:** Our study establishes heredity as an important component behind individual differences in physical activity in adult men and women. This may be one reason behind difficulties in convincing people to adopt an active lifestyle. Still, this study shows that there is a substantial influence on physical activity from environmental factors unique to the individual. **Key Words:** EPIDEMIOLOGY, HEREDITY, MEN, WOMEN

Despite growing evidence of major beneficial health effects and public health recommendations, many adults do not exercise regularly. According to recent publications, the prevalence of a sedentary lifestyle in the European Union ranges from about 40% in Sweden to almost 90% in Portugal (20). The development of health promotion strategies to increase physical activity in adults may be improved by better knowledge about the determinants of physical activity.

It has been shown that the level of physical activity that people engage in during their leisure time is influenced by social, demographic, psychological, and physiological factors (7,17,20). Evidence from a fairly small number of family and twin studies suggests that genetic factors also influence physical activity (reviewed in Frederiksen and Christensen (5)). However, the magnitude of this influence is not clear; previous studies suggest that genetic effects explain a small, 29% in the Quebec family study (15), to moderately large, 62% in the Finnish Twin Cohort (6), part of the individual variation in mean physical activity levels. Data in adolescents suggest that the genetic component to physical activity is stronger in men than in women (2,3,11). Whether this holds true in adults is not known. Previous studies were based on men (6,9) or analyzed men and women together (5,15) so there is little gender-specific information and no data on females separately. It has been suggested that the genetic component is most important for vigorous physical activity (6,9), but few studies have addressed the respective genetic effects on high and low level of physical activity.

Twins offer a natural study population for genetic epidemiology because monozygotic (MZ) twins are genetically identical, whereas dizygotic (DZ) twins, like ordinary siblings,

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share half of their segregating genes. Thus, by comparing concordance of physical activity between DZ and MZ twin pairs, the magnitude of genetic effects can be investigated. In contrast to family studies, it is possible to disentangle the familial pattern into hereditary or environmental factors. The Swedish Twin Registry is currently the largest in the world and provides a unique opportunity for evaluating genetic factors (10). The aim of this study was to investigate the genetic effects on physical activity using this data base.

METHODS

The Swedish Twin Registry. The Swedish Twin Registry includes three cohorts collected in slightly different ways. The analyses of this study were based on the middle cohort, which was established in 1970. This cohort includes all twins born from 1926 through 1958 who were alive and living in Sweden in 1970 (12). In 1972, all same-sexed pairs received a questionnaire including questions on lifestyle factors such as physical activity. Reponses that allowed a determination of zygosity were received from 16,120 pairs: 2,936 MZ male pairs; 3,337 MZ female pairs; 4,833 DZ male pairs; and 5,014 DZ female pairs. The response rate was 88%. The analyses of this study are based on data from the 13,362 twin pairs with complete information on physical activity. The Swedish Twin Registry has been approved by both the data inspection and the ethical committees at Karolinska Institutet.

Zygosity. Zygosity of twins (MZ, DZ, and unclassified) was classified based on the question: ''Were you as children as alike as two peas in a pod?'' When both twins answered affirmatively, they were defined as MZ, and when both answered no, they were defined as DZ. This method has been proven to correctly classify more than 95% of the twins (10).

Physical activity. Information on physical activity was collected by a question on average physical activity during leisure time in the past year, with seven response options ranging from ''almost never'' to ''exercise very much'' (Table 2). We defined low physical activity as exercising ''almost never'' to ''hardly ever,'' moderate physical activity as ''very little'' to ''quite a lot,''and high physical activity was defined as exercising ''a lot'' to ''very much.''

Other "covariates." The questionnaire included questions on height and weight that were used to calculate body mass index as the weight in kilograms divided by the square of height in meters. Subjects were also asked whether they had ever had any long-term or serious illness.

Data analyses. The first step of the analysis was to determine whether genetic effects were present. Because the variable of interest was ordinal, the similarity within twins with regard to physical activity was assessed by the polychoric correlation coefficients (sometimes referred to as ''correlation in liability'') separately for MZ and DZ twin pairs. The interpretation of these analyses is that when correlation is higher in MZ twins than in DZ twins, genetic effects are likely to explain some of the variation in physical activity levels.

To investigate the question of whether both high and low physical activity are inherited, we used multivariate logistic regression, conditional on pair membership, to estimate odds ratios (OR) with 95% confidence interval (CI) of low physical activity (categories 1–2, exercise ''almost never'' to ''hardly ever'') and high physical activity (categories 6–7, exercise ''a lot'' to ''very much''). The remaining three middle categories (''exercise very little'' to ''exercise quite a lot'') were used for reference purposes. The ratio of the MZ and DZ OR were interpreted as indicators of genetic effects on high and low physical activity.

Correlations and OR can test whether genetic effects are important. However, they are not informative about the *magnitude* of the genetic effects. Therefore, in a third step, we used data from both MZ and DZ twins simultaneously in structural equation models (13), which made it possible to quantify how much of the variance in physical activity could be explained by additive genetic effects, common environmental effects, and unique environmental effects. Common environmental effects reflect twin similarity that is not explained by heritable genetic influence but that results from factors shared by the family unit such as values, dietary habits, leisure-time activities, socioeconomic situation, and neighborhood. Unique environmental effects are those explained by environmental factors unique to the individual.

The analyses of this study were based on the usual assumptions made in twin studies: that the genetic similarity is half as great for DZ as for MZ twin pairs, whereas common environmental influences contribute equally to making MZ and DZ pairs similar, and that twins are representative of the general population (13).

RESULTS

Characteristics. There were 5334 MZ (2440 male and 2894 female) and 8028 (3804 male and 4224 female) DZ twin pairs. The age range was 14–46 yr. Only modest differences in age, body mass index, prevalence of disease, and overweight were seen between zygosity groups (Table 1) in both males and females.

Physical activity levels for male and female subjects. MZ and DZ twins had similar distributions across the seven levels of physical activity, with about 20% (males) to 25% (females) reporting that they hardly ever exercised (Table 2). Males were more active than females; 16% (DZ) to 17% (MZ) of male twins reported high physical activity compared with 5% (DZ) to 6% (MZ) of female twins (Table 2). These results show that twins and

TABLE 1. Characteristics of monozygotic and dizygotic male and female twins.

	Males		Females	
	MZ	DZ	MZ	DZ
No. of twins	4880	7608	5788	8448
Mean age (yr) (SD)	28.1 (9.1)	28 (9.2)	28.2 (9.1)	29 (9.3)
Mean body mass index (SD)	22.4 (2.8)	22.5 (2.8)	21.0 (2.8)	21.3 (3.0)
Long-term or serious illness	15.1%	14.9%	14.3%	14.1%
Overweight (BMI ≥ 25)	15.8%	17.6%	8.2%	9.8%

TABLE 2. Distribution of twin pairs across categories of physical activity.

	First Twin															
	Monozygotic Twins								Dizygotic Twins							
How Often Do You Engage in Physical Activity During Your Leisure Time?	Almost Never	Hardly Ever	Very Little	Not Much	Quite A Lot	A Lot	Very Much	Total	Almost Never	Hardly Ever	Very Little	Not Much	Quite a Lot	A Lot	Very Much	Total
Cotwin																
Males																
Almost never	105								92							
Hardly ever	87	45							87	59						
Very little	85	88	99						128	119	105					
Not much	100	84	198	253					200	208	319	343				
Quite a lot	57	53	106	241	242				131	148	196	421	269			
A lot	14	9	29	57	133	103			45	48	63	147	173	94		
Very much	4	3	9	23	52	59	102		30	23	26	76	94	82	78	
Total	557	414	713	1209	1126	507	354	4880	805	751	1061	2057	1701	746	487	7608
	11.4%	8.5%	14.6%	24.8%	23.1%	10.4%	7.3%	100%	10.6%	9.9%	13.9%	27%	22.4%	9.8%	6.4%	100%
Females																
Almost never	146								129							
Hardly ever	116	108							181	92						
Very little	99	140	155						172	197	166					
Not much	109	211	294	409					258	325	466	538				
Quite a lot	44	66	128	300	314				118	181	241	516	306			
A lot	7	9	6	34	72	55			16	22	31	66	84	41		
Very much	3	1	8	5	14	11	30		5	4	8	21	21	11	8	
Total	670	759	985	1771	1252	249	102	5788	1008	1094	1447	2728	1773	312	86	8448
	11.6%	13.1%	17%	30.6%	21.6%	4.3%	1.8%	100%	11.9%	12.9%	17.1%	32.3%	21%	3.7%	1%	100%

Percentage is the number of twins in that physical activity category by total number of twins, separately in males and females and monozygotic and dizygotic twins.

TABLE 3. Polychoric correlation (correlation in liability) of physical activity and genetic and common environmental factors on physical activity as percentage of variance explained and as odds ratios.

					Twin Odds Ratio	
Sex	Zygosity	Polychoric Correlation	Variance Explained by Genetic Factors[a]	Variance Explained by Common Environmental Factors[a]	High Physical Activity#	Low Physical Activity$
Males	Monozygotic	0.62	0.57 (0.49–0.63)	0.03 (0–0.10)	14.36 (11.98–17.22)	5.27 (4.49–6.19)
	Dizygotic	0.31			5.13 (4.45–5.92)	1.83 (1.61–2.09)
	Monozygotic/dizygotic	2			2.80	2.88
Females	Monozygotic	0.58	0.50 (0.49–0.55)	0.06 (0–0.12)	33.61 (25.66–44.02)	5.36 (4.69–6.12)
	Dizygotic	0.30			10.68 (8.31–13.74)	2.33 (2.09–2.59)
	Monozygotic/dizygotic	1.93			3.15	3.20

Figures in parentheses are 95% confidence intervals.
[a] Variance components estimated by structural equation modeling.
Odds ratio of high physical activity (categories 6–7, ''exercise a lot'' to ''exercise very much'') in twins with a cotwin with high physical activity compared with twins with a moderately active cotwin (categories 3–5, ''exercise very little'' to ''exercise quite a lot'').
$ Odds ratio of low physical activity (categories 1–2 ''almost never exercise'' to ''hardly ever exercise'') in twins with a cotwin with low physical activity compared with twins with a moderately active cotwin (categories 3–5, ''exercise very little'' to ''exercise quite a lot'').

cotwins tended to fall in the same or adjacent categories of physical activity and that there were few twin pairs with contrasted reported physical activity.

Physical activity in MZ versus DZ twin pairs. The polychoric correlation of physical activity for MZ males was 0.62, whereas the correlation for DZ males was 0.31 (Table 3). The correlation of physical activity in females was 0.58 and 0.30 for MZ and DZ, respectively. The correlation of physical activity was thus about twice as high in MZ compared with DZ twins (Table 3). To assess the magnitude of the genetic component, structural equation analyses were performed. These analyses indicate that about half of the variation in physical activity, 57% in males and 50% in females, was attributable to genetic factors. Less than 7% of the variation in physical activity was explained by common environmental factors. Consequently, the influence of unique environmental factors on physical activity was 40% (95% CI = 37–42%) in males and 44% (95% CI = 43–46%) in females. When these analyses were stratified by age, the genetic component was 64% in males aged 14–28 yr and 40% in males aged 29–46 yr. In females, the corresponding estimates were 51 and 41%, respectively (Table 4).

High versus low physical activity. The genetic effects on high and low physical activity were assessed by separate analyses of the OR of high and low physical activity. Male MZ twins were 14 times more likely to be very active themselves if their cotwin was very active compared with if the cotwin was moderately active. The corresponding figure in DZ twins was about five. For low physical activity, male MZ twins with a cotwin with low physical activity were five times more likely to be inactive than if the cotwin was moderately active, and this increase was about 1.8 in DZ twins. Thus, in males, the ratio of MZ/DZ OR was about 3 for both high and low physical activities, indicating genetic effects at both ends of the physical activity spectrum (Table 3). In females, twins with very active cotwins were 33.6 (MZ) and 10.7 (DZ) times more likely to be very active themselves than if the cotwin was moderately active. For low physical activity, the

TABLE 4. Familial and genetic effects on physical activity as percentage of variance explained and as odds ratios.

					Twin Odds Ratio	
Sex	Age (yr)	Variance Explained by Genetic Factors[a]	Variance Explained by Common Environmental Factors[a]*	Zygosity	High Physical Activity#	Low Physical Activity*$
Males	14–28	0.64 (0.55–0.72)	0.07 (0–0.15)	Monozygotic	20.18 (15.82–25.75)	8.60 (6.79–10.89)
				Dizygotic	5.35 (4.48–6.38)	2.32 (1.92–2.79)
				MZ/DZ	3.77	3.71
	29–46	0.40 (0.30–0.45)	0 (0–0.07)	Monozygotic	6.62 (4.91–8.91)	3.36 (2.69–4.19)
				Dizygotic	3.51 (2.71–4.56)	1.48 (1.24–1.78)
				MZ/DZ	1.89	2.27
Females	14–28	0.51 (0.48–0.60)	0.15 (0.13–0.18)	Monozygotic	44.23 (31.28–62.56)	8.62 (7.09–10.48)
				Dizygotic	14.0 (10.25–19.13)	3.03 (2.59–3.55)
				MZ/DZ	3.16	2.84
	29–46	0.41 (0.30–0.45)	0 (0–0.08)	Monozygotic	14.31 (8.79–23.31)	3.44 (2.86–4.13)
				Dizygotic	4.90 (3.0–8.01)	1.84 (1.59–2.13)
				MZ/DZ	2.92	1.87

Figures in parentheses are 95% confidence intervals.
[a] Variance components estimated by structural equation modeling.
Odds ratio of high physical activity (categories 6–7, ''exercise a lot'' to ''exercise very much'') in twins with a cotwin with high physical activity compared with twins with a less active cotwin (categories 3–5, ''exercise very little'' to ''exercise quite a lot'').
$ Odds ratio of low physical activity (categories 1–2 ''almost never exercise'' to ''hardly ever exercise'') in twins with a cotwin with low physical activity compared with twins with a less active cotwin (categories 3–5, ''exercise very little'' to ''exercise quite a lot'').
* The coverage of the 95% confidence intervals may be questioned due to small numbers.

corresponding estimates were 5.4 (MZ) and 2.3 (DZ), respectively. When these results were stratified by age (Table 4), similar results were seen in younger (14–28 yr) as well as older subjects (29–46 yr).

DISCUSSION

Our study demonstrates that MZ twin pairs are more similar in their leisure-time physical activity than DZ twins. This indicates that genetic factors influence the level of physical activity in which a person engages. The genetic component was estimated to be 57 and 50% in males and females, respectively. These values are higher than what was reported in most previous studies (5) but consistent with results reported in the Finnish Twin cohort (6). This is the first twin study to have investigated hereditary effects on physical activity in males and females separately. According to our results, the magnitude of these effects were equally strong in both genders.

A number of studies have shown that physical performance of an individual measured as aerobic performance, muscle strength, muscle endurance, and anaerobic performance is influenced by genetic factors (21). Phenotypes involved in physical functioning such as muscle mass, grip, and leg extensor strength as well as bone density and bone size also display a moderate to strong genetic component (1,14,16,18). In a recent Swedish study, it was also shown that the individual response to a certain level of physical activity is heritable (19). Relatively few studies have addressed the genetic effects on the behavioral aspect of physical activity measured as sports participation or leisure-time physical activity. Previous studies, including the Danish Twin study (5) and a study of 1587 Dutch adolescent twin pairs (8), found that hereditary factors explained 45–49% of the variation in sports participation. For overall leisure-time physical activity, genetic effects explained 38% in males in the Vietnam Era Twin Study (9) and 29% in males and females in the Canadian Family study (15). The strongest genetic effect (by magnitude of heritability coefficients) on physical activity measured as an activity scored based on amount, intensity, and duration was 62% in males reported in the Finnish Twin Cohort (6). One possible explanation for this large effect is that genetic factors are more important for physical activity in men than in women. Such gender differences have been reported in adolescents (2,3,11). However, our findings do not support a gender difference because the genetic component was similar in men and women.

Another potential explanation for the discrepancies between study results is that the genetic effect on physical activity is dependent on age. In the present study, a larger part of the variation in physical activity was explained by hereditary factors in adolescents and young adults (aged 14–28 yr) than in middle-aged subjects (aged 29–46 yr) (approximately 60 and 40%, respectively). On the other hand, Kaprio et al. (6) investigated twins from 18 to older than 60 yr of age and showed that the heritability coefficients did not change systematically with age. Correspondingly, Fredriksen and Christensen (5) indicated heritability of 50% in twins aged 45–68 yr, which is very similar to our findings in younger adults and adolescents. Hence, whether genetic effects differ across the age spectrum remains unclear. It should be noted that some difference in heritability coefficients between studies is to be expected because these studies differ in the methods used to capture physical activity and in the type of activities in which people engage. Further, there may also be genetic differences between the populations investigated.

Few studies have investigated genetic effects at different levels of physical activity. Kaprio et al. (6) suggested that genes may be more important for high physical activity. Similarly, data from the Vietnam Era Twin study indicated higher heritability estimates for participation in vigorous compared with moderate activity (8). In the present study, the results seem to indicate that both high physical activity and a sedentary lifestyle are, in part, heritable, although the MZ/DZ OR were more pronounced for high than for low physical activity for females. Thus, genetic effects are important for all types of physical activity, but it is still not clear whether the genetic effects are less important for low physical activity.

An important finding of the present study was that the influence of common environmental factors on the distribution of physical activity was small compared with the influence of hereditary and environmental factors unique to the individual. These are factors shared by the family unit such as values, dietary habits, leisure-time activities, socioeconomic situation, and neighborhood. Similar findings have been reported in previous studies of adult twins (5,9). A small influence of common environmental factors indicates that besides heritage, environmental factors unique to the individual influence physical activity in adults. In adolescents, common environmental factors seem to be very important for physical activity (2,18). Stubbe et al. (18) show that the genetic effect on physical activity starts to appear in late adolescence and that there is a shift in the determinants of sports participation from adolescence to adulthood in that common environmental factors cease to be of importance in favor of genetic factors and individual environmental factors. Our analyses in subjects aged 14–28 yr indicate that genetic factors influenced physical activity, although not as much as in 29- to 46-yr-old subjects. Common environmental factors did not play a significant role except in females aged 14–28 yr. The difference in our findings compared with previous work may be due to our small number of adolescents.

A limitation of the present study was that we investigated leisure-time physical activity measured in 1970. The physical activity pattern 36 yr ago probably differs from the pattern today. One assumption is that everyday activities such as walking and bicycling, in the absence of other modes of transportation, were probably more common in the 1970s. Today, organized sports almost certainly make up a larger proportion of overall activities. For this reason, the relationship between genetic effects and physical activity may be slightly different today. It seems possible that because participation in organized sports reflects an active choice, the genetic component may be more important for such activities than for overall physical activity. If this is true, then the genetic effects on physical activity may be even stronger today. Another limitation was that physical activity was measured with a single question on leisure-time activities. If MZ and DZ twins differ with regard to reliability of self-reported physical activity, the results may be confounded. However, we have no reason to believe that this is the case. It is possible that imprecise information on physical activity may have led us to underestimate the genetic effects.

One issue is the generalizability of our results. Evans and Martin (4) argue that twins are representative of the general population with respect to most health and behavioral outcomes, and we have no reason to believe that this is not true also for physical activity.

CONCLUSION

In summary, this study confirms that genetic effects play an important role in explaining individual differences in physical activity in adults. The genetic component seems to be present and substantial in males and females. In addition, our results suggest that both active and inactive lifestyles are, in part, inherited. The genetic effects on physical activity may be one reason for the difficulties in convincing people to adopt an active lifestyle. Still, this study shows that there is a substantial influence on physical activity from unique environmental factors.

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