

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/7334658>

Regular Exercise, Anxiety, Depression and Personality: A Population-Based Study

Article in *Preventive Medicine* · May 2006

DOI: 10.1016/j.ypmed.2005.12.002 · Source: PubMed

CITATIONS

439

READS

4,023

5 authors, including:



[Marleen Hm de Moor](#)

Vrije Universiteit Amsterdam

166 PUBLICATIONS 4,474 CITATIONS

[SEE PROFILE](#)



[Janine Stubbe](#)

Codarts Rotterdam

117 PUBLICATIONS 4,335 CITATIONS

[SEE PROFILE](#)



[Dorret I Boomsma](#)

Vrije Universiteit Amsterdam

2,508 PUBLICATIONS 155,703 CITATIONS

[SEE PROFILE](#)



[Eco J C de Geus](#)

Vrije Universiteit Amsterdam

1,173 PUBLICATIONS 89,101 CITATIONS

[SEE PROFILE](#)

Some of the authors of this publication are also working on these related projects:



GWAS of Personality [View project](#)



Genetics of ANS [View project](#)

Regular exercise, anxiety, depression and personality: A population-based study

M.H.M. De Moor^{*}, A.L. Beem, J.H. Stubbe,
D.I. Boomsma, E.J.C. De Geus

Department of Biological Psychology, Vrije Universiteit, van der Boechorststraat 1, 1081 BT, Amsterdam, The Netherlands

Available online 24 January 2006

Abstract

Objectives. To examine whether regular exercise is associated with anxiety, depression and personality in a large population-based sample as a function of gender and age.

Methods. The sample consisted of adolescent and adult twins and their families ($N = 19,288$) who participated in the study on lifestyle and health from The Netherlands Twin Registry (1991–2002). Exercise participation, anxiety, depression and personality were assessed with self-report questionnaires.

Results. The overall prevalence of exercise participation (with a minimum of 60 min weekly at 4 METs (Metabolic Energy Expenditure Index)) in our sample was 51.4%. Exercise participation strongly declined with age from about 70% in young adolescents to 30% in older adults. Among adolescents, males exercised more, whereas, among older adults, females exercised more. Exercisers were on average less anxious (-0.18 SD), depressed (-0.29 SD) and neurotic (-0.14 SD), more extraverted ($+0.32$ SD) and were higher in dimensions of sensation seeking (from $+0.25$ SD to $+0.47$ SD) than non-exercisers. These differences were modest in size, but very consistent across gender and age.

Conclusions. This study corroborates and extends previous findings: regular exercise is cross-sectionally associated with lower neuroticism, anxiety and depression and higher extraversion and sensation seeking in the population.

© 2006 Elsevier Inc. All rights reserved.

Keywords: Exercise; Mental health; Personality

The relationship between exercise behavior and mental health has been examined by many researchers (Byrne and Byrne, 1993; Folkins and Sime, 1981; Gauvin and Spence, 1996; North et al., 1990; Salmon, 2000; Scully et al., 1998). However, population studies on the association between exercise and mental health are scarce. To our knowledge, only two large population studies have examined the cross-sectional association in both males and females across a wide age range (Farmer et al., 1988; Weyerer, 1992). Although the instruments to measure depression have greatly differed and exercise was based on a single question only, these two studies converge on the main finding that regular exercise is associated with less depression in the population. Both studies only examined the relationship between exercise and depression. The association of exercise with

other prominent aspects of mental health, such as anxiety, remains unexplored in population-based samples, as does the association with personality traits.

Both anxiety and depression are known to be correlated with personality, most prominently with neuroticism, but also with extraversion (Costa and McCrae, 1980; Middeldorp et al., 2005). Because personality traits can index the risk for anxious and depressive psychopathology, they could potentially mediate the co-morbidity between exercise and anxiety and depression. Personality traits like sensation seeking seem independent of anxiety and depression but predict lifestyle factors such as smoking or drinking (Koopmans, 1997; Vink et al., 2003) and possibly also exercise behavior. The aim of the present paper, therefore, is to examine the association of exercise with anxiety, depression and personality in a large population-based sample. By using data from multiple surveys in the same population, we obtained a sample size that allowed us to study these associations as a function of gender and age.

^{*} Corresponding author. Fax: +31 20 598 8832.

E-mail address: mhm.de.moor@psy.vu.nl (M.H.M. De Moor).

Materials and methods

Study population

This study was part of an ongoing study on lifestyle and the health of adolescent and adult twins and their families (i.e., their siblings, parents and spouses) in The Netherlands (Boomsma et al., 2002; Vink et al., 2004). All subjects are voluntary participants in The Netherlands Twin Registry (NTR) and receive surveys on lifestyle and health every 2 years. Questionnaires were collected in 1991, 1993, 1995, 1997, 2000 and 2002. The procedure by which subjects were recruited is described in detail elsewhere (Boomsma et al., 2002).

The total number of participants in the study on lifestyle and health was 19,469. We excluded seven subjects from our analyses because they were younger than 10 years, and 174 subjects because their exercise behavior was unknown. This resulted in a total sample of 19,288 subjects. There were 7342 subjects (38.1%) who returned a questionnaire on only one wave, 4705 subjects (24.4%) who participated twice in the study and 7241 subjects (37.5%) who participated three or more times. Only twins had the opportunity to participate at all occasions. Parents and siblings could participate on four waves and spouses only twice. The information of all subjects at all time points was used resulting in 43,888 observations.

There were 8773 males (45.5%) and 10,515 females (54.5%). The mean age was 33.0 years (SD = 14.4). Participants were divided into age groups, each with a range of 5 years. Regarding variables such as socio-economic status, smoking behavior and religious background, the sample used in this study is fairly representative of the Dutch population (Boomsma et al., 2002).

Measures

Exercise participation was measured in detail in each survey. First, the participants were asked whether they exercised regularly ('Yes' or 'No'). If the participants responded affirmative, further information on type, frequency and duration of exercise was gathered to calculate their MET scores. The MET is an index for metabolic energy expenditure. A MET score of 1 equals the rate of energy expended when at rest (1 kcal/kg/h). Subjects were classified as exerciser if they exercised at least 60 min per week with a MET score of 4 or more. Since the focus was on self-initiated exercise, physical education at school by adolescents was not counted as exercise. More details are given by Stubbe et al. (2005).

Four variables reflecting anxiety or depression and six personality traits were measured. Table 1 summarizes which variables were measured in each survey in subjects with complete information on age, gender and exercise participation.

Anxiety and depression were measured with the short version of the Beck's Depression Inventory (BDI, 13 items, average internal consistency over waves $\alpha = 0.80$) (Beck et al., 1961), the anxious depression scale from the Young Adult Self Report (YASR, 16 items, $\alpha = 0.85$) (Achenbach, 1990) and the Spielberger State-Trait Anxiety Inventory trait version (STAI, 20 items, $\alpha = 0.91$) (Spielberger et al., 1970). Additionally, the social problems scale from the YASR was used (8 items, $\alpha = 0.54$).

Six personality traits were measured: neuroticism, extraversion and the four dimensions of sensation seeking. Neuroticism and extraversion were measured with the Amsterdamse Biografische Vragenlijst (Wilde, 1970), a Dutch questionnaire based on the Eysenck Personality Questionnaire (EPQ) (Eysenck and Eysenck, 1964). The neuroticism scale consisted of 30 items ($\alpha = 0.89$) and the extraversion scale of 21 items ($\alpha = 0.84$). The four dimensions of sensation seeking were measured with the Dutch translation of the Sensation Seeking Scale (SSS) from Zuckerman (Feij and Van Zuilen, 1984; Feij et al., 1997; Zuckerman, 1971). The dimension 'Thrill and adventure seeking' contained 12 items ($\alpha = 0.87$), 'Experience seeking' 14 items ($\alpha = 0.69$), 'Boredom susceptibility' 13 items ($\alpha = 0.66$) and 'Disinhibition' 12 items ($\alpha = 0.79$).

Statistical analyses

Linear mixed modeling was used to test for differences in means on anxiety, depression and personality traits between exercisers and non-exercisers. Linear mixed models allow for modeling statistical dependencies among observations by including random effects, such as dependencies due to nested sampling. In our sample, the data were nested at two levels: individuals were nested within families and repeated measurements were nested within individuals.

The effects of exercise participation, gender and categorized age (including interaction effects) on the anxiety, depression and personality variables were modeled by including them as fixed effects in the model. The means of the repeated measurement were modeled by including a constant as a fixed effect for each measurement occasion. The model included a family effect that varied randomly over families. Within family, covariances were estimated by the single variance component associated with this effect. Variances and covariances among the repeated measurements were estimated by the unrestricted residual variances and covariances. We used the statistical package S-Plus for the analyses (S-Plus, 2001). As expected, both the variances of the family effect on anxiety, depression and personality and the correlations between repeated measurements over time within the same individual significantly differed from zero. This indicates that the correction for family structure and repeated measurements was necessary.

The analyses were performed for all ten dependent variables. The overall significance level was set to $\alpha = 0.01$. To correct for multiple testing, we used the Bonferroni method to obtain the significance level used for every test. With ten dependent variables and eight different fixed effects, this led to the use of an α of 0.00013 for each fixed effect.

Results

Prevalence of exercise participation

Fig. 1 depicts the prevalences of exercise participation in The Netherlands across gender and age groups. The overall

Table 1
Measurement of anxiety, depression and personality over waves, Netherlands twin family study on lifestyle and health, 1991–2002

	Year of measurement						Total observations	Total families
	1991	1993	1995	1997	2000	2002		
Exercise participation	6366	7852	8120	4732	6628	10,190	43,888	4923
Depression (BDI)		7745		4705			12,450	2864
Anxious depression (YASR)	3315 ^a		3303 ^a	4685	6533	9975	27,811	4767
Anxiety (STAI)	6284	7759		4693	6600	10,089	35,425	4908
Social problems (YASR)	3315 ^a		3303 ^a	4685	6533		17,836	4226
Neuroticism (ABV)	6269	7733		4694	6568	9852	35,116	4898
Extraversion (ABV)	6281	7760		4694	6573	9857	35,165	4898
Thrill adventure seeking (SSS)	6304	7774		4695	6551	9968	35,292	4900
Experience seeking (SSS)	6295	7763		4694	6527	10,063	35,343	4901
Boredom susceptibility (SSS)	6293	7757		4692	6531	10,068	35,341	4902
Disinhibition (SSS)	6299	7765		4691	6533	10,074	35,362	4902

^a Only twins filled in the YASR questionnaire on these waves.

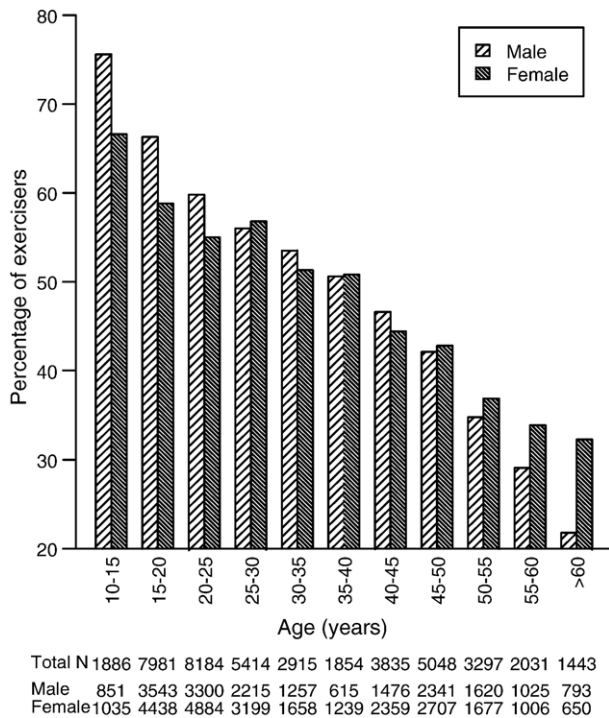


Fig. 1. Prevalence of exercise participation across gender and age, Netherlands twin family study on lifestyle and health, 1991–2002.

prevalence of exercise participation (in percentage exercising subjects) for this sample is 51.4%. The overall prevalence for men is 52.0% and for women 50.9%. There is a clear decline in the prevalences over age for both males and females: older subjects exercise less. In the young age (10 to 25 years), more men than women exercise, in the older age (45 years and older), more women exercise than men.

Effects of exercise participation, gender and age on anxiety and depression

In the upper part of Table 2, the results of the significance tests of the effects of exercise, gender and age on anxiety and depression are given, based on approximate *F* tests. The upper part of Table 3 contains the observed means for anxiety and

depression as a function of exercise. Fig. 2 shows the observed means of anxiety and depression for the exercise and gender groups over age. All main effects are significant, except for the effects of gender and age on social problems. Exercisers on average score lower on anxiety, depression and social problems than non-exercisers. Expressed in pooled standard deviations, exercisers are 0.29 SD lower in depression, 0.18 SD lower in anxious depression, 0.19 SD lower in anxiety and 0.15 SD lower in social problems.

Effects of exercise participation, gender and age on personality

In the lower part of Table 2, the results of the significance tests of the effects of exercise, gender and age on personality are shown. The lower part of Table 3 gives the observed means of the personality traits as a function of exercise. Fig. 3 presents the observed means of personality for the exercise and gender groups over age. Main effects of exercise, gender and age on personality are found for all personality measures, except for an effect of exercise on experience seeking and boredom susceptibility and an effect of gender on extraversion. Exercisers on average score higher on extraversion (+0.32 SD), thrill and adventure seeking (+0.47 SD) and disinhibition (+0.25 SD) and lower on neuroticism (−0.14 SD).

Discussion

The primary findings from this investigation are that exercisers are on average less anxious and depressed (effect sizes from −0.18 to −0.29 SD), less neurotic (effect size −0.14 SD), more extraverted (effect size +0.32 SD), higher in thrill and adventure seeking (effect size +0.47) and higher in disinhibition (effect size +0.25 SD) than non-exercisers. Although the differences between exercisers and non-exercisers are small (Cohen, 1969), they are very consistent across gender and age. Strikingly, the associations with exercise participation were independent of the well-known main effect of age on exercise prevalence, that is, all associations held for 20-year-olds when exercise prevalence is still 70% but also for 60-year-olds when exercise prevalence has dropped below 30%.

Table 2

Effects of exercise participation, gender and age on anxiety, depression and personality, Netherlands twin family study on lifestyle and health, 1991–2002

		Main effects			2-way interactions			3-way interaction
		Exercise	Gender	Age	Ex * Gender	Ex * Age	Gender * Age	Ex * Gender * Age
	<i>df</i>	1	1	10	1	10	10	10
Depression (BDI)	<i>F</i>	32.5 *	49.6 *	23.1 *	0.0	1.4	1.0	1.0
Anxious depression (YASR)	<i>F</i>	23.7 *	740.7 *	6.9 *	0.2	0.8	3.2	1.9
Anxiety (STAI)	<i>F</i>	71.0 *	523.5 *	11.9 *	0.2	0.9	5.1 *	0.9
Social problems (YASR)	<i>F</i>	16.1 *	5.3	3.3	0.5	1.0	2.3	1.0
Neuroticism (EPQ)	<i>F</i>	46.4 *	833.2 *	40.4 *	2.2	1.4	2.0	2.6
Extraversion (EPQ)	<i>F</i>	115.9 *	6.8	93.4 *	0.0	1.2	4.4 *	0.5
Thrill adventure seeking (SSS)	<i>F</i>	167.6 *	2657.8 *	975.2 *	5.8	0.9	20.7 *	1.4
Experience seeking (SSS)	<i>F</i>	9.4	438.0 *	80.7 *	1.2	2.3	10.1 *	1.4
Boredom susceptibility (SSS)	<i>F</i>	4.3	206.5 *	38.1 *	0.8	2.1	5.2 *	1.1
Disinhibition (SSS)	<i>F</i>	14.6 *	3328.8 *	390.8 *	0.1	1.7	10.8 *	1.2

* *P* < 0.00013.

Table 3

Anxiety, depression and personality as a function of exercise participation, Netherlands twin family study on lifestyle and health, 1991–2002

Exercise	No		Yes	
	N	M (SD)	N	M (SD)
Depression (BDI)	5738	2.3 (3.1)	6712	1.5 (2.4)
Anxious depression (YASR)	12,586	6.0 (5.2)	15,225	5.1 (4.6)
Anxiety (STAI)	17,088	34.2 (9.1)	18,337	32.6 (8.2)
Social problems (YASR)	7186	2.6 (2.1)	10,650	2.3 (2.0)
Neuroticism (EPQ)	16,908	50.5 (25.2)	18,208	47.2 (23.7)
Extraversion (EPQ)	16,945	55.7 (17.2)	18,220	61.1 (16.1)
Thrill adventure seeking (SSS)	16,996	30.2 (11.3)	18,296	35.5 (11.2)
Experience seeking (SSS)	17,032	32.6 (8.3)	18,311	33.5 (7.6)
Boredom susceptibility (SSS)	17,025	35.6 (7.5)	18,316	36.4 (7.3)
Disinhibition (SSS)	17,044	28.9 (8.2)	18,318	30.9 (8.0)

The association of exercise with anxiety and depression corroborates previous reports. Lack of exercise was found to be cross-sectionally associated with depression in population samples with a broad age range (Farmer et al., 1988; Weyerer, 1992) and in samples consisting of young (Steptoe et al., 1997; Steptoe and Butler, 1996) or older adults (Kritz-Silverstein et al., 2001; Strawbridge et al., 2002). In a sample of adolescents, however, Allison et al. (2005) found that regular exercise was associated with better social functioning, but not with less anxiety and depression.

To date, only a few other studies have addressed the relation between exercise and personality, although none in a large population-based European sample. Our results are concordant with these previous reports. In a large Japanese population study (Arai and Hisamichi, 1998), exercisers scored higher on extraversion and lower on neuroticism. In a sample of South African students (Potgieter and Venter, 1995), adherers to exercise score significantly higher on extraversion and lower on neuroticism than subjects who drop out from an exercise program. Two of three small studies examining exercise and sensation seeking (Jack and Ronan, 1998; Potgieter and Bisschoff, 1990; Franken et al., 1994) reported higher sensation seeking in exercisers (Jack and Ronan, 1998; Potgieter and Bisschoff, 1990).

We classified subjects of all ages as exercisers only when they met a minimum criterion of 60 min at 4 METs weekly. This is a rather strict criterion in comparison to previous studies on exercise and depression (Camacho et al., 1991; Farmer et al., 1988; Weyerer, 1992). However, the prevalences of exercise participation in our sample are quite consistent with prevalences for the Dutch population in 1999 estimated by Statistics Netherlands (50%; Van der Gils et al., 2002) and the Social and Cultural Planning Office of The Netherlands (65%; Van der Meulen, 2003), although in both of these studies a broader classification of exercise was used. Both studies found the

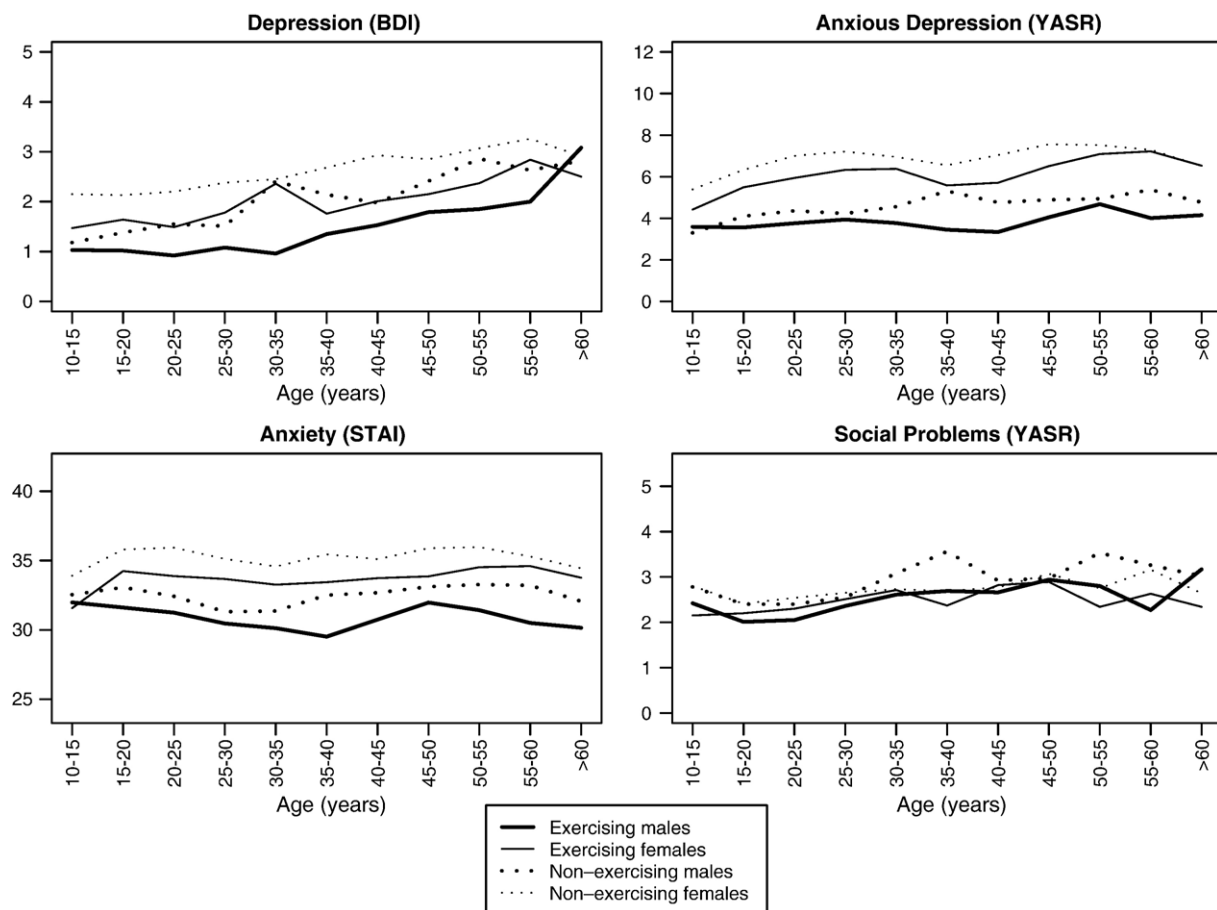


Fig. 2. Anxiety and depression as a function of exercise, gender and age, Netherlands twin family study on lifestyle and health, 1991–2002. Note: to allow for comparison between graphs, values on the y axes range from mean –1 SD to mean +1 SD for all variables.

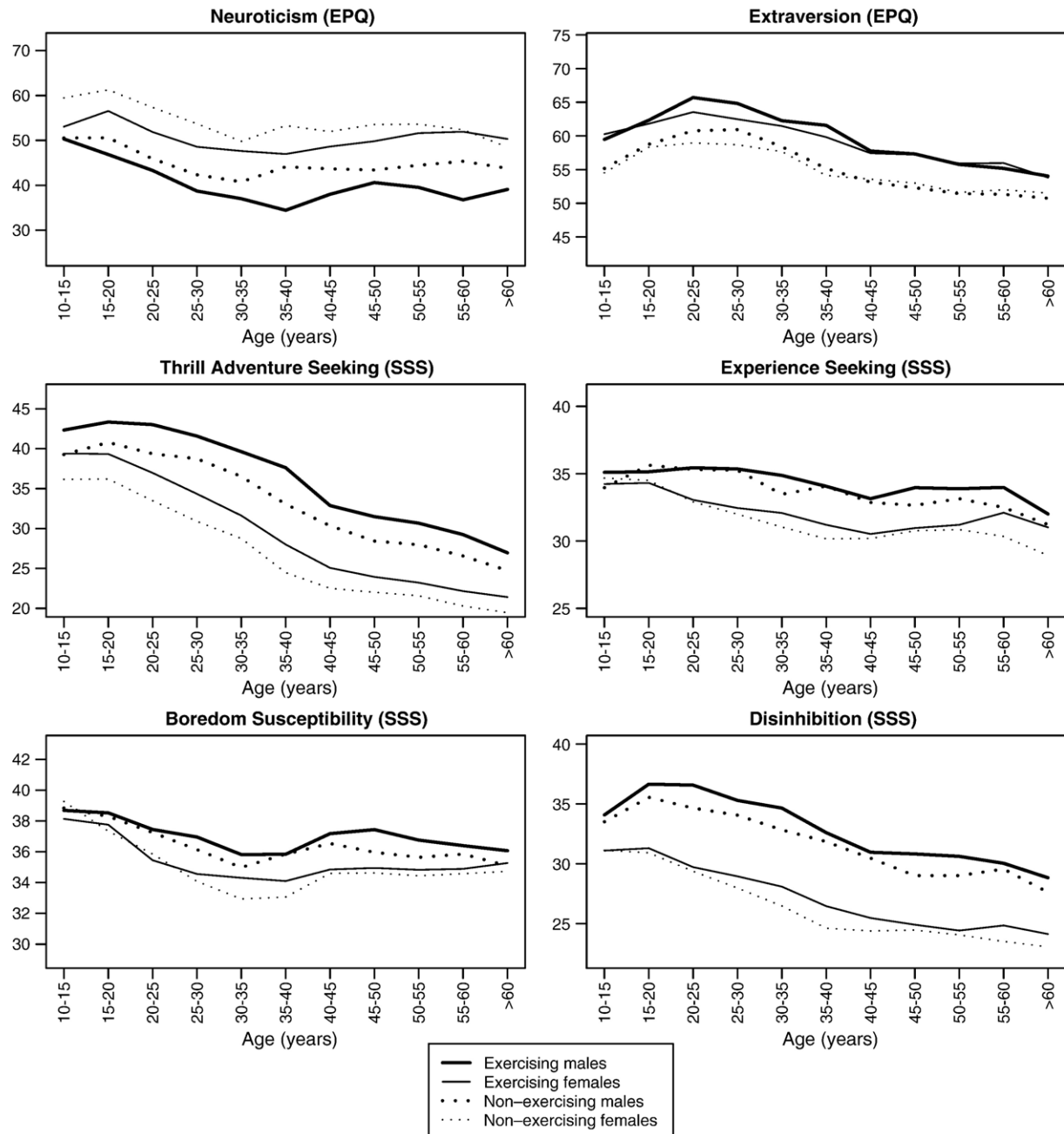


Fig. 3. Personality as a function of exercise, gender and age, Netherlands twin family study on lifestyle and health, 1991–2002. Note: to allow for comparison between graphs, values on the y axes range from mean -1 SD to mean $+1$ SD for all variables.

difference between males and females in main prevalence of exercise to be negligible, and they observed the same strong decline with age. The consistency of the pattern of prevalence of exercise participation in our study with these reports indicates that our sample is representative for the Dutch population.

Cross-sectional analyses, as presented here, cannot inform us on the causal structure between exercise, personality, anxiety and depression. The most direct test of causality is an experimental design in which exercise behavior is manipulated, preferably in a combined training/detraining design (De Geus et al., 1993). Many training studies on different aspects of mental health have been performed.

Careful meta-analyses and qualitative reviews of these studies yield an incoherent picture (Craft and Landers, 1998; De Geus et al., 1993; Long and Vanstavel, 1995; Salmon, 2000). A fundamental problem with training studies may be that they use selected samples, in which two groups of subjects are always underrepresented: those who already exercise vigorously and those who are persistently sedentary and refuse to participate (or drop out early). This makes the results of training studies inherently difficult to generalize to the population because they may fail to fully capture the source of the association between exercise and mental health in the population at large.

An alternative approach to causality, therefore, is the use of prospective analyses in large population-based samples. A prospective association between lack of exercise at baseline and depression or anxiety at follow-up was found in some population studies (Camacho et al., 1991; Farmer et al., 1988; Strawbridge et al., 2002) but was absent in other studies (Allison et al., 2005; Cooper-Patrick et al., 1997; Kritz-Silverstein et al., 2001; Weyerer, 1992). These studies did not, unfortunately, examine the reverse causality, where depression or anxiety at baseline may predict reduced exercise participation at follow-up. Such reverse causality may be particularly plausible as an explanation for the association between exercise behavior and neuroticism and extraversion. These traits show stable individual differences from an early age onward (Caspi and Roberts, 2001) that may precede active choices for voluntary leisure time exercise behavior.

Even if we accept a model where personality influences exercise behavior, exercise may still have a direct causal effect on anxiety and depression. Effectively, this would mean that the risk conveyed by personality on mental health acts through its influence on exercise behavior. In a different scenario, exercise may have an indirect causal effect by moderating the “normal” effects of personality on mental health. Various other scenarios can be conceived, and none can be ruled out based on the present data. Finally, all three variables – exercise, personality and mental health – may derive from “third” underlying factors such as socio-economic background or pleiotropic genes affecting the (neuro)biology crucial to these variables simultaneously.

By showing a small but robust cross-sectional association of exercise with anxiety, depression and personality that holds in both genders and across age, this study paves the way for future investigation of the causal structure of the associations of exercise with personality and anxiety and depression in population-based samples.

Acknowledgment

This study was supported by the Netherlands Organization for Scientific Research (NWO-MW 904-61-193, NWO 575-25-006 and NWO 985-10-002).

References

- Achenbach, T.M., 1990. The young adult self report. University of Vermont, Dept of Psychiatry, Burlington, VT.
- Allison, K.R., Adlaf, E.M., Irving, H.M., Hatch, J.L., Smith, T.F., Dwyer, J.J. M., Goodman, J., 2005. Relationship of vigorous physical activity to psychological distress among adolescents. *J. Adolesc. Health* 37, 164–166.
- Arai, Y., Hisamichi, S., 1998. Self-reported exercise frequency and personality: a population-based study in Japan. *Percept. Mot. Skills* 87, 1371–1375.
- Beck, A.T., Ward, C.H., Mendelson, M., Mock, J., Erbaugh, J., 1961. An inventory for measuring depression. *Arch. Gen. Psychiatry* 4, 561–571.
- Boomsma, D.I., Vink, J.M., Van Beijsterveldt, T.C., De Geus, E.J., Beem, A.L., Mulder, E.J., Derks, E.M., Riese, H., Willemsen, G.A., Bartels, M., Van den, B.M., Kupper, N.H., Polderman, T.J., Posthuma, D., Rietveld, M.J., Stubbe, J.H., Knol, L.I., Stroet, T., Van Baal, G.C., 2002. Netherlands twin register: a focus on longitudinal research. *Twin Res.* 5, 401–406.
- Byrne, A., Byrne, D.G., 1993. The effect of exercise on depression, anxiety and other mood states—A review. *J. Psychosom. Res.* 37, 565–574.
- Camacho, T.C., Roberts, R.E., Lazarus, N.B., Kaplan, G.A., Cohen, R.D., 1991. Physical activity and depression: evidence from the Alameda county study. *Am. J. Epidemiol.* 134, 220–231.
- Caspi, A., Roberts, B.W., 2001. Personality development across the life course: the argument for change and continuity. *Psychol. Inq.* 12, 49–66.
- Cohen, J., 1969. Statistical power analysis for the behavioral sciences. Academic Press, New York.
- Cooper-Patrick, L., Ford, D.E., Mead, L.A., Chang, P.P., Klag, M.J., 1997. Exercise and depression in midlife: a prospective study. *Am. J. Public Health* 87, 670–673.
- Costa Jr., P.T., McCrae, R.R., 1980. Influence of extraversion and neuroticism on subjective well-being: happy and unhappy people. *J. Pers. Soc. Psychol.* 38, 668–678.
- Craft, L.L., Landers, D.M., 1998. The effect of exercise on clinical depression and depression resulting from mental illness: a meta-analysis. *J. Sport Exerc. Psychol.* 20, 339–357.
- De Geus, E.J., Van Doornen, L.J., Orlebeke, J.F., 1993. Regular exercise and aerobic fitness in relation to psychological make-up and physiological stress reactivity. *Psychosom. Med.* 55, 347–363.
- Eysenck, H.J., Eysenck, S.B.G., 1964. Eysenck personality inventory. Educational and Industrial Testing Service, San Diego, CA.
- Farmer, M.E., Locke, B.Z., Moscicki, E.K., Dannenberg, A.L., Larson, D.B., Radloff, L.S., 1988. Physical activity and depressive symptoms: the NHANES I epidemiologic follow-up study. *Am. J. Epidemiol.* 128, 1340–1351.
- Feij, J.A., Van Zuijlen, R.W., 1984. Handleiding bij de Spanningsbehoeflijst (SBL). Swets and Zeitlinger, Lisse.
- Feij, J.A., Dekker, P.H., Koopmans, J.R., Boomsma, D.I., 1997. Nieuwe Normen en Stabiliteitsgegevens voor de Spanningsbehoeflijst (SBL). *Ned. Tijdschr. Psychol.* 52, 131–134.
- Folkens, C.H., Sime, W.E., 1981. Physical fitness training and mental health. *Am. Psychol.* 36, 373–389.
- Franken, R.E., Hill, R., Kierstead, J., 1994. Sport interest as predicted by the personality measures of competitiveness, mastery, instrumentality, expressivity, and sensation seeking. *Pers. Individ. Differ.* 17, 467–476.
- Gauvin, L., Spence, J.C., 1996. Physical activity and psychological well-being: knowledge base, current issues, and caveats. *Nutr. Rev.* 54, S53–S65.
- Jack, S.J., Ronan, K.R., 1998. Sensation seeking among high- and low-risk sports participants. *Pers. Individ. Differ.* 25, 1063–1083.
- Koopmans, J.R., 1997. The relation between sensation seeking, alcohol use and smoking: a multivariate genetic analysis. In *The genetics of health-related behaviors: a study of adolescent twins and their parents*, dissertation, Vrije Universiteit, Amsterdam, 71–87.
- Kritz-Silverstein, D., Barrett-Connor, E., Corbeau, C., 2001. Cross-sectional and prospective study of exercise and depressed mood in the elderly—The Rancho Bernardo study. *Am. J. Epidemiol.* 153, 596–603.
- Long, B.C., Vanstavel, R., 1995. Effects of exercise training on anxiety—A meta analysis. *J. Appl. Sport Psychol.* 7, 167–189.
- Middeldorp, C.M., Cath, D.C., Van den Berg, M., Beem, A.L., Van Dyck, R., Boomsma, D.I., 2005. The association of personality with anxious and depressive psychopathology. In: Canli, T. (Ed.), *The biological basis of personality and individual differences*. Guilford Press, New York.
- North, T.C., McCullagh, P., Tran, Z.V., 1990. Effect of exercise on depression. *Exerc. Sport Sci. Rev.* 18, 379–415.
- Potgieter, J.R., Bisschoff, F., 1990. Sensation seeking among medium- and low-risk sports participants. *Percept. Mot. Skills* 71, 1203–1206.
- Potgieter, J.R., Venter, R.E., 1995. Relationship between adherence to exercise and scores on extraversion and neuroticism. *Percept. Mot. Skills* 81, 520–522.
- Salmon, P., 2000. Effects of physical exercise on anxiety, depression, and sensitivity to stress: a unifying theory. *Clin. Psychol. Rev.* 21, 33–61.
- Scully, D., Kremer, J., Meade, M.M., Graham, R., Dudgeon, K., 1998. Physical exercise and psychological well being: a critical review. *Br. J. Sports Med.* 32, 111–120.
- Spielberger, C.D., Gorsuch, R.L., Lushene, R.E., 1970. STAI manual for the state-trait anxiety inventory. Consulting Psychologists Press, Palo Alto, CA.

- S-Plus 6 for Windows User's Guide, 2001. Insightful Corporation, Seattle, WA.
- Steptoe, A., Butler, N., 1996. Sports participation and emotional wellbeing in adolescents. *Lancet* 347, 1789–1792.
- Steptoe, A., Wardle, J., Fuller, R., Holte, A., Justo, J., Sanderman, R., Wichstrom, L., 1997. Leisure-time physical exercise: prevalence, attitudinal correlates, and behavioral correlates among young Europeans from 21 countries. *Prev. Med.* 26, 845–854.
- Strawbridge, W.J., Deleger, S., Roberts, R.E., Kaplan, G.A., 2002. Physical activity reduces the risk of subsequent depression for older adults. *Am. J. Epidemiol.* 156, 328–334.
- Stubbe, J.H., Boomsma, D.I., de Geus, E.J.C., 2005. Sports participation during adolescence: a shift from environmental to genetic factors. *Med. Sci. Sports Exerc.* 37, 563–570.
- Van der Gils, V.W.V., Hildebrandt, V.H., Otten, F., 2002. Sporten, Wandelen en Fietsen in Nederland. In: Ooijendijk, W.T.M., Hildebrandt, V.H., Stiggelbout, M. (Eds.), *Tendrapport Bewegen en Gezondheid 2001/2002*. TNO Arbeid, Hoofddorp, pp. 39–62.
- Van der Meulen, R., 2003. Beoefening. In: Breedveld, K. (Ed.), *Rapportage sport 2003*. Sociaal Cultureel Planbureau, Den Haag, pp. 71–97.
- Vink, J.M., Willemsen, G., Engels, R.C.M.E., Boomsma, D.I., 2003. Smoking status of parents, siblings and friends: predictors of regular smoking? Findings from a longitudinal twin-family study. *Twin Res.* 6, 209–217.
- Vink, J.M., Willemsen, G., Stubbe, J.H., Middeldorp, C.M., Ligthart, R.S.L., Baas, K.D., Dirkzwager, H.J.C., De Geus, E.J.C., Boomsma, D.I., 2004. Estimating non response bias in family studies: application to mental health and lifestyle. *Eur. J. Epidemiol.* 19, 623–630.
- Weyerer, S., 1992. Physical inactivity and depression in the community. Evidence from the upper Bavarian field study. *Int. J. Sports Med.* 13, 492–496.
- Wilde, G.J.S., 1970. Neurotische labiliteit gemeten volgens de vragenlijst-methode (The questionnaire method as a means of measuring neurotic instability). Van Rossen, Amsterdam.
- Zuckerman, M., 1971. Dimensions of sensation seeking. *J. Consult. Clin. Psychol.* 36, 45–52.