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Genetic architecture of motives for leisure-time physical activity: a twin study

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The aim of this study was to estimate the contribution of genetic and environmental influences on motives for engaging in leisure-time physical activity. The participants were obtained from the FinnTwin16 study. A modified version of the Recreational Exercise Motivation Measure was used to assess the motives for leisure-time physical activity in 2542 twin individuals (mean age of 34.1 years). Linear structural equation modeling was used to investigate the genetic and environmental influences on motive dimensions. The highest heritability estimates were found for the motive dimensions of "enjoyment" [men 33% (95% CI 23–43%), women 53% (95% CI 45–60%)] and "affiliation" [men 39% (95% CI 0.28–0.49%), women 35% (95% CI 0.25–0.43%)]. The lowest heritability estimates were found for others' expectations [men 13% (95% CI 0.04–0.25%), women 15% (95% CI 0.07–0.24%)]. Unique environmental influences explained the remaining variances, which ranged from 47% to 87%. The heritability estimates for summary variables of intrinsic and extrinsic motives were 36% and 32% for men and 40% and 24% for women, respectively. In conclusion, genetic factors contribute to motives for leisure-time physical activity. However, the genetic effects are, at most, moderate, implying the greater relative role of environmental factors.

Physical inactivity is a major global public health issue (Hallal et al., 2012). An increasing body of research has examined the correlates and determinants of physical activity behavior. Multiple factors at individual, social, environmental, and policy levels can all have effects on physical activity behavior (Bauman et al., 2012). Variation in physical activity behavior is known to be explained at least moderately by genetic differences (de Vilhena e Santos et al., 2012; Aaltonen et al., 2014a; de Geus et al., 2014). In twin studies, heritability estimates (i.e., the proportion of variance explained by genetic differences) of physical activity have ranged from about 30% to 80% (de Geus et al., 2014). However, specific molecular genetic studies have found no robustly replicated genes for physical activity behavior (de Vilhena e Santos et al., 2012; de Geus et al., 2014). On the other hand, research focusing on the psychological correlates of physical activity behavior has indicated that motives for physical activity are likely to be a key factor in understanding individual differences in leisure-time physical activity behavior (Dacey et al., 2008; Garcia Calvo et al., 2010; Bauman et al., 2012). Motives give a direction to physical activity behavior. Self-Determination Theory focuses on the importance of intrinsic motives in driving human behavior suggesting that intrinsically motivated behavior is based on three fundamental needs that must be satisfied: competence, autonomy, and relatedness (Deci & Ryan, 1985). Intrinsically motivated people follow their innate needs and interests, while extrinsic motives are related to rewards and punishments. In general, intrinsic motives, such as enjoyment, are linked to regular physical activity behavior (Teixeira et al., 2012).

The disparate findings of previous research lines raises an interesting question of whether the motives for physical activity themselves can be heritable. In the mid-sixties, an American study with a small sample size (61 female twin pairs of 6– 10 years of age) showed low to moderate heritability estimates (i.e., 26–40%) for aspects of motives for physical activity (Scarr, 1966). Since studies on the heritability estimates of motives are scant, studies on exercise attitudes may be relevant. Motives and attitudes are not conceptually identical, but both can be considered to influence behavior: motives start the physical activity behavior and represent the individual's feelings toward physical activity, while attitudes determine the direction of the activity (Droba, 1933). Two studies on exercise attitudes have indicated a genetic basis for exercise attitudes. First, Olson et al. (2001) estimated the genetic basis of several attitudes, including attitudes toward athleticism by comparing the similarity of monozygotic (MZ, genetically identical) and dizygotic (DZ, genetically full siblings) twins. They found that genetic factors contribute moderately to the variation in attitudes toward athleticism; the heritability estimate was 54%. More recently, in 2014, a Dutch study of adult twins and their siblings indicated that genetic influences play a role in explaining individual differences in exercise attitudes (Huppertz et al., 2014). In this study, the heritability of the attitude components of physical activity ranged between 21% and 49%, indicating moderate genetic variation in exercise attitudes: lack of enjoyment in men (47%) and embarrassment (49%) in women showed the highest heritability.

Inherent differences in brain reward activation in voluntary physical activity behavior have been shown in animal studies (Rhodes et al., 2003; Garland et al., 2011; Roberts et al., 2014). Recently, a study among rats selectively bred to possess low vs high voluntary running behavior demonstrated that the mechanisms underlying motives for physical activity behavior are likely to have a partial genetic basis (Roberts et al., 2014). More specifically, medium spiny neuron maturation differences in the nucleus accumbens seemed to be responsible for differences in voluntary running motivation in rats. In a similar genetic selection study on mice, there was evidence for the evolution of certain brain regions responsible for increasing motivation for wheel running (voluntary running distance was considered an index of motivation for wheel running) (Rhodes et al., 2003). These studies suggest that genetic factors may also influence motives to engage in physical activity in humans.

Much uncertainty still exists regarding the overall genetic architecture of motives for physical activity behavior. Thus, quantitative genetic analyses in twins can provide a novel understanding of the contribution of genetic factors to motives to be physically active. Our dataset of Finnish twins offers an opportunity to investigate motives for leisure-time physical activity and to disentangle genetic variation from environmental variation. In the present study, the objective was to better understand the role of genetic and environmental factors behind the individual differences in motives for engaging in leisure-time physical activity. We aimed to estimate to what extent motives for leisure-time physical activity are heritable among adults in their mid-thirties and also to examine whether heritability estimates differ between intrinsic and extrinsic motive dimensions. With regard to the estimates found for exercise attitudes, we hypothesized that the heritability estimates of the motive dimensions of leisure-time physical activity range between 20% and 50% (Olson et al., 2001; Huppertz et al., 2014).

Moreover, we hypothesized that extrinsic motive dimensions are less heritable than intrinsic motive dimensions, since intrinsic motives seem to be important for the progression to and maintenance of actual activity, while extrinsic motives, such as the expected appearance consequences of physical activity, are found to be dominant during the early stages of physical activity behavior adoption (Deci & Ryan, 1985; Ryan et al., 1997; Segar et al., 2008). Intrinsic activities highlighted in Self-Determination Theory are those that people do naturally and spontaneously when they follow their inner interests (Deci & Ryan, 1985), and, thus, intrinsic motive dimensions related to people's inner interests may have a higher genetic predisposition than extrinsic motive dimensions. Extrinsic motive dimensions may be influenced more by external factors, such as cultural and social factors. Finally, we will investigate to what extent different motive dimensions of leisure-time physical activity behavior share the same genetic and environmental variations. We present the results of genetic modeling by gender, since previous studies have shown that motives for physical activity differ between men and women (Gill et al., 1996; de Andrade Bastos et al., 2006; Dacey et al., 2008).

Materials and methods

Participants

The data were derived from the latest data collection wave of the FinnTwin16 study, which was conducted between the years 2010 and 2012 (Kaprio, 2013). The twins were originally identified via Finland's Central Population Register, and they have been taking part in the study since the age of 16. For the fifth wave of data collection, an invitation letter to participate in an Internet survey was sent to all twins in the birth cohorts between the years October to December 1974 and 1975 to 1979, and who lived in Finland. Of the 6132 twins who were contacted irrespective of their participation in earlier study waves, 4414 twins participated in this wave of the survey (response rate 72%). The mean age of the twins who completed the online questionnaire was 34.1 (SD 1.16) years. The zygosity of the twins had been determined earlier using a well-validated questionnaire (Jelenkovic et al., 2011).

Altogether 3933 twin individuals responded to the items on the motives for leisure-time physical activity. Missing data rates for single motive items ranged from 5% to 6%. Since we know that pregnancy can reduce the ability to be physically active in women, we excluded pregnant women from the analysis (n = 191), and twins with unknown/uncertain zygosity were also excluded (n = 201). After these exclusions, we had data available on 3541 twin individuals. Data on all motive dimensions for both co-twins of a twin pair were available for 1271 twin pairs (2542 twin individuals). Of these, 183 were MZ and 196 were DZ male twin pairs, 275 were MZ and 198 were DZ female twin pairs, and 419 were DZ twin pairs of opposite gender.

Assessment of the motives for leisure-time physical activity

To evaluate the participants' motives for leisure-time physical activity, a modified version of the Recreational Exercise Motivation Measure (REMM) (Rogers & Morris, 2003; Aaltonen et al., 2014b) was used. The REMM measure is designed to assess adults' physical activity motives and it is based on Self-Determination Theory (Deci & Ryan, 1985). The original version of the REMM measure consisted of 73 items representing both intrinsic and extrinsic motives for leisure-time physical activity. They form eight dimensions of 8 to 13 items. In the FinnTwin16 study, each of the eight dimensions was represented by only one item due to restrictions on space on the online survey questionnaire.

The dimensions of the REMM measures were (representative item in parentheses) (1) mastery ("improve skills and/or get better at an activity"), (2) enjoyment ("have a good time and enjoy exercising"), (3) affiliation ("be with friends and/or do activity with others"), (4) competition/ego ("be fitter and/or look better than others"), (5) others' expectations ("conform to others' expectations"), (6) physical fitness ("be physically fit"), (7) psychological state ("improve psychological health/wellbeing"), and (8) appearance ("maintain/improve appearance and body shape"). The dimensions of "mastery" and "enjoyment" represent intrinsic motives, whereas all the others represent aspects of extrinsic motivation. Participants were asked to rate each item on a 5-point Likert scale ranging from strongly disagree (1) to strongly agree (5). All the items were introduced by the stem "I exercise...".

In addition to the single motive dimensions, we created summary scores for intrinsic and extrinsic motives. The grouping is in accordance with Self-Determination Theory. The intrinsic motive summary score was constructed by summing over the single motive dimensions representing intrinsic motives namely "mastery" and "enjoyment", whereas the extrinsic motive summary score was constructed by summing over the dimensions representing extrinsic motives namely "affiliation", "competition/ego", "others' expectations", "physical fitness", "psychological state", and "appearance". After adding up the single dimensions, the sum was divided by how many dimensions there where, i.e., two in the summary score of intrinsic motives and six in extrinsic motives. Thus, the new intrinsic and extrinsic motive summary variables varied between the values 1 and 5, similarly to the values of the initial single motive dimensions.

The developers of the REMM have validated the original REMM measure (Rogers & Morris, 2003). The Finnish version of the 73-item REMM has also been validated (Pajunen, 2004) and the internal consistencies of the dimensions were found to be similar to those cited by the developers of the original measure, Rogers and Morris (2003) (Rogers & Morris, 2003). Nevertheless, the use of the abbreviated scale may have consequences for the validity and reliability of the measure, even though the dimensions of the modified REMM questionnaire are exactly the same as those used in the original version of the REMM questionnaire.

Ethics of the study

The ethics committee of the Department of Public Health of the University of Helsinki, Helsinki, Finland and the Institutional Review Board of Indiana University, Bloomington, Indiana, U.S. approved the FinnTwin16 study protocol. The fifth wave of data collection was also approved by the Ethics Committee of the Central Finland Health Care District in Jyväskylä, Finland. The participating twins and families were provided with information about the study at baseline (1st wave, 1991–1996) and the twins also provided informed consent at the fifth wave of data collection, which was related to the measurement of motives for leisure-time physical activity (2010–2012).

Statistical methods

First we produced the descriptive statistics of the motive dimensions using Stata 13.0 (StataCorp, College Station, Texas, USA). Furthermore, data were analyzed with quantitative genetic modeling to examine the extent to which variation in a trait is accounted for by genetic and environmental influences in a particular population at a particular time (Plomin et al., 2000). The proportion of variation accounted for by genetic influences is called heritability. Standard deviations (SD) for the means and 95% confidence intervals (CI) for the correlations between MZ and DZ twins and for the estimates of genetic and environmental influences are reported.

In general, twin studies are a valuable source of information about complex traits as they can uncover underlying genetic and environmental influences. The trait variance, here the variance of the motives for leisure-time physical activity, can consist of four sources of variation: additive genetic variation (A), dominant genetic variation (D), common environmental variation (C), and unique environmental variation (E) (Rijsdijk & Sham, 2002). Measurement error is included in the unique environmental variation. The quantitative genetic method is based on the different genetic relatedness of MZ and DZ co-twins. Whereas MZ co-twins share approximately all of their genetic material (the correlation is 1 for additive (A effects) and dominant (D effects) genetic influences), DZ co-twins share, on average, 50% of their segregating genes (the correlation is 0.5 for additive and 0.25 for dominant genetic influences). Common environmental effects (C effects) refer to all environmental influences that make members of a twin pair alike as they correlate 1.0 in both MZ and DZ twins. Unique environmental effects (E effects) denote all environmental influences that make members of a twin pair unlike as they are uncorrelated in both MZ and DZ twins. In the classical twin design having only twins reared together, dominant genetic and common environmental influences cannot be estimated simultaneously.

Statistical modeling was carried out with OpenMx (version 2.0.1) software, which is a package for extended structural equation modeling on the R statistical platform (Boker et al., 2011; Revelle, 2015). We started with information on the resemblances of MZ and DZ twins. By estimating intraclass correlation coefficients, we quantified the degrees to which MZ and DZ twins resemble each other with regard to motives for leisure-time physical activity. If MZ co-twins more closely resemble each other than DZ co-twins, it is evidence of a genetic component. Furthermore, if the DZ correlation is more than half of the MZ correlation, this suggests the potential presence of common environmental factors.

The heritability estimates of the motives for leisure-time physical activity were assessed with genetic models. First, univariate models were fitted to find the best-fitting model for each motive dimension, starting with the ACE model to determine whether additive genetic, common, and/or unique environmental factors explain variation in the motive dimensions (Plomin et al., 2000). Thus, model-fitting analyses were started by computing a series of univariate models. Then, the AE models were compared to the full ACE models to determine whether common environmental factors explain variation in the motive dimensions. Subsequently, we tested whether gender-specific genetic factors were related to motives for leisure-time physical activity. In practice, we tested whether the genetic correlations for opposite-gender twins could be constrained to be 0.5. The analyses revealed no gender-specific genetic effects (*P*-values ranged from 0.20 to 0.94), indicating that the same genetic components affect motives for leisure-time physical activity in men and women. Then, we tested whether there were differences in the absolute genetic and environmental variances between men and women. These results showed significant differences in genetic and environmental variances in several motive dimensions between men and women: "enjoyment" $P = 0.01$, "physical fitness" $P < 0.001$, "psychological state" $P < 0.001$ and "appearance" $P = 0.002$ (Table S1). In addition to testing absolute variances, we further tested whether there were differences in the relative genetic and environmental variances (i.e., in standardized variances) between men and women. These analyses revealed that the magnitude of additive genetic variances (i.e., heritability) was significantly different in the motive dimensions of "enjoyment" $P = 0.001$ and "competition/ego" $P = 0.01$ in men and women.

A similar procedure was used to analyze the summary variables for intrinsic and extrinsic motives for leisure-time physical activity. Analyses revealed neither gender-specific genetic effects related to intrinsic or extrinsic motives (*P*-values of 0.35 and 0.67), nor significant differences in the relative genetic and environmental effects between men and women (*P*-values of 0.35 and 0.67). However, there was a significant difference in the absolute genetic and environmental variances between men and women in the summary variable of extrinsic motives $P < 0.001$ (Table S1).

Next, a multivariate Cholesky decomposition was conducted to estimate genetic and environmental correlations. We used a correlated factor solution of the Cholesky decomposition (Neale & Cardon, 1992). Genetic and environmental correlations were examined to see to what extent the variation in the motive dimensions was explained by the same genetic and environmental factors. The structure of the Cholesky decomposition was based on the univariate model-fitting results. To increase statistical power, we used also the Cholesky decomposition to estimate the relative genetic and environmental variations of motives for leisure-time physical activity.

Results

The means and standard deviations of the motive dimensions for leisure-time physical activity stratified by zygosity and gender are provided in Table 1. There were no significant differences by zygosity groups. In all groups, physical fitness and psychological well-being were the highest and others' expectations the least rated reasons for engaging in leisure-time physical activity. Intraclass correlations of the motives to engage in leisure-time physical activity within twin pairs are presented in Table 2. Correlations for MZ twins were clearly higher than correlations for DZ twins, suggesting the presence of genetic variation. The exception was the dimension related to the willingness to conform to others' expectations in women.

We started the genetic modeling by selecting the best fitting models to be used in the further analyses. The comparison of different models showed that common environmental components could be dropped from the model, since dropping the C path coefficients did not lead to a significant deterioration of model fit (Table S1, *P*-values ranged from 0.44 to 1). Full ACE models are presented in Table S2, and the best fitting AE models are presented in Table 3. According to the best fitting AE models, the heritability estimates of the motives for leisure-time physical activity ranged from 13% to 39% in men and from 15% to 53% in women. The motive dimensions of "enjoyment" and "affiliation" showed the highest heritability estimates in both genders, while the lowest heritability estimates were seen in the dimensions of "conform to others' expectations" in both genders and "mastery" in women. The low estimates of genetic influences indicate a greater role of unique environmental influences. As expected, the motive dimension of "enjoyment", as a strong intrinsic motive dimension, was among the most heritable traits, while the heritability estimate of the other intrinsic motive dimension in our measure, "mastery", was estimated to be low, especially in women. The motive dimension "enjoyment" had the greatest difference in heritability estimates between men (33%) and women (53%).

Trait correlations between the eight motive dimensions fluctuated strongly, but were consistent for both genders, ranging from −0.04 to 0.79 in men and from −0.13 to 0.75 in women (Table 4). The motive dimensions for leisure-time physical activity were mainly positively correlated with each other. The willingness to conform to others' expectations regarding leisure-time physical activity behavior was the only motive dimension negatively correlated with several other dimensions (Table 4). In men, the motive dimensions "affiliation" and "appearance" were also negatively correlated with each other. The highest trait correlations were found between the dimensions of "physical fitness" and "psychological state", both in men (0.79) and women (0.75). The additive genetic influences explained from 2% to 77% of the trait correlations. Table 4 shows the trait correlations between all the motive dimensions of the study. The additive genetic correlations between the

Table 1. Means and standard deviations of motive dimensions in twins by zygosity and gender

Motive dimension	gender	MZ twins Means ± SD	DZ twins same gender Means ± SD	DZ twins opposite gender Means ± SD
Mastery	♂	3.91 ± 1.07	3.81 ± 1.11	3.88 ± 1.12
	♀	3.62 ± 1.19	3.64 ± 1.18	3.58 ± 1.19
Enjoyment	♂	4.07 ± 1.02	4.12 ± 0.98	4.19 ± 0.93
	♀	4.17 ± 0.98	4.12 ± 1.02	4.18 ± 1.00
Affiliation	♂	3.27 ± 1.22	3.35 ± 1.23	3.34 ± 1.25
	♀	3.18 ± 1.27	3.12 ± 1.25	3.14 ± 1.25
Competition/ego	♂	3.23 ± 1.25	3.28 ± 1.18	3.26 ± 1.21
	♀	3.34 ± 1.25	3.15 ± 1.35	3.18 ± 1.27
Others' expectations	♂	1.90 ± 1.02	1.83 ± 1.00	1.81 ± 1.01
	♀	1.70 ± 0.98	1.71 ± 0.97	1.71 ± 0.98
Physical fitness	♂	4.52 ± 0.78	4.52 ± 0.74	4.53 ± 0.80
	♀	4.71 ± 0.55	4.70 ± 0.58	4.65 ± 0.63
Psychological state	♂	4.43 ± 0.80	4.42 ± 0.83	4.45 ± 0.85
	♀	4.66 ± 0.58	4.67 ± 0.61	4.60 ± 0.71
Appearance	♂	3.25 ± 1.20	3.20 ± 1.22	3.16 ± 1.20
	♀	3.87 ± 1.09	3.85 ± 1.10	3.77 ± 1.09

The number of twin individuals in the motive dimensions ranged from 485 (psychological state in monozygotic men) to 700 (mastery, enjoyment and physical fitness in monozygotic women).

MZ = monozygotic; DZ = dizygotic; SD = standard deviation.

Table 2. Intraclass correlation coefficients for twins by zygosity and gender

Motive dimension	gender	Intraclass correlation		
		MZ twins r^2 (95% CI) (N = 458 pairs)	DZ twins same sex r^2 (95% CI) (N = 394 pairs)	DZ twins opposite sex r^2 (95% CI) (N = 419 pairs)
Mastery	♂	0.29 (0.15–0.42)	0.09 (−0.05 to 0.23)	0.01 (−0.09 to 0.10)
	♀	0.26 (0.15–0.37)	0.11 (−0.03 to 0.24)	
Enjoyment	♂	0.33 (0.20–0.46)	0.17 (0.03–0.30)	0.16 (0.07–0.26)
	♀	0.53 (0.44–0.61)	0.19 (0.06–0.32)	
Affiliation	♂	0.40 (0.27–0.51)	0.26 (0.12–0.39)	0.11 (0.01–0.2)
	♀	0.32 (0.21–0.42)	0.21 (0.08–0.34)	
Competition/ego	♂	0.30 (0.17–0.43)	0.18 (0.04–0.31)	0.07 (−0.03 to 0.16)
	♀	0.20 (0.08–0.31)	0.06 (−0.07 to 0.20)	
Others' expectations	♂	0.16 (0.02–0.29)	0.01 (−0.13 to 0.15)	0.12 (0.03–0.21)
	♀	0.09 (−0.03 to 0.21)	0.10 (−0.04 to 0.24)	
Physical fitness	♂	0.24 (0.10–0.37)	0.11 (−0.02 to 0.24)	0.06 (−0.04 to 0.15)
	♀	0.12 (0.00–0.25)	0.07 (−0.06 to 0.21)	
Psychological state	♂	0.23 (0.09–0.36)	0.10 (−0.04 to 0.23)	0.15 (0.06–0.24)
	♀	0.23 (0.11–0.34)	0.17 (0.03–0.29)	
Appearance	♂	0.24 (0.10–0.37)	0.13 (−0.01 to 0.26)	0.10 (0.00–0.19)
	♀	0.30 (0.19–0.40)	0.06 (−0.08 to 0.19)	

MZ = monozygotic; DZ = dizygotic; CI = confidence intervals.

motive dimensions ranged from very small correlations (0.01 between the dimensions of "affiliation" and "physical fitness" in men) to very highly correlated motive dimensions (0.92 between the dimensions of both "physical fitness" and "mastery" and "physical fitness" and "psychological state", in women) (Table 4). In most cases, the unique environmental correlations between the motive dimensions were lower than the genetic correlations, ranging from zero to 0.77. There were no consistent gender differences.

For the summary variables of both intrinsic and extrinsic motives for leisure-time physical activity, the best fitting models were AE models (Table S1). The heritability estimates of intrinsic motives for men and women were 36% and 40%, respectively (Table 3). For extrinsic motives, the heritability estimates were 32% for men and 24% for women. The trait correlations between the summary variables of intrinsic and extrinsic motives for leisure-time physical activity were 0.58 for men and 0.44 for women (Table 4). The additive genetic correlations between the intrinsic and extrinsic motives for leisure-time physical activity were similar for men and women (0.71 and 0.73, respectively). However, the unique environmental correlations between the intrinsic and

Table 3. Parameter estimates for the motive dimensions of leisure-time physical activity and for the summary variables of intrinsic and extrinsic motives by gender in the best-fitting AE models

Motive dimension	gender	Relative variance components	
		A (95% CI)	E (95% CI)
Mastery	♂	0.23 (0.11–0.34)	0.77 (0.66–0.89)
	♀	0.15 (0.06–0.26)	0.85 (0.74–0.96)
Enjoyment	♂	0.33 (0.23–0.43)	0.67 (0.57–0.77)
	♀	0.53 (0.45–0.60)	0.47 (0.42–0.55)
Affiliation	♂	0.39 (0.28–0.49)	0.61 (0.51–0.72)
	♀	0.35 (0.25–0.43)	0.65 (0.57–0.75)
Competition/ego	♂	0.27 (0.16–0.38)	0.73 (0.62–0.84)
	♀	0.19 (0.09–0.28)	0.81 (0.72–0.91)
Others' expectations	♂	0.13 (0.04–0.25)	0.87 (0.75–0.96)
	♀	0.15 (0.07–0.24)	0.85 (0.76–0.93)
Physical fitness	♂	0.24 (0.14–0.35)	0.76 (0.65–0.86)
	♀	0.20 (0.12–0.29)	0.80 (0.71–0.88)
Psychological state	♂	0.24 (0.14–0.35)	0.76 (0.65–0.86)
	♀	0.29 (0.19–0.39)	0.71 (0.61–0.81)
Appearance	♂	0.23 (0.12–0.33)	0.77 (0.67–0.88)
	♀	0.28 (0.17–0.37)	0.72 (0.63–0.83)
Intrinsic motives	♂	0.36 (0.24–0.46)	0.64 (0.54–0.76)
	♀	0.40 (0.31–0.49)	0.60 (0.51–0.69)
Extrinsic motives	♂	0.32 (0.21–0.42)	0.68 (0.58–0.79)
	♀	0.24 (0.14–0.34)	0.76 (0.66–0.86)

A = additive genetic influences; E = unique environmental influences.

extrinsic motives were higher for men 0.52 than women 0.31 as indicated by non-overlapping confidence intervals (Table 4).

Discussion

In this study, we analyzed genetic and environmental variations behind the individual differences in motives for leisure-time physical activity behavior. The results indicate that additive genetic and unique environmental factors explain the variation in motives for leisure-time physical activity. The heritability estimates of the motive dimensions for leisure-time physical activity ranged from low to moderate in both men and women. Motives related to enjoyment and the social aspects of physical activity behavior were revealed to have the highest heritability in both genders. When intrinsic and extrinsic motives were analyzed as summary variables, the heritability estimate of intrinsic motives was slightly higher, especially in women, than the heritability estimate of extrinsic motives (even though confidence intervals overlapped also in women). Because the heritability estimates were moderate at most, the relative role of unique environmental influences was also important. Some of the heritability estimates for the motives for engaging in leisure-time physical activity were slightly different for men and women. We observed differences in genetic and environmental variances in the summary variable of extrinsic motives as well as in four single motive dimensions between men and women: "enjoyment", "physical fitness", "psychological state", and "appearance". However, the magnitude of additive genetic effects (i.e., heritability) was significantly different only in the dimension of "enjoyment" between men and women. The additive genetic influences differed also in the dimension of "competition/ego" between genders, but there was no significant difference in the absolute variance in this dimension.

The heritability estimates of our study are in line with those obtained by previous studies of exercise attitudes (Olson et al., 2001; Huppertz et al., 2014) and the study of genetic factors in activity motivation (Scarr, 1966). These previous studies found that the heritability estimates of exercise attitudes and activity motivation ranged from 21% to 54%, and from 24% to 40%, respectively, whereas we found at range from 13% to 53% for the heritability estimates of the motives for leisure-time physical activity. Interestingly, the highest heritability estimates seem to be associated with the feeling of enjoyment in two of these studies; the lack of enjoyment was estimated to be the most highly heritable in men in the Dutch study (Huppertz et al., 2014) and the motive dimension named "enjoyment" had one of the highest heritability estimates in our study. The relatively modest heritability estimates raise the possibility that motives are context-specific, and hence part of the variability fluctuates over time as circumstances change (e.g., the transition from student to work life) rather than being attributed to specific and more stable environmental factors (such as parental models of physical activity). While we have not measured either of these influences, their existence has implications for policies aiming to increase physical activity by enhancing motives.

Previous animal studies have suggested that genetic influences may play a role in naturally rewarding exercise (Rhodes et al., 2003; Garland et al., 2011; Roberts et al., 2014). These studies have shown that the brain areas and functions associated with the motives for physical activity seem to be inherently different between the physically active and inactive rodents. Rodents with a high propensity to run may naturally reward themselves by running, and the reward the rodents obtain for running is the enhancement of the feeling of enjoyment. Thus, the feeling of enjoyment may be associated with brain areas inherently different for reward activation in voluntary physical activity behavior. This phenomenon is in line with our results, which showed that "enjoyment" was the highest heritable motive dimension for engaging in leisure-time physical activity.

Our hypothesis of the higher heritability of intrinsic motives was supported by the result that the heritability estimate of the summary variable of intrinsic

Table 4. Trait correlations between the motive dimensions of leisure-time physical activity and between the summary variables of intrinsic and extrinsic motives along with correlations between the latent genetic and unique environmental factors for twins

Trait 1	Trait 2	Men					Women				
		Trait correlation	Additive genetic factors		Unique environmental factors		Trait correlation	Additive genetic factors		Unique environmental factors	
		r_{trait} (95% CI)	r_A (95% CI)	% Explained of r_{trait}	r_E (95% CI)	% Explained of r_{trait}	r_{trait} (95% CI)	r_A (95% CI)	% Explained of r_{trait}	r_E (95% CI)	% Explained of r_{trait}
Mastery	Enjoyment	0.45 (0.40–0.49)	0.87 (0.71–0.98)	54	0.29 (0.20–0.38)	46	0.40 (0.35–0.44)	0.91 (0.68–1.0)	64	0.23 (0.13–0.33)	36
Mastery	Affiliation	0.16 (0.11–0.22)	0.36 (−0.14 to 0.64)	65	0.08 (−0.03 to 0.24)	35	0.17 (0.12–0.22)	0.44 (0.19–0.68)	59	0.10 (0.01–0.18)	41
Mastery	Competition/ego	0.37 (0.33–0.42)	0.48 (0.22–0.71)	32	0.34 (0.24–0.42)	68	0.23 (0.18–0.28)	0.40 (0.10–0.69)	29	0.20 (0.12–0.28)	71
Mastery	Others' expectations	0.14 (0.08–0.19)	0.04 (−0.36 to 0.44)	5	0.16 (0.07–0.25)	95	0.10 (0.06 to 0.16)	−0.22 (−0.59 to 0.15)	*	0.16 (0.09–0.23)	*
Mastery	Physical fitness	0.48 (0.43–0.52)	0.73 (0.52–0.90)	36	0.40 (0.31–0.48)	64	0.29 (0.24–0.33)	0.92 (0.75–1.0)	55	0.16 (0.07–0.24)	45
Mastery	Psychological state	0.41 (0.36–0.45)	0.77 (0.56–0.94)	45	0.29 (0.20–0.38)	55	0.28 (0.23–0.33)	0.77 (0.54–0.93)	57	0.16 (0.07–0.24)	43
Mastery	Appearance	0.38 (0.33–0.42)	0.46 (0.18–0.71)	28	0.35 (0.26–0.43)	72	0.28 (0.23–0.33)	0.45 (0.04–0.7)	33	0.24 (0.14–0.34)	67
Enjoyment	Affiliation	0.46 (0.41–0.50)	0.68 (0.51–0.87)	54	0.34 (0.23–0.43)	46	0.32 (0.27–0.36)	0.47 (0.33–0.61)	64	0.20 (0.10–0.3)	36
Enjoyment	Competition/ego	0.20 (0.15–0.26)	0.33 (0.07–0.63)	49	0.15 (0.04–0.26)	51	0.16 (0.10–0.21)	0.24 (0.01–0.48)	49	0.13 (0.02–0.23)	51
Enjoyment	Others' expectations	−0.04 (−0.10 to 0.13)	0.13 (−0.25 to 0.55)	*	−0.09 (−0.19 to 0.01)	*	−0.11 (−0.16 to −0.05)	−0.38 (−0.64 to −0.14)	*	0.00 (−0.09 to 0.10)	*
Enjoyment	Physical fitness	0.50 (0.46–0.54)	0.53 (0.30–0.71)	30	0.49 (0.41–0.57)	70	0.42 (0.37–0.46)	0.90 (0.73–1.0)	70	0.21 (0.11–0.30)	30
Enjoyment	Psychological state	0.50 (0.45–0.54)	0.54 (0.31–0.72)	31	0.48 (0.40–0.56)	69	0.44 (0.38–0.48)	0.82 (0.68–0.96)	73	0.21 (0.10–0.31)	27
Enjoyment	Appearance	0.16 (0.10–0.21)	0.36 (0.09–0.63)	63	0.08 (−0.03 to 0.18)	37	0.12 (0.06–0.17)	0.18 (−0.01 to 0.38)	59	0.08 (−0.02 to 0.19)	41
Affiliation	Competition/ego	0.06 (0.01–0.12)	0.07 (−0.19 to 0.33)	36	0.06 (−0.06 to 0.18)	64	0.09 (0.04–0.14)	−0.19 (−0.52 to 0.10)	*	0.19 (0.09–0.28)	*
Affiliation	Others' expectations	0.02 (−0.03 to 0.08)	0.13 (−0.24 to 0.52)	*	−0.01 (−0.12 to 0.10)	*	−0.01 (−0.06 to 0.04)	−0.39 (−0.72 to −0.10)	*	0.11 (0.01–0.2)	*
Affiliation	Physical fitness	0.16 (0.11–0.22)	0.01 (−0.26 to 0.26)	2	0.24 (0.13–0.34)	98	0.11 (0.06–0.16)	0.29 (0.02–0.57)	68	0.05 (−0.05 to 0.14)	32
Affiliation	Psychological state	0.20 (0.15–0.26)	0.02 (−0.27 to 0.27)	3	0.29 (0.18–0.39)	97	0.15 (0.10–0.19)	0.30 (0.07–0.54)	63	0.08 (−0.02 to 0.18)	37
Affiliation	Appearance	−0.02 (−0.07 to 0.04)	0.04 (−0.23 to 0.33)	*	−0.05 (−0.16 to 0.07)	*	0.01 (−0.04 to 0.06)	−0.18 (−0.42 to 0.05)	*	0.10 (−0.01 to 0.2)	*
Competition/go	Others' expectations	0.33 (0.28–0.38)	0.66 (0.26–0.97)	39	0. 25 (0. 15–0.35)	61	0.31 (0.27–0.36)	0.53 (0.18–0.82)	29	0.27 (0.19–0.35)	71
Competition/ego	Physical fitness	0.32 (0.27–0.37)	0.51 (0.22–0.77)	41	0.26 (0.15–0.36)	59	0.12 (0.07–0.17)	0.21 (−0.15 to 0.57)	34	0.10 (0.01–0.19)	66
Competition/ego	Psychological state	0.23 (0.18–0.28)	0.39 (0.08–0.68)	44	0.17 (0.07–0.28)	56	0.13 (0.08–0.18)	0.14 (−0.19 to 0.45)	23	0.13 (0.04–0.23)	77
Competition/ego	Appearance	0.52 (0.47–0.56)	0.78 (0.54–0.97)	38	0.43 (0.34–0.51)	62	0.41 (0.36–0.45)	0.67 (0.41–0.92)	38	0.33 (0.24–0.41)	62
Others' expectations	Physical fitness	−0.02 (−0.07 to 0.04)	−0.07 (−0.47 to 0.39)	77	0.00 (−0.10 to 0.09)	23	−0.13 (−0.18 to −0.08)	−0.31 (−0.66 to 0.06)	41	−0.09 (−0.18 to −0.01)	59

Table 4. (Continued)

Trait 1	Trait 2	Men: Trait correlation r_{trait} (95% CI)	Men: Additive genetic factors r_A (95% CI)	Men: Additive genetic factors % Explained of r_{trait}	Men: Unique environmental factors r_E (95% CI)	Men: Unique environmental factors % Explained of r_{trait}	Women: Trait correlation r_{trait} (95% CI)	Women: Additive genetic factors r_A (95% CI)	Women: Additive genetic factors % Explained of r_{trait}	Women: Unique environmental factors r_E (95% CI)	Women: Unique environmental factors % Explained of r_{trait}
Others' expectations	Psychological state	−0.02 (−0.07 to 0.04)	0.05 (−0.39 to 0.49)	*	−0.03 (−0.13 to 0.07)	*	−0.11 (−0.17 to −0.06)	−0.36 (−0.69 to −0.02)	66	−0.05 (−0.14 to 0.04)	34
Others' expectations	Appearance	0.35 (0.3–0.4)	0.61 (0.23–0.87)	30	0.30 (0.21–0.38)	70	0.26 (0.21–0.31)	0.61 (0.29–0.87)	47	0.18 (0.09–0.27)	53
Physical fitness	Psychological state	0.79 (0.77–0.81)	0.86 (0.72–0.95)	26	0.77 (0.72–0.81)	74	0.75 (0.72–0.77)	0.92 (0.81–0.99)	29	0.70 (0.65–0.74)	71
Physical fitness	Appearance	0.34 (0.29–0.39)	0.69 (0.41–0.91)	48	0.24 (0.14–0.33)	52	0.31 (0.26–0.35)	0.42 (0.11–0.65)	32	0.27 (0.18–0.36)	68
Psychological state	Appearance	0.29 (0.24–0.34)	0.64 (0.33–0.89)	52	0.18 (0.08–0.29)	48	0.29 (0.24–0.34)	0.34 (0.08–0.56)	34	0.27 (0.17–0.36)	66
Intrinsic motives	Extrinsic motives	0.58 (0.54–0.62)	0.71 (0.55–0.85)	41	0.52 (0.43–0.48)	59	0.44 (0.39–0.48)	0.73 (0.55–0.92)	52	0.31 (0.22–0.40)	48

CI = confidence intervals.
*Cannot be calculated.

motives was somewhat higher than what was the estimate of extrinsic motives. In addition, when the motive dimensions were analyzed separately, enjoyment in engaging in leisure-time physical activity was one of the most heritable motive dimensions. Enjoyment is considered a strong intrinsic motive. Previous studies have revealed that intrinsic motives seem to be key factors in maintaining physical activity behavior (Ryan et al., 1997; Ingledew et al., 1998), which could partly be explained by the high genetic basis of enjoyment found in this study. However, the relationship between heritability and intrinsic motives may not be that simple. Against our hypothesis, the other intrinsic motive dimension of the REMM measure, the dimension of "mastery", was only slightly heritable; especially in women, individual environmental factors were clearly more important than genetic influences. Thus, our study was unable to fully support the hypothesis that intrinsic motives have a higher heritability. Based on Self-Determination Theory, the satisfaction of the psychological needs for autonomy, competence, and relatedness should be met to enjoy the activity per se. It may be that these needs of intrinsic motives are not thoroughly met in the dimension of "mastery" and, therefore, the heritability estimate of the dimension somewhat contradicted our hypothesis.

In general, the highest ranked motives for leisure-time physical activity among twins were "physical fitness" and "psychological state". High trait correlation and genetic correlation were found between these motives in both genders. The high trait correlation suggests that those who are motivated highly by the state of their body and/or the ability to perform physical duties are also motivated highly by the mental well-being offered by exercise. Furthermore, the high genetic correlations between these motive dimensions suggest that these dimensions partly share the same genetic characteristics. Very high genetic correlation was also found between the motives related to the willingness to improve one's skills and the enjoyment of engaging in physical activity in both genders. In addition, the dimension of "mastery", or skill improvement, was very highly genetically correlated with physical fitness in women. Overall, no clear pattern of gender differences was seen in genetic correlations between the motive dimensions, although the highest genetic correlations were observed in women; men had no correlations over 0.9, while three motive dimensions correlated higher than 0.9 in women. Genetic correlations found between the summary variables of intrinsic and extrinsic motives for leisure-time physical activity were also high and very similar for both genders.

A key strength of the present study is its good statistical power. The large sample size of twins ensures that the statistical power is enough to capture the differences between the genetic and environmental influences on motives for leisure-time physical activity. Moreover, various selection biases are unlikely in our study due to a rather high participation rate in the survey and the inclusion of multiple domains in the questionnaire.

However, some limitations also need to be considered. The assumption we made for the twin analysis is that the twins' motives for engaging in leisure-time physical activity do not differ from those of the general population. However, twins are often born premature and hence lower in weight than average singleton newborns (Buckler & Green, 2004), but these differences between singletons and twins disappear in adolescence and are not present in adults. The psychological profile of twins and singletons is also very similar. Thus, it is unlikely that our results cannot be generalized to other same-aged adults in industrialized countries. Twin studies assume that mate selection is random. To our knowledge no studies examine the motives for physical activity in spouse pairs. Non-random mate selection would increase the estimate of the common environmental component and thus underestimate heritability (Neale & Cardon, 1992). However, evidence for a common environmental component was not found in the present study. Moreover, one critical assumption of the twin analyses is that the non-genetic causes of similarity are the same for MZ and DZ pairs. In the present study, the similarity of means and variances suggests that this assumption is not violated.

All the survey items in our study were self-reported, which can also be an issue. Socially acceptable answers by participants can affect a survey. However, the motives for leisure-time physical activity may be less biased as they may not have such strictly socially desirable requirements as those for physical activity behavior or nutrition. In addition, to better control for measurement error related to self-reports, we created the summary scores for intrinsic and extrinsic motives for leisure-time physical activity.

Although this study extends our knowledge of the genetic basis of the motives for leisure-time physical activity, longitudinal genetic studies are needed since quantitative genetic modeling can provide heritability estimates only at a particular time; a follow-up of the trait is needed to obtain the longitudinal evolution of genetic and environmental influences. In addition, the motives for physical activity seem to vary with age (Finkenberg et al., 1994; Trujillo et al., 2004), which would also support longitudinal examination of the phenomenon.

Highly heritable attitudes have been suggested to be psychologically "stronger" traits than low heritability attitudes, and these traits can also be more difficult to change (Tesser, 1993). As far as we know, this idea has not been tested for motives, but as mentioned earlier, attitudes and motives as a concept are closely related. Based on this idea and our results, enjoyment of leisure-time physical activity can be seen as this kind of psychologically "stronger" trait. Thus, those who enjoy exercising may be very likely to continue their habit. The question remains of how to support those who do not enjoy exercising. Even though highly heritable and psychologically "stronger" traits are more difficult to change, they can still be learned since both genes and environment play a role in influencing complex traits.

To conclude, this study with a large sample size provided a novel understanding of the contribution of genetic and environmental influences on the motives for physical activity behavior in humans. The study has identified low to moderate heritability estimates for motives to engage in leisure-time physical activity, suggesting the greater relative role of environmental factors. Motives related to the enjoyment and social aspect of physical activity behavior showed the highest heritability estimates along with the summary variable of intrinsic motives. The results of the multivariate analysis showed high genetic correlations between physical fitness and psychological well-being and between the willingness to improve one's skills and enjoyment in both genders.

Perspective

Motives affect leisure-time physical activity behavior and individual differences in motives are explained by various factors. The present study gives evidence that genetic differences between individuals explain a part of the variation in motives for leisure-time physical activity, although the proportions are not high. The heritability estimates were somewhat higher for the intrinsic than for extrinsic motives. It is known from previous studies that intrinsic motives are more important than extrinsic motives to induce consistent physical activity (Deci & Ryan, 1985; Ryan et al., 1997; Ingledew et al., 1998; Segar et al., 2008). Clinically, the question remains of how to advise those who are not intrinsically motivated for physical activity. In general, however, complex traits are always a product of both genes and environment along with their possible interactions; learning can be possible of even highly heritable motives for leisure-time physical activity, leading to the adoption of greater physical activity levels. Further studies are needed to elucidate how various environmental factors studied by interventions may modify the genetic and environmental components of the different motive dimensions of leisure-time physical activity, especially among those with low levels of intrinsic motives for physical activity.

Key words: Exercise, heritability, motivation, twins.

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Supporting Information

Additional Supporting Information may be found online in the supporting information tab for this article:

Table S1. Univariate model fitting results.

Table S2. Parameter estimates for the motive dimensions of leisure-time physical activity and for the summary variables of intrinsic and extrinsic motives by gender in the full ACE models.

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