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Title: Genetic and Environmental Effects on the Individual Variation and Continuity of Participation in Diverse Physical Activities

Year: 2021

Version: Accepted version (Final draft)

Please cite the original version:

Kaartinen, S., Silventoinen, K., Korhonen, T., Kujala, U. M., Kaprio, J., & Aaltonen, S. (2021). Genetic and Environmental Effects on the Individual Variation and Continuity of Participation in Diverse Physical Activities. Medicine and Science in Sports and Exercise, 53(12), 2495-2502. https://doi.org/10.1249/mss.0000000000002744

Medicine & Science in Sports & Exercise

The Official Journal of the American College of Sports Medicine
www.acsm-msse.org

. . . Published ahead of Print

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Accepted for Publication: 30 June 2021

Medicine & Science in Sports & Exercise, Publish Ahead of Print
DOI: 10.1249/MSS.0000000000002744

Genetic and Environmental Effects on the Individual Variation and Continuity of Participation in Diverse Physical Activities

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The research work has been supported by the Academy of Finland (grants 265240 and 312073 to J.K.), the Finnish Ministry of Education and Culture (to U.M.K.), the Juho Vainio Foundation (to S.A. and U.M.K.) and the Finnish Cultural Foundation (to S.A.) and the Doctoral Program of Public Health, University of Helsinki (S.K.). Data collection of the FinnTwin16 study has also been supported by the U.S. National Institute of Alcohol Abuse and Alcoholism (grants AA-

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ABSTRACT

Introduction: Participation in diverse physical activities has beneficial health effects. However, little is known on how genetic and environmental factors affect this trait. Thus, we examined to what extent these factors explain participation in diverse leisure-time physical activities from late adolescence to adulthood using a twin study design.

Methods: The participants were Finnish twins who reported their participation in diverse leisure-time physical activities at ages 17 (N=5429) and 34 years (N=4246). The number of physical activities engaged in were analyzed using applications of structural linear modeling for twin data.

Results: On average, the total number of physical activities engaged in during leisure time was slightly over three at both ages and in both sexes, with moderate heritability estimates (40–58%) from adolescence to adulthood. Environmental factors shared by co-twins (e.g., childhood family environment) influenced only in adolescence, being higher for women. Environmental influences unique to each co-twin explained the remaining variances (34–57%), being higher at age 34. Participation in diverse leisure-time physical activities correlated moderately between ages 17 and 34 (r_{TRAIT}=0.30 95% CI 0.25–0.35 in men and 0.26 95% CI 0.22–0.31 in women). Additionally, genetic influences on participation in physical activities correlated moderately between adolescence and adulthood (r_A=0.51 95% CI 0.39–0.64 and 0.44 95% CI 0.34–0.55, respectively). These common genetic influences explained 93% of the trait correlations found in men and 85% in women.

Conclusions: Genetic and unique environmental influences explain a large proportion of variation in the number of leisure-time physical activities. However, the estimates vary by age and sex. Common genetic background mainly explains the continuity of the participation in diverse leisure-time physical activities between adolescence and adulthood.

Key Words: Behavior Genetics, Exercise, Heritability, Longitudinal, Physical Activity, Twins, Sex Differences

INTRODUCTION

Decline in the physical activity found already in early adolescence has worrying public health consequences (1, 2). Participation in diverse physical activities might be a way to cope with this problem since several population-based studies, including our study, have shown that participation in several physical activities during adolescence is related to higher overall physical activity levels both in adolescence and later in adulthood (3–7). Moreover, an intensive participation in a single sport activity can increase the risk of overuse injuries, burnout, and even dropout from sports among young athletes, thus, also increasing the risk of a decline in the overall level of physical activity (8, 9). The recent global physical activity guidelines have addressed this topic: the guidelines include recommendations for multicomponent physical activity emphasizing not only activities at different intensities but also muscle- and bone-strengthening as well as balance training activities (1, 2). However, only a limited number of individuals meet these health-enhancing, evidence-based physical activity recommendations to engage in diverse physical activities (3, 4).

Understanding people's participation in diverse physical activities is complicated because multiple factors affect physical activity behavior (10). Many human behavioral traits, including physical activity, have a strong polygenic component and the heritability estimates between different physical activity traits have been shown to range between 20% and 90% (11, 12). Although participation in diverse physical activities has grown in importance in the field of sport and physical activity research, we are not aware of a single study of the genetic influences on this trait.

To estimate the influences of genetic and environmental factors on the individual differences in the diversity of leisure-time physical activity, we use longitudinal twin data from late adolescence to adulthood. Moreover, we estimate to what extent genetic and environmental factors contribute to the continuity in participation in diverse leisure-time physical activities. We examine the total number of leisure-time physical activities but also, as additional subgroup analyses, the number of individual and team physical activities separately. We use the term “physical activities” to refer to both recreational and goal-oriented physical activities engaged in during leisure time. Based on previous findings of genetic and environmental influences on physical activity, we expect that the variation in participation in diverse leisure-time physical activities is also due to underlying genetic and environmental influences. We assume that the estimates of genetic influences are higher in adolescence, whereas the role of environmental influences may increase towards adulthood, such as has been found when studying the levels of leisure-time physical activity (11, 13, 14). In addition, we seek to study sex-differences.

METHODS

PARTICIPANTS

The participants were drawn from the longitudinal FinnTwin16 study - a nationwide cohort of twins born in Finland between 1974 and 1979 and their families focusing on health and behavior (15). Twins were identified via Finland’s Population Register Center. The first survey wave was launched within 60 days of the twins’ 16^{th} birthdays (N=2773 twin pairs), and additional surveys have taken place at the mean ages of 17.1, 18.6, 24.5 and 34.1 years. The data for the current study were collected through mailed questionnaires at the second wave (i.e., age 17) and web-based questionnaires at the most recent (i.e., age 34) wave. The response rates to these survey waves were 95% and 72%, respectively. Zygosity was determined using a questionnaire method validated against genetic markers in this cohort (16).

DIVERSITY OF LEISURE-TIME PHYSICAL ACTIVITY

Altogether, 5429 twins (53% women) reported their participation in diverse leisure-time physical activities at age 17 and 4246 twins (55% women) at age 34. They reported all leisure-time physical activities they engaged in at the time the survey questionnaire was conducted (i.e., at age 17 or age 34), except school- or work-related physical activities, by responding to the following question: “What is your leisure-time physical activity/exercise like?”. Twins received the survey questionnaire either in Finnish or Swedish based on their native language (Finland is a bilingual country). However, because approximately only 5% of Finns speak Swedish as their native language, the majority of the twins received the questionnaire in Finnish. In the original version of the Finnish question, the word “liikunta” was used. This word refers as much to physical activity as to goal-oriented exercise. Therefore, the question reflects broadly both recreational and goal-oriented physical activities engaged in during leisure time.

The multiple-choice question we used consisted of 18 (age 17) or 26 (age 34) different physical activities, including endurance, power and game activities, such as walking, jogging, cycling, swimming, working out in a gym, ice hockey, soccer and basketball. Additionally, there was an open-ended item for potential physical activities not mentioned in the choices given and a maximum of three additional physical activities were taken into account. Based on twins’ responses, we calculated the number of different physical activities they engaged in their leisure time at ages 17 and 34 used as the indicator of the diversity of physical activities in the analyses: the range was 0–15 at age 17 and 0–12 at age 34 (Figure 1). In addition, we calculated the numbers of individual physical activities (the range was 0–11 at both ages 17 and 34) and team physical activities (the range was 0–7 at age 17 and 0–5 at age 34) for our subgroup analyses. The frequency, duration, and intensity of participation in individual physical activities was not asked for.

STATISTICAL METHODS

We first calculated the means and standard deviations of the number of leisure-time physical activities engaged in at ages 17 and 34 separately for monozygotic (MZ) and dizygotic (DZ) twins using Stata 16.1 software (17). Then, we quantified the degree to which MZ and DZ twins resemble each other by using intraclass correlations. Higher similarity within MZ co-twins than those found within DZ co-twins suggests the influence of genetic factors, whereas DZ correlations that are more than half of the MZ correlations indicate a potential presence of shared environmental factors (18). In our data, both genetic and shared environmental components, except a shared environmental component among women at age 34, were indicated to be present (Table 1). Further, DZ correlations for opposite-sex twin pairs were lower than for same-sex twin pairs (more so at age 34), suggesting that partly different genetic factors operate in men and women with regard to participation in diverse leisure-time physical activities.

We continued the analyses using the quantitative genetic modeling based on structural linear equations. The genetic twin modeling is based on the different genetic relatedness of MZ and DZ co-twins (MZ co-twins have virtually the same DNA sequence, whereas DZ co-twins share, on average, 50% of their segregating genes). The genetic twin design allows decomposing the variation in the diversity of leisure-time physical activities into genetic and environmental components (19, 20). Based on this method, the trait variation was decomposed into three components: additive genetic variation (A), shared environmental variation (C), and unique environmental variation (E) (includes measurement error) (21). The proportion of variation accounted for by genetic influences (A effects) is called heritability (genetic influences correlate 1.0 in MZ and 0.5 in DZ twins). Shared environmental influences (C effects) refer to all environmental influences that make members of a twin pair alike (these influences correlate 1.0 in both MZ and DZ twins). Shared environmental influences typically refer to such factors as parents, siblings, peers, friends in common, household and neighborhood. Unique environmental influences (E effects) denote all environmental influences that make members of a twin pair unlike (uncorrelated in both MZ and DZ twins). Unique environmental influences are such factors as own friends, illnesses and accidents. The modeling was performed by OpenMx package (version 3.4.4) of the R statistical software (22).

We began genetic modeling by comparing different univariate models to select the best-fitting model at each age to be used in the further analyses (see Table, Supplemental Digital Content 1, Univariate model-fitting statistics for the number of leisure-time physical activities at ages 17 and 34, http://links.lww.com/MSS/C377). First, we determined whether shared environmental factors were present to explain the variation in the twins' participation in diverse leisure-time physical activities by comparing the full ACE model to the AE model at each age separately. In terms of the total number of leisure-time physical activities, univariate model-fitting results suggested that there were significant differences in model fit between the full ACE and AE models at age 17 ($p=0.02$), indicating that the simpler AE models would not describe the data as adequately as the more complex ACE model. In the subgroup analyses, we also detected significant differences between the full ACE and AE models when the number of individual and team physical activities were analyzed separately at age 17 (p-values 0.02 and <0.001, respectively).

Subsequently, we tested whether there was evidence for sex-specific genetic factors related to participation in diverse leisure-time physical activities by analyzing whether the genetic correlations for opposite-sex DZ twins could be constrained to 0.5 (i.e., the same as for same-sex DZ twins). Although the intraclass correlations suggested that partly different genetic factors operate in men and women, this further analysis proposed no evidence for a sex-specific genetic effect in participation in diverse leisure-time physical activities at any age (p=0.60). Similarly, our subgroup analyses suggested no sex-specific genetic effect in participation in diverse individual physical activities (p=0.13) or diverse team physical activities (p=0.99) at age 17.

Next, we tested whether there were differences in the absolute and relative (i.e., standardized) genetic and environmental variances in participation in diverse leisure-time physical activities between sexes. Regarding the total number of leisure-time physical activities, there were no differences in these variances at age 34 (p=0.11 and 0.14, respectively), but the significant differences in the absolute and relative genetic and environmental variances of participation of diverse leisure-time physical activities between men and women at age 17 (p<0.001) suggested to favor genetic models that are conducted separately by sex. Subgroup analyses for the number of individual and team physical activities also showed significant differences in the absolute and relative genetic and environmental variances between men and women, except participation in diverse individual physical activities at age 34 (p=0.36 absolute variances and p=0.11 relative variances). This also suggests separate genetic models for men and women when the subgroup analyses are conducted for the number of individual or team physical activities separately.

Finally, we conducted a bivariate Cholesky decomposition. The Cholesky decomposition is a method that can be used for examining the effects of genetic and environmental influences on the development of a trait over time – i.e., to what extent the covariation of the trait at different times is explained by the same genetic and environmental factors. Thus, we estimated the correlations for the diversity of leisure-time physical activity (trait correlation) as well as genetic and environmental correlations found in participation in diverse leisure-time physical activities between ages 17 and 34 (23). Additionally, the proportions of the trait correlations explained by genetic and environmental factors can be estimated by using this bivariate Cholesky decomposition. The correlations were initially performed based on the univariate model-fitting results showing that the shared environmental components (C components) could not be dropped from the main or subgroup analyses at age 17 (i.e., ACE models) (see Table, Supplemental Digital Content 1, Univariate model-fitting statistics for the number of leisure-time physical activities at ages 17 and 34, http://links.lww.com/MSS/C377). However, the lack of shared environmental paths to participation in diverse leisure-time physical activities as well as in diverse individual and team physical activities in our subgroup analyses at age 34 causes situations in which shared environmental correlations may not be reliably estimated in the initial full ACE bivariate models. To make sure that dropping shared environmental influences (C components) from the final bivariate models would not cause any significant loss to the models, we compared ACE and AE bivariate models. The comparison suggested no significant differences between the models (p-values from 0.05 to 0.97), except for the number of team physical activities in women ($p<0.001$). Therefore, we present the AE bivariate models without shared environmental influences as the best-fitting models to our data. However, the full ACE model results are also presented.

ETHICS OF THE STUDY

The ethics committees of the University of Helsinki (Helsinki, Finland) and the Central Finland Health Care District (Jyväskylä, Finland) along with the Institutional Review Board of Indiana University (Bloomington, Indiana, USA) approved the FinnTwin16 study protocol. All study methods were carried out in accordance with the approved guidelines. The twins themselves provided informed consent for participation in the measurement waves of the FinnTwin16 study used in this study. The cover letter inviting participation provided detailed information about the study, and returning the questionnaire was taken as consent.

RESULTS

At age 17, the mean numbers of leisure-time physical activities were 3.18 for men and 3.17 for women (p=0.92 for sex difference). The numbers were almost the same in adulthood at age 34, being 3.11 in men and 3.21 in women (p=0.13 for sex difference). The corresponding numbers for individual physical activities were 2.22 for men and 2.86 for women (p<0.001 for sex difference) at age 17 and 2.65 for men and 3.12 for women (p<0.001 for sex difference) at age 34, while the mean numbers of team physical activities were 0.96 for men and 0.32 for women (p<0.001 for sex difference) at age 17 and 0.46 for men and 0.08 for women (p<0.001 for sex difference) at age 34. In addition, there were only some differences by zygosity groups (Table 2).

The combination of jogging and bicycling was the most common combination of two physical activities at age 17 in both sexes. This combination was most often supplemented with some ball games (such as soccer or floorball) among men and swimming among women. At age 34, the most common combination of two physical activities was walking and bicycling in both sexes, being most often complemented with gym workout among men and swimming among women.

The heritability estimates of participation in diverse leisure-time physical activities were 58% and 40% in 17-year-old men and women, respectively (Table 3). At age 34 years, the heritability estimate was 50% in men and 43% in women. Shared environmental influences contributed to participation in diverse leisure-time physical activities only at age 17 and were clearly more important for women (26%) than for men (5%). The relative role of unique environmental influences in participation in diverse leisure-time physical activities was more important in adulthood than in adolescence: 50% *versus* 37% in men and 57% *versus* 34% in women.

In the subgroup analyses, rather similar patterns of heritability and environmental influence estimates were observed when the number of individual and team physical activities were analyzed separately. A major exception was found in terms of the relative roles of genetic and shared environmental influences for participation in diverse team physical activities in women at age 17 (Table 3). In this subgroup analysis, no genetic influences were present in women's participation in diverse team physical activities (the heritability estimate was 0%), whereas shared environmental influences contributed very strongly (60%) to participation in diverse team physical activities in 17-year-old women. However, this result of non-existing genetic influences was not statistically significant.

The longitudinal associations between participation in diverse leisure-time physical activities in adolescence and adulthood are shown separately by sex in Table 4. With regard to the trait correlations, participation in diverse leisure-time physical activities was moderately correlated between ages 17 and 34, being 0.30 for men and 0.26 for women. Based on the AE bivariate model, genetic correlations (A component) between adolescence and adulthood were moderate, being r_A=0.51 (95% CI 0.39 to 0.64) in men and r_A=0.44 (95% CI 0.34 to 0.5) in women. These common genetic influences explained a very substantial proportion of the association between participation in diverse leisure-time physical activities in adolescence and adulthood (i.e., 93% in men and 85% in women). The correlations between unique environmental influences (E component) contributing to participation in diverse leisure-time physical activities in adolescence and adulthood were clearly lower than those of genetic correlations, being r_E=0.05 (95% CI -0.07 to 0.17) in men and r_E=0.09 (95% CI 0.00 to 0.18) in women. The longitudinal associations found in the subgroup analyses were very much in line with the longitudinal association results of the total number of leisure-time physical activities.

DISCUSSION

The purpose of this study was to better understand the role of genetic and environmental influences in the individual differences in participation in diverse leisure-time physical activities from late adolescence to adulthood using a genetically informative twin design. Our results showed that in men nearly two-thirds of the total variance in participation in diverse leisure-time physical activities was explained by genetic factors in adolescence, whereas this relative role decreased to 50% in adulthood. In women, the heritability estimates were around 40% in both adolescence and adulthood, being slightly higher in adulthood. The importance of shared environmental influences, such as childhood family environment, was identified in adolescence but not in adulthood and was greater among women than men. In both sexes, unique environmental influences explained about one-third of the variance of participation in diverse leisure-time physical activities in adolescence, while in adulthood about half of the variance was explained by unique environmental influences.

In addition to the total number of leisure-time physical activities, we stratified the data by the types of leisure-time physical activities: individual and team physical activities. Compared to the total number of leisure-time physical activities, the patterns of genetic and environmental contributions to participation in diverse individual and team physical activities were quite similar, except diverse team physical activities in women at age 17. Interestingly, though not statistically significantly, we found no genetic influences contributing to diverse team physical activities in women at age 17. Instead, a large amount of variance in participation in diverse team physical activities was explained by shared environmental influences in women at that age.

Our longitudinal study design indicated that the associations between participation in diverse leisure-time physical activities measured at late adolescence and adulthood were positive and moderate. The longitudinal results further indicated that the common genetic influences that explain the associations between participation in diverse leisure-time physical activities at ages 17 and 34 were substantial. These common genetic influences were even more important for men than women, which considered not only all leisure-time physical activities, but also individual and team physical activities – overlapping genetic influences explained 92–95% of the associations between men's participation in diverse leisure-time physical activities in adolescence and adulthood compared to 77–93% in women. The overlapping unique environmental influences were minor.

As far as we know, this was the first study to investigate the genetic and environmental influences on participation in diverse leisure-time physical activities, measured as the number of different physical activities engaged in. As hypothesized, we were able to show that both the genetic and environmental influences account for variation in participation in diverse leisure-time physical activities. Our results further indicated that genetic factors mainly have a considerable effect on the diversity of leisure-time physical activity, particularly in adolescents, but also in adults. Although there are no previous behavior genetic studies on this physical activity diversity behavior, our results reflect those of the heritability of overall leisure-time physical activity behavior: regardless of study designs, physical activity criteria, study populations, the ages or sexes of the participants, the heritability estimates of overall leisure-time physical activity have ranged from 20% to 90% (11, 13, 14). The statistically significant heritability estimates of 40–64% that we found for participation in diverse leisure-time physical activities, individual physical activities and team physical activities, lie in the same range as most of these earlier heritability estimates of leisure-time physical activity behavior.

Previous studies have also shown that genetic influences contributing to leisure-time physical activity phenotypes are higher in adolescence than later in life (13, 14). This was also partly found in our study, yet we examined a different aspect of physical activity behavior – in our main analyses (the total number of leisure-time physical activities), men followed the pattern found in previous studies showing higher genetic influences in adolescence, whereas women followed that same pattern in the subgroup analyses related to the number of individual physical activities. However, contrary to previous results and our hypothesis, genetic influences contributing to participation in all leisure-time physical activities and team physical activities were higher among adult women. One explanation for this finding might be that among women the influence of the shared family environment on diversity of leisure-time physical activities was high in adolescence and, thus, the role of genetic factors was lower in adolescence than in adulthood.

Contrary to previous longitudinal behavior genetic studies using other physical activity phenotypes (11–14), we found a very high correlation between genetic influences measured at the two different time points. For example, our previous study (13) that investigated the longitudinal leisure-time physical activity behavior in the same Finnish twin dataset found that the common genetic influences explained only around 19% of the association between leisure-time physical activity in adolescence and young adulthood (at the mean age 24.5 years). In the present study, the corresponding explanation percentages were 77% and over. Of note is that at the time of our previous study, the latest follow-up time point of the FinnTwin16 study cohort (age 34 years) was not available and this may cause inconsistency between the results along with the different phenotypes used. In general, genetic and environmental correlations often decrease when the time difference between the assessments of those genetic or environmental influences increase. In this sense, our present genetic correlations based on the genetic influences around 17 years apart should have been lower than the corresponding genetic correlations of genetic influences only 7 years apart in our previous study. However, and importantly, the phenotypes in question are different (even though they are significantly correlated leisure-time physical activity phenotypes) and, thus, some differences are expected.

Interestingly, the influence of the shared environment was more important for women than men at age 17 in the current study. The greatest difference between the sexes was found to be related to the number of team physical activities (9% in men *versus* 60% in women). This was also inconsistent with our previous study examining the genetic and environmental influences on the level of leisure-time physical activity (13). In that previous study, we found that shared environmental influences were equally important for men's and women's leisure-time physical activity behavior at age 17 and the differing roles of shared environmental influences were seen only at age 24 (13). As a definition, the shared environment includes all aspects of the environment that are the same for both co-twins. Therefore, at age 17, the most important shared environment is very likely the family environment if the co-twins have been reared in the same household. Manz et al. (2016) found that household income, potential migrant background, family form, and residential area size are more likely to affect girls' participation in organized sports compared to boys (24). These may be some of the shared environmental factors that also play a role in our present results.

A few studies have shown that participation in diverse physical activities decreases during and after adolescence (4, 7), especially among women (6, 24). In our study, this indeed holds true, but only with team physical activities. No such decrease was seen elsewhere. Interestingly, the number of team physical activities engaged in seemed to follow the extent to which the relative role of shared environmental influences explained the participation in diverse team physical activities: the relative role of shared environmental influences was higher in adolescence when the number of team physical activities engaged in was also higher. Similar to previous studies, this phenomenon was more clear in women than men, potentially suggesting that women's choices of leisure-time physical activities, particularly team physical activities, may be more affected by the home environment than men's choices in adolescence. In adulthood, when the number of team physical activities was decreased, participation in diverse team physical activities was more due to an individual's genetic susceptibility – thus, the inherent abilities of the individual play a larger role in adulthood.

The mean number of all leisure-time physical activities was around three both in adolescence and adulthood and was actually slightly higher in women compared to men at age 34. Despite these equal number of all leisure-time physical activities in the current study, we showed in our previous study with the same sample of the twins we used in this study that the average level and intensity of leisure-time physical activity was higher in men than in women at age 34 (3). This finding related to the intensity of physical activity is in agreement with those obtained by some earlier studies indicating more frequent participation in vigorous physical activities among men than women (10, 13). Our current result on men's more frequent participation in team physical activities also seems to reflect these previous results on the sex differences regarding the intensity of physical activity and participation in vigorous physical activities. In light of our results, we can speculate that women may potentially compensate for their lower intensity of leisure-time physical activity by participating in the high number of physical activities in an aim to reach the level of physical activity recommended. Additionally, women may be likely to try out a higher number of physical activities than men and remain engaged in them.

Our study is limited by its subjective nature because participation in diverse leisure-time physical activities was self-reported by the participants. We acknowledge that recall bias cannot be avoided regarding this kind of self-report. Moreover, it is possible that some participants have reported physical activities they do not engage in on a regular basis and, thus, exaggerated the number of their physical activities. Because of this issue, we excluded one participant who reported a suspiciously large number of physical activities (i.e., 20 physical activities), while reporting being physically active only on a random basis. In this context, it is also important to keep in mind that the alternation of the four seasons in Finland strongly affects the population's physical activity habits. Therefore, it is possible that the participants reported all the physical activities they engaged in during all seasons of the year. This may also have increased the number of physical activities. However, the validity of physical activity questionnaires used in Finnish twins has been demonstrated to be good (25, 26).

A major strength of our study is that we were able to investigate participation in diverse leisure-time physical activities longitudinally from late adolescence to adulthood. Therefore, we were able to quantify changes in the magnitude of genetic and environmental influences at different stages of life. This is important because genetic and environmental influences are not stable over time. Our leisure-time-related focus also better reflects voluntary behavior and/or inherent abilities of the individual than, for example, school-based physical activities. Moreover, we were able to examine not only the total number of leisure-time physical activities but also split the data into individual and team physical activities. An additional strength of this study is the large population-based sample with relatively equal sex representation and high response rates. Although this offers excellent generalizability of the study findings, the findings are limited to individuals at 17 and 34 years of age while other ages remain poorly studied. Any further selection biases are unlikely because the questionnaires used in the study included multiple domains of health and behavior, not just leisure-time physical activity behavior.

According to our results, a practical implication to increase participation in diverse leisure-time physical activities in adolescence might require interventions in family and other environments shared by siblings such as schools and peer networks. In adulthood in contrast, individual-based interventions might be more useful to increase this behavior. Because genes and environment work together to influence physical activity diversity behavior, a favorable environment may also support individual's potential genetic predisposition to the higher numbers of leisure-time physical activities. This may further be the way to increase the overall level of leisure-time physical activity as well. Our findings also raise the intriguing questions of whether similar genetic and environmental influences could be seen in other populations. Future research should not only replicate genetic and environmental influences on participation in diverse leisure-time physical activities in other age groups (such as younger children and older adults) and populations but also focus on the specific types of leisure-time physical activities, making our novel findings of the phenomenon potentially even more robust.

CONCLUSIONS

We have been able to provide fresh insights into participation in diverse leisure-time physical activities by utilizing unique twin resources with repeated measures. We demonstrated that genetic effects mainly have a significant influence on both cross-sectional and longitudinal participation in diverse leisure-time physical activities. The importance of genetic factors was particularly highlighted by the longitudinal finding that the observed association in participation in diverse leisure-time physical activities between adolescence and adulthood was for the most part explained by the common genetic influences. Despite of the large influence of genetic factors, environmental influences were also found to have an evident contribution on the cross-sectional participation in diverse leisure-time physical activity: in adolescence the contribution of shared environmental influences was highlighted, while in adulthood the unique environmental influences stood out along with genetic influences. Therefore, our results suggest that participation in diverse leisure-time physical activities is not only a genetically driven behavior but is also possible to promote by interventions.

AKNOWLEDGEMENTS

The research work has been supported by the Academy of Finland (grants 265240 and 312073 to J.K.), the Finnish Ministry of Education and Culture (to U.M.K.), the Juho Vainio Foundation (to S.A. and U.M.K.) and the Finnish Cultural Foundation (to S.A.) and the Doctoral Program of Public Health, University of Helsinki (S.K.). Data collection of the FinnTwin16 study has also been supported by the U.S. National Institute of Alcohol Abuse and Alcoholism (grants AA-12502, AA-00145 and AA-09203 to Prof. Richard J. Rose) and by Academy of Finland (grant numbers 100499, 205585, 141054 to J.K.).

AUTHOR CONTRIBUTIONS

S.K. and S.A. conceived and designed the study, analyzed and interpreted the data and drafted the manuscript. K.S. participated in the planning of the study, provided statistical expertise as well as revised and edited the manuscript. T.K. contributed to the study design, data interpretation and manuscript revision. U.M.K. and J.K. conceived, designed and contributed to the data collection of the FinnTwin16 cohort and critically revised and edited the manuscript. All authors read and approved the final manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest. The results of the present study do not constitute endorsement by the American College of Sports Medicine.

The authors state that the results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

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Figure 1 The number of leisure-time physical activities by sex at ages 17 and 34.

Table 1 Intra-class correlations for the number of leisure-time physical activities variable with 95% confidence intervals (CI) at age 17 and 34 within twin pairs by sex and zygosity.

Table 2 Characteristics of the study sample.

Table 3 The relative contributions of genetic and environmental factors to variances in number of leisure-time physical activities with 95% confidence intervals (CI) at age 17 and 34 by sex. The results are based on the best-fitting model at each age.

Table 4 Trait correlations (r_{trait}) along with the correlations between additive genetic (r_A), shared environmental (r_C) and unique environmental (r_E) influences for participation in diverse leisure-time physical activities with 95% confidence intervals (CI) for the full ACE and best-fitting AE models by sex.

Supplemental Digital Content 1. Supplemental Table 1 Univariate model-fitting statistics for the number of leisure-time physical activities at ages 17 and 34.

Figure 1

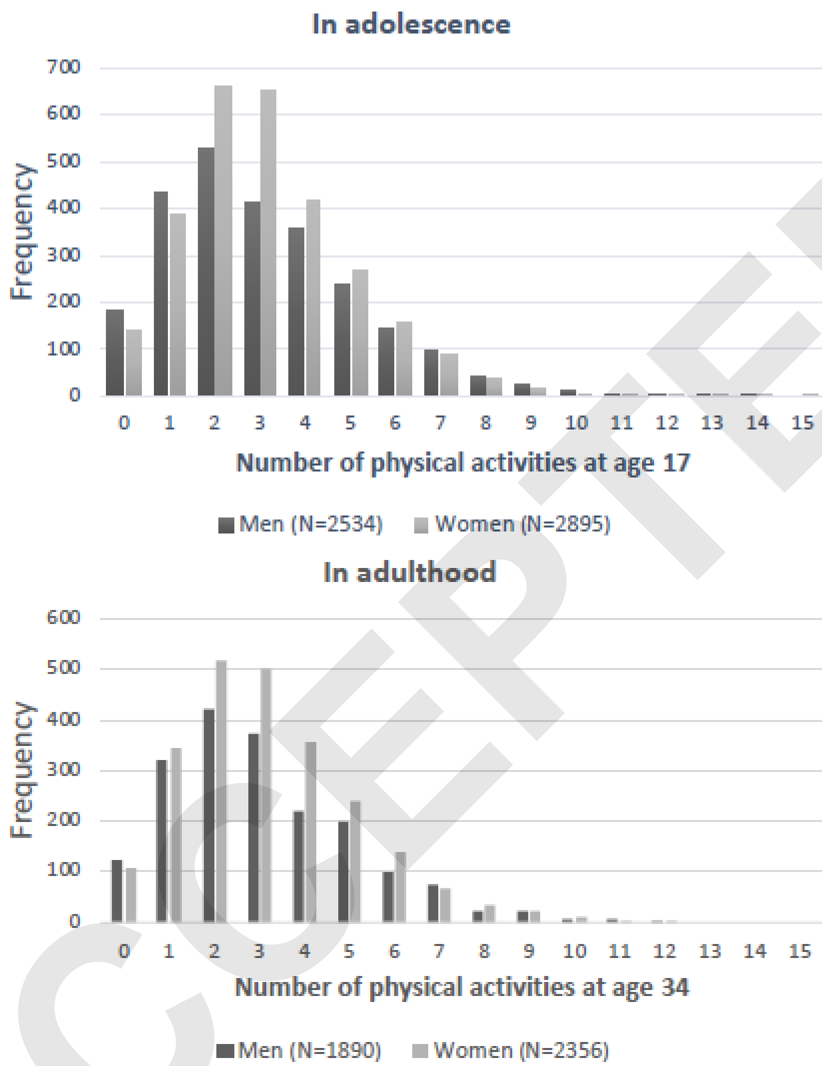
In adolescence
Frequency
700
600
500
400
300
200
100
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Number of physical activities at age 17
Men (N=2534)
Women (N=2895)
In adulthood
Frequency
600
500
400
300
200
100
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Number of physical activities at age 34
Men (N=1890)
Women (N=2356)

Table 1 Intra-class correlations for the total number of leisure-time physical activities variable with 95% confidence intervals (CI) at age 17 and 34 within twin pairs by sex and zygosity.

Variables	Sex	Intra-class correlation					
		MZ twins		DZ twins same sex		DZ twins opposite sex	
		r^2 (95% CI)	Number of twin pairs	r^2 (95% CI)	Number of twin pairs	r^2 (95% CI)	Number of twin pairs
Total number of leisure-time physical activities							
At age 17	♂	0.64 (0.58 to 0.70)	335	0.33 (0.25 to 0.42)	419	0.23 (0.14 to 0.32)	858
	♀	0.67 (0.62 to 0.72)	496	0.42 (0.34 to 0.50)	428		
At age 34	♂	0.48 (0.37 to 0.58)	203	0.27 (0.15 to 0.38)	230	0.7 (-0.06 to 0.19)	518
	♀	0.42 (0.33 to 0.50)	345	0.21 (0.10 to 0.32)	277		

MZ=monozygotic, DZ=dizygotic

Table 2 Characteristics of the study sample

Variables		MZ twins		DZ twins same sex		DZ twins opposite sex		
	Sex	Mean (SD)	Number of twin individuals	Mean (SD)	Number of twin individuals	Mean (SD)	Number of twin individuals	Test for mean differences p-value
Total number of leisure-time physical activities								
At age 17	♂	3.08 (2.25)	685	3.14 (2.18)	861	3.31 (2.25)	871	0.09
	♀	3.17 (2.04)	1007	3.05 (1.89)	871	3.29 (2.02)	938	0.04
At age 34	♂	3.18 (2.08)	507	3.06 (2.03)	617	3.14 (2.17)	624	0.65
	♀	3.22 (1.97)	790	3.09 (1.91)	679	3.31 (2.17)	789	0.12
Number of individual physical activities								
At age 17	♂	2.21 (1.72)	685	2.07 (1.60)	861	2.36 (1.69)	871	0.12
	♀	2.84 (1.78)	1007	2.76 (1.70)	871	2.96 (1.74)	938	0.40
At age 34	♂	2.72 (1.81)	507	2.59 (1.83)	617	2.69 (1.93)	624	0.44
	♀	3.14 (1.90)	790	3.01 (1.86)	679	3.23 (2.08)	789	0.11
Number of team physical activities								
At age 17	♂	0.87 (1.14)	685	1.07 (1.19)	861	0.95 (1.21)	871	0.005
	♀	0.33 (0.73)	1007	0.29 (0.60)	871	0.33 (0.73)	938	0.40
At age 34	♂	0.46 (0.76)	507	0.48 (0.80)	617	0.45 (0.79)	624	0.80
	♀	0.08 (0.35)	790	0.08 (0.31)	679	0.08 (0.35)	789	0.95

MZ=monozygotic, DZ=dizygotic, SD=standard deviation

Table 3 The relative contributions of genetic and environmental factors to variances in number of leisure-time physical activities with 95% confidence intervals (CI) at age 17 and 34 by sex. The results are based on the best-fitting model at each age.

		Relative variance components		
	Sex	Additive genetic influences (95% CI)	Shared environmental influences (95% CI)	Unique environmental influences (95% CI)
Total number of leisure-time physical activities				
At age 17	♂ ♀	0.58 (0.38 to 0.68) 0.40 (0.23 to 0.57)	0.05 (0.00 to 0.22) 0.26 (0.10 to 0.40)	0.37 (0.31 to 0.43) 0.34 (0.30 to 0.39)
At age 34	♂ ♀	0.50 (0.40 to 0.58) 0.43 (0.35 to 0.50)	– –	0.50 (0.42 to 0.60) 0.57 (0.50 to 0.65)
Number of individual physical activities				
At age 17	♂ ♀	0.42 (0.23 to 0.63) 0.51 (0.35 to 0.68)	0.17 (0.00 to 0.33) 0.18 (0.02 to 0.32)	0.41 (0.35 to 0.47) 0.31 (0.27 to 0.35)
At age 34	♂ ♀	0.46 (0.36 to 0.55) 0.42 (0.33 to 0.49)	– –	0.54 (0.46 to 0.64) 0.58 (0.51 to 0.67)
Number of team physical activities				
At age 17	♂ ♀	0.63 (0.48 to 0.72) 0.00 (0.00 to 0.13)	0.09 (0.01 to 0.21) 0.60 (0.48 to 0.64)	0.29 (0.25 to 0.34) 0.40 (0.36 to 0.44)
At age 34	♂ ♀	0.64 (0.55 to 0.70) 0.53 (0.47 to 0.59)	– –	0.36 (0.30 to 0.44) 0.47 (0.41 to 0.53)

Table 4 Trait correlations (r_{trait}) along with the correlations between additive genetic (r_A), shared environmental (r_C) and unique environmental (r_E) influences for participation in diverse leisure-time physical activities with 95% confidence intervals (CI) for the full ACE and best-fitting AE models by sex.

			Trait correlation	Additive genetic correlation		Shared environmental correlation		Unique environmental correlation	
Trait 1	Trait 2		r_{trait} (95% CI)	r_A (95% CI)	% Explained of r_{trait}	r_C (95% CI)	% Explained of r_{trait}	r_E (95% CI)	% Explained of r_{trait}
Total number of leisure-time physical activities									
AE model									
Number of physical activities age 17	Number of physical activities age 34	♂ ♀	0.30 (0.25 to 0.35) 0.26 (0.22 to 0.31)	0.51 (0.39 to 0.64) 0.44 (0.34 to 0.55)	93% 85%	– –	– –	0.05 (-0.07 to 0.17) 0.09 (-0.00 to 0.18)	7% 15%
ACE model									
Number of physical activities age 17	Number of physical activities age 34	♂ ♀	0.30 (0.25 to 0.35) 0.27 (0.22 to 0.31)	0.58 (0.42 to 1.00) 0.33 (-0.03 to 0.68)	94% 43%	-0.04 (-0.97 to 0.70) 0.66 (0.01 to 1.00)	0% 40%	0.04 (-0.08 to 0.17) 0.09 (0.00 to 0.18)	6% 16%
Number of individual physical activities									
AE model									
Number of individual physical activities age 17	Number of individual physical activities age 34	♂ ♀	0.28 (0.23 to 0.33) 0.24 (0.20 to 0.29)	0.52 (0.39 to 0.65) 0.43 (0.33 to 0.53)	95% 93%	– –	– –	0.03 (-0.08 to 0.15) 0.04 (-0.05 to 0.13)	5% 7%
ACE model									
Number of individual physical activities age 17	Number of individual physical activities age 34	♂ ♀	0.28 (0.23 to 0.33) 0.24 (0.19 to 0.28)	0.59 (0.37 to 0.99) 0.56 (0.35 to 0.90)	* *	-0.04 (-1.00 to1.00) -0.87 (1.00 to1.00)	* *	0.04 (-0.08 to 0.15) 0.05 (-0.05 to 0.14)	* *
Number of team physical activities									

AE model									
Number of team physical activities age 17	Number of team physical activities age 34	♂ ♀	0.35 (0.30 to 0.40) 0.25 (0.20 to 0.29)	0.49 (0.40 to 0.57) 0.34 (0.25 to 0.44)	92% 77%	– –	– –	0.08 (-0.05 to 0.22) 0.13 (0.04 to 0.22)	8% 23%
ACE model									
Number of team physical activities age 17	Number of team physical activities age 34	♂ ♀	0.35 (0.30 to 0.40) 0.26 (0.21 to 0.30)	0.52 (0.24 to 0.70) -0.60 (-0.95 to 0.23)	85% *	0.31 (-0.16 to1.00) 0.49 (0.22 to 0.70)	8% *	0.07 (-0.07 to 0.31) 0.11 (-0.03 to 0.19)	6% *

*= cannot be calculated

Supplemental Table 1 Univariate model-fitting statistics for the number of leisure-time physical activities at ages 17 and 34.

		Model fit statistics					
		-2LL	df	AIC	ΔLL	Δdf	*p*-value
Total number of leisure-time physical activities							
At age 17	ACE: sex-specific variances	17771.56	5216	7339.56	-	-	-
	ACE: constraining the genetic correlation among opposite-sex twin pairs to be 0.5	17771.84	5217	7337.84	0.28	1	0.60
	ACE: constraining variances to be equal in men and women	17817.74	5219	7379.74	46.18	3	<0.001
	ACE: constraining standardized variances to be equal in men and women	17814.70	5217	7376.70	43.14	1	<0.001
	AE compared to ACE	17779.82	5218	7343.82	8.26	2	0.02
At age 34	ACE: sex-specific variances	13776.34	3976	5824.34	-	-	-
	ACE: constraining the genetic correlation among opposite-sex twin pairs to be 0.5	13776.61	3977	5822.61	0.27	1	0.60
	ACE: constraining variances to be equal in men and women	13782.35	3979	5824.35	6.00	3	0.11
	ACE: constraining standardized variances to be equal in men and women	13778.50	3977	5820.50	2.16	1	0.14
	AE compared to ACE	13776.79	3978	5820.79	0.45	2	0.80
Number of individual physical activities							
At age 17	ACE: sex-specific variances	16530.22	5216	6098.22	-	-	-
	ACE: constraining the genetic correlation among opposite-sex twin pairs to be 0.5	16532.54	5217	6098.54	2.32	1	0.13
	ACE: constraining variances to be equal in males and females	16538.67	5219	6100.67	8.45	3	0.04
	ACE: constraining standardized variances to be equal in males and females	16538.21	5217	6100.21	7.99	1	0.005
	AE compared to ACE	16538.21	5218	6102.21	7.98	2	0.02
At age 34	ACE: sex-specific variances	13573.75	3974	5625.75	-	-	-
	ACE: constraining the genetic correlation among opposite-sex twin pairs to be 0.5	13578.38	3975	5628.38	4.63	1	0.03
	ACE: constraining variances to be equal in males and females	13576.96	3977	5622.96	3.21	3	0.36
	ACE: constraining standardized variances to be equal in males and females	13576.30	3975	5622.30	2.55	1	0.11
	AE compared to ACE	13574.04	3976	5622.04	0.29	2	0.87
Number of team physical activities							

At age 17	ACE: sex-specific variances	10683.57	5216	251.57	-	-	-
	ACE: constraining the genetic correlation among opposite-sex twin pairs to be 0.5	10683.57	5217	249.57	<0.001	1	0.99
	ACE: constraining variances to be equal in males and females	11354.36	5219	916.36	670.80	3	<0.001
	ACE: constraining standardized variances to be equal in males and females	10947.29	5217	509.29	263.72	1	<0.001
	AE compared to ACE	10730.68	5218	294.68	47.11	2	<0.001
At age 34	ACE: sex-specific variances	4284.48	3974	-3663.52	-	-	-
	ACE: constraining the genetic correlation among opposite-sex twin pairs to be 0.5	4285.52	3975	-3664.48	1.04	1	0.31
	ACE: constraining variances to be equal in males and females	5503.85	3977	-2450.15	1219.37	3	<0.001
	ACE: constraining standardized variances to be equal in males and females	4554.38	3975	-3399.62	269.90	1	<0.001
	AE compared to ACE	4285.18	3976	-3666.82	0.70	2	0.71

LL=log-likelihood, df=degrees of freedom, AIC=Akaike's information criterion, ΔLL=log-likelihood difference (chi-squared) between the initial model and the fitted sub-model, Δdf=increment in degrees of freedom with respect to the initial model, A=additive genetic influences, C=shared environmental influences, E=unique environmental influences.