ORIGINAL RESEARCH

A Twin-Sibling Study on the Relationship Between Exercise Attitudes and Exercise Behavior

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Abstract Social cognitive models of health behavior propose that individual differences in leisure time exercise behavior are influenced by the attitudes towards exercise. At the same time, large scale twin-family studies show a significant influence of genetic factors on regular exercise behavior. This twin–sibling study aimed to unite these findings by demonstrating that exercise attitudes can be heritable themselves. Secondly, the genetic and environmental cross-trait correlations and the monozygotic (MZ) twin intrapair differences model were used to test whether the association between exercise attitudes and exercise behavior can be causal. Survey data were obtained from 5,095 twins and siblings (18–50 years). A genetic contribution was found for exercise behavior (50 % in males, 43 % in females) and for the six exercise attitude components derived from principal component analysis: perceived benefits (21, 27 %), lack of skills, support and/or resources (45, 48 %), time constraints (25, 30 %), lack of energy (34, 44 %), lack of enjoyment (47, 44 %), and embarrassment (42, 49 %). These components were predictive of leisure time exercise behavior ($R^2 = 28$ %). Bivariate modeling further showed that all the genetic ($0.36 < |r_A| < 0.80$) and all but two unique environmental ($0.00 < |r_E| < 0.27$) correlations between exercise attitudes and exercise behavior were significantly different from zero, which is a necessary condition for the existence of a causal effect driving the association. The correlations between the MZ twins' difference scores were in line with this finding. It is concluded that exercise attitudes and exercise behavior are heritable, that attitudes and behavior are partly correlated through pleiotropic genetic effects, but that the data are compatible with a causal association between exercise attitudes and behavior.

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Introduction

The prevention of non-communicable diseases, such as coronary heart disease, diabetes, and cancer, has become a cornerstone of medical approaches in modern urbanized societies. Increasing regular leisure-time exercise behavior in the general population is a promising strategy to counteract these diseases (Garber et al. 2011; Warburton et al. 2010). Despite numerous attempts to increase exercise participation, the majority of adults does not meet the

recommended guidelines (Martínez-González et al. 2001; Troiano et al. 2008).

To increase the success of interventions, it is important to understand the determinants of exercise behavior. Much research on these determinants has been based on social cognitive models of health behavior that emphasize the role of attitudes and beliefs (Biddle and Nigg 2000; King et al. 1992), such as the Health Belief Model (Becker 1974), the Theory of Planned Behavior (Ajzen 1985; Hagger et al. 2002), and the Health Action Process Approach (HAPA, Schwarzer 1992). Attitudes are defined as "a psychological tendency that is expressed by evaluating a particular entity with some degree of favor or disfavor" (Eagly and Chaiken 1993). A person, who perceives the advantages of exercising to outweigh the disadvantages, is likely to have a positive attitude towards exercising, and to adopt and maintain exercise activities (Becker 1974).

Many studies have shown that there is a robust association between perceived benefits/barriers and exercise behavior (for reviews and meta-analyses see Allender et al. 2006; Hagger et al. 2002; Petter et al. 2009; Rhodes et al. 2009; Trost et al. 2002). However, this association does not necessarily imply the assumed direction of causation from attitude to behavior. A reversed causal mechanism may be in play where attitudes *follow* behavior. Regular exercisers may increase the perceived benefits of their lifestyle choice and decrease the potential downsides through the social psychological mechanism of cognitive dissonance (Festinger 1957). Furthermore, the association may (partly) reflect an underlying set of "third" factors, including genetic factors, which affect both exercise behavior and the perception of its benefits and barriers. An increasing number of studies has provided evidence that genetic influences contribute appreciably to individual differences in exercise behavior (Stubbe and de Geus 2009; van der Aa et al. 2010; Huppertz et al. 2012) with peak heritabilities in late adolescence (≈ 80 %), and heritabilities of around 50 % across most of the life span (in particular adulthood). Typical perceived benefits of exercising are "meeting new people", "a sense of accomplishment", and "feeling energized". Perception of these may be related to heritable traits like extraversion, exercise ability, and the acute psychological mood response to exercise (Bryan et al. 2007; de Geus and de Moor 2011). Those heritable traits may either underlie the adoption and maintenance of regular exercise behavior through their effects on attitudes (or vice versa), or they may independently influence attitudes and behavior. If this influence is due to shared genes, the latter case is known as genetic *pleiotropy*, where low level biological variation has independent effects on multiple complex traits at the organ and behavioral level (de Geus & de Moor 2011).

The hypothesis that exercise attitudes and behavior are related through pleiotropic genetic factors implies that both attitudes and behavior are heritable. Numerous studies have demonstrated the heritability of exercise behavior (Stubbe and de Geus 2009; De Vilhena e Santos et al. 2012). Little is known about the heritability of exercise attitudes, but studies have shown a striking heritability for attitudes across various domains such as religious, social and political attitudes (Eaves and Hatemi 2008; Hatemi et al. 2010; Martin 1978; Martin et al. 1986; Olson et al. 2001). Olson et al. (2001) assessed the general attitude towards three categories of physical activities, with a single item for each category, in a sample of 336 twin pairs. Genetic effects explained 44, 36, and 52 % of the phenotypic variance in attitudes towards "doing athletic activities", "exercising", and "playing organized sports", respectively. This suggests that attitudes towards leisure time exercise behavior are likely to be heritable.

De Moor et al. (2008) pioneered two non-experimental tests of the causal hypothesis against the null hypothesis of pleiotropic genetic effects using cross-sectional twin data. First, if perceived benefits and barriers causally influence exercise behavior, all genetic and environmental factors influencing individual differences in the perception of these benefits and barriers will also, through the causal chain, influence individual differences in exercise behavior. The same principle applies to the reverse case where exercise behavior causally influences the perceived benefits and barriers. This can be tested in a bivariate genetic model by computing genetic and environmental correlations between two traits (Neale and Cardon 1992). The finding that the genetic and the environmental correlations are significant would be consistent with a causal association between the traits. If only the environmental correlation or only the genetic correlation is found to be significant, the causal hypothesis would be rejected, in favor of underlying environmental or genetic factors, respectively, affecting both the perception of benefits/barriers and engagement in exercise activities. Second, if the perceived benefits/barriers are causally related to exercise behavior, within-pair differences in the perceived benefits/barriers of exercise should be associated with within-pair differences in exercise behavior in genetically identical twins. A non-significant association between the two would falsify the hypothesis of causality in either direction and point towards genetic factors driving the association.

The first aim of this study was to investigate the heritability of exercise attitudes based on commonly used survey items on the perceived benefits of and barriers towards physical exercise. The second aim was to better understand the nature of the association by computing (1) the genetic and environmental correlations between exercise attitudes and exercise behavior, and (2) the phenotypic cross-trait correlations between the within-trait difference scores in genetically identical twins.

Method

Participants

This study is part of ongoing research by the Netherlands Twin Register where twins and their relatives (parents, siblings, spouses, and adult offspring) are voluntarily registered (Boomsma et al. 2002, 2006; Willemsen et al. 2013). Since 1991, adult participants have been invited to complete surveys about their health, lifestyle, and behavior every 2–3 years. Data on both exercise attitudes (perceived benefits and barriers) and exercise behavior (type, frequency, and duration) were available for the year 2002. Data of twins and a maximum of two full brothers and two full sisters were selected ($N = 5,887$). Exclusion criteria were unknown zygosity (53 individuals) and being younger than 18 or older than 50 years old (739).

The final sample consisted of 3,906 twin individuals and 1,189 siblings from 2,795 families. The mean age was 30.5 (SD = 7.0) years. For 5,060 individuals, data were available on *both* exercise behavior and at least one of the attitude components that were subsequently derived from principal component analysis (PCA). For 1,273 twin pairs, data on exercise behavior and *all* the attitude components were available for *both* individuals. Of these, 189 pairs were monozygotic male (MZM), 81 were dizygotic male (DZM), 512 were monozygotic female (MZF), 248 were dizygotic female (DZF) and 243 were dizygotic of opposite-sex (DOS). Zygosity of same-sex twins was determined by DNA typing (62.7 %) or was based on longitudinal assessment of six items on physical similarity and the frequency of confusion of the twins by parents, other family members, and strangers (37.3 %). Zygosity classification based on these items has shown 97 % agreement with DNA polymorphisms (Willemsen et al. 2005). The data collection protocol was approved by the Medical Research Ethics Committee of the VU University Medical Centre.

Measures

Exercise participation was assessed in two parts (Stubbe et al. 2006, 2007). First, the question "Do you exercise regularly?" could be answered with either "yes" or "no". If the answer was affirmative, follow-up questions concerned type of exercise (for example health club exercise, soccer, or running), frequency (times a week), and duration (minutes each time). The trait of interest was *leisure time exercise* behavior, explicitly excluding non-leisure physical activities (e.g., cycling or walking to get somewhere, gardening, house cleaning, etc.). Ainsworth's compendium of physical activities (Ainsworth et al. 2000) was used to recode each activity into its metabolic equivalent of task (MET), with one MET corresponding to the rate of energy expenditure of an individual at rest, i.e., approximately one kcal/kg/h. Weekly MET hours were computed as the respective MET score multiplied by the number of hours per week, calculated per reported exercise type, and then summed up over exercise types. The six-months test–retest reliability of this measure was 0.82 (de Moor et al. 2008). Individuals that did not participate in any exercise activities received a weekly MET hours score of zero. Because of the skewed distribution of weekly MET hours, data were log-transformed prior to analysis.

Perceived benefits of exercise behavior were measured by 10 items with a four-point response scale, ranging from "strongly disagree", "disagree", "agree", to "strongly agree". Seven items were derived from a questionnaire by Devereaux Melillo et al. (1997). The remaining three items were taken from a questionnaire by Sechrist et al. (1987). The internal consistency of the 10 items was high (Cronbach's $\alpha = 0.91$). Perceived barriers towards exercise behavior were measured by 23 items derived from a questionnaire by Sallis et al. (1989) (van Sluijs et al. 2005). Each item could be answered on a five-point reponse scale (ranging from "never", "rarely", "sometimes", "often", to "very often"). Again, the internal consistency of these 23 items was high (Cronbach's $\alpha = 0.90$, ranging from 0.66 to 0.83 for the subscales that were subsequently derived from PCA, see below). The English back translation of the questionnaire can be found in the supplementary material.

Statistical analyses

A PCA was run in SPSS for Windows (version 20.0, SPSS Inc.) on the 33 attitude items to establish whether they could be reduced to a smaller number of components. Because of the dependency of observations coming from twins and siblings from the same family, we randomly selected one individual per family to confirm results of the PCA. After a direct oblimin rotation, the number of components was determined by selecting all components with an eigenvalue larger than one. An item belonged to a component if the absolute value of the component loading was larger than 0.4 (the absolute was used because components can be scaled negatively). It could therefore happen that one item belonged to more than one component if it loaded high on more than one component. For each component, the mean was computed over those items with an absolute component loading larger than 0.4. Mean scores were coded as missing if more than 25 % of the items for the component was missing (as suggested by van Sluijs et al. 2005). The resulting attitude component scores were used in subsequent analyses, one per individual for each of the six components. A multiple regression analysis

was run in STATA to determine the amount of variance in exercise behavior explained by the attitude components, while taking into account familial relatedness.

Modeling of the twin and sibling data was performed using structural equation modeling in openMx (Boker et al. 2011). Bivariate analyses were run separately for each attitude component with exercise behavior. These analyses were run in two steps. First, in a series of saturated models, the strength of the relationships between exercise behavior and each of the attitude components (phenotypic correlations) and the twin and sibling resemblances for exercise behavior and each attitude component (twin/sibling pair correlations, *within*-trait and *cross*-trait) were estimated in each twin zygosity group separately (MZM, DZM, MZF, DZF and DOS). It was tested whether age should be included as a fixed effect by regressing it on the means, and whether separate parameters should be estimated for males and females. Significance was tested against an alpha level of 0.05. In these analyses, full sibling and twin/sibling correlations were equated to dizygotic (DZ) twin correlations as these pairs all share on average 50 % of their segregating genes, whereas monozygotic (MZ) twins are genetically identical. Comparing the MZ- with the DZ cross-twin/sibling within-trait correlations provides a first indication of the sources of variation observed for each trait. Possible sources of variation are additive genetic influences (A), dominant genetic influences (D), common environmental influences (C) and unique environmental influences (E). Due to the differences in genetic similarity between MZ versus DZ twins and siblings, additive genetic effects are suggested for a trait if its MZ cross-twin within-trait correlation is substantially larger than the correlation of DZ twins and siblings, whereas dominant genetic effects are suggested if the DZ correlation is smaller than half the MZ correlation. If the DZ correlation is larger than half the MZ correlation, common environmental effects (C) are implied. Finally, as MZ twins share the same genes and the same common environment, an MZ cross-twin within-trait correlation less than unity indicates unique environmental effects (E; including measurement error; Plomin et al. 2008). Similar to the comparison of MZ and DZ cross-twin/sibling *within*-trait correlations, the comparison of the MZ with the DZ cross-twin/sibling *cross*-trait correlations is informative to determine the sources of *co*variation between traits. For example, larger MZ cross-twin cross-trait correlations compared with the DZ cross-twin/sibling cross-trait correlations suggest that common genetic factors explain part of the observed phenotypic correlation between two traits.

Second, heritability of the attitude components and exercise behavior and the genetic and environmental correlations between the two were assessed in a series of genetic models. In the first model, the full bivariate ACE

model, the variances of the respective attitude components and exercise behavior were decomposed into variance explained by A, C, and E. In addition, the covariances among the attitude components and exercise behavior were decomposed into covariance due to A, C and E (i.e., those A, C and E influences that overlap among the traits). Guided by the within- and cross-twin/sibling correlations, the correlational approach to scalar and non-scalar sex limitations was applied, as described by Neale et al. (2006). The A, C, and E path coefficients were estimated for both traits, for males and females separately. In addition, the additive genetic correlations between the two traits were estimated for males and females, as well as the common environmental and the unique environmental correlations. The correlation between genotypes of opposite sex was estimated *between* traits too. If the cross-twin/sibling *within*-trait DOS correlation in the saturated model was significantly lower than what would be expected based on the DZ correlation for a trait, its genetic within-trait correlation was freely estimated (for a path diagram, see Fig. 6 in Neale et al. 2006). Finally, means were estimated for the two traits, for each sex separately, and age was included as a fixed effect by regressing it on the mean(s), if it was significant in the saturated model. Again, significance was tested against an alpha level of 0.05.

The full ACE-model was compared to an AE-model in which the common environmental component was dropped. Subsequently, it was tested whether quantitative sex differences could be omitted. Genetic structural equation modeling in openMx was used with the raw-data Maximum Likelihood procedure for estimation of parameters. Nested submodels were compared by hierarchic χ^2 tests. The χ^2 statistic is computed by subtracting $-2LL$ (log-likelihood) of a reduced model from that of the full model [$\chi^2 = -2LL_0 - (-2LL_1)$]. This χ^2 statistic is distributed with (df) equal to the difference in the df between the two models ($\Delta df = df_0 - df_1$). If constraining the model did not give a significant deterioration of fit (using an alpha level of 0.05), the most parsimonious model was accepted as the best fitting model.

It was tested whether dropping the genetic and environmental cross-trait correlations led to a significant deterioration of the model fit. As suggested by de Moor et al. (2008), testing the significance of the genetic and environmental cross-trait correlations provides a test of whether an association between traits can be causal. If all genetic and environmental correlations between the respective attitude component and exercise behavior are significantly different from zero, this would be consistent with the hypothesis that a causal effect drives the association (necessary condition), although it would not constitute proof of causality. If one of the genetic or environmental correlations was non-significant, this would falsify the

Table 1 Untransformed means and standard deviations of the attitude components and exercise behavior and phenotypic correlations of the attitude components with exercise behavior

Variable name	Sex	Means (SD)	Phenotypic correlations
Lack of enjoyment	♂	0.71 (0.69)	−0.44 (−0.47; −0.42)
	♀	0.83 (0.73)	−0.44 (−0.47; −0.42)
Time constraints	♂	1.68 (0.88)	−0.37 (−0.41; −0.33)
	♀	1.68 (0.88)[a]	−0.28 (−0.31; −0.25)
Benefits	♂	2.13 (0.51)	0.32 (0.29; 0.35)
	♀	2.16 (0.46)	0.32 (0.29; 0.35)
Lack of skills, support and/or resources	♂	0.58 (0.55)	−0.36 (−0.39; −0.31)
	♀	0.70 (0.60)	−0.40 (−0.43; −0.37)
Embarrassment	♂	0.35 (0.51)	−0.20 (−0.23; −0.18)
	♀	0.69 (0.71)	−0.20 (−0.23; −0.18)
Lack of energy	♂	0.83 (0.60)	−0.34 (−0.37; −0.32)
	♀	1.14 (0.68)	−0.34 (−0.37; −0.32)
Weekly MET hours	♂	12.10 (17.14)	
	♀	8.70 (13.03)	

[a] Males and females were combined as their means were not significantly different from each other

hypothesis that exercise attitudes and exercise behavior are causally related, for that specific component.

Finally, the within-trait difference scores for the attitude components and for exercise behavior were calculated for MZM and MZF twins. Subsequently, the difference score of each attitude component was correlated with the difference score of exercise behavior. Using MZ twin data removes the possibility of genetic confounding, and a significant correlation would therefore show that the relationship between the two phenotypes is not merely due to genes (see MZ twin intrapair differences model; de Moor et al. 2008). This would thus be consistent with (but not proof of) a causal association, whereas a non-significant correlation would falsify the hypothesis of causality.

Results

The PCA including all attitude items yielded six components with an eigenvalue larger than one. The component loadings of all items on the six components are provided as supplementary material. The first component includes items related to available equipment and support, and is labeled 'Lack of skills, support and/or resources' (Cronbach's α for these items = 0.80). The second component consists of the 10 perceived benefits items and is labeled 'Benefits' (α = 0.91). The third component contains items related to perceived lack of time and is labeled 'Time constraints' (α = 0.83). The fourth component includes

items that relate to a lack of energy/will-power and having a bad health. This component is labeled 'Lack of energy' (α = 0.78). The fifth component includes items about lack of interest and pleasure to exercise and is labeled 'Lack of enjoyment' (α = 0.74). Items belonging to the sixth component are related to being overweight and insecurities about physical appearance. This component is labeled 'Embarrassment' (α = 0.66). The means and standard deviations of the attitude components and exercise behavior (weekly MET hours) are provided in Table 1.

Exercise behavior was positively related to the perceived benefits component, and negatively related to the perceived barriers components (Table 1). 'Lack of enjoyment' was most strongly associated with exercise behavior in both sexes ($r = -0.44$), 'Embarrassment' was least associated ($r = -0.20$, Table 1). The multiple regression revealed that all six attitude components were significant predictors of exercise behavior ($p < 0.01$) and that together they explained 28 % of the variance in exercise behavior.

The within-trait MZ correlations were larger than the within-trait DZ twin/sibling correlations for all attitude components and exercise behavior (Table 2). This indicates that genetic factors are of importance in all phenotypes. Most DZ twin/sibling correlations were not larger than half the MZ correlations, suggesting that common environmental factors are of minor importance for attitudes towards exercise behavior as well as actual exercise behavior. For 'Lack of skills, support and/or resources', 'Lack of enjoyment', 'Embarrassment', and exercise behavior, the within-trait DOS correlations were significantly lower than what would be expected based on the DZ correlations, indicating qualitative sex differences.

All absolute MZ cross-twin *cross*-trait correlations were larger than the DZ cross-twin/sibling cross-trait correlations, with the exception of 'Time constraints' and 'Embarrassment' in men (Table 2). The phenotypic correlations between attitudes towards exercise and exercise behavior thus seem at least partly explained by overlapping genetic factors.

In the bivariate ACE models, dropping the C-paths did not lead to a significant deterioration of the model fit, whereas subsequently constraining the A and E parameters to be equal across sex did (supplementary material; α < 0.05). Therefore, AE models that allowed for quantitative and qualitative sex differences were fitted to the data. The heritabilities of the attitude components and exercise behavior in the best fitting models are provided in Table 3. Heritability estimates ranged from 21 to 50 %. The attitude components 'Lack of skills, support and/or resources', 'Lack of enjoyment' and 'Embarrassment' were among the most heritable, whereas the heritabilities of 'Benefits' and 'Time constraints' were lower, indicating a greater role of unique environmental influences on individual differences in these components.

Table 2 Cross-twin/sibling *within*-trait (1) and *cross*-trait correlations (2) of the attitude components and exercise behavior (95 % CIs)

	Within/cross	MZM	DZM/siblings	MZF	DZF/siblings	DOS/siblings
Benefits	1	0.26 (0.19; 0.32)	0.11 (0.07; 0.16)	0.26 (0.19; 0.32)	0.11 (0.07; 0.16)	0.11 (0.07; 0.16)
	2	0.21 (0.16; 0.25)	0.07 (0.04; 0.11)	0.21 (0.16; 0.25)	0.07 (0.04; 0.11)	0.07 (0.04; 0.11)
Lack of skills, support and/or resources	1	0.46 (0.41; 0.51)	0.25 (0.19; 0.31)	0.46 (0.41; 0.51)	0.25 (0.19; 0.31)	0.16 (0.09; 0.22)
	2	−0.27 (−0.31; −0.22)	−0.13 (−0.16; −0.09)	−0.27 (−0.31; −0.22)	−0.13 (−0.16; −0.09)	−0.13 (−0.16; −0.09)
Time constraints	1	0.29 (0.23; 0.35)	0.14 (0.10; 0.19)	0.29 (0.23; 0.35)	0.14 (0.10; 0.19)	0.14 (0.10; 0.19)
	2	−0.18 (−0.23; −0.14)	−0.19 (−0.25; −0.13)	−0.18 (−0.23; −0.14)	−0.11 (−0.15; −0.06)	−0.09 (−0.14; −0.05)
Lack of energy	1	0.42 (0.36; 0.47)	0.19 (0.15; 0.24)	0.42 (0.36; 0.47)	0.19 (0.15; 0.24)	0.19 (0.15; 0.24)
	2	−0.22 (−0.26; −0.17)	−0.10 (−0.14; −0.07)	−0.22 (−0.26; −0.17)	−0.10 (−0.14; −0.07)	−0.10 (−0.14; −0.07)
Lack of enjoyment	1	0.46 (0.40; 0.51)	0.17 (0.11; 0.23)	0.46 (0.40; 0.51)	0.17 (0.11; 0.23)	0.12 (0.05; 0.18)
	2	−0.31 (−0.35; −0.27)	−0.11 (−0.15; −0.07)	−0.31 (−0.35; −0.27)	−0.11 (−0.15; −0.07)	−0.11 (−0.15; −0.07)
Embarrassment	1	0.45 (0.39; 0.51)	0.29 (0.23; 0.34)	0.45 (0.39; 0.51)	0.29 (0.23; 0.34)	0.08 (0.01; 0.14)
	2	−0.16 (−0.21; −0.12)	−0.19 (−0.26; −0.11)	−0.16 (−0.21; −0.12)	−0.10 (−0.15; −0.05)	−0.01 (−0.06; 0.04)
Exercise behavior	1	0.45 (0.39; 0.50)	0.21 (0.16; 0.27)	0.45 (0.39; 0.50)	0.21 (0.16; 0.27)	0.15 (0.09; 0.21)

MZM monozygotic male, *DZM* dizygotic male, *MZF* monozygotic female, *DZF* dizygotic female, *DOS* dizygotic of opposite-sex

In accordance with the cross-twin/sibling within-trait DOS correlations of the saturated model, the within-trait correlations between the latent genetic factors were lower among DOS twins compared to same-sex DZ twins and siblings for 'Lack of skills, support and/or resources', 'Lack of enjoyment', 'Embarrassment', and exercise behavior, indicating that genetic factors influencing those phenotypes are (for a part) qualitatively different in men and women (Table 3).

Table 4 displays how much of the *co*variance between exercise attitudes and exercise behavior can be explained by genetic and environmental factors (A and E add up to 1). Genetic factors explained considerably more of the association between attitude and behavior than environmental factors did.

Table 5 displays the estimates and 95 % confidence intervals of the additive genetic and the unique environmental cross-trait correlations. None of the genetic correlations could be dropped without a significant deterioration of the model fit. The unique environmental correlations were significant as well, with the exception of the attitude components 'Benefits' and 'Embarrassment' for males. Similarly, the phenotypic cross-trait correlations between the intrapair MZ difference scores were significant for all attitude components but 'Benefits' and 'Embarrassment' for males (Table 6).

Discussion

The main aims of this study were (1) to test the heritability of perceived benefits of and barriers towards exercise behavior, and (2) to test whether a causal effect could be a valid explanation for the phenotypic association.

Six main attitude components emerged from commonly used items by means of a PCA: 'Benefits', 'Lack of skills, support and/or resources', 'Time constraints', 'Lack of energy', 'Lack of enjoyment', and 'Embarrassment'. The perceived benefits component was positively related to exercise behavior, whereas the perceived barriers were negatively related to exercise behavior. The attitude components explained 28 % of the variance in exercise behavior. Heritability of the attitude components ranged from 21 to 49 %.

What can give rise to the heritability of attitudes? Personality is a first possible trait that may mediate attitude formation after initial exposures to exercise activities (Olson et al. 2001). Personality traits are known to have a partly genetic basis (e.g., de Moor et al. 2012; Jang et al. 1996) and are also known to be associated with exercise behavior (de Moor et al. 2006). A meta-analysis concluded that there is a positive association of exercise behavior with extraversion and conscientiousness and a negative

Table 3 Heritabilities of attitude components and exercise behavior in six bivariate models, separately for males and females (95 % CIs), and the genetic within-trait correlations across DOS twins

Variable name	Males		Females		DOS correlations
	A	E	A	E	
Benefits	0.21 (0.11; 0.31)	0.79 (0.69; 0.89)	0.27 (0.20; 0.33)	0.73 (0.67; 0.80)	0.5[b]
Lack of skills, support and/or resources	0.45 (0.35; 0.54)	0.55 (0.46; 0.65)	0.48 (0.42; 0.54)	0.52 (0.46; 0.58)	0.26 (0.12; 0.41)
Time constraints	0.25 (0.15; 0.35)	0.75 (0.65; 0.85)	0.30 (0.23; 0.36)	0.70 (0.64; 0.77)	0.5[b]
Lack of energy	0.34 (0.23; 0.44)	0.66 (0.56; 0.77)	0.44 (0.38; 0.49)	0.56 (0.51; 0.62)	0.5[b]
Lack of enjoyment	0.47 (0.36; 0.56)	0.53 (0.44; 0.64)	0.44 (0.38; 0.50)	0.56 (0.50; 0.62)	0.19 (0.03; 0.35)
Embarrassment	0.42 (0.31; 0.52)	0.58 (0.48; 0.69)	0.49 (0.42; 0.54)	0.51 (0.46; 0.58)	0.16 (0.02; 0.30)
Exercise behavior[a]	0.50 (0.41; 0.58)	0.50 (0.42; 0.59)	0.43 (0.37; 0.49)	0.57 (0.51; 0.63)	0.31 (0.16; 0.45)

A Proportion of variance explained by additive genetic factors (=heritability); *E* Proportion of variance explained by unique environmental factors

[a] Taken from the first model (benefits)

[b] Model with genetic twin/sibling resemblance fixed to 0.5 fitted the data

Table 4 Proportions of the phenotypic covariances between exercise attitude components and exercise behavior that can be explained by additive genetic (A) and unique environmental (E) effects, separately for males and females

Attitude component	Males		Females	
	A	E	A	E
Benefits	0.82 (0.59; 1.04)	0.18 (−0.04; 0.41)	0.57 (0.42; 0.71)	0.43 (0.29; 0.58)
Lack of skills, support and/or resources	0.65 (0.45; 0.83)	0.35 (0.17; 0.55)	0.71 (0.61; 0.81)	0.29 (0.19; 0.39)
Time constraints	0.59 (0.39; 0.78)	0.41 (0.22; 0.61)	0.69 (0.53; 0.84)	0.31 (0.16; 0.47)
Lack of energy	0.67 (0.43; 0.89)	0.33 (0.11; 0.57)	0.64 (0.52; 0.75)	0.36 (0.25; 0.48)
Lack of enjoyment	0.78 (0.63; 0.92)	0.22 (0.08; 0.37)	0.66 (0.56; 0.76)	0.34 (0.24; 0.44)
Embarrassment	0.99 (0.59; 1.43)	0.01 (−0.43; 0.41)	0.82 (0.63; 1.00)	0.18 (0.00; 0.37)

association with neuroticism (Rhodes and Smith 2006). Courneya and Hellsten (1998) (also see Davis et al. 1995) investigated the relationship between the big five personality dimensions and exercise motives and barriers. They found that conscientious individuals were more likely to exercise for health reasons, and were less likely to report barriers such as a lack of energy or a lack of motivation. This makes intuitive sense as conscientiousness is related to being ordered and self-disciplined (Rhodes and Smith 2006). Extraverts, in turn, mainly exercised for social reasons and enjoyment of physical activity, which is compatible with the tendency of extraverts to be sociable and to seek excitement (Rhodes and Smith 2006). Finally, individuals who scored highly on neuroticism mainly exercised to improve their physical appearance and for weight control. They reported a lack of energy, lack of motivation and embarrassment as barriers to exercise. Neurotic individuals tend to be emotionally less stable and self-conscious (Rhodes and Smith 2006), and are probably predisposed to be worried about their physical appearance and the judgmental reactions of others (Courneya and Hellsten 1998).

The affective responses to acute exercise may form another link between attitudes and exercise behavior. Individual differences in the acute mood effects of exercise have long been neglected, but recent research has produced interesting findings (Ekkekakis 2008; Parfitt and Hughes 2009). Ekkekakis et al. (2005) have proposed an evolutionary-based model on the affective reactions to exercise. They argue that low-intensity exercise is likely to evoke rewarding reactions in most individuals, whereas high-intensity exercise is likely to evoke aversive reactions. However, with respect to intermediate levels of exertion, there is large variability in reactions between individuals, with some of them reporting a positive response (pleasure) and others a negative response (displeasure). Differences in the acute mood effects of exercise are likely to be (for a part) genetically determined (de Geus and de Moor 2008). Perceiving exercise benefits or a lack of energy and enjoyment, in turn, is likely to be affected by the acute mood effects of exercise.

Whether or not exercise activities make someone feel better may also depend on fitness and exercise ability as most people favor doing things they are good at (de Geus

Table 5 Estimated genetic (r_A) and unique environmental (r_E) cross-twin cross-trait correlations with exercise behavior (95 % CIs), separately for males (m) and females (f)

Attitude component	r_{Am}	r_{Af}	r_{Em}	r_{Ef}
Benefits	0.80 (0.57; 1.00)	0.54 (0.42; 0.68)	0.09 (−0.02; 0.20)[a]	0.22 (0.15; 0.28)
Lack of skills, support and/or resources	−0.47 (−0.60; −0.33)	−0.64 (−0.73; −0.56)	−0.23 (−0.34; −0.11)	−0.22 (−0.29; −0.15)
Time constraints	−0.61 (−0.80; −0.42)	−0.55 (−0.68; −0.43)	−0.24 (−0.34; −0.13)	−0.14 (−0.21; −0.07)
Lack of energy	−0.50 (−0.68; −0.33)	−0.54 (−0.64; −0.44)	−0.18 (−0.29; −0.06)	−0.23 (−0.29; −0.16)
Lack of enjoyment	−0.70 (−0.83; −0.58)	−0.68 (−0.76; −0.59)	−0.19 (−0.30; −0.07)	−0.27 (−0.33; −0.20)
Embarrassment	−0.36 (−0.54; −0.20)	−0.40 (−0.50; −0.29)	0.00 (−0.13; 0.12)[a]	−0.07 (−0.15; 0.00)

r_{Am} additive genetic correlation for males, r_{Af} additive genetic correlation for females, r_{Em} unique environmental correlation for males, r_{Ef} unique environmental correlation for females

[a] Can be dropped without a significant deterioration of the model fit ($\alpha < 0.05$)

Table 6 Cross-trait correlations between the cross-twin within-trait difference scores for monozygotic male (MZM) and female (MZF) twins (number of pairs)

	Benefits	Lack of skills, support and/or resources	Time constraints	Lack of energy	Lack of enjoyment	Embarrassment
MZM	0.11 (196)	−0.27** (194)	−0.32** (194)	−0.25** (194)	−0.24** (194)	−0.08 (192)
MZF	0.22** (532)	−0.25** (527)	−0.16** (527)	−0.26** (528)	−0.28** (528)	−0.12** (522)

** Significant at the 0.01 level (two-tailed)

and de Moor 2008). Numerous studies have looked at individual differences in sport performance (for an overview, see Bouchard and Hoffman 2011). Even for highly standardized training interventions, large individual differences have emerged for changes in fitness indices such as VO$_2$max, heart rate, cholesterol levels and blood pressure (Bouchard and Rankinen 2001) and genetic factors are likely to play a major role in causing those differences (Bouchard and Hoffman 2011). Depending on their genetic predisposition, some people may improve fast in a given exercise activity, whereas others may improve slowly or not at all. Slow-improvers may conclude that they are "not the sporty type" or even feel embarrassed, and drop out, whereas fast-improvers may enjoy the activity and further improve through training (Brutsaert and Parra 2006; de Geus and de Moor 2008). Olson et al. (2001) have indeed found a large genetic correlation ($r = 0.63$) between "attitudes toward athleticism" and self-reported athletic ability. Similar mechanisms may lead to individual differences in activity-induced weight loss (Hainer et al. 2008), again influencing exercise attitudes. Finally, a genetic predisposition to have higher (baseline) levels of fitness should positively affect an individual's capacity to take on many tasks before succumbing to physical and mental fatigue which could be related to the perception of time constraints, an often cited barrier to regular exercise. Thus, there are various mechanistic connections between traits with a known or plausible heritable component and exercise attitudes. The above overview is not exhaustive and the suggested mechanisms are probably interrelated.

It should be noted that, despite our focus on genetics, the largest amount of variance in exercise attitudes could be explained by unique environmental factors, providing support for the assumption that individuals form their attitudes based on their experiences (although this component does include measurement error as well; Olson et al. 2001).

There was a significant phenotypic correlation between all the attitude components and exercise behavior for both men and women. The strength of the association is in line with previous studies (Hagger et al. 2002; Rhodes et al. 2009). The second aim of this study was to better understand the nature of this relationship. Based on the above it might have been expected that genetic factors influencing personality, acute mood effects of exercise, and fitness/exercise ability, affect the formation of exercise attitudes and increase the chance of adoption and/or maintenance of exercise behavior. However, the main question is whether these genetic factors influence exercise behavior *independently* of attitude formation (pleiotropy) or whether the data are compatible with the main hypothesis held by exercise interventionists stating that attitudes causally contribute to exercise behavior. Given that not only the genetic correlations, but also the environmental correlations and the cross-trait correlations between the MZ twin difference scores were significant (the latter two with the exception of 'Benefits' and 'Embarrassment' in males), the data are indeed compatible with a causal effect of attitudes on exercise behavior, in that a different pattern might have led to falsification of this hypothesis. Such falsification was

for instance illustrated for the effects of exercise behavior on mental health (de Moor et al. 2008) and subjective well-being (Bartels et al. 2012). However, it should be noted that the data do not constitute proof of causality, and that due to the cross-sectional design, the *direction* of any causality remains unknown. Adding longitudinal follow-up data is needed to reveal the direction of causality and to provide more definitive support for the common practice of targeting attitudes in exercise intervention programs (Hagger et al. 2002). For males, the non-significant environmental correlation and the non-significant cross-trait correlations between the MZ twin difference scores for 'Benefits' and 'Embarrassment' point towards genetic pleiotropy, in the absence of causality, for these specific attitude components. However, this finding should be treated with caution as the unique environmental cross-trait correlations explain only a small amount of the phenotypic correlations between these attitude components and exercise behavior for males.

The limitations of this study should be addressed. First of all, a single compound exercise score was used. However, it is likely that perceived benefits and barriers affect subcomponents of exercise behavior such as adoption/maintenance and frequency/duration to different degrees. More than two decades ago, Dishman (1990) stated that "knowledge and belief in the health benefits of physical activity may motivate initial involvement and return to activity following relapse, but feelings of enjoyment and well-being seem to be stronger motives for continued participation" (p.83). Studies have shown that the predictors of exercise adoption indeed tend to differ from the predictors of exercise maintenance (Buckworth et al. 2007; Nigg et al. 2008). Schwetschenau et al. (2008) investigated the difference between internal (e.g. embarrassment) and external (e.g. inadequate exercise facilities) barriers at an on-site corporate fitness center. External barriers mainly accounted for not joining the fitness center, whereas internal barriers mainly accounted for frequency of fitness center visits.

Secondly, the assumption that DZ twins and siblings are genetically about half as similar as MZ twins only holds true under the assumption of random mating. As soon as spouses select each other based on their phenotypic similarity (e.g., when exercisers are attracted by other exercisers), DZ correlations are higher than expected which would overestimate common environmental effects (de Moor et al. 2011; Eaves 1977). However, no significant impact of the common environment was found in this study, suggesting that the potential distortion through assortment was limited.

Finally, the classical twin design is based on the equal environment assumption which posits that non-genetic sources of differential treatment of MZ versus DZ twins do not inflate the MZ twin resemblance for the phenotype

under study (Derks et al. 2006; Scarr and Carter-Saltzman 1979). A more similar treatment of MZ versus DZ twins might arise when MZ twins resemble each other more in athletic appearance than DZ twins. This differential treatment may influence their attitude formation. However, the equal environment assumption is violated only if the differential treatment is caused simply by zygosity status, but not when it is indirectly caused by, for instance, exercise ability which itself has been shown to be substantially heritable (Bouchard and Hoffman 2011).

Despite these limitations, the present study provides an important extension of the literature as it is the first one to investigate the heritability of perceived exercise benefits and barriers and their (genetic) association with exercise behavior in a large group of twins and their siblings.

Health promotion strategies often aim to change the populace's attitudes towards exercise behavior by educating people on the health benefits of regular exercise and ways to reduce barriers to engage in exercise activities. This study showed that the perception of exercise benefits and barriers will partly depend on an individual's genetic makeup, but that substantial environmental influences are present as well. Furthermore, after taking genetic pleiotropy into account, our data were compatible with a causal association between exercise attitudes and exercise behavior. Replication in longitudinal studies is now needed to more firmly establish this causality and its direction.

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