Effect of Shared Environmental Factors on Exercise Behavior from Age 7 to 12 Years

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ABSTRACT

HUPPERTZ, C., M. BARTELS, C. E. M. VAN BEIJSTERVELDT, D. I. BOOMSMA, J. J. HUDZIAK, and E. J. C. DE GEUS. Effect of Shared Environmental Factors on Exercise Behavior from Age 7 to 12 Years. *Med. Sci. Sports Exerc.*, Vol. 44, No. 10, pp. 2025–2032, 2012. **Introduction**: The aim of this study was to investigate the relative influence of genetic and environmental factors on children's leisure time exercise behavior through the classic twin design. **Methods**: Data were taken from The Netherlands Twin Register. The twins were 7 (n = 3966 subjects), 10 (n = 3562), and 12-yr-olds (n = 8687), with longitudinal data for 27% of the sample. Parents were asked to indicate the children's regular participation in leisure time exercise activities, including frequency and duration. Resemblance between monozygotic and dizygotic twins for weekly MET-hours spent on exercise activities was analyzed as a function of their genetic relatedness. **Results**: Average weekly MET-hours increased with age for both boys (age 7 yr: 14.0 (SD = 11.8); age 10 yr: 22.6 (SD = 18.7); age 12 yr: 28.4 (SD = 24.9)) and girls (age 7 yr: 9.7 (SD = 9.5); age 10 yr: 15.3 (SD = 15.1); age 12 yr: 19.3 (SD = 19.8)). Around 13% of boys and girls across all age groups did not participate in any regular leisure time exercise activities. Tracking of exercise behavior from age 7 to 12 yr was modest ($0.168 < r < 0.534$). For boys, genetic effects accounted for 24% (confidence interval, 18%–30%) of the variance at age 7 yr, 66% (53%–81%) at age 10 yr, and 38% (32%–46%) at age 12 yr. For girls, this was 22% (15%–30%), 16% (9%–24%), and 36% (30%–43%), respectively. Environmental influences shared by children from the same family explained 71%, 25%, and 50% of the variance in boys (age 7, 10, and 12 yr) and 67%, 72%, and 53% in girls. The shared environment influencing exercise behavior was partially different between boys and girls. **Conclusion**: Our results stress the important role of shared environment for exercise behavior in young children. **Key Words:** TWIN DESIGN, PHYSICAL ACTIVITY, HERITABILITY, GENES, TRACKING, CHILDHOOD

Regular exercise behavior in leisure time is increasingly accepted to be a main contributor to children's health (22). Despite this, the proportion of children that are active enough to benefit from exercise is low, with girls consistently less active than boys (3). A better understanding of why certain children exercise and others do not is important to develop successful health-promoting exercise interventions for children and adolescents.

Previous research provides evidence that environmental and social factors are related to being physically active (7), such as access to exercise facilities, socioeconomic status, and support by family and peers (31,39). However, even taking into account these factors, a good deal of variance remains unexplained. More recently, it has been suggested that irrespective of the surrounding environment, some people may be more predisposed toward exercising than others (13)—because individuals differ concerning their internal "need" to be active, exercise ability, and personality factors. These factors, hypothesized to be genetically influenced, may trigger either rewarding or negative physiological responses to exercise (11,13).

Twin studies provide a unique opportunity to disentangle the environmental and genetic influences on exercise behavior. They can be used to decompose environmental factors into those that are shared by the twins (such as the family environment) and those environmental factors that are unique to each child. Several twin studies have investigated leisure time exercise behavior in adolescents (15,34,38) and in adults (6,23,33,35). The relative contribution of genetic and environmental influences is different for males and females, and it changes vastly across the lifespan (13). For example, Van der Aa et al. (38) investigated leisure time exercise behavior in twins 13–18 yr old. For both sexes, heritability estimates at ages 16–18 yr were very high (80%). For 13- to 14-yr-old boys, genetic factors accounted for 80% of the variance in exercise behavior. For girls, genes accounted for only 38% of the variance with the shared environment being more influential (46%). In adult twins, heritability estimates decrease from the peak value in adolescence to values between 40% and 70%. The remaining

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variance is due to unique environmental factors, and the shared environment is no longer of importance (35).

There are no published twin studies that have specifically investigated the heritability of leisure time exercise behavior in children. The aim of this study is to bridge this gap by examining the relative influence of genetic and environmental factors on this behavior in children that are age 7, 10, and 12 yr. Similar to previous studies (e.g., [34,38]), we have deliberately chosen to focus on the narrow but well-defined trait of leisure time exercise behavior and not on general physical activity. Survey research can be reliably used to query participation in regular exercise activities but has more difficulty in detecting overall energy expenditure, which should be measured preferentially with objective methods like accelerometry. Shared family environment is expected to be a strong contributor to exercise behavior in children because children are likely to be dependent on their parents when it comes to exercise activities (e.g., need to get rides to and from facilities). On the basis of the adolescent findings, we also expect significant genetic contribution to exercise behavior in this period, particularly in boys.

METHODS

Participants. Data were available for young twins registered with The Netherlands Twin Register, which was established by the Department of Biological Psychology at the VU University Amsterdam in 1987 (9). Young twins are registered by their parents shortly after birth. Mothers and fathers are then invited to complete surveys about their children's health, lifestyle, and behavior when the children are approximately 0, 2, 3, 5, 7, 10, and 12 yr old (4). The children live in all regions of The Netherlands (9). Until today, parents of more than 32,000 twin pairs have taken part in research projects.

For the present study, data of 209 children with diseases or disabilities that may prevent them from being physically active were excluded. In addition, data from 11 twin pairs were excluded due to missing zygosity information. This resulted in the following samples: age 7 yr (n = 3966 children, mean = 7.45 yr, SD = 0.32, 49.6% males), age 10 yr (3562, 10.12, 0.33, 49.0%), and age 12 yr (8687, 12.29, 0.40, 48.8%). The children's parents were classified as lower educated (19.1%), average educated (44.8%), or higher educated (33.2%, 2.9% missing), and the large majority was born in The Netherlands (95%), with no differences across zygosity groups. Of the monozygotic (MZ) twins, 92.5% were conceived naturally, 2.4% after hormone treatment, and 1.7% with *in vitro* fertilization (3.4% missing). For the dizygotic (DZ) twins, this was 62%, 11.9%, and 20.2%, respectively (5.9% missing). The children's body mass index (BMI) was comparable across zygosity groups: For male MZ twins, it was 15.3 (SD = 1.7) for age 7 yr, 16.4 (2.2) for age 10 yr, and 17.5 (2.4) for age 12 yr. For female MZ twins, this was 15.3 (1.9), 16.5 (2.2), and 17.6 (2.7), respectively. For male DZ twins, BMI was 15.4 (1.7), 16.4 (2.1), and 17.6 (2.6), and for female DZ twins, 15.5 (1.9), 16.5 (2.3), and 17.8 (2.7). Finally, male DZ twins of opposite sex pairs had a BMI of 15.3 (1.6), 16.3 (2.0), and 17.4 (2.4). For the girls, this was 15.4 (1.9), 16.6 (2.4), and 17.7 (2.5). For only a modest part (26.8%) of the children, there were data at more than one age because the detailed survey items on exercise behavior were introduced to the parental surveys in 2004/2005. Therefore, some of the children were already too old to be rated based on these items in the first or second wave of parental data collection, whereas others had not received a second or third survey at all at the time of data analysis.

Zygosity was determined by blood group or DNA typing for 11.8% of the same-sex twin pairs. For the remaining same-sex twin pairs, zygosity was based on survey items on physical similarities and confusion by family members and strangers. This has been shown to result in accurate determination for 93% of same-sex twin pairs (30). The subjects' parents provided consent to be approached for survey research at enrollment in The Netherlands Twin Register. The data collection protocol was approved by the Medical Research Ethics Committee of the VU University Medical Center. Table 1 summarizes the number of twin pairs by sex and zygosity.

Measures. We provided parents with a list of the 17 most common exercise activities in The Netherlands (athletics, badminton, ballet/dance, basketball, fitness training, gymnastics, handball, jogging/running, hockey, netball, horseback riding, (ice-)skating, tennis, martial arts, soccer, swimming, and volleyball), plus the option to add up to two additional unlisted activities. We then asked them to indicate for each activity a) whether or not the child participated in the activity, and if so, b) for how many years, c) for how many months a year, d) how many times a week, and e) how many minutes each time. If the "unlisted activity" option was used, we excluded activities that barely increase energy expenditure such as playing chess. Activities related to transportation (walking, biking) or compulsory exercise in physical education (PE) classes were also not included because they are often not self-initiated or voluntary.

TABLE 1. Number of (complete) twin pairs and twin correlations (95% CIs) for exercise behavior.

	Age 7 yr		Age 10 yr		Age 12 yr	
	N	***r***	***N***	***r***	***N***	***r***
MZM	302 (297)	0.94 (0.93–0.95)	290 (284)	0.90 (0.88–0.92)	732 (719)	0.88 (0.86–0.89)
DZM	350 (345)	0.83 (0.80–0.86)	310 (298)	0.56 (0.48–0.63)	700 (668)	0.69 (0.65–0.73)
MZF	355 (351)	0.90 (0.89–0.92)	339 (336)	0.86 (0.83–0.88)	831 (821)	0.88 (0.86–0.89)
DZF	310 (304)	0.80 (0.76–0.83)	290 (284)	0.76 (0.71–0.80)	689 (670)	0.74 (0.70–0.77)
DOS	681 (671)	0.39 (0.32–0.45)	572 (559)	0.48 (0.42–0.54)	1449 (1408)	0.42 (0.38–0.46)

Separately for each sex × zygosity × age group.
MZM, MZ male twin pair; DZM, DZ male twin pair; MZF, MZ female twin pair; DZF, DZ female twin pair; DOS, DZ opposite sex twin pair.

Each activity was recoded into a metabolic equivalent (MET) score based on the compendium of energy expenditures for youth of Ridley et al. (29). A MET is defined as "the ratio of work metabolic rate to a standard resting metabolic rate of 1.0 (4.184 kJ)$\cdot$kg$^{-1}\cdot$h^{-1}" (1, p. 498). This standard resting metabolic rate equals quiet sitting. By multiplying the MET score, the frequency, and the duration of each exercise activity and then summing all activities that the children undertook, weekly MET-hours spent on exercise activities were calculated for each individual. We did not apply a minimum weekly frequency or duration, but we included only those activities in which the children participated at least 3 months a year, representing *regular* leisure time exercise behavior. Also, activities had to have been initiated at least 6 months ago. A total of 3.8% of the reported activities were dropped on the basis of these inclusion criteria. Importantly, the majority of these activities were holiday specific (i.e., skiing during winter holidays, swimming during summer holidays, sailing camps, etc.).

Statistical analyses. For age 7, 10, and 12 yr, 55.1%, 53.4%, and 40.7% of the surveys were filled out by both parents, respectively, and 1.7%, 2.5%, and 1.4% were filled out by the fathers only. For the remaining surveys, only the mothers reported on the child. As the correlations between fathers' and mothers' ratings were—for both children—high at all ages with a median correlation of 0.820 (range, 0.779–0.833), averaged weekly MET-hours were used when both parents had reported on the same child. If either the frequency or the duration of an activity were not indicated, they were replaced with a median of the age group within the respective exercise activity. In total, 1.54% of the missing data on either frequency or duration was replaced with a median. Missingness in MZ versus DZ twin pairs was very similar (1.6% vs. 1.3%). Different wording of the items within a part of the sample at age 12 yr (times a month instead of times a week) led to a slight difference in means ("batch effect"), which was corrected before the analyses. We verified that this correction affected only the means but not the twin correlations.

The correlations between MZ and DZ twins were estimated separately for each sex to evaluate the relative influence of genetic and environmental factors on exercise behavior. MZ twins originate from the same fertilized egg and therefore share (nearly) 100% of their genetic material. DZ twins only share, on average, 50% of their segregating genes—the same amount as nontwin siblings do. The shared environment includes all factors that the two children of a twin pair share such as the family environment, the neighborhood and recreational environment, and possibly the school and common friends. The shared environment is therefore by definition the same for both MZ and DZ twins (100% resemblance). On the basis of the differing genetic relatedness of MZ and DZ twins, it is possible to estimate the relative influence of genes, the shared environment, and the environment that is unique to an individual on an outcome variable (26). The last component includes variance due to measurement error. If the MZ correlation is larger than the DZ correlation (and thus MZ twins resemble each other more than DZ twins), this implies genetic influences. If the DZ correlation is larger than half the MZ correlation, influence of shared environment is likely to be significant as well.

Twin correlations also allow a rough understanding of quantitative and qualitative sex differences for a trait. Quantitative sex differences are present when the relative contribution of genes, shared environment, and nonshared environment differs for boys and girls. Qualitative differences are likely when the DZ opposite sex (DOS) correlation cannot be predicted on the basis of the DZ male–male (DZM) and DZ female–female (DZF) correlations. For instance, if the DOS correlation is lower than the DZM correlation and the DZF correlation, there is a weaker relationship between two children of a different sex than two children of the same sex, suggesting that different genetic or shared environmental factors operate in boys and girls (18).

Twin correlations were estimated with the software package openMx (8) for each sex by zygosity group (i.e., MZ male twin pair, DZM, MZ female twin pair, DZF, and DOS). A model that estimated all parameters freely (saturated model) was fitted to the data. It was tested whether constraining the means and variances to be equal across 1) MZ and DZ twins; 2) MZ, DZ, and DOS twins; and 3) across sex led to a significant deterioration of the model fit.

To gain further insight into the genetic architecture of exercise behavior, a univariate genetic model was then fitted to the data for each age group. Individual differences in exercise behavior were expected to be due to differences in additive genetic effects (A), common environmental effects (C) shared by twins from the same family, and nonshared environmental effects (E). These latent factors are expected to correlate differently for MZ and DZ twins. Because MZ twins share approximately 100% of their genes, the genetic correlation (rg) between twin 1 and twin 2 was fixed to 1.0 for MZ pairs. For DZ twins that share, on average, 50% of their genes, this was 0.5. For both MZ and same-sex DZ twins, the shared environmental correlation (rc) was—by definition—fixed to 1.0. To identify the most parsimonious and best-fitting model, various constraints were stepwise imposed on the model. The various nested models were then compared with the log-likelihood ratio test, which evaluates the difference in minus two times the log-likelihood between two models based on its χ^2 distribution and using the difference in degrees of freedom (*df*) between those models. As long as the model fit did not significantly decrease ($P > 0.05$), constraints were kept to support parsimony of the model.

RESULTS

Table 2 depicts the average weekly MET-hours spent on exercise activities for boys and girls across the three age groups. Exercise behavior did increase over time in both sexes ($P < 0.001$) but was lower for girls across all ages

TABLE 2. Average weekly MET-hours spent on regular leisure time exercise behavior (SD) and number (percentage) of children participating in a) team sports only, b) individual activities only, c) both kinds of activities, and d) no exercise activities at all.

	Age 7 yr		Age 10 yr		Age 12 yr	
	Boys	Girls	Boys	Girls	Boys	Girls
Weekly MET-hours	13.99 (11.78)	9.74 (9.47)	22.57 (18.69)	15.29 (15.12)	28.39 (24.93)	19.33 (19.80)
a) Team sports only	546 (27.7%)	140 (7.0%)	652 (37.4%)	260 (14.3%)	1569 (37.0%)	807 (18.1%)
b) Individual activities only	744 (37.8%)	1392 (69.7%)	497 (28.5%)	1034 (56.9%)	1140 (26.9%)	2346 (52.7%)
c) Both	398 (20.2%)	203 (10.2%)	390 (22.3%)	296 (16.3%)	926 (21.8%)	677 (15.2%)
d) Nonexercisers	281 (14.3%)	262 (13.1%)	206 (11.8%)	227 (12.5%)	604 (14.2%)	618 (13.9%)
Total number	1969	1997	1745	1817	4239	4448

For boys and girls, separately for the three age groups.

($P < 0.001$). Around 13% of all children did not take part in any leisure time exercise activity (Table 2). MET-hours spent on PE classes and leisure time exercise activities were only weakly correlated across all ages ($r < 0.140$, data not shown). PE was therefore not deemed a confounder and not further included in the analyses. Tracking of exercise behavior from age 7 to 12 yr was modest with estimates ranging from 0.28 to 0.51 (Table 3). The means of MZ, DZ, and DOS twins were equal within each age group, and the MZ and DZ variances were equal within ages 7 and 10 yr ($P < 0.01$). Sex differences were found across all ages.

Table 1 presents the twin correlations (95% confidence interval (CI)) of each sex by zygosity group for MET hours spent on exercise activities, based on the most parsimonious model. The MZ twin correlations were always higher than the DZ twin correlations, suggesting genetic influence. Because the DZ twin correlations were also larger than half the MZ twin correlations across all ages, the shared environment was likely to play a role in children's exercise behavior. Finally, the DOS correlations tended to be lower than the DZ correlations, which implied qualitative sex differences.

Genetic model fitting results are presented in Table 4. The shared environmental correlations between DOS twins (rcdos) were freely estimated in model 1. In model 2, rcdos was fixed to 1.0, which resulted in significant deterioration of model fit for age 7 and 12 yr, but not for age 10 yr. Subsequently, it was tested whether constraining the parameter estimates a, c, and e to be equal for boys and girls (model 3), constraining the genetic parameters to zero (boys: model 4a; girls: model 4b) or constraining the environmental parameters to zero (boys: model 5a; girls: model 5b) led to significant deterioration of the model fit. For ages 7 and 12 yr, model 1 appeared to be most parsimonious. For age 10 yr, this was model 2.

Table 5 represents the proportions of variance explained by additive genetic (A), shared environmental (C), and unique environmental factors (E) of the most parsimonious and best-fitting models for the three age groups (95% CIs added in parentheses). To increase comparability over age, both model 1 and model 2 (best-fitting model) are presented for age 10 yr. Except for boys 10 yr old, shared environmental factors consistently explained the largest part of the variance in exercise behavior, followed by additive genetic factors.

TABLE 3. Correlations across age groups.

	Age 7–10 yr	Age 10–12 yr	Age 7–12 yr
Boys	0.31* (n = 170)	0.36* (n = 1223)	0.28* (n = 532)
Girls	0.51* (n = 179)	0.43* (n = 1243)	0.28* (n = 522)

Number of children in parentheses.* $P < 0.01$.

DISCUSSION

The main purpose of this study was to investigate the relative influence of genetic and environmental factors on children's participation in leisure time exercise activities. Average weekly MET-hours spent on exercise activities in young Dutch twins doubled from age 7 to 12 yr, but this was mainly due to those who were already active, increasing their MET-hours further. Thirteen percent of boys and girls of all ages were inactive in that they did not participate in any regular leisure time exercise activities. In accordance with previous findings, boys were more active than girls (e.g., [3]). For boys, additive genetic effects accounted for 23.7%, 65.7%, and 38.3% of the variance in exercise behavior at ages 7, 10, and 12 yr. For girls, this was 22.1%, 16.3%, and 36.1%. Within all three age groups, shared environmental factors explained the largest part of the variance (70.5%, 24.6%, and 50.1% for boys and 67.3%, 72.3%, and 53.4% for girls). The correlation between shared environmental factors influencing exercise behavior in boys and girls (rcdos) was less than unity, suggesting that boys and girls in the same family do not receive the same level of familial support.

The important role of shared environmental factors for children's regular exercise behavior is consistent with results of smaller-sized twin studies that focused on total physical activity rather than leisure time exercise activities (19,20,27). Fisher et al. (19) measured time spent in moderate and vigorous physical activity by accelerometry in a sample of two hundred and thirty-four 9- to 12-yr-old twins. Shared environmental factors accounted for 61% of the variance, with the remaining 39% being explained by unique environmental effects. No genetic influence was found. Franks et al. (20) measured physical activity energy expenditure in two hundred 4- to 10-yr-old twins using respiratory gas exchange and doubly labeled water with very similar results (shared environment: 69%, unique environment: 31%). Plomin and Foch (27) investigated 1-week pedometer counts in a sample of one hundred and seventy-four 7.6-yr-old twins (SD = 1.6 yr). Again, the shared environment was by far the most

TABLE 4. Univariate model fitting results, separately for the three age groups.

Model	Vs.	−2LL	df	χ^2	Δdf	P
Age 7						
1. **ACE: sex differences, rcdos estimated**	—	**27,861.87**	**3957**	—	—	—
2. ACE: sex differences, rcdos fixed at 1	1	27,962.18	3958	100.31	1	<0.0001
3. ACE: no sex differences	1	27,949.8	3960	87.93	3	<0.0001
4a. CE: boys, ACE: girls	1	27,955.22	3958	93.35	1	<0.0001
4b. ACE: boys, CE: girls	1	27,904.97	3958	43.09	1	<0.0001
5a. AE: boys, ACE: girls	1	28,040.9	3958	179.03	1	<0.0001
5b. ACE: boys, AE: girls	1	28,010.08	3958	148.2	1	<0.0001
Age 10						
1. ACE: sex differences, rcdos estimated	—	28,757.33	3553	—	—	—
2. ACE: sex differences, rcdos fixed at 1	**1**	**28,761**	**3554**	**3.67**	**1**	**0.0554**
3. ACE: no sex differences	2	28,923.21	3557	162.21	3	<0.0001
4a. CE: boys, ACE: girls	2	28,959.7	3555	198.7	1	<0.0001
4b. ACE: boys, CE: girls	2	28,778.86	3555	17.86	1	<0.0001
5a. AE: boys, ACE: girls	2	28,804.33	3555	43.33	1	<0.0001
5b. ACE: boys, AE: girls	2	28,867.67	3555	106.67	1	<0.0001
Age 12						
1. ACE: sex differences, rcdos estimated	—	**74,950.01**	**8678**	—	—	—
2. ACE: sex differences, rcdos fixed at 1	1	75,066.17	8679	116.16	1	<0.0001
3. ACE: no sex differences	1	75,212.1	8681	262.09	3	<0.0001
4a. CE: boys, ACE: girls	1	75,111.73	8679	161.72	1	<0.0001
4b. ACE: boys, CE: girls	1	75,133.16	8679	183.15	1	<0.0001
5a. AE: boys, ACE: girls	1	75,078.92	8679	128.91	1	<0.0001
5b. ACE: boys, AE: girls	1	75,105.02	8679	155.01	1	<0.0001

Most parsimonious models are printed in boldface type.
−2LL, −2 log likelihood; A, additive genetic factors; C, common environmental factors; E, unique environmental factors.

important contributor to physical activity (MZ correlation: 0.99, DZ correlation: 0.94).

As previously outlined, the shared environment is made up of all environmental factors that twins share. Thus, the strong shared environmental effect in the present study may be explained by factors such as the neighborhood and recreational environment, school, and common friends. These factors may all be related to (accessibility of) exercise opportunities. However, because parents often act as gatekeepers to children's leisure time activities (5,21), parenting behavior may be one of the more prominent shared environmental influences on children's exercise behavior. Their support of their children's exercise behavior depends on their attitudes regarding these activities (2,37), which may vary across families. In a recent review, Beets et al. (5) identified four categories of parental influence on their children's physical activity. Parents may or may not provide tangible support by organizing transportation to exercise location and pay for sport clubs and equipment (*instrumental support*) and by being physically present during their children's exercise activities or even coach/ participate themselves (*conditional support*). They may also provide intangible support to increase children's self-efficacy and attitudes toward physical activity by encouragement and praise (*motivational support*) or by providing advice, suggestions, and information about (the benefits of) being active (*informational support*). This theory predicts that parental influence on their children's exercise activities should wane when the children get older and become less dependent on others for transportation and less willing to imitate their parents' behavior or adopt their attitudes (25,32). The decrease in common environmental influences from age 7 to 12 yr is entirely compatible with this prediction and continues during adolescence as has been shown by Van der Aa et al. (38). The important role of tangible support is further supported by the finding that around two thirds of the twin pairs had at least one type of exercise activity in common (age 7 yr: 69.5%, age 10 yr: 65.9%, age 12 yr: 61.5%), which is much higher than could be expected on the basis of the frequency of each of the types of exercise activities (approximately 20%). It is likely more convenient for parents to organize transportation and cheer their children at a single exercise location as opposed to handling two locations.

As the environmental correlation between DOS twin pairs was not unity for ages 7 and 12 yr, (some of) the shared environmental influences must be qualitatively different for

TABLE 5. Relative contribution of additive genetic, common environmental and unique environmental factors and the environmental correlation between DOS twins (SE) of the best-fitting models to explain exercise participation in three age groups, separately for boys and girls (95% CIs added in parentheses).

		A	C	E	rcdos
Age 7 yr	Boys	0.24 (0.18–0.30)	0.71 (0.64–0.76)	0.06 (0.05–0.07)	0.47 (0.05)
	Girls	0.22 (0.15–0.30)	0.67 (0.60–0.74)	0.11 (0.09–0.12)	
Age 10 yr, model 1	Boys	0.66 (0.53–0.81)	0.25 (0.09–0.38)	0.10 (0.08–0.12)	0.65 (0.10)
	Girls	0.16 (0.09–0.24)	0.72 (0.64–0.79)	0.11 (0.10–0.14)	
Age 10 yr, model 2	Boys	0.80 (0.74–0.85)	0.10 (0.06–0.16)	0.10 (0.08–0.12)	1
	Girls	0.15 (0.08–0.23)	0.73 (0.66–0.79)	0.12 (0.10–0.14)	
Age 12 yr	Boys	0.38 (0.32–0.46)	0.50 (0.43–0.57)	0.12 (0.10–0.13)	0.45 (0.04)
	Girls	0.36 (0.30–0.43)	0.53 (0.47–0.59)	0.11 (0.10–0.12)	

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boys and girls. Given the parents' influential role, a look at their differential treatment of sons and daughters concerning exercise activities is warranted. Although the findings are not unanimous, boys tend to receive more parental support than girls (5,21). In addition, mother–daughter and father–son correlations for physical activity are generally higher than opposite sex correlations (21), indicating a sex-specific influence of parents on their children. Accordingly, Edwardson and Gorely (16) found a positive association between fathers' explicit modeling and their son's moderate-to-vigorous physical activity, but no association for girls. Anderson et al. (2) reported that parents deemed boys' participation in team sports to be more important than girls' participation—for higher educated parents, this bias was also apparent for individual activities—and that boys are more similar to their parents concerning the value placed on being active ("parent–child attitude congruence"). Parents may not only provide more support to their sons—they may also differ in the initial choice of which type of activity their sons and daughters should participate in. This may be a main reason why girls

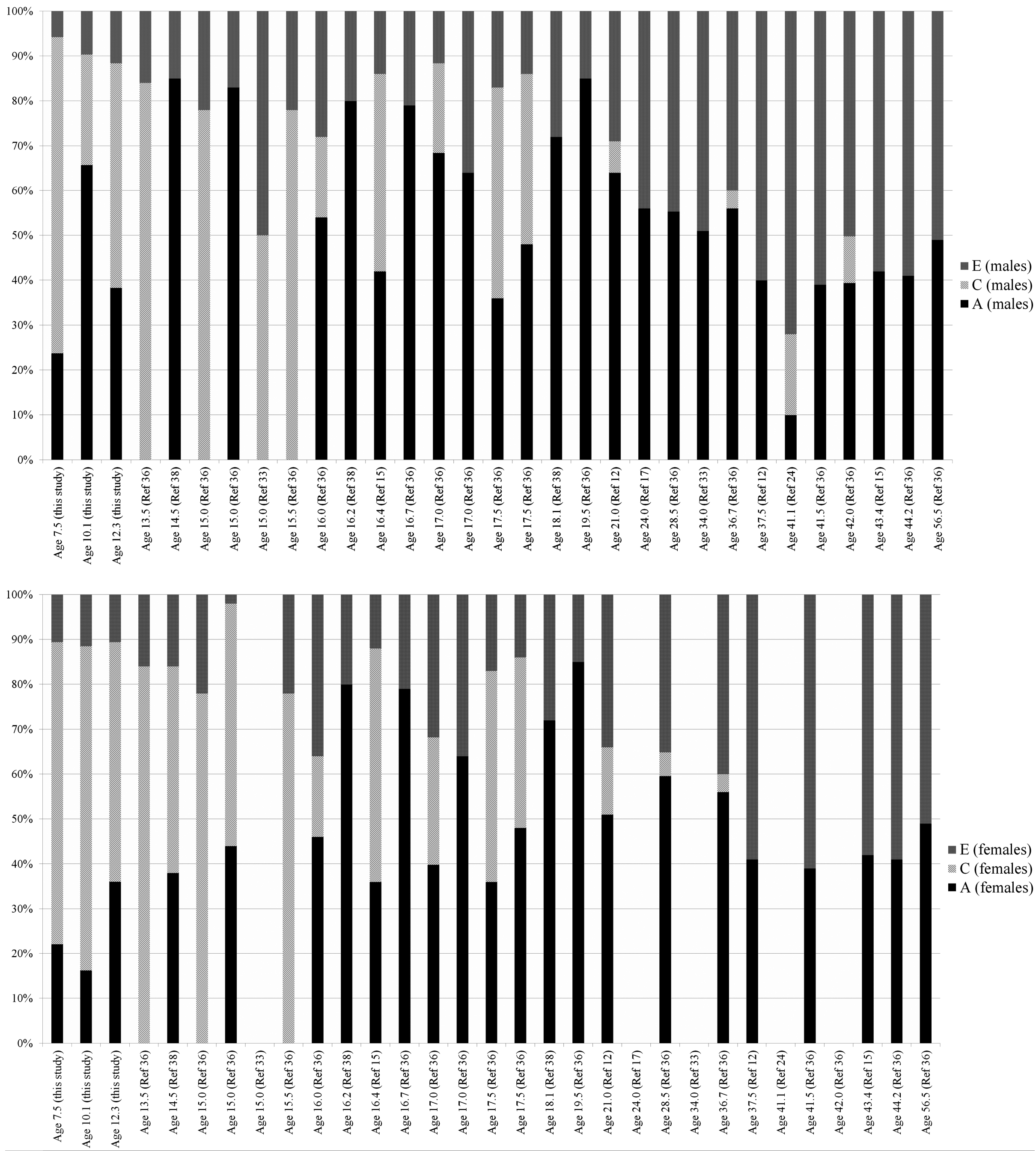

FIGURE 1—Summary of (previous) study results. *Top panel* shows the relative influence of genes (A), the shared environment (C), and the unique environment (E)—indicated as percentages—on leisure time exercise behavior across the lifespan for males. *Bottom panels* shows A, C, and E for females.

in our study engaged predominantly in individual exercise activities, whereas boys participated in all kinds of activities, including the more vigorous team sports (Table 2 and [25]). Accordingly, the percentage of opposite sex siblings that share at least one activity dropped to 46.5%, which is clearly lower than that for same-sex siblings (75.0%).

The relative contribution of genetic factors was much larger in 10-yr-old boys compared with 7- and 12-yr-olds. This pattern was not seen in girls. Because we used identical parental surveys, the difference cannot be attributed to a change in study methods. Also, there are no major changes in the educational system at this age (high school starts at least 2 yr later). One possible explanation is that most clubs, whether in team sports (e.g., soccer) or individual sports (e.g., tennis), increasingly start selecting for ability around this age. The amount of training is usually larger in the "first teams" compared with the lower ranked teams. Because exercise abilities are strongly heritable (10), this may have boosted heritability of participation in these types of activities in boys, who may be more sensitive to their relative ranking among peers than girls. However, it is unclear why this effect has dissipated at age 12 yr. Replication in larger samples is needed before drawing definitive conclusions.

After numerous studies using adolescent and adult twin data (e.g., [35,38]), this study is the first to investigate the relative contribution of genes and the environment on exercise behavior in children younger than 12 yr. Our findings fit the existing literature rather well as shown in Figure 1, which summarizes the results of all existing twin studies on leisure time exercise behavior. The figure includes the twin studies that were listed by Stubbe and De Geus (36), extended with additional studies (12,15,17,24,33,38) and the present one.

From childhood onward, the heritability of exercise behavior increases to a peak during late adolescence and then decreases again to reach stable proportions in adulthood. The substantial effect of shared environmental influences is only found in children. Our group (13) has hypothesized that the heritability of leisure time exercise behavior reflects three major sources: individual differences in a homeostatic need for activity, exercise ability, and acute psychological effects of exercise (also see [11]). Personality, itself a heritable trait, may be a fourth important determinant of stable individual differences in exercise participation (14,28).

A limitation of the present study is the reliance on parental ratings of leisure time exercise behavior. Subjective ratings by the parents may tend to overestimate the actual exercise behavior of the children. However, the correlations between mothers' and fathers' ratings were high and the results were remarkably comparable with similar studies that used objective measurements of general physical activity, to which leisure time exercise activities make an important contribution (19,20,27). Our use of a fixed list of the most common exercise activities performed by Dutch children probably helped to increase the reliability of parental reporting. It should be noted, however, that by focusing on these structured and well-defined exercise activities, we have ignored an important other contribution to children's leisure-time physical activity, namely, active play. Active play probably contributes to overall leisure time physical activity in different proportions across different age groups, with less opportunity for play in the 12-yr-olds once they enter high school. How this affects the heritability/environmentability of participation in regular structured exercise activities remains uncharted. A specific limitation of using twins, although in general the best design to estimate heritability, is that the findings may not generalize to families with siblings of different ages or a single child. Because twins have the same age, it could be argued that the role of tangible support (a shared environmental factor) is greater, because it is more convenient for the parents to handle the twins as a pair, than would be for siblings with larger age differences. To balance these limitations, this study had a very large sample size, estimated heritability in groups with a confined age range, and deliberately focused on participation in well-defined leisure time exercise activities, which are easier to assess in a standardized way than overall physical activity.

Our analyses confirmed the important role of shared environmental factors for children's exercise behavior that gradually give way to genetic influences when they reach early adolescence. The shared family environment is likely to be an important target for the development of successful interventions on childhood exercise behavior, but family-based strategies may become less useful in adolescence.

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APPLIED SCIENCES

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