# Sports Participation during Adolescence: A Shift from Environmental to Genetic Factors

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**ABSTRACT**

STUBBE, J. H., D. I. BOOMSMA, and E. J. C. DE GEUS. Sports Participation during Adolescence: A Shift from Environmental to Genetic Factors. *Med. Sci. Sports Exerc.*, Vol. 37, No. 4, pp. 563–570, 2005. **Purpose:** A twin design was used to assess the relative contribution of genetic and environmental influences on the variation in sports participation of Dutch male and female twins between the ages of 13 and 20 yr. **Methods:** Survey data from 2628 complete twin pairs were available (443 male and 652 female monozygotic twin pairs, 377 male and 434 female dizygotic twin pairs, and 722 opposite-sex twin pairs). Subjects were classified as participating in sports if they engaged in competitive or noncompetitive leisure-time sports activities with a minimal intensity of 4 METs for at least 60 min$\cdot$wk$^{-1}$. **Results:** An overall main effect of age and sex was found on the sports participation dichotomy. Younger twins participated more in sports than older twins, and for each age group males participated more often than females. Genetic analyses of twin resemblance showed a shift in the factors contributing to sports participation from adolescence to adulthood. Between the ages of 13 and 16 yr, environmental factors shared by children from the same family largely account for individual differences in sports participation (78–84%), whereas genes are of no importance. At the age of 17–18 yr, genetic influences start to appear (36%), and the role of common environment decreases (47%). After the age of 18 yr, genes largely explain individual differences in sports participation (85%), and common environmental factors no longer contribute. **Conclusions:** Environmental factors shared by family members determine sports participation in young adolescence but cease to be of importance in adulthood when individual differences in sports participation are largely due to genetic variation. **Key Words:** TWINS, HERITABILITY, DETERMINANTS, EXERCISE BEHAVIOR, PHYSICAL ACTIVITY

Research has clearly established that regular exercise is a key contributor to health (3). Despite these well-documented benefits, the majority of people do not engage in exercise on a regular basis (8). To ensure more successful intervention on this important health behavior, much research has been devoted to the determinants of exercise behavior. These studies have mainly focused on personality and on social and environmental characteristics (14,23), but innate biological mechanisms are increasingly being considered as additional factors influencing exercise behavior (21). The innate drive to exercise will be most obvious in leisure-time (i.e., self-chosen) exercise behavior that can be operationalized as regular participation in sports.

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Studies of genetically related subjects have confirmed a familial component affecting sports participation, although there are inconsistencies in the estimates of its magnitude, which may be caused by the use of various definitions of sports participation with different restrictions in terms of minimal intensity, duration, and frequency of activities used to classify subjects as sports participants or nonparticipants. Parent–offspring correlations, for instance, have ranged from low (0.09) for participation defined as activities requiring at least five times the resting oxygen consumption (19), to moderate (0.29–0.37) for sports participation defined as a dichotomous variable using the single question "Do you participate in sports?" (15).

Twin studies can, as opposed to parent–offspring family designs, discriminate between genetic and environmental influences within a family by comparing the resemblance in sports participation in monozygotic (MZ) twins and dizygotic (DZ) twins. MZ twins are genetically identical, whereas DZ twins share on average only half of their segregating genes. Therefore, a greater resemblance of MZ twins makes a strong case for the contribution of genetic factors to individual differences in sports participation. Beunen and Thomis (4) have reviewed the existing twin studies on sports participation and confirmed that heritability estimated for sports participation ranges widely. Besides the problem of defining sports participation differently, most twin studies so far have been based on samples with different age ranges, and different sample sizes, which may also explain the fact that heritability estimates of sports participation are widely divergent, ranging from moderate genetic effects (6) to a high heritability (4).

In this paper we focus on the relative contribution of genes and common environment to individual differences in sports participation in a large Dutch twin sample.

Sports participation was assessed by the question, "Do you participate in sports regularly?" and could be answered with "yes" or "no," resulting in a dichotomous variable. Using the standard twin design (5), genetic and common environmental contributions to the liability to sports participation were computed separately within age groups 13–14 yr, 15–16 yr, 17–18 yr, and 19–20 yr. This period of time is of particular interest because several studies have shown that sports participation in both sexes significantly declines with increasing age, and that this decline is particularly steep in the adolescent period, although changes in participation with age depend on the characteristics and types of the sports behavior investigated (25–27). The use of 2-yr periods was deemed optimal in terms of temporal resolution and statistical power in model comparison. In view of the known sex difference in the prevalence of sports participation (13), we tested whether the relative contribution of genetic and environmental factors to sports participation is different in males and females, and whether different genetic and environmental factors influence sports participation in males and females.

## METHODS

**Subjects.** This study is part of an ongoing study on health and lifestyle in twin families registered with the Netherlands Twin Registry (NTR). Adolescent twins and their families were recruited by contacting city councils in The Netherlands for addresses of twins in 1991. Later, additional twins were contacted via city councils, as well as by advertisements in the media and in the information bulletin of The Netherlands Twin Registry and through the Dutch Twin Club (7).

Since 1991, every 2–3 yr twins and their families have received a survey sent by mail containing a large number of personality inventories, and items about health, sports behavior, alcohol consumption, and smoking behavior. Data were collected in 1991, 1993, 1995, 1997, and 2000. In 1991 and 1993, twins and their parents were asked to fill in surveys. Siblings and spouses of twins were recruited into the study in 1995 and 2000, respectively. The exact procedures have been described in detail elsewhere (7). Written informed consent was obtained from the subjects, and approval of the study was obtained from the medical ethics committee of the Vrije Universiteit.

In this article, we focus on sports participation of MZ and DZ twins between the ages of 13 and 20 yr. Data from the five surveys were used to create a maximal cross-sectional data set that had adequate numbers of twins in each of the age categories. First, data of complete twin pairs in 1991 were used to define sports participation. If no data on sports participation were available in 1991, then data on sports participation of complete twin pairs in 1993 were used. This was done until all five surveys had been used as a possible source of information, resulting in a sample of 2628 complete twin pairs.

Zygosity of 352 same-sex twin pairs was determined on the basis of DNA typing. For the remaining 1554 same-sex twin pairs, zygosity was based on questions on physical similarity and confusion in identifying the twins by family members, friends, and strangers. In our sample, agreement between zygosity based on questionnaire data and zygosity based on DNA results was 98%. Grouped according to zygosity and sex, the sample consisted of 443 monozygotic male twin pairs (MZM), 377 dizygotic male twin pairs (DZM), 652 monozygotic female twin pairs (MZF), 434 dizygotic female twin pairs (DZF), and 722 dizygotic opposite-sex twin pairs (DOS). We subdivided participants into the age groups 13–14 yr, 15–16 yr, 17–18 yr, and 19–20 yr.

Sports participation was a dichotomous variable, based primarily on the question, "Do you participate in sports regularly?" which could be answered with "yes" or "no." Although different cultural meaning is attached to the term "sports" in other countries, in The Netherlands it is unambiguously taken to mean any form of leisure-time exercise, including solitary jogging, dancing, or a workout at a fitness center. To further qualify sports participation, those answering "yes" were asked what kind of sport (name of the sport) they were involved in, whether they did it competitively or noncompetitively, and how much time ($min \cdot wk^{-1}$) they spent on these sports. Ainsworth's compendium of physical activity was used to recode each sport into METs, representing 1 MET as the rate of energy expenditure of an individual at rest, which is approximately 1 $kcal \cdot kg^{-1} \cdot h^{-1}$ (1). The compendium is organized by "activity types" and includes sections on daily living or self-care, leisure and recreation, occupation, bicycling, running, sports, and rest activities. We only used METs scores listed under the major headings: sports, conditioning exercises, dancing, bicycling, and running.

Twins were classified as participating in sports if 1) they answered "yes" to the question "Do you participate in sports regularly?" 2) the minimum intensity of at least one of the sports was 4.0 METs, and 3) the time spent on the sports that exceeded the 4.0-MET criterion totaled at least 60 $min \cdot wk^{-1}$. They were classified as nonparticipants otherwise. Dutch adolescents are obliged to participate in 1–3 h of physical education at school per week. Note that in our classification we discarded all sports engaged in only during such compulsory physical education. Furthermore, physical activity, even vigorous activity, related to manual labor, household activities, or transportation did not classify as sports participation.

**Analytic approach.** We used a standard liability threshold model to estimate genetic and environmental contributions to sports participation (11). A categorical characteristic such as sports participation is assumed to have an underlying liability, which is continuous and normally distributed in the population. The underlying normal distribution can be separated by one or more thresholds into different categories. In the current study, the liability to sports participation is divided into two categories, participating and not participating in sports, separated by a single threshold. The threshold is obtained from the observed proportions in the two categories and can be interpreted as a z-value. Individuals falling below the threshold do not participate in sports; those exceeding the threshold do participate in sports regularly.

Information about twin resemblance in liability is given by tetrachoric correlations. Comparing the MZ correlations with the DZ correlations provides a first estimate of the sources of variation in individual differences in liability. Although MZ pairs are genetically identical, DZ pairs share on average only half of their segregating genes. Additive genetic effects on sports participation are suggested if the intrapair correlation in MZ twins is larger than in DZ twins. Common environmental effects, in contrast to genetic effects, are assumed to be unrelated to zygosity. Hence, resemblance due to common environment is similar in MZ and DZ twins, leading to significant but comparable intrapair correlation in MZ and DZ twins (20). Finally, because MZ twins have identical common environment and identical genes, an intrapair correlation different from unity indicates unique environmental effects on sports participation. Specific information on sex differences derives from the correlation in DOS twins. If the phenotypic correlation in DOS twins is lower than in same-sex dizygotic twins (DZM and DZF), this might be due to shared environmental effects that influence one sex but not the other, or genetic effects that are expressed in one sex but not in the other.

**Model-fitting procedure.** Structural equation model fitting was used to partition the variance in the latent liability into three sources: genes, common environment (factors shared by members of a twin pair), and unique environment (factors not shared by members of a twin pair plus measurement error). Using the software package MX (17), we fitted different models on raw ordinal data.

First, we fitted a saturated model to describe the correlation structure between twin pairs in each zygosity group. We tested whether the thresholds for males in the MZ and DZ pairs could be constrained to be equal and whether the thresholds for females in these zygosity groups were the same. In MX, twice the negative loglikelihood (−2LL) of the raw data of each twin pair is calculated and summed over all pairs. When two models are nested, subtracting the two −2LL from each other yields a statistic that is asymptotically distributed as $\chi^2$ with degrees of freedom (*df*) equal to the difference in the number of parameters in the two models. According to the principle of parsimony, models with fewer parameters are preferred if they do not give a significant deterioration of the fit ($P > 0.05$). Akaike's information criterion ($AIC = \chi^2 - 2\ df$) was also used to guide model selection. The model with the lowest AIC (i.e., largest negative) reflects the best balance between goodness of fit and parsimony.

In all models, the threshold in each age group was allowed to differ in magnitude between males and females and thresholds across age groups could also differ. We tested whether the tetrachoric correlation of DOS twins differed significantly from the correlations of the DZ same-sex twins. Therefore, the saturated model was compared to a model in which the correlations of the DOS and same-sex DZ twin pairs were constrained to be equal. A much lower DOS correlation in comparison with the correlation of DZ same-sex twins indicates that different environmental factors and/or different genes are expressed in males and females. Because we only had one observed statistic to model these qualitative sex differences (i.e., DOS correlation), we had to make an *a priori* decision to evaluate whether different genes or different environmental factors were expressed. We based this decision on the best fitting genetic model that was obtained from a genetic analysis in the four groups of same-sex twins (i.e., MZM, DZM, MZF, and DZF).

To obtain estimates for the proportions of variance explained by genes (G), common environment shared by family members (C), and unique environment (E), analyses without DOS data were carried out. The first step was to analyze these four zygosity groups; a model in which A, C, and E were allowed to differ between males and females was compared with a model in which these parameters were constrained to be equal. This approach tested whether the magnitude of the contribution of genes and environment to individual differences in sports participation was the same in males and females. The last step in the analyses without DOS twins was to test whether genes and/or environmental factors played a crucial role in sports participation by successively constraining the A and C to zero. Both parameters were also dropped at the same time.

After selecting the most parsimonious model in the analyses without the DOS twins, we added this group to the analyses and tested whether genetic or shared environmental correlation between DOS twins could be fixed at 0.5 or at 1, respectively. In the first test, the genes that contribute to the liability to sports participation in males and females were allowed to differ. In the other test, the environmental factors operating in both sexes may differ.

## RESULTS

Prevalence of sports participation for the four age groups is shown in Figure 1. A Pearson chi-square test yielded an overall sex difference in sports participation ($\chi^2 = 28.63$, $df = 1$, $P = 0.00$). *Post-hoc* testing within each age group showed that the sex difference was present in all age groups, except for the 17- to 18-yr-old twins ($\chi^2 = 3.43$, $df = 1$, $P = 0.06$). Figure 1 shows that there is a large decrease in sports participation when subjects grow older. The Kruskal–Wallis test indicated that the four groups differ significantly on sports participation ($\chi^2 = 94.59$, $df = 3$, $P = 0.00$). For pairwise comparisons, we used the Mann–Whitney test. The

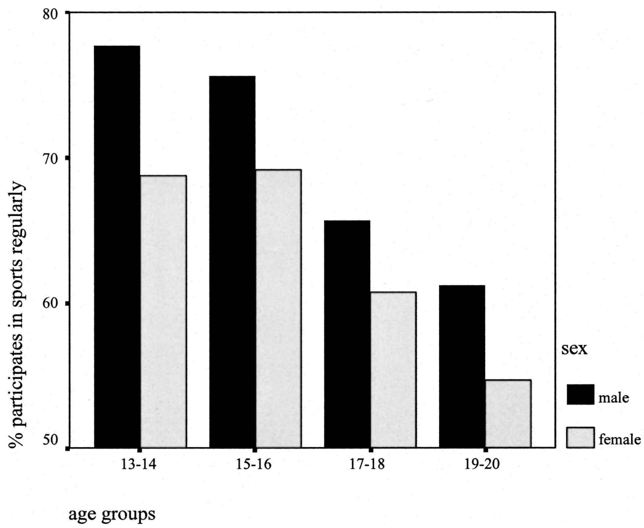


**FIGURE 1—Prevalence of sports participation for the different age groups.**

difference in sports participation between the ages of 13–14 yr and 15–16 yr was not significant (Z = −0.32; *P* = 0.75); however, a significant decrease in participation was found from the ages of 15–16 yr to 17–18 yr (Z = −5.23; *P* = 0.00) and from the ages of 17–18 yr to 19–20 yr (Z = −2.78; *P* = 0.01). The pattern of age-related changes was similar in males and females.

Table 1 displays the tetrachoric correlations for all zygosity groups in the different age cohorts. In the two youngest age groups the correlations for MZ and DZ twins were almost the same, indicating that common environmental factors play an important role in explaining individual differences in sports participation. In the two oldest age groups, the resemblance in sports participation between MZ twins was higher than in DZ twins, indicating genetic influences on sports participation. Furthermore, the differences between the correlations became more substantial with increasing age, suggesting that the influence of genes on individual differences in sports participation gain importance during late adolescence. DOS correlations generally were smaller than DZ same-sex correlations.

Model-fitting results for all age groups are shown in Table 2. In all models, thresholds for MZ and DZ pairs within one sex could be set to be equal. Thresholds had to be allowed to differ for males and females and across age groups to accommodate the age and sex differences in the prevalence of sports participation. The first six models in Table 2, under the heading "Model: 4 groups" are based on analyses using the four groups of same-sex twins. These analyses without DOS twins first tested for sex differences in the relative contribution of genetic and common and unique environmental influences. For every age group, the AIC of the model without sex differences (model 3) was lower than the AIC of the model with sex differences (model 2), indicating that the model without sex differences was the most parsimonious model. The *P* value for model 3 in every age group was higher than 0.05, which shows that constraining the variance components to be equal across sexes did not lead to a significant worsening of the fit.

In models without sex differences, we next tested whether genes and/or environmental factors play a crucial role in sports participation (models 4–6). According to the principle of parsimony, a model in which the genetic component was set to be zero was preferred for the two youngest age groups. Again, AIC was lowest for the CE model (model 5), and dropping the genetic component did not give a deterioration of the fit (AIC = −7.74; *P* = 0.324). In the 17- to 18-yr-old twins no parameters could be dropped, leading to an ACE model as the most parsimonious model. Finally, in the oldest age groups the common environment parameter could be constrained to zero, resulting in an AE model.

Adding DOS twins allowed us to test whether *different* genetic or environmental influences operated in males and females, even though their relative contribution was shown to be the same. Under the heading "model: 5 groups," Table 2 shows that for the two youngest age groups, the environmental correlation could not be set at 1.0 but was estimated at approximately half of it, indicating that partly different environmental influences act in males and females. In the age group 17–18 yr, the environmental correlation was even lower and was estimated at its boundary of 0.00, suggesting that common environmental factors influencing sports participation in males do not play a role in influencing sports participation in females and vice versa. In the oldest age group, the genetic correlation between the DOS twins was estimated and could be fixed at 0.5. Because DOS twins share on average half of their genes, this means that the same genes act in males and females.

Table 3 shows parameter estimates and 95% confidence intervals of the best-fitting models of the five groups analyses for the different age groups. The heritability estimates for sports participation in the two youngest age groups could be set to zero, whereas common environment explained about 80% of the variance in sports participation. In the 17–18 yr old twins, both genetic and common environment accounted for individual differences in sports participation, 36% and 47%, respectively. In the oldest age group, common environmental factors did not play a role in explaining individual differences in sports participation, whereas genetic factors explained 85% of the variance in sports participation.

## DISCUSSION

An overall main effect of age and sex on sports participation was found. Younger twins participated more in sports than older twins, and within each age group males were more physically active than females. There was a decline in sports participation from adolescence to adulthood that was particularly steep in the period between the ages of 15 and 19 yr, which was observed in both males and females. These findings correspond to results obtained in a large Finnish population sample (25,26). In that study, self-reported physical activity was measured from 1980 to 1989, resulting in data covering ages 9–27. Frequency of physical activity as

TABLE 1. Number of complete twin pairs in each group with the tetrachoric twin correlations for sports participation (95% confidence intervals added in parentheses).

| | 13–14 yr | 15–16 yr | 17–18 yr | 19–20 yr |
|---|---|---|---|---|
| MZM | $N$ = 115 | $N$ = 136 | $N$ = 100 | $N$ = 92 |
| | 0.88 (0.71 to 0.96) | 0.80 (0.62 to 0.91) | 0.88 (0.73 to 0.96) | 0.86 (0.68 to 0.95) |
| DZM | $N$ = 87 | $N$ = 112 | $N$ = 96 | $N$ = 82 |
| | 0.82 (0.56 to 0.94) | 0.68 (0.41 to 0.85) | 0.65 (0.38 to 0.83) | 0.35 (−0.01 to 0.63) |
| MZF | $N$ = 161 | $N$ = 185 | $N$ = 148 | $N$ = 158 |
| | 0.87 (0.74 to 0.94) | 0.83 (0.70 to 0.92) | 0.80 (0.64 to 0.90) | 0.83 (0.70 to 0.92) |
| DZF | $N$ = 109 | $N$ = 115 | $N$ = 113 | $N$ = 97 |
| | 0.84 (0.67 to 0.94) | 0.81 (0.62 to 0.92) | 0.68 (0.45 to 0.84) | 0.53 (0.24 to 0.74) |
| DOS | $N$ = 174 | $N$ = 215 | $N$ = 186 | $N$ = 147 |
| | 0.47 (0.23 to 0.67) | 0.46 (0.25 to 0.63) | 0.18 (−0.05 to 0.39) | 0.48 (0.25 to 0.67) |

MZM, monozygotic males; DZM, dizygotic males; MZF, monozygotic females; DZF, dizygotic females; DOS, dizygotic opposite-sex twins.

measured by the question "How often do you engage in physical activity during leisure time for at least half an hour each time?" and frequency of participation in organized sports both show a marked decline from the age of 12. Our results are also in keeping with the results from a cross-national comparison between two large longitudinal studies of adolescents in Glasgow, Scotland and Dunedin, New Zealand (28). In interviews at ages 15 and 18, subjects were asked what kind of physical activities they were involved in. These activities included activities undertaken as part of school programs, competitive sports, and leisure-time activities undertaken for exercise or recreation. In both locations, participation in physical activity declined. Finally, Dovey et al. (10) found in a longitudinal cohort study of 775 adolescents that there was a 37% reduction in total time spent in sports and leisure-time physical activity at age 18 compared with age 15. However, other studies measuring physical activity in a broader sense than sports participation alone suggest that changes over age may vary across different aspects of physical activity (25–27). In a Dutch study over a 15-yr period covering adolescence and young adulthood, a gradual decline was observed in the total weekly time spent on physical activities exceeding 4 METs and in the weekly time spent on nonorganized sports activities, but *not* for the time spent on organized sports activities (27).

The main aim of our study was to assess the relative contribution of genetic and environmental influences in the period from adolescence to adulthood. To our knowledge, no other study has used fine-grained age groups, as were used here. Genetic analysis strongly confirmed the expected age-dependency of the factors influencing variation in sports participation. A shift was observed from environmental to genetic factors from adolescence to adulthood in both males and females. Between the ages of 13 and 16 yr, environmental factors shared by children in the same family accounted for the differences in sports participation. In these age groups, such influence may still include peer support and peer physical activity, which have been a source of influence on sports participation in children (2). A review of 108 studies on factors influencing physical activity levels of children and adolescents (aged 13–18 yr), however, suggests parental support and direct help from parents as the environmental factors most consistently associated with the physical activity levels of adolescents (24). At the age of 17–18 yr, the role of common environment starts to decrease in favor of genetic influences. In The Netherlands, the majority of children finish high school when they are 16 or 17. As long as they attend high school, children are obliged to participate in compulsory physical education classes. The ending of those classes may cause part of the decline in

TABLE 2. Univariate model fitting results for twins in the four different age groups; comparisons of models are shown. The first six models are based on analyses using the four groups of same-sex twins (i.e., MZM, DZM, MZF, and DZF) and are listed under the heading "model: 4 groups." After selecting the most parsimonious model in the analyses without the DOS twins, this fifth group was added to the analyses. Results of these five group analyses are listed under the heading "model: 5 groups."

| | | 13–14 yr | | | | 15–16 yr | | | | 17–18 yr | | | | 19–20 yr | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | vs | −2LL | *df* | *P* | AIC | −2LL | *df* | *P* | AIC | −2LL | *df* | *P* | AIC | −2LL | *df* | *P* | AIC |
| Model: 4 groups | | | | | | | | | | | | | | | | | |
| 1) Saturated model | | 913.317 | 932 | — | — | 1094.163 | 1084 | — | — | 1043.218 | 902 | — | — | 1017.405 | 834 | — | — |
| 2) ACE: sex diff. | 1 | 922.379 | 938 | 0.170 | −2.94 | 1107.864 | 1090 | 0.033 | 1.70 | 1051.034 | 908 | 0.252 | −4.18 | 1021.081 | 840 | 0.720 | −8.32 |
| 3) ACE: no sex diff. | 2 | 922.607 | 940 | 0.892 | −6.71 | 1108.676 | 1092 | 0.666 | −1.49 | **1052.072** | **910** | **0.595** | **−7.15** | 1021.509 | 842 | 0.807 | −11.90 |
| 4) AE: no sex diff. | 3 | 940.387 | 941 | 0.000 | 9.07 | 1120.194 | 1093 | 0.001 | 8.03 | 1058.547 | 911 | 0.011 | −2.67 | **1021.535** | **843** | **0.872** | **−13.87** |
| 5) CE: no sex diff. | **3** | **923.580** | **941** | **0.324** | **−7.74** | **1110.520** | **1093** | **0.175** | **−1.64** | 1056.513 | 911 | 0.035 | −4.71 | 1037.001 | 843 | 0.000 | 1.60 |
| 6) E: no sex diff. | 5 | 1095.995 | 942 | 0.000 | 162.68 | 1264.385 | 1094 | 0.000 | 150.22 | 1189.958 | 912 | 0.000 | 126.74 | 1140.787 | 844 | 0.000 | 103.38 |
| Model: 5 groups | | | | | | | | | | | | | | | | | |
| 1) Saturated model | | 1301.202 | 1277 | — | — | 1605.403 | 1511 | — | — | 1540.028 | 1271 | — | — | 1400.665 | 1119 | | |
| 2) ACE (rc estimated) | 1 | 1313.268 | 1287 | 0.281 | −7.93 | 1622.018 | 1521 | 0.083 | −3.39 | 1551.026 | 1281 | 0.358 | −9.00 | 1408.609 | 1129 | 0.634 | −12.06 |
| 3) ACE (rc fixed at 0) | 2 | — | — | — | — | — | — | — | — | **1551.026** | **1282** | **1.000** | **−11.00** | — | — | — | — |
| 4) ACE (rc fixed at 1) | 2 | — | — | — | — | — | — | — | — | 1562.606 | 1282 | 0.001 | 0.58 | — | — | — | — |
| 5) CE (rc estimated) | 2 | **1314.232** | **1288** | **0.326** | **−8.97** | **1623.893** | **1522** | **0.171** | **−3.51** | — | — | — | — | — | — | — | — |
| 6) CE (rc fixed at 0) | 5 | 1327.612 | 1289 | 0.000 | 2.41 | 1641.200 | 1523 | 0.000 | 11.797 | — | — | — | — | — | — | — | — |
| 7) CE (rc fixed at 1) | 5 | 1329.834 | 1289 | 0.000 | 4.63 | 1636.239 | 1523 | 0.000 | 6.836 | — | — | — | — | — | — | — | — |
| 8) AE (rg estimated) | 2 | — | — | — | — | — | — | — | — | — | — | — | — | 1408.841 | 1130 | 0.630 | −13.82 |
| 9) AE (rg fixed at 0) | 8 | — | — | — | — | — | — | — | — | — | — | — | — | 1423.583 | 1131 | 0.000 | −1.08 |
| 10) AE (rg fixed at 0.5) | 8 | — | — | — | — | — | — | — | — | — | — | — | — | **1408.841** | **1131** | **1.000** | **−15.82** |

rg, genetic correlation between DOS twins; rc, common environmental correlation between DOS twins; vs, versus and indicates which model the submodel is compared to; −2LL, −2 loglikelihood; *df*, degrees of freedom; *P*, *P* value. Most parsimonious solutions are printed in boldface type.

TABLE 3. Parameter estimates and 95% confidence intervals of the best-fitting models of the five groups analyses for the different age groups.

| | $h^2$ (95% CI) | $c^2$ (95% CI) | $e^2$ (95% CI) | rc |
|---|---|---|---|---|
| 13–14 | — | 0.84 (0.77–0.90) | 0.16 (0.10–0.23) | 0.55 |
| 15–16 | — | 0.78 (0.70–0.85) | 0.22 (0.15–0.30) | 0.58 |
| 17–18 | 0.36 (0.09–0.64) | 0.47 (0.21–0.71) | 0.17 (0.10–0.27) | 0.00 |
| 19–20 | 0.85 (0.76–0.91) | — | 0.15 (0.09–0.24) | — |

$h^2$, heritability; 95% CI, 95% confidence interval; $c^2$, common environmental variance component; $e^2$, unique environmental variance component; rc, environmental correlation between DOS twins.

sports participation in this age period, and could also contribute to the shift from common environmental to genetic factors.

After the age of 18, common environmental factors cease to contribute to individual differences in sports participation, and genes entirely account for the remaining familial resemblance. Thus, our study confirms a major role of genetic influences on adult sports participation (9), and suggests that the influence of these genes start to appear in late adolescence. Two major pathways for genetic influences to affect sports behavior may be through personality characteristics (e.g., sensation seeking or extraversion) or physical fitness parameters (e.g., muscle strength, muscle endurance, and aerobic power), both of which are highly heritable (5,18).

Several previous studies have examined genetic and environmental determinants of sports participation. In a partly overlapping Dutch sample, Koopmans et al. (15) looked at sports participation in 13- to 22-yr-old twins, but did not divide the sample into different age cohorts. As in our study, sports participation was based on the question "Do you participate in sports regularly?" which resulted in a dichotomous variable. Models fitted on the total sample, which had a mean age of 17.7 yr, resulted in a heritability and common environment estimate of 48 and 38%, respectively. This corresponds closely to our findings in the age group of 17- to 18-yr-old twins. Boomsma et al. (6) also investigated heritability of sports participation in a sample of the Dutch Twin Registry by analyzing responses from 90 adolescent Dutch twin pairs aged 14–20 yr (average age = 17 yr old), using the single question "Have you been involved in sports activities during the last 3 months?" The heritability estimate was 35% for females, and 77% for males. For a single model in which the variance components across sexes were constrained to be equal, an estimated heritability of 64% was found.

In a small sample of 92 Flemish male twin pairs and 91 female twin pairs aged 15 yr, Beunen and Thomis (4) found a slightly different pattern than that seen in Dutch 15 yr olds. For girls, 44% of the variation in sports participation was explained by genetic factors, and 54% by common environment factors. For boys, genetic factors already explained about 83% of the total variance at age 15. However, these results were not based on sports participation as a dichotomous variable, but on the number of hours spent on sports each week. It might be that higher heritability estimates for sports participation are obtained if it is defined by a continuous variable.

No sex differences were found in the relative contributions of genetic and environmental factors to sports participation. This extends previous findings in a comparable sample from The Netherlands Twin Registry, where sex differences in variance components were also absent for sports participation (15). However, a study of 411 Portuguese twins aged 12–25 yr and a study on 183 Flemish 15-yr-old twins showed larger heritability estimates in males than in females (4,16). In this study, sports participation was based on continuous data rather than on a dichotomy, which may explain the different finding. It is also possible that familial resemblance in social learning and parental role modeling is different for males and females in Portugal and Belgium, but less so in The Netherlands. Alternatively, because of the modest sample size of the groups of same-sex twins, these studies may simply have been more vulnerable to accidental results due to sampling variation.

Although the relative contribution of the variance components was of similar magnitude in males and females, a key finding of our study was that shared environmental influences do appear to differ across sexes. Except for the 19- to 20-yr-old male twins, DOS correlations were significantly smaller than dizygotic same-sex correlations. This pattern of correlations signals that different environmental factors contribute to variation in sports participation in boys and girls aged 13–16 yr. A study by Whitehead et al. (29) helps qualify these findings by showing that sports activities were more important to boys than to girls. Furthermore, there is some suggestive evidence that parental sports involvement on sports participation influences boys and girls differently. Results showed that the effect of parents on sports participation is larger for girls than for boys (22). Boomsma et al. (6) also found a difference in the socialization of males and females into sports. The environment of spouses and female twins was highly correlated, but for male twins this correlation was absent.

A correlation between the phenotypes of spouses may be a problem influencing genetic and environmental factors contributing to individual differences in sports participation in twin studies. Assortative mating refers to nonrandom selection of spouses (11). In the example of sports participation, nonrandom mating can occur when sports participants become members of a sports club, thereby enlarging the change of selecting an exercising spouse. Boomsma et al. (6) indeed found positive correlations between sports participation of spouses. Assortment results in a larger genetic resemblance of offspring than the average 50% predicted under the standard biometric model. In twin studies this will result in a greater similarity of DZ twins relative to MZ twins, resulting in underestimation of heritability in favor of overestimated common environmental influences. It is very difficult to envision how assortment could have resulted in the pattern of findings reported in this paper, because overestimation of common environment should not show any age dependency. Nonetheless, in future research, parents and spouses of twins could be added to the twin design to help resolve this issue.

Future studies could also address two further limitations of this study: the use of a dichotomy rather than a continuous variable, and the cross-sectional design. In our study, sports participation was assessed as a yes/no dichotomy, using sports activities with a minimal intensity of 4 METs for at least 60 $\text{min}\cdot\text{wk}^{-1}$ as the arbitrary cutoff. Within those who satisfied our criterion of sports participation, huge individual differences may still exist in the total duration and intensity of sports behavior. By modeling a liability response pattern and not a continuous variable expressing type, duration, intensity, and frequency, we defined a narrow phenotype that is probably more reliably extracted from self-report data, but need not generalize to a quantitative measure of the total weekly energy expenditure attained in sports. Such individual differences in weekly energy expenditure may, but need not, be influenced by the same genetic and environmental influences that determine who regularly participates in sports. A combined model has been proposed to explicitly address this question in twin samples (12). This approach, however, requires a more detailed survey of the frequency, duration, and intensity of sports behavior than was available here.

A second limitation of the study is that we used a cross-sectional twin design to assess the relative contribution of genes and environmental influences on variation in sports participation of Dutch male and female twins between the ages of 13 and 20 yr. Although little cohort effects are likely to have occurred in such a brief time span, the shift in genetic architecture is most properly addressed in a longitudinal design. However, due to sample size we were unable to provide a longitudinal design. Unfortunately, even in our large sample a longitudinal genetic analysis would still be underpowered, because the number of twin pairs in each of the five zygosity groups that filled out the survey on all time points was too small.

In summary, this twin study showed that common environmental factors determine sports participation in young adolescence, but cease to be of importance in adulthood, when individual differences in sports participation are largely genetic. These results may have implications for the promotion of physical activity in children and adolescents. Future physical activity interventions in children between the ages of 13 and 16 yr should do well to target the common environment. This prominently included the parents whose support and direct help can play an important role in the physical activity levels of children. Furthermore, school exercise programs or community-based programs could take advantage of the influence that peers have on sports participation. Because shared environmental influences do appear to differ across sexes in the ages of 13–16 yr, it may be important to develop different exercise programs for males and females. From adolescence onward, genetic influences seem to determine sports participation. This is often mistakenly interpreted as a life sentence for those who are sedentary. Future understanding of the pathways from gene to exercise behavior may well yield novel strategies for promoting physical activity in (young) adults, for instance, by tailoring exercise programs to fit a wider range of abilities and personalities.

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