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Leisure-Time Physical Activity in a Finnish Twin Study

Genetic and Environmental Influences as Determinants and Motives as Correlates

JYVÄSKYLÄN YLIOPISTO

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“Research is what I'm doing when I don't know what I'm doing.”

Wernher von Braun

ABSTRACT

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The purpose of this study was to quantify longitudinally genetic and environmental influences on leisure-time physical activity and to examine the associations between motives or barriers and longitudinal leisure-time physical activity.

Participants were either from the FinnTwin16 study or from the Finnish Twin Cohort. In the genetic analyses, at baseline the samples comprised 5 216 adolescent (mean age 16.2 years) and 13 556 adult (mean age 29.6 years) monozygotic and dizygotic twin individuals. At follow-up, the numbers of participants were 4 531 (mean age 24.5 years) and 13 822 (mean age 35.6 years), respectively. To examine motives for physical activity, 2 308 twin participants (mean age 33.9 years) were drawn from the FinnTwin16 study. For the TWINACTIVE study, 16 twin pairs (mean age 60.4 years) were recruited from the Finnish Twin Cohort on the basis of 32-year leisure-time physical activity discordance. Motives for and barriers to physical activity were assessed among these participants. Physical activity assessment was based on leisure-time MET hours/day or the frequency of leisure-time physical activity. The Recreational Exercise Motivation Measure was used to examine motives for leisure-time physical activity, and a 25-item questionnaire was used to examine barriers to physical activity. The statistical analyses included quantitative genetic modeling, within-pair and individual-based analyses.

Genetic influences accounted for 43%–52% of the total variance in leisure-time physical activity in adolescence (ages from ~16 to ~18 years), declining to 30% in young adulthood (age ~25 years). A decline in genetic influences was also seen from age ~30 years, 44%, to age ~36 years, 34%. From adolescence to young adulthood, the remaining variance was due to both shared and specific environmental influences. Shared environmental influences increased markedly in young adulthood, especially in women. At age 30 and over, only specific environmental influences were present. Mastery, physical fitness, and psychological state were the major motivation factors associated with consistent leisure-time physical activity behavior. Pain, diseases and lack of time were the most often-cited barriers to physical activity. No differences in barriers between the consistently active and inactive co-twins were observed.

The results indicate the existence of age-specific genetic and environmental influences on leisure-time physical activity. Variations in environmental factors seem to explain the observed deterioration in leisure-time physical activity levels. The results also indicate that intrinsic motivation factors are important for engagement in leisure-time physical activity.

Keywords: genetic influences, heritability, motivation, physical activity, twins

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Jyväskylä, May 2013

Sari Aaltonen

LIST OF ORIGINAL PUBLICATIONS

The thesis is based on the following original publications, which will be referred to in the text by their Roman numerals. In addition, some previously unpublished results are included in the thesis.

I Aaltonen, S., Ortega-Alonso, A., Kujala, U. M. & Kaprio, J. 2013. Genetic and environmental influences on longitudinal changes in leisure-time physical activity from adolescence to young adulthood. Twin Research and Human Genetics, doi:10.1017/thg.2013.9.

II Aaltonen, S., Ortega-Alonso, A., Kujala, U. M. & Kaprio, J. 2010. A longitudinal study on genetic and environmental influences on leisure time physical activity in the Finnish twin cohort. Twin Research and Human Genetics 13, 475–481.

III Aaltonen, S., Rottensteiner, M., Kaprio, J. & Kujala, U. M. 2013. Motives for physical activity among active and inactive persons in their mid-30s. Scandinavian Journal of Medicine & Science in Sports, doi: 10.1111/sms.12040.

IV Aaltonen, S., Leskinen, T., Morris, T., Alén, M., Kaprio, J., Liukkonen, J. & Kujala, U. M. 2012. Motives for and barriers to physical activity in twin pairs discordant for leisure time physical activity for 30 years. International Journal of Sports Medicine, 33, 157–163.

ABBREVIATIONS

A	additive genetic influences
AIC	Akaike's information criterion
ANOVA	Analysis of variance
BIC	Bayesian information criterion
BMI	body mass index
C	shared environmental influences
CI	confidence interval
cm	centimeter
D	dominant genetic influences
df	degrees of freedom
DIC	deviance information criterion
DZ	dizygotic
DNA	deoxyribonucleic acid
E	specific environmental influences
H	hydrogen
HIT	high-intensity training
ICC	intraclass correlation coefficient
IPAQ	international physical activity questionnaire
kcal	kilocalorie
kg	kilogram
LL	log-likelihood
LRT	likelihood-ratio test
m	meter
ml	milliliter
MZ	monozygotic
N	number of participants
O	oxygen
P	phenotypic variance
p	p-value
PA	physical activity
PCC	polychoric correlation coefficients
r	correlation
SD	standard deviation
REMM	Recreational Exercise Motivation Measure
MET	metabolic equivalent
VA	variance of genotypic values
VC	variance of shared environmental deviations
VE	variance of specific environmental deviations
VO_{2peak},	maximal oxygen uptake
WHO	World Health Organization

CONTENTS

1 INTRODUCTION

To sustain life, we all need to perform physical activity to at least a small amount. However, the amount of physical activity above the level needed to survive varies largely from person to person, although there is strong evidence that reducing physical inactivity by engaging in regular physical activity is vital for health (Garber et al. 2011, Booth et al. 2012). Physical activity has several positive effects on the human body. The pulmonary function, cardiovascular system, skeletal muscles, and endocrine system of the human body benefit from physical activity (Bouchard & Shephard 1994, McArdle et al. 2001). Due to its impact on the various biological events, physical activity helps to maintain physical functioning of the human body, reduces risks for obesity and for several chronic diseases, and even reduces mortality (Morris et al. 1980, Paffenbarger et al. 1986, Kujala et al. 1998, Laaksonen et al. 2004, Physical Activity Guidelines Advisory Committee 2008, World Health Organization 2009, Garber et al. 2011, Booth et al. 2012). Physical activity also improves mental health (Paluska & Schwenk 2000, Strohle 2009, Suija et al. 2013). The recent study of Lee et al. (2012) revealed that physical inactivity causes 6–10% of the major non-communicable diseases such as type 2 diabetes, coronary heart diseases, and breast and colon cancers. In addition, they estimated that by eliminating physical inactivity, the life expectancy of the world’s population could increase by 0.68 years.

Given all these widely published benefits of physical activity, one might expect participation in physical activity to be the norm. Unfortunately, this is not the case. A substantial proportion of people, especially in the most developed countries do not participate in sufficient physical activity to obtain the necessary health benefits (Physical Activity Guidelines Advisory Committee 2008), while a part of the population remains nearly wholly sedentary (Pratt et al. 1999, Martínez-González et al. 2001). Generally, in the high-income countries physical activity, especially during working hours, has decreased due to technological change. Although technological changes in leisure time have also been dramatic, physical activity during leisure-time has increased (Hallal et al. 2012). This gives researchers a reason to focus on leisure-time physical activity behavior. Moreover, leisure-time physical activity is within the reach of everyone and thus can be viewed as a good general health promoter.

Since several chronic diseases develop slowly, people need to participate regularly and consistently in physical activity to benefit from it. To become a regular exerciser, a person has to adopt the belief that a physically active lifestyle confers enough benefits to outweigh its costs. Duncan et al. (2010) concluded that persons who value the benefits associated with regular physical activity have incorporated that behavior into their sense of identity. Those persons are more likely to engage in lifelong physical activity. Not surprisingly, the largest attrition has been shown to occur within 6 months of starting physical activity, when a person has not realized any of the health benefits of that activity (Dishman 1990). It can be assumed that complex behaviors, such as physical activity, are regulated by environmental, genetic and biological aspects and that the stimuli to first become and then to remain physically active are determined by various factors and their interplay (Bauman et al. 2012). It is known that people may respond differently to physical activity according to their genetic liability and that the social-psychological environment can play an imposing role in getting some people attracted to physical activity (Perusse et al. 1989, Duncan et al. 2008).

The fact that many different factors play a role in leisure-time physical activity behavior presents a challenge for researchers interested in exploring the reasons for physical activity. Leisure-time physical activity level may partly be selected on the basis of personal traits, needs and interest, and partly on the basis of determinants at the environmental and policy levels (Bouchard & Shephard 1994, Bouchard et al. 2007, Bauman et al. 2012). Some of these factors may make it easier or harder for some individuals to achieve high levels of physical activity. However, it is important to remember that environmental and genetic factors always work in conjunction. A child of physically active parents may have a genetic tendency to physical activity, but such parents are also very likely to create a family environment that encourages the child to engage in physically active behavior. For some time now, serious attempts have been made to clarify the role of different factors in physical activity behavior. This might help to answer the question "Why are some people physically active and some not?" So far, studies have reported various findings and consensus has not been reached. However, age, sex, self-efficacy and health status at least seem to be associated with physical activity level (Bauman et al. 2012).

Genetic studies are a new area of physical activity research, mainly because genetics seems to be a possible determinant of physical activity (Bauman et al. 2012). These studies attempt to identify the genetic factors contributing to the propensity to be physically active. The contribution of genetic factors to variation in physical activity is often examined with help of twin studies. Twin study designs are popular in behavioral genetics, as they provide an opportunity to disentangle the effects of genes and environment (Boomsma et al. 2002, van Dongen et al. 2012). In addition to genetics, motivation is a personal characteristic that also may be one of the key factors for understanding why people spend their leisure time doing physical activity when it could be spent in many other ways. This may be the reason why motives have been widely studied. However, to date little is known about the motives for physical activity over the life course or about differences in motivational factors between active and inactive individuals. Many of the possible motivation factors associated with physical activity have their roots in childhood and family experiences (Dishman et al. 1985, Tammelin et al. 2003, Telama et al. 2005, Eriksson et al. 2008). Being continuously physically active in childhood may lead to high intrinsic motivation and a high level of motor skills, which, in turn, increase the probability of being active in later life (Dishman et al. 1985, Telama et al. 2005). Because childhood is shared by twins, studying twin pairs differing in leisure-time physical activity level later in life would allow examination of the role of motivation factors while adjusting for family background.

Unfortunately, so far, most studies seeking to resolve the factors involved in physical activity behavior have used cross-sectional study designs. Cross-sectional designs do not reveal causal associations and may not bring out the true effects of aging, as they only evaluate people at a single point in time. Thus, cross-sectional studies are not appropriate for examining the reasons for long-term consistent leisure-time physical activity that is a prerequisite for the prevention of several chronic diseases. In contrast to cross-sectional study designs, longitudinal study designs can be used to identify factors that have a causal association with leisure-time physical activity (Bauman et al. 2012) and to investigate the widely known fact that leisure-time physical activity levels change over the life course (Sherwood & Jeffery 2000, Vink et al. 2011). Leisure-time physical activity behavior is one of the health-related changes that is susceptible to change during the transition from adolescence to young adulthood (Kimm et al. 2002, Allender et al. 2006, Dumith et al. 2011).

A consensus of the factors involved in leisure-time physical activity behavior has not been reached. The reasons for the failure of different lifestyle programs also remain poorly known. Overall, increased knowledge of the longitudinal genetic and environmental factors influencing leisure-time physical activity, and increased knowledge of the potential differences in physical activity motivation and barriers to physical activity among physically active and physically inactive persons may increase our understanding of why some people fail to engage in regular, long-term physical activity during their leisure time. In the present thesis, genetic and environmental influences on the longitudinal evolution of leisure-time physical activity behavior from adolescence to young adulthood, and also over a 6-year follow-up period in adulthood, were estimated in an attempt to peer behind the curtain of leisure-time physical activity behavior. Genetic and environmental determinants of stability and change in leisure-time physical activity were examined using quantitative genetic models. Furthermore, the motives for leisure-time physical activity and barriers to engagement in leisure-time physical activity among consistently physically active and inactive persons were examined. The uniqueness of the study with regard to motivation and barriers lies in the investigation of twin pairs discordant for physical activity over 30 years.

2 REVIEW OF THE LITERATURE

2.1 Leisure-time physical activity

Physical activity is a complex concept and a complex trait. It is complex to define and complex to assess, mostly because it is a behavior that occurs in various forms and contexts. However, definitions have been attempted. Mainly, these definitions agree that physical activity is body movement produced by the skeletal muscles. Body movement causes a substantial increase in energy demands over resting energy expenditure (Caspersen et al. 1985, Bouchard and Shephard 1994, Vanhees 2005, Bouchard et al. 2007). Dose is an important term in the context of physical activity. The amount of physical activity performed can be referred to as a dose. Specifically, the total dose is determined by three indicators that are important in producing improvements in performance and in health: frequency, duration and intensity of physical activity (Haskell 2007). Thus, dose-response refers to the relationship between the physical activity performed and the health-related changes produced. The precise dose-response relationships for many health outcomes has not been clarified, although there is evidence that more physical activity will induce greater health benefits (Haskell 2007). Some health benefits are achieved through the benefits to fitness, but direct health improvements also exist (Figure 1).

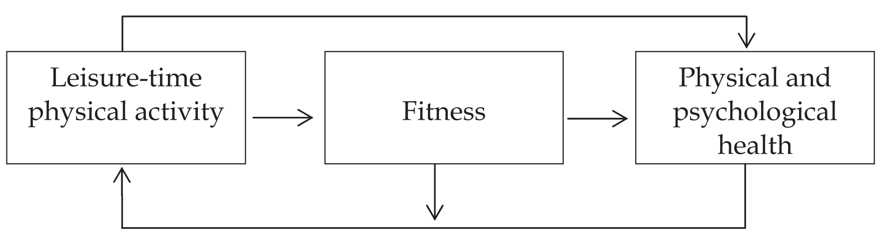

FIGURE 1 Physical activity and fitness are positively associated with health, but healthier people are also more inclined to be active (modified from Bouchard et al. 2007).

For most individuals, an increase in physical activity levels produces an increase in physical fitness. However, the magnitude of the response to the exercise stimulus is under genetic control, and for this reason, the amount of adaptation in fitness to a constant exercise stimulus can vary widely (Blair et al. 2001). This may lead to the results reported in the review by Blair et al. (2001), indicating that there is a higher dose-response relationship between fitness and health outcomes than between physical activity and health outcomes.

First of all, physical activity is a complex concept, but it is also a large concept that can be subcategorized further according to when and where it is done; for example, at work or in leisure time. Leisure time is something people have after all their daily duties, such as work and domestic chores have been done. In developed societies, leisure time is about 3–4 hours per day (Bouchard et al. 2007). According to Statistics Finland, the mean leisure time of Finns was 6.4 hours/day in the years 2009–2010 (Official Statistics of Finland 2011). There is a wide variation in how people spend their leisure-time; activities are selected according to personal needs and interests. Physical activity is one of the beneficial ways of spending leisure time. Specifically, leisure-time physical activity is defined as "physical activities performed by a person that are not required as essential activities of daily living and are performed at the discretion of the person" (Physical Activity Guidelines Advisory Committee 2008). Leisure-time physical activity can include physical activity during exercise training and sports, household activities, transportation and other recreational activities such as going for a walk, dancing, and gardening (Caspersen et al. 1985, Bouchard and Shephard 1994). Although the terms physical activity and exercise are often used interchangeably, the term exercise is a subcategory of physical activity. The biggest difference between these terms is that exercise is planned, structured and repetitive, and its objective is to maintain or improve physical fitness components (Caspersen et al. 1985). Further, physical activity involving a competition is generally called sport (Bouchard & Shephard 1994). It should be borne in mind that physical activity is not the same thing as physical fitness either, although they are strongly correlated (Caspersen et al. 1985).

The total level of physical activity as well as physical activity during working hours have decreased (Brownson et al. 2005, Borodulin & Jousilahti 2012, Hallal et al. 2012). The nature of occupational work changed throughout the 20th century, which is why the importance of physical activity in leisure time has increased. Physical activity in leisure time increases total daily energy expenditure and may prevent weight gain. During the past few decades, physical activity in leisure time has increased in the high-income countries (Borodulin et al. 2008a, Hallal et al. 2012). However, recent results from Finland reveal that increase in leisure-time physical activity seems to have stopped (Borodulin & Jousilahti 2012). It has been shown that normal weight, high education, non-smoking status, and being single are associated with high levels of physical activity during leisure time (Martinez-Gonzalez et al. 2001, Varo et al. 2003, Borodulin et al. 2008b, Hallal et al. 2012). Interestingly, outside of the physical activity context, being single seems to be a risk factor for unhealthy behavior (Schoenborn 2004) and for excess mortality (Manzoli et al. 2007). Furthermore, there seem to be differences between income (Mäkinen et al. 2009) and occupational (Mäkinen et al. 2010) groups in leisure-time physical activity: those in the higher income and occupational groups seem to be more physically active during their leisure time than those in the lower groups. However, there are indications that leisure-time physical activity level declines with age (Crespo et al. 1996, Sallis 2000, Martinez-Gonzalez et al. 2001, Hallal et al 2012). The same age-specific phenomenon can be seen in body weight; obesity increases with age (Jackson et al. 2012). Not surprisingly, there seems to be an association between these two factors, but at the moment, it is not clear whether obesity is a contributor to leisure-time physical inactivity or vice versa (Bauman et al. 2012), and to what degree the association is causal.

Several studies have estimated the prevalence of physical activity and inactivity during leisure time. Recently, it has been estimated that about 30% of adults are physically inactive: the prevalence is lowest in the low-income Southeast Asian countries and the highest in the United States of America and the eastern Mediterranean countries (Hallal et al. 2012). Studies among the member states of the European Union have showed that the Scandinavian countries have the highest prevalence of leisure-time physical activity and the lowest prevalence of leisure-time physical inactivity (Martinez-Gonzalez et al. 2001, Varo et al. 2003). Leisure-time physical inactivity was more common in the southern member states of the European Union. Overall, about 73% of European Union citizens practice some kind of leisure-time physical activity, and almost 92% of Finns were physically active in their leisure time (Martinez-Gonzalez et al. 2001). Based on a recent national study in Finland, the situation seemed not to be as good as suggested by the study of the member states of the European Union. According to the Finnish study, almost one-third of Finns are physically inactive in their leisure time, meaning that they do not take part in any activity requiring physical activity outside working hours and daily duties (Mäkinen et al. 2012).

The amount of time spent sitting is also a growing area in physical inactivity studies. In order to differentiate the concepts from physical inactivity, the term “sedentary behavior” is usually used when the time spent sitting is of interest. Worldwide, the proportion of adults spending at least four hours per day sitting have been assessed to be about 42% (Hallal et al. 2012), and interestingly, daily time spent sitting has been shown to be an independent risk factor for multiple health outcomes, including mortality (Katzmarzyk et al. 2009, Dunstan et al. 2010, Grontved & Hu 2011, Thorp et al. 2011, Dunstan et al. 2012). Although there are studies, including a large Finnish population-based study among youth (Tammelin et al. 2007), suggesting that sedentary behavior has replaced the time spent in physical activity, it has also been shown that sedentary time (e.g. TV viewing, computer use) is independent of physical activity (Ekelund et al. 2006, Burton et al. 2011) and that physical activity for fitness does not decrease the time of muscular inactivity (Finni et al. 2012).

Moreover, some differences between the sexes in the amount of physical activity and inactivity have been reported. All in all, there seem to be clear sex differences in leisure-time physical activity levels that persist all the way from childhood (Katzmarzyk 2007). There are suggestions that in countries with higher levels of physical activity men are more inactive than women, and conversely, that women tend to be more physically inactive than men in countries with lower levels of physical activity. However, in most countries, including Finland, physical inactivity is higher in women than in men (Borodulin et al. 2008b, Hallal et al. 2012). This was also revealed by the Physical Activity Guidelines Advisory Committee (2008). According to the committee report, the prevalence of U.S. women regularly engaging in physical activity was 46.7%, while among the U.S. men the prevalence was 49.7%. Generally, when discussing physical activity and inactivity, it should be noted that physical activity and inactivity may not be linked to the same behavioral paradigm (de Vilhena e Santos 2012) and that they may be associated with different factors. Thus, physical inactivity would not be the low end of the physical activity continuum. Furthermore, it has been hypothesized that the role of physical inactivity on health may be independent of physical activity per se (Katzmarzyk 2010), and that the physiology of exercise might differ from the physiology of inactivity (Hamilton et al. 2007).

In addition to general estimations of leisure-time physical activity and inactivity levels, specific forms of leisure-time physical activity have been studied. Walking has a strong role in leisure-time physical activity behavior. It is an accessible and inexpensive form of leisure-time physical activity. About 64% of adults have reported to walk for at least 10 minutes consecutively on five or more days per week (Hallal et al. 2012). Active transportation, such as walking, cycling or commuting in any other physically active way to and from work, is also an excellent way to increase daily energy expenditure. However, active transportation seems to vary highly between countries: many European countries only have a moderate prevalence of active transportation (Hallal et al. 2012), while during the past decades, the prevalence of commuting physical activity has also been shown to have decreased (Borodulin et al. 2008a, Borodulin & Jousilahti 2012). Furthermore, participation in vigorous-intensity physical activity can be regarded as one of the key indicators of leisure-time physical activity level. About 31% of adults report vigorous-intensity physical activity on three or more days per week, and men are more likely to participate in vigorous physical activity than women (Hallal et al. 2012).

2.1.1 Leisure-time physical activity recommendations

During the last four to five decades, experts in the area of health and medicine have been worried about increased inactivity, sedentariness and the negative consequences on health of the decline in physical activity in western countries (Physical Activity Guidelines Advisory Committee 2008). Many attempts to promote physical activity behavior have been made. Both global and local strategies on physical activity, including public physical activity recommendations, have been a part of these attempts (Kohl et al. 2012). At the moment, several local and worldwide physical activity recommendations exist. The most extensive recommendations have been issued by the World Health Organization (World Health Organization 2010) and the Physical Activity Guidelines Advisory Committee of the U.S. Department of Health and Human Services (Physical Activity Guidelines Advisory Committee 2008).

Although there are several sets of leisure-time physical activity recommendations and different ones for different age groups, they all follow much the same pattern. The World Health Organization (2010) recommends that healthy adults should perform at least 150 minutes of moderate-intensity aerobic physical activity throughout the week or perform at least 75 minutes of vigorous-intensity aerobic physical activity throughout the week or an equivalent combination of moderate- and vigorous-intensity activity to achieve substantial health benefits. Aerobic activity should be performed in bouts of at least 10 minutes duration. Muscle-strengthening activities involving the major muscle groups should be done on two or more days a week. Likewise, the Physical Activity Guidelines for Americans (2008) recommends at least 30 minutes of moderate-intensity physical activity on at least five days every week or somewhat fewer minutes of vigorous-intensity physical activity on at least three days every week for 18-to 64-year-old adults. It is also possible to combine aerobic activities of different types and intensities into a single measure of amount of activity, and muscle strengthening activities are also recommended. According to the Physical Activity Guidelines for Americans (2008), children and adolescents should do at least 60 minutes of physical activity daily most of which should be aerobic physical activity including vigorous-intensity physical activity on at least three days a week. In addition, muscle- and bone-strengthening physical activity should be included on at least three days a week. Older adults should follow the instructions for adults if able. If their health status restricts their ability to be physically active, older adults should be as physically active as their situation allows. Balance training is also recommended for older adults.

In Finland, a Working Group appointed by the Finnish Medical Society Duodecim and the Executive Board of Current Care (Physical activity and exercise training: Current Care Summary, 2012) has established very similar leisure-time physical activity recommendations for Finnish people as those of the World Health Organization and the Physical Activity Guidelines Advisory Committee. In order to gain additional and more extensive health benefits, individuals should increase the amount of physical activity. The World Health Organization (2010) and Physical Activity Guidelines for Americans (2008) recommend increasing moderate-intensity aerobic physical activity to 300 minutes per week, and vigorous-intensity aerobic physical activity to 150 minutes per week for additional health benefits.

The aforementioned official physical activity recommendations are based on scientific evidence and consensus among physical activity science experts. The experts have reviewed all the available scientific research evidence on physical activity. For example, a number of health benefits are consistently observed at 150 minutes per week of moderate to vigorous intensity physical activity according to several studies quoted by the Physical Activity Guidelines Advisory Committee (2008). However, it needs to be recognized that the amount of recommended physical activity may not in fact be beneficial for all individuals. There seem to be considerable heterogeneity between individuals in their responsiveness to physical activity (Bouchard & Rankinen 2001) and it has been revealed that some individuals may have a non-existent response to exercise (Buford et al. 2013). According to these results, the importance of individualized exercise prescription should be highlighted.

The recommendations for physical activity in bouts of 10 minutes or longer have traditionally been based on the idea that this is the amount of time needed to produce improvements in cardiorespiratory fitness. However, there is more and more evidence that bouts of less duration are also beneficial. High-intensity interval training (HIT), defined as repeated bouts of 10 seconds to 5 minutes of exercise, often performed at an intensity greater than the anaerobic threshold, have been shown to increase cardiorespiratory capacity, and also reduce risks for metabolic diseases (Laursen & Jenkins 2002, Perry et al. 2008, Gibala & McGee 2008, Babraj et al. 2009). However, at the moment there are far too few positive HIT studies published to change the official recommendations.

Again, despite the scientific evidence, large numbers of people do not reach the present leisure-time physical activity recommendations. Broadly, it has been suggested that worldwide three out of every ten individuals aged 15 or over do not reach the present physical activity recommendations (Hallal et al. 2012). Further, about half of the adults in the United States of America are estimated to meet current public health recommendations for moderate-to-vigorous physical activity (Physical Activity Guidelines Advisory Committee 2008).

2.1.2 Assessment of physical activity

Due to the fact that physical activity is a complex trait, no single instrument is able to capture the essence of physical activity. Assessment of physical activity needs to be based on several underlying indicators. Physical activity habits are commonly assessed as the total dose of physical activity consisting of the frequency, duration and intensity of physical activity, as mentioned earlier. Frequency of physical activity refers to the number of physical activity events during a specific time period, duration refers to the time spent on a single bout of physical activity, and intensity refers to the physiological effort associated with participating in a specific type of physical activity (Warren et al. 2010). Energy expenditure during physical activity can also often be assessed. Overall, measurements of physical activity range from subjective techniques, such as questionnaires, to direct objective observations. Behavioral observations, mechanical and electronic devices, and sophisticated standard laboratory tests assessing physiological markers, such as energy cost and heart rate, can be used as objective assessment methods (Vanhees et al. 2005, Westerterp 2009, Ainsworth et al. 2011).

Subjective physical activity questionnaires, diaries and interviews are commonly used, because of their inexpensiveness and easy applicability among large populations (Warren et al. 2010). Global physical activity questionnaires have also been developed to assess physical activity and inactivity cross-nationally (Craig et al. 2003, Helmerhorst et al. 2012). However, subjective methods may be unreliable: over- and underreporting may exist (Arvidsson et al. 2005, Westerterp 2009) and they may be culturally dependent (Warren et al. 2010). A certain cognitive capacity is also needed; answering may be difficult for children and the elderly (Warren et al. 2010). Bias related to subjective methods may also be possible due to the general fact that people easily tend to forget past details. Several objective methods, such as pedometers, accelerometers and heart rate monitoring, are also very often used to assess physical activity, as they are also relatively inexpensive, easy to wear, and they can be used to assess physical activity in free-living conditions. Pedometer and accelerometer methods are based on registering body movements associated with physical activity in one or several planes. Specifically, accelerometers measure the amplitude and frequency of acceleration. However, the inability to measure all activities equally well restricts the use of accelerometers (Warren et al. 2010). Heart rate monitoring relies on the linear relationship between heart rate and oxygen consumption in the moderate to vigorous range of physical activity (Schutz et al. 2001, Vanhees et al 2005).

Physical activity can also be measured as energy expenditure. This is based on the fact that physical activity is defined as bodily movements resulting in energy expenditure. The larger the muscle mass involved, the larger the energy expenditure. Total energy expenditure can be used to measure the daily energy cost, normally as kcal/day. Total energy expenditure consists of the resting metabolic rate, diet-induced energy expenditure, and energy expenditure due to physical activity (McArdle 2001). The resting metabolic rate is the main component of the equation. Energy expenditure due to physical activity includes physical activity during the whole day i.e. during work, leisure time, exercise training, sports, household activities and transportation. However, physical activity-associated energy expenditure is always influenced by body weight, body composition, the movement efficiency of the person, and by other factors, such as environmental conditions (Jetté et al. 1990, Schutz et al. 2001, Vanhees 2005).

Doubly labeled water, indirect calorimetry and direct observations are the gold standards of physical activity assessment methods. Doubly labeled water measures the average metabolic rate of an organism over a period of time by utilizing a known abundance of isotopes of hydrogen (^{2}H) and oxygen (^{18}O) (McArdle et al. 2001). Indirect calorimetry measures a person’s oxygen consumption during physical activities giving an indirect estimate of energy expenditure (McArdle et al. 2001). As gold standards of the most reliable and valid physical activity assessment methods, doubly labeled water and indirect calorimetry based on energy expenditure or oxygen uptake should be used as criterion methods against which other physical activity assessment methods should be validated (Schutz et al. 2001).

Metabolic equivalents (METs) are often used to classify physical activity energy expenditure. The MET value is defined as a multiple of the resting metabolic rate (McArdle 2001). One MET is defined as the amount of oxygen consumed sitting at rest, and is equal to approximately 3.5 ml of oxygen per 1 kg of body weight multiplied by minutes (Jetté et al. 1990). One liter of oxygen is equal to 5 kcal. Work performed at two METs requires twice the resting metabolism, three METs requires three times the resting metabolism, and so on. Most physical activities can be performed at a variable intensity: <2 METs are generally considered to be of very light intensity, 2–2.9 METs light intensity, 3.0–5.9 METs moderate intensity, and 6.0–8.7 METs vigorous intensity of physical work. Consequently, 8.8 METs and higher values are considered to be near-maximal or maximal physical work (Garber et al. 2011). MET-hour or MET-minute scores can be computed by multiplying the activity MET value by the duration of the activity in hours or minutes. This is a great help if time spent at different MET levels are combined to an overall activity score. With the purpose of providing a comprehensive list of self-reported physical activities and their associated MET values, the Compendium of Physical Activity has been developed and updated since 1993. The latest update is from 2011 (Ainsworth et al. 2011). This Compendium includes 21 major types of physical activities, such as home activities, occupation activities, transportation activities, water activities, and volunteer activities, and their associated MET values. Although the MET value is very useful and often used, it is important to remember that physical activity-associated energy expenditure is always influenced by several factors. The MET value is an estimate of the resting oxygen consumption of a man around middle age who weighs 70 kg, and probably over- or underestimates the real values of resting oxygen consumption for a heterogeneous sample of people (Jetté et al. 1990, Byrne et al. 2005, Kozey et al. 2010).

2.2 Heritability of leisure-time physical activity

In a broad sense, heritability is a concept summarizing how heritable a phenotype is (Visscher et al. 2008). A comparison of the relative importance of genes and environment to the variation of trait within and across population is possible by an assessment of heritability. It should be noted that heritability is assessed at a particular time and age, and above all, it is an estimate of the genetic influences to individual differences on a population level, not an estimate pertaining to a single individual (Plomin et al. 2000, Visscher et al. 2008). There are two types of assessments related to the heritability of leisure-time physical activity. The unmeasured genotype approach estimates the contribution of heritability to phenotypic variance, and the measured genotype approach includes the direct measurements of genetic variation at the protein or DNA (deoxyribonucleic acid) levels (Bouchard & Perusse 1994). These two approaches provide evidence for the presence of genetic effects in physical activity behavior, and both the unmeasured genotype and the measured genotype approaches are used to study the role of genes in leisure-time physical activity behavior. The present section considers the unmeasured genotype approaches providing indirect evidence of the heritability of leisure-time physical activity. Definitions of important heritability-related terms and detailed principles of quantitative genetics are presented in chapter 2.5, headed Quantitative genetics and twin study designs.

A number of twin studies using the unmeasured genotype approach have shown that genetic influences play an important role in explaining individual differences in leisure-time physical activity (Kaprio et al. 1981, Aarnio et al. 1997, Beunen & Thomis 1999, Maia et al. 2002, Carlsson et al. 2006, Stubbe et al. 2006, Stubbe & de Geus 2009, Mustelin et al. 2012, Carlsson et al. 2013). The largest of these studies pooled data on leisure-time exercise behavior from seven different countries (GenomEUtwin project), and found that the heritability of exercise participation ranged from 48% to 71%, with the exception of Norwegian men 27% (Stubbe et al. 2006). The heritability estimate was moderate, 41%, among young adults, with specific environmental factors accounting for rest of the trait variance (Mustelin et al., 2012). Overall, genetic influences seem to be higher for vigorous activity or sports compared to non-vigorous activity (Beunen & Thomis 1999, Maia et al. 2002, Mustelin et al. 2012). However, in a very few studies, environmental factors have been shown to exert the strongest influence on physical activity participation. Duncan et al. (2008) demonstrated that specific environmental factors provided the strongest influence, 72% of the variance, on leisure-time physical activity in twins in their thirties. Twenty years earlier, greater environmental influences were also seen in the family study by Perusse et al. (1989). In this study the most of the leisure-time physical activity was accounted for by environmental influences, 88%.

As the above paragraph indicates, there is heterogeneity in the results of studies related to genetic influences on leisure-time physical activity. In addition to possible methodological issues, it is likely that a significant proportion of this heterogeneity may derive from changes in the genetic contribution to this trait across the age range. It is assumed that not only environmental but also genetic factors vary over the lifespan. However, to date little is known about longitudinal genetic and environmental changes in leisure-time physical activity behavior. It has not been possible to test the potential age dependency of genetic influences on physical activity over the lifespan, mainly because the existing studies have been based on cross-sectional data. True aging effects may be reflected through cross-sectional studies, but uncertainty remains, as cohort effects may also account for such differences between age groups.

Only a few studies have investigated the genetic and environmental influences on longitudinal leisure-time physical activity. On a general level, Simonen et al. (2004) reported change across the lifespan in heritability estimates for leisure-time physical activity. More specifically, earlier studies have reported a shift between genetic and environmental influences during adolescence and young adulthood, although at different times in different studies, and in different directions. A recent comparative twin study in seven countries found that the genetic drive to engage in leisure-time physical activity is increasingly constrained by environmental factors as people get older (Vink et al. 2011). This is supported by van der Aa et al. (2010), who found that variation in adolescent leisure-time physical exercise behavior was mostly accounted for by genetic factors at ages 13–14 in boys and at ages 15–16 in girls. In late adolescence, genetic influences have decreased among both sexes. The remaining proportion of the variance was explained by specific environmental influences, except in girls aged 13–14 years, when shared environmental influences were substantial part of the variation. The heritability of leisure-time physical activity behavior ranged, except to girls aged 13–14 years, from 72% to 85%. A decline in the heritability estimate was also noticed by Eriksson et al. (2006): genetic influences on leisure-time physical activity declined from 0.65 to 0.54 during a 4-year follow-up among young Swedish men in their twenties. Specific environmental influences explained the remaining variance of leisure-time physical activity at both time points. In contrast to these studies, Stubbe et al. (2005) found that between the ages of 13 and 16 years genetic influences (estimates from 0 to 0.36) were not important, whereas, between the ages of 19 and 20 years genetic influences (estimate 0.85) largely explained individual differences in leisure-time physical exercise participation. Similarly, a longitudinal animal study by Turner et al. (2005) showed a high genetic influence on age-related changes in physical activity, although in the opposite direction, as at about 12 weeks of age in the mouse (late adolescence), the genetic influence on physical activity markedly increased.

Heritability analyses of leisure-time physical activity have revealed many details, such as gender-differences, in physical activity domain (Maia et al. 2002, Carlsson et al. 2006, van der Aa et al. 2010). However, despite the indications that the heritability of physical activity is affected by age, at least with respect to younger ages, the age spectrum remains somewhat unclear. Although this work should be continued, confounding factors, which may have an effect on the phenomenon should not be forgotten. In heritability studies of physical activity, epigenetic effects may be a potential confounding factor (Rankinen & Bouchard 2007, Ehlert et al. 2013). An epigenetic effect refers to chemical modification of DNA (methylation, acetylation) and histone proteins that change gene expression without affecting the DNA sequence of the gene. However, such changes in gene function can be heritable although they are not explained by changes in DNA sequence. Overall, the changes are important for understanding of developmental process, tissue-specific effects and phenotypic traits (Henikoff & Matzke 1997, Lewin 1998, van Speybroeck 2002). So far, epigenetic effects related to physical activity have not been demonstrated. It has been suggested that epigenetic effects may play a substantial role in the determination of persons' potential in sports and may be a possible reason for not finding a strong genotype-phenotype association in physical performance (Ehlert et al. 2013).

2.3 Motives for leisure-time physical activity

Motivation is something that energizes and gives direction to behavior. It is also one answer to the question why people think and behave as they do. Motivational factors can vary, but somehow they always are linked to the individual's needs and the meanings attached to behavior (Deci & Ryan 1985, McClelland 1987, Weiner 1992). Leisure-time physical activity is no exception; one needs to have a reason for physical activity, and such reasons can be very different. Motivation levels vary widely between people, starting from those who lack any kind of motivation to engage in any form of physical activity, and ending with those who exercise because of their inherent interest and enjoyment of the activity itself (Dacey et al. 2008, Garcia Calvo et al. 2010).

Motivation is a widely studied topic and several theories related to motivation have been proposed. Each theory has its strengths and weaknesses, and theories provide only a partial account of how motives are translated into real action (Armitage & Conner 2000). There are also specific motivation theories related to health behavior. Some of these motivational theories are briefly presented here. The Health Belief Model may be the most widely used theory in the field of the health behavior (Strecher et al. 1997, Armitage & Conner 2000). The model consists of six components that are independent predictors of behavior. According to the Health Belief Model, a person may be motivated to engage in a behavior if she/he perceives a threat of disease and is aware of the benefits deriving from the behavior performed. Furthermore, only a few barriers should exist and the person should believe that the barriers are outweighed by the benefits (Strecher et al. 1997). The Protection Motivation Theory is based on the function of two appraisal processes (Rogers 1983, Boer & Seydel 1996). These processes are threat and coping. The threat appraisal process is related to fear appeal, and it is determined by perceived vulnerability and perceived severity, which are very similar to the Health Belief Model (Rogers 1983). The coping process is a response that may prevent a noxious event from occurring. The Theory of Reasoned Action posits that intention is the proximal determinant of behavior (Ajzen & Fishbein 1980). Intention is the motivation that is required to perform a behavior. According to the theory, a person's intention is a function of both personal and social influences. The more on intends to perform a behavior, the more likely it is to happen. The Theory of Planed Behaviour is an extension of the Theory of Reasoned Action (Ajzen 1991). Again, a main factor in the theory is the person's intention to perform a behavior. However, the Theory of Planned Behaviour extends the limitation of the Theory of Reasoned Action by including perceived behavioral control as a determinant of intentions and behavior (Armitage & Conner 2000,Ajzen 2005).

Another motivation theory is the Self-Determination Theory by Deci & Ryan (1985). Although the Self-Determination Theory is not a theory that derives from the field of health psychology, it is a well-constructed motivation theory. It provides a strong foundation for understanding the goals and motives for behavior, and focuses on the importance of intrinsic motivation in driving human behavior. The theory is based on the concept of self-determination, meaning that people experience a choice regarding their behavior (Deci & Ryan 1985, Deci & Ryan 2000). Specifically, the Self-Determination Theory suggests that motivated behavior is based on three fundamental needs that must be satisfied in the social context: competence, autonomy and relatedness. Perceived competence is the belief that one effectively masters challenging tasks one's environment. Autonomy refers to behaviors that are freely initiated by the individual. Relatedness is a feeling of a meaningful connection with others in one's social milieu (Deci & Ryan 1985, Ryan et al. 2008, Wilson et al. 2008, Ryan et al. 2009, Garcia Calvo et al. 2010).

The three fundamental needs form a continuum of internalization, from externally regulated motives to intrinsically regulated motives**.** Extrinsic motivation leads us to perform to obtain rewards and outcomes that are separate from the behavior itself, such as money and sanctions. People may feel they are controlled by such rewards or punishments, and they feel pressure to perform the task (Deci & Ryan 2000). Intrinsic motivation regulation is when the individual participates for the experience of the activity as pleasant, fun or satisfying; here motivation emerges spontaneously from internal tendencies (Deci & Ryan, 1985, Iso-Ahola & St. Clair 2000, Dacey et al. 2008). When people are intrinsically motivated, they follow their innate needs and interests, they experience enjoyment, they feel competent and self-determined, and in some case they may even experience so called flow (Deci & Ryan 1985). Flow is a state where a person is so absorbed in an activity as to even forego eating and postpone sleeping until the task is completed. Intrinsic motivation seems to decrease following repeated negative feedback, which implies incompetence, whereas events that support feelings of autonomy and competence will enhance intrinsic motivation (Deci & Ryan 2000, Ryan et al. 2009). Furthermore, positive performance feedback can maintain intrinsic motivation in situation of losing (Vansteenkiste & Deci 2003).

During recent years, research applying the Self-Determination Theory to health care has increased, and the approach has been shown to be a relevant theory in the field of patient care and health promotion, such as increasing leisure-time physical activity (Ryan et al. 2009, Deci & Ryan, 2012, Teixeira et al. 2012). This research trend is understandable, as the Self-Determination Theory strongly seeks to comprehend behavioral engagement and persistence in varied domains such as health (Ryan et al. 2009, McLachlan & Hagger 2011). The Self-Determination Theory thus seems to be a motivational theory that can be used in assessing motives for leisure-time physical activity. Motives for participation in leisure-time physical activity, and especially the intention to continue participation, are essential. Most physical activities entail a combination of intrinsic and extrinsic motives (Ryan et al. 2009), and there is evidence that increased motivation seems to lead to increased participation in leisure-time physical exercise (Tsorbatzoudis et al. 2006). Specifically, enjoyment has been shown to be linked more strongly to sport participation than to physical activity overall, which supports the association between intrinsic motives and consistent target-oriented physical activity (Kilpatrick et al. 2005). Similarly, a recent review by Teixeira et al. (2012) showed a consistent positive association between intrinsic motives and physical activity. Several studies have suggested that extrinsic motives could be dominant during the early stages of exercise adoption, but that intrinsic motives, such as enjoyment and the satisfaction of exercise would be important for progression to and maintenance of actual activity (Deci & Ryan 1985, Ryan et al. 1997, Ingledew et al. 1998, Frederick-Recascino & Schuster-Smith 2003, Segar et al. 2008). In addition, strong feelings of relatedness and autonomy seem to explain the maintenance of physical activity, while amotivation and external regulation seem to be associated with exercise drop-out (Garcia Calvo et al. 2010).

Many studies have been published on motivation for physical activity, all seeking to understand why people are physically active in their leisure time. Several of these studies have reported that an important factor motivating participation in leisure-time physical activity among adult age groups, both younger and older adults, is health (Ashford et al. 1993, Kolt et al. 2004, Dacey et al. 2008, Murcia et al. 2008, Sit et al. 2008, Caglar et al. 2009). Among the citizens of the European Union member states almost half of those aged over 15 years reported good health as the most important reason for participation in physical activity (Zunft et al. 1999). Despite the general importance of health as a factor motivating leisure-time physical activity, it seems to be a factor, which varies by region (Iannotti et al. 2013). In addition to health benefits, appearance (Kilpatrick et al., 2005), fitness (Sit et al. 2008), enjoyment (Sit et al. 2008), and body image (Brudzynski & Ebben, 2010) are motives highly linked to physical activity among young adults. However, it is important to remember that motives may change during the stages of physical exercise adoption (Frederick & Ryan, 1993). Differences may also exist by exercise type (Ryan et al. 1997, de Andrade Bastos et al. 2006), gender, and age (Frederick & Ryan 1993, Finkenberg et al. 1994, Gill et al. 1996, Dacey et al. 2008), whereas time of day has not been shown to have an influence on motives (Trembath et al. 2002).

So far, only some of the published studies have examined differences in motives between physically active and inactive persons, but none of these studies have been longitudinal. Studies have been based on the hypothesis that the level of leisure-time physical activity is explained by differences in motivation factors. One study suggested that physical activity is mostly associated with environmental factors and inactivity with socio-demographic factors (Gordon-Larsen et al. 2000). Overall, when physically active persons were compared to physically inactive persons, health, fitness, and enjoyment were identified as the major motivation factors for leisure-time physical activity among the active persons (Reid & McGowan 1986, Dacey et al. 2008, Sit et al.

2008). Physically active older adults and physically active university teachers also gave higher ratings for stress management as a motivation factor than their inactive counterparts (Reid & McGowan 1986, Dacey et al. 2008,). In addition, anxiety was also scored higher among physically active teachers than physically inactive teachers (Reid & McGowan 1986). Social reasons were highlighted by physically active persons but not by physically inactive persons in a recent study by Costello et al. (2011). In that study, physically inactive persons wanted leisure-time physical activity to be purposeful, social and fun. A randomized controlled study by Silva et al. (2010) used the Self-Determination Theory to promote physical activity, and they found that women whose intervention focused on promoting autonomous forms of exercise regulation and intrinsic motivation showed higher physical activity levels than controls. However, some contrary findings have also been reported. For instance, in the study by Segar et al. (2008) health benefits were, surprisingly, pursued by middle-aged women, who engaged in the lowest level of physical activity.

2.4 Barriers to leisure-time physical activity

However, motivation itself may not be enough to persuade people to be physically active in their leisure time. Many barriers to leisure-time physical activity also exist. Although people are aware of the benefits of physical activity for their health, there are many barriers that may limit or prevent engaging in physical activity. Real or perceived barriers to leisure-time physical activity can be sorted into several categories: personal factors, social factors and environmental factors (Stutts 2002, Andajani-Sutjahjo et al. 2004, Cerin et al. 2010). Personal factors include internal barriers and barriers caused by physical limitations or restrictions, and social factors refer to all the barriers caused by other people. Barriers seem to be highly related to motivation factors (Cohen-Mansfield et al. 2003). While the study by Leyk et al. (2012) found that it is just one or few barriers at the most that typically influence physical activity behavior, it has also been suggested by Reichert et al. (2007) that the higher the number of perceived barriers, the more likely the person is to be physically inactive. Recently, Fox et al. (2012) pointed out that individual barriers correlated with lower physical activity levels, and not the presence of environmental barriers. Furthermore, it is even possible that practical barriers, such as childcare responsibilities and lack of time, may mask other more complex barriers (Withall et al. 2011).

Barriers to leisure-time physical activity have been identified in data from several sources. These studies have listed large numbers of barriers, as most investigations have used participants from heterogeneous groups. In addition, like motivation factors, barriers differ between groups (Booth et al. 1997). Overall, there seem to be a few often-repeated reasons why people find it difficult to be physically active in their leisure-time. Primarily, lack of time (Booth et al. 1997, Stutts 2002, Andajani-Sutjahjo et al. 2004, Dunton &

Schneider 2006, Kowal & Fortier 2007, Jewson et al. 2008, Sit et al. 2008, Butt et al. 2011, Napolitano et al. 2011, Fox et al. 2012) and being too tired or having too little energy (Kowal & Fortier 2007, Napolitano et al. 2011, Fox et al. 2012) have emerged as the most commonly self-reported barriers to leisure-time physical activity among adults. Furthermore, among Europeans the most important barriers to increase leisure-time physical activity were work or study commitments and the belief that one was not the sporty type (Zunft et al. 1999). Pain experienced with exercise (Fox et al. 2012), dislike of exercise (Fox et al. 2012), anxiety in unfamiliar surroundings and lack of both social networks and role models (Allender et al. 2006) have also been identified as general barriers to leisure-time physical activity among adults. Based on a review of the qualitative studies, high cost and an unsafe environment were also perceived as barriers to leisure-time physical activity (Allender et al. 2006). Withall et al. (2011) reported that cost was the key barrier for low-income groups of people to be physically active in their leisure time. Barriers related to gender and age, and to socioeconomic differences have also been reported. Not surprisingly, younger adults and women experienced daily activities and child care as the important barriers to leisure-time physical activity (Booth et al. 1997, Andajani-Sutjahjo et al. 2004, Kowal & Fortier 2007). Among obese women, lack of self-discipline or willpower was felt to be great barrier to physical activity (Napolitano et al. 2011). Also, lack of the support of family or friends may restrict women's participation in physical activity (Sit et al. 2008, Andajani-Sutjahjo et al. 2004). Older people often cited poor health (Booth et al. 1997, Schutzer & Graves 2004) and potential risk for injury (Costello et al. 2011) as barriers to leisure-time physical activity.

Again, as with motives, the barriers reported seem to depend on the person's activity level. For example, Chinese physically active women scored significantly lower on all the studied barriers to physical activity than less active women (Sit et al. 2008). Young exercisers in the study by Ebben & Brudzynski (2008) reported that the most common barriers to their participation in exercise were lack of time, lack of extra motivation, not having a sport to train for, and too many study and other time commitments. Those, who were not physically active also reported lack of time and motivation as the main barriers. In addition, inactive individuals also mentioned laziness, other priorities, and tiredness as important factors influencing their lack of engagement in leisure-time physical activity. Similarly, Kowal & Fortier (2007) and Jewson et al. (2008) found that inactive women felt lazier and more tired than active women. Young men who had never exercised as an adult rated barriers related to the items "sports are no fun" and "sufficient physical activity in daily life" significantly higher than young men who had intermittently been engaged in sports (Leyk et al. 2012). In addition to quantitative methods, a qualitative design has also been used to gain insight into barriers: again both active and inactive groups reported lack of time and risk for potential injury as major barriers (Costello et al. 2011). Furthermore, the inactive group reported barriers such as lack of self-discipline and motivation, which also have been highlighted by other studies, while a new barrier, intimidation, was nominated by the inactive group.

2.5 Quantitative genetics and twin study designs

Quantitative genetics seeks answers to the question of how genes and environment influence behavior. The specific aim of quantitative genetics is to examine the extent to which variation in a trait is accounted for by genetic and environmental influences. The proportion of variation accounted for by genetic influences is called heritability (Plomin et al. 2000, Visscher et al. 2008). A heritability of 1 implies that the variation is all genetic, whereas a heritability of 0 implies it is all environmental. In this connection, environmental means living environment and living conditions. Quantitative genetics does not reveal what the specific genes or environmental factors are (Rijsdijk & Sham 2002), but provides statistics that describe the relative contribution of genetic and environmental differences to observed differences among individuals in a particular population at a particular time (Plomin et al. 2000). Quantitative genetics utilizes samples of relatives who are genetically or environmentally relate: these can be twin, family or adoption samples. Of these, the twin study design is the most widely used.

Twin studies are a valuable source of information about complex traits based on underlying common genetic or environmental influences. Classical twin studies compare a resemblance within pairs of monozygotic (MZ) (genetically identical) twins to the resemblance within pairs of dizygotic (DZ) (often called non-identical) twins (Plomin et al. 2000). Since identical MZ twins derive from one zygote they share 100% of their genes, whereas non-identical DZ twins on average share 50% of their segregating genes (Hall 2003). If MZ twins are more similar than DZ twins, this is considered a sign that genetic influences underlie the phenotype of interest (Plomin et al. 2000, Boomsma et al. 2002, van Dongen et al. 2012). Shared environment between co-twins (the birth partner of a twin) is assumed to contribute equally to the similarity between them in both MZ and DZ pairs. Within-pair differences are considered to result from individual-specific environmental factors. Same-sex twins can be classified as MZ or DZ on the basis of DNA markers. If a pair of twins differs for any DNA marker, they must be non-identical. However, it may be sometimes difficult and costly to perform DNA analysis (Hrubec & Robinette 1984). Thus, certain physical similarities such as eye color, hair color and texture, can be used to diagnose whether twins are identical or not. Even a single question can adequately sum up such physical traits. The question: "When the twins were young, how difficult was it to tell them apart?" has been shown to yield results that are more than 90% accurate when compared to DNA markers (Sarna et al. 1978, Chen et al. 1999).

Specifically, in quantitative genetic modeling, phenotype is assumed to represent an individual's deviation from the population mean. Furthermore, the modeling states that every individual's phenotype is made up of genetic and environmental contributions. In other words, variation in an observed trait (phenotype) can be decomposed into variance components originating from genetic and environmental influences. The total genetic contribution to a phenotype is the sum of additive genetic influences (A), representing the sum of the effects of the individual alleles at all loci that influence the trait and dominant genetic influences (D), which are non-additive genetic influences representing interactions between alleles at the same locus. Environmental influences can be divided into shared environmental influences (C), representing the effects of environmental factors shared, for example, by the co-twins in a pair, and specific environmental influences (E), which represent unique environmental influences (Rijsdijk & Sham 2002). Specific environmental influences result in differences between the co-twins of a pair. In addition, environmental influences are assumed to include potential measurement error (Plomin et al. 2000). In algebraic terms the phenotypic variance (P) is: P=A+D+C+E.

The variance components are estimated as degrees of correlation for both additive and dominant genetic influences and for shared and specific environmental influences in both MZ and DZ twins. The correlation is 1 for both additive and dominant genetic influences in MZ pairs, whereas the respective values for DZ pairs are 0.5 and 0.25. In both MZ and DZ twins, the correlation is 1 for shared environmental influences if the co-twins are reared together in the same home and 0 for specific environmental influences (Figure 2). If the correlations for MZ twins are higher than those for DZ twins, that is to say MZ are more similar than DZ twins, genetic influences are indicated. If the correlations for DZ twins are equal to those for MZ twins, shared environmental influences are indicated. If the MZ correlations are lower than 1, this implies that specific environmental influences play a role (Plomin et al. 2000, Boomsma et al. 2002). However, it is important to notice that dominant genetic influences and shared environmental influences may be confounded in the twin design, and it is possible that they cannot be estimated simultaneously if the only information available is that the MZ and DZ twins were reared together (Plomin et al. 2000, Posthuma et al. 2003). Shared environmental influences will cause the MZ-DZ correlations to be more alike and dominant genetic influences will cause them to be more different from each other. It is almost always wished to retain the specific environmental variance component in the model, mainly because in quantitative genetics random measurement error is included in specific environmental influences, and it is naive to assume there is no measurement error (Plomin et al. 2000). Despite this, the twin correlations can be used to provide an initial assessment as to which of these variance components is more likely to be present and which is to be modeled.

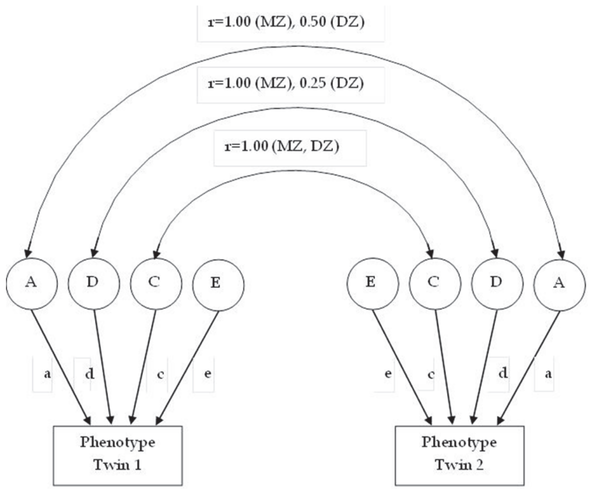

FIGURE 2 Path diagram for a univariate twin model. Correlations for additive genetic influences (A), dominant genetic influences (D), shared environmental influences (C) in MZ and DZ twin pairs are presented above the double-headed arrows. Specific environmental influences (E) are uncorrelated between co-twins (modified from Neale & Cardon 1992).

Modern genetic studies among twins are typically analyzed by using an approach called model fitting. Model fitting is based on an explicit model for the expected and observed variance-covariance matrix for twins for the genetic and environmental variance components. The variance of the phenotype (VP) is given by VP=VA+VC+VE where VP represents the variance of the phenotypic values, VA represents the variance of the genotypic values, VC represents the variance of the shared environmental deviations, and VE represents the variance of the specific environmental deviations. Model fitting tests the significance of the fit between a model of genetic and environmental relatedness against the observed data. On the other words, model fitting tries to create expected variance-covariance matrices with parameter values, which match the observed data as closely as possible. One possibility for performing model fitting is to use the Mx program (Neale & Cardon 1992, Rijsdijk & Sham 2002). Data can be entered in the Mx program as a summary format such as covariance matrices, or as a raw data format. Nowadays, models are commonly fitted directly to the raw data using full information of data. This allows greater flexibility and enables many missing data problems to be better handled (Rijsdijk & Sham 2002).

In model fitting, different models can be compared, and the best-fitting model is used to estimate the effect sizes of the genetic and environmental influences of interest (Plomin et al. 2000). Usually, the best-fitting model is the one with the smallest number of parameters. A general statistical principle for finding the best estimate representing the true parameter values is parsimony, meaning that a simpler theory is always preferred if it accounts equally well for the observations (Plomin et al. 2000). There are many indices for finding best-fit statistics. Likelihood-ratio tests (LRT) are based on the deviance variation (-2ln(L) and degrees of freedom) between an initial, less constrained model and a candidate, hypothetical model (Neale & Cardon 1992). In the case where the likelihood of the hypothetical sub-model is statistically different ($p \leq 0.05$) from that of the initial model, the fit of the sub-model is considered to be poorer and may be rejected. The likelihood-ratio test tends to favor models with more estimated parameters. The Bayesian information criterion (BIC) (Schwartz 1978), the deviance information criterion (DIC) (Spiegelhalter et al. 2002) and Akaike's information criterion (AIC) (Akaike 1987) compare models on the basis of parsimony. If a discrepancy is noticed between these criteria, preference is given to the models showing the best fit with the AIC, BIC and DIC, as they are thought to perform better than the other criteria in more complex models with relatively large sample sizes (Markon & Krueger 2004). Instead of performing measurements on continuous data, the model fitting approach can also be used for categorical data, such as the presence or absence of a disease etc. However, in such a situation it is assumed that the ordered categories reflect an imprecise measurement of an underlying normal distribution of liability, which is further assumed to have one or more thresholds to discriminate between the categories (Neale & Cardon 1992, Rijsdijk & Sham 2002).

The model-fitting method described above examines the genetic-environmental nature of the variance of one trait in one time point and it is often termed the univariate approach. If multiple measures have been assessed in twin pairs, model-fitting analysis can be used as well, but then it is termed multivariate analysis. Model-fitting analysis is useful for longitudinal data because of the complexity of dealing with multiple measurements for each participant. Multivariate analysis can also be modeled for two or more traits. Genetic and environmental age-to-age changes or continuities can be seen in longitudinal data, in which individuals are assessed several times; assessment of the possible new genetic or new environmental influences starting to operate at specific points in time can be arranged. The analysis is based on the cross-covariance between twins; in other words, whether a trait in one co-twin at one time point is associated with the same trait in the other co-twin at another time point. There are several methods for examining the effects of genetic and environmental influences on the development of a trait over time. The most often used method is the Cholesky decomposition. The Cholesky decomposition, as with all the other similar approaches, examines what has been described, i.e. to what extent the variation of the phenotype at different times is explained by the same genetic and environmental factors acting at the different time points. In addition, the aim is to establish how much of the genetic and environmental variation is time-specific (Neale & Cardon 1992, Posthuma et al. 2003, Kaprio & Silventoinen 2011).

To analyze longitudinal data one needs to take the serial correlations between consequent measurements of the phenotype into consideration (Posthuma et al. 2003). Phenotypic correlation between time points can be decomposed into genetic and environmental components, and their relative contribution can also be estimated. Estimation of genetic and environmental correlations allows estimation of the overlap of genetic and environmental influences between the time points as well. If the correlation is 1, the sets of influences at two time points overlap completely. Thus, genetic correlation implies that all genetic influences on the trait at the first time point also impact at the second time point (Posthuma et al. 2003). Potential changes in genetic influences may be caused by the fact that genes are turned on and off during follow-up, or simply that genetic influences at one age differ from genetic influences at another age (Plomin et al. 2000, Rijsdijk & Sham 2002).

Path analysis is closely related to model fitting. Path analysis provides a visual way to represent a model describing the observed data and it can be translated directly into structural equations (Posthuma et al. 2003). The twin model of the path analysis for one variable can be depicted as in Figure 2. The observed trait for twin 1 and twin 2 are represented by rectangles, unobserved genetic and environmental variables are represented by circles. The causal paths are drawn as single-headed arrows, reflecting the statistical effects (a, c, and e) of the variable on the observed trait, independent of all the other variables. The curved double-headed arrows between the latent variables represent the correlations between the variables. Path analysis also provides an easy way to represent multivariate analysis. A multivariate ACE model path analysis of two measurement time points is shown in Figure 3. The new parameters in this model are r_a representing the genetic correlation, r_c representing the shared environmental correlation and r_e representing the specific environmental correlation. The observed correlations are the correlations of the two sets of phenotypic traits between the two time points.

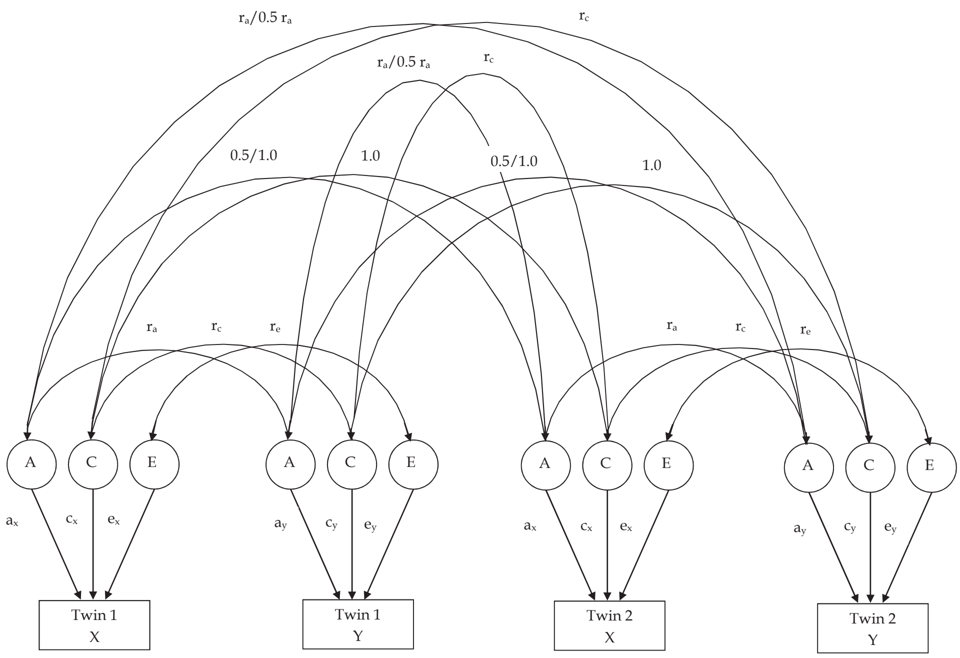

FIGURE 3 Multivariate ACE path diagram. The expected variance-covariance matrix can be derived from the figure by tracing the paths (modified from Plomin et al. 2000).

In addition to the assignment of zygosity, a number of assumptions need to be made in twin studies to obtain refined estimate of the genetic influences (Rijsdijk & Sham 2002). One of the most important assumptions is that the twins do not differ from the general population in terms of the trait. There is evidence that being a twin does not affect mortality (Kaprio 2013), personality traits or behavior (Johnson et al. 2002, Pulkkinen et al. 2003), blood pressure (de Geus et al. 2001) or several lifestyle or disease-related characteristics (Andrew et al. 2001). As mentioned earlier, the equal environments assumption of the twin method assumes that environment is shared by the twin pair, and that shared environmental influences would act in the same way if the pair has been reared together. It is also assumed that people mate randomly. On the other words, there would not be any correlation between the mother's and father's genes. Non-random mating would increase the genetic variance in a population, and it would also affect estimates of heritability (Rijsdijk & Sham 2002, Posthuma et al 2003). Concerning leisure-time physical activity, Aarnio et al. (1997) demonstrated random mating in a study of three generations. Finally, it is assumed that the gene–environment correlations and interactions are minimal for the trait (Rijsdijk & Sham 2002).

Specific types of twin studies are co-twin control studies. These are for MZ twins who are perfectly matched for age, segregating genes, family background, and perhaps for other less well-defined social and medical variables (Hrubec & Robinette 1984, Boomsma et al. 2002). A co-twin control study can be used to study the non-genetic reasons why one identical twin is affected and the other is not. These designs have been used to examine a wide variety of medical hypotheses, and in particular for distinguishing if two traits are affected by the same genetic or environmental influences rather than one trait causing the other (van Dongen et al. 2012). Twins are termed discordant if one twin represents a trait or behavior or has a disease and the other does not (Plomin et al. 2000). Interestingly, discordant MZ twins show that disease outcome or behavioral trait outcome can be different for two individuals with an identical genetic make-up. They provide direct proof of non-genetic influences. This was demonstrated in a study by Kujala et al. (2002) on leisure-time physical activity and mortality and in a study by Waller at el. (2010) on leisure-time physical activity and type 2 diabetes. On the other hand, MZ twin concordance may give important information, for example on disease penetrance (Boomsma et al. 2002).

3 AIM OF THE STUDY

The purpose of the present thesis was to examine the factors predisposing people to be physically active or inactive in their leisure-time. Specifically, the main aims of the study were to quantify genetic effects influencing leisure-time physical activity, and to identify the potential motives for and barriers to leisure-time physical activity. Longitudinal study designs were utilized to enable the examination of true aging effects and the associations between the factors of interest. In detail, the specific aims of the study were:

1. To estimate genetic and environmental influences longitudinally on the evolution of leisure-time physical activity behavior among men and women twins, first, from adolescence to young adulthood, and, second, in adulthood. (Studies I, II)

2. To examine the motives for leisure-time physical activity among consistently active and inactive men and women in their mid-thirties. (Study III)

3. To examine the motives for and barriers to engagement in long-term leisure-time physical activity among middle-aged and older men and women twin pairs discordant for leisure-time physical activity over 30 years. (Study IV)

4 PARTICIPANTS AND METHODS

All the participants of the studies of the present thesis were twins drawn from the older Finnish Twin Cohort and from the FinnTwin16 study. Originally, the twins in both cohorts were identified from the Central Population Registry of Finland with the purpose of forming a national resource for genetic epidemiological studies (Kaprio & Koskenvuo 2002, Kaprio 2006). The data on the cohorts used in the thesis have mainly been collected through mailed or online questionnaires. The data for study IV were also partly drawn from clinical examinations. The questionnaires were extensive medical-social questionnaires including several items related to factors such as health behavior, health status, diseases, lifestyle choices and substance use (Kaprio 2006). The language of the questionnaires was Finnish, except for the small proportion of participants who were native Swedish-speakers. Approximately 5% of the twins received a questionnaire in Swedish as Finland is officially a bilingual country, with both Finnish and Swedish as official languages. The participants in each study of the present thesis are presented in Figure 4.

Zygosity determination of twin pairs using a blood test is costly and also time-consuming in large cohorts like those here. In these cohorts, the zygosity of the twins was defined on the basis of validated questions according to whether people always confused the twins in childhood and how similar in appearance they were. Further validation of the questions among the Finnish Twin Cohort was done among two samples (samples of 104 twin pairs and 52 twin pairs). The verification of the zygosity determination questionnaire was carried out with blood markers among these samples. The level of agreement between the results of the blood tests and the questionnaire diagnosis of zygosity was 100% (Kaprio et al. 1978, Sarna et al. 1978). Over the years, zygosities based on these questions have mainly been used in the studies based on the two cohorts. However, whenever possible, blood tests using DNA extracted from a venous blood sample have been used to confirm the zygosity of the twin pairs in the different subsamples of the cohort, as in Leskinen et al. (2009b). Possible corrections of zygosity have always been included in the cohort data, but such verified zygosities cover only a part of the cohort.

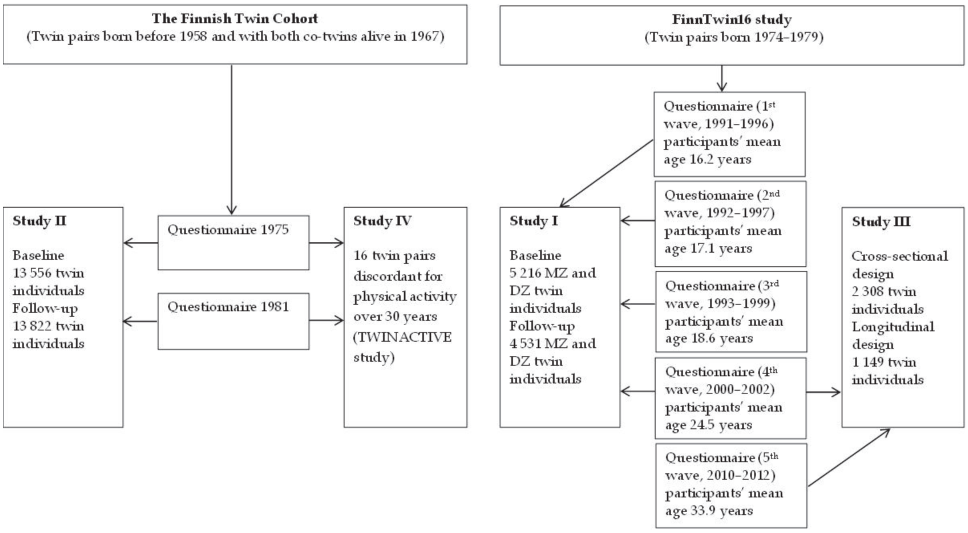

FIGURE 4 Participants in the studies of the thesis.

4.1 Participants

4.1.1 Finnish Twin Cohort

The Finnish Twin Cohort study started in 1975. Originally, the cohort consisted of same-sex twins born in Finland before 1958 and with both co-twins alive in 1967. Opposite-sex twin pairs were added later. Altogether, a total of 13 888 twin pairs have been identified (Kaprio et al. 1978, Kaprio et al. 1990). During the study the twins have participated in follow-up mail surveys – in 1981 and 1990 – and numerous clinical examinations for various sub-samples have been carried out. In addition, cohort members have been followed up for morbidity using national medical registers (Kaprio & Koskenvuo, 2002).

The participants for the study related to genetic influences on leisure-time physical activity (Study II) were drawn from the Finnish Twin Cohort study. The data used in the study were collected through mail surveys at two time points, 1975 and 1981. Response rates were 89% and 84%, respectively. The study consisted of 4 280 MZ and 9 276 DZ twin individuals at baseline in 1975 and 4 383 MZ and 9 439 DZ twin individuals at follow-up in 1981. Overall, 4 000 MZ and 8 660 DZ twin individuals participated at both baseline and follow-up. The participants who were working in 1981 and supplied complete questionnaire data on the intensity of their leisure-time physical activity at both time points and were aged 24–60 years on January 1, 1982 were included in the study. These inclusion criteria were needed because work status may partly determine level of leisure-time physical activity. Because chronic diseases may also restrict the ability to be physically active, at baseline subjects with specific chronic diseases (angina pectoris, myocardial infarction, diabetes mellitus, cardiovascular disease other than hypertension or venous diseases, obstructive pulmonary disease and incidence of malignant cancer) were excluded. Persons receiving reimbursable medication for selected chronic diseases were also excluded. Details on the exclusion procedure are given in Kujala et al. (2002).

4.1.2 TWINACTIVE study

As stated earlier, several sub-samples have been drawn from the Finnish Twin Cohort. The TWINACTIVE study is one of these. Twin pairs discordant for leisure-time physical activity over 30 years were selected for the TWINACTIVE study. The recruitment of the participants from the larger cohort was implemented using the following procedure. At baseline, the cohort comprised 5 663 healthy twin pairs with completed questionnaire data on leisure-time physical activity in 1975 and 1981 (Kujala et al. 1998, Kujala et al. 2002). Follow-up interviews were carried out during 2005–2007, and included questions on current and past (1980–2007) leisure-time physical activity (Leskinen et al. 2009b). Twin pairs with consistent baseline (1975) and follow-up (1980–2007) leisure-time physical activity discordance were invited to participate in the TWINACTIVE study (Leskinen et al. 2009b). A total of 16 same-sex middle-aged and older (age range 50–74 years) twin pairs (7 MZ and 9 DZ, total 5 women pairs) fulfilled the 32-year physical activity discordance criterion and participated in the study measurements performed in 2007. The physical activity discordance was based on MET hours/day. At baseline, the mean leisure-time MET index for the physically active co-twins was 4.0 MET hours/day and for the physically inactive co-twins 0.5 MET hours/day. At the last follow-up point, the mean MET indexes for active and inactive co-twins were 8.4 MET hours/day and 1.6 MET hours/day, respectively (see Table 1). In the present thesis, the data on the participants of the TWINACTIVE study were used to investigate the motives for and barriers to long-term engagement in leisure-time physical activity (Study IV).

4.1.3 FinnTwin16 study

The twin cohort comprising younger Finns born in 1974–1979 is called the FinnTwin16 study, and was initiated in 1991. The cohort is a nationwide longitudinal study of twins born between 1975 and 1979 and their parents and siblings. Twins born in the last three months of 1974 have participated as pilot subjects for testing the functioning of the questionnaire at all phases. The baseline assessment was conducted for all the twins within 60 days of their 16th birthday. Altogether, 2 773 pairs agreed to participate. Twins were surveyed again in adolescence at the mean ages of 17.1 and 18.6 years (Kaprio & Koskenvuo 2002, Kaprio 2006) and again when they were young adults at the mean age of 24.5 years. The last data collection wave was reformed recently, during the years 2010–2012, when twins were in their mid-thirties (Kaprio 2013).

The participants for study I, which estimated genetic and environmental influences on the longitudinal evolution of leisure-time physical activity behavior from adolescence to young adulthood, were identified from the first four waves (participants' mean ages 16.2–24.5 years) of the data collection of the FinnTwin16 study. The potential study sample of the study comprised 996 MZ and 716 DZ men, 877 MZ and 891 DZ women, and 1 853 DZ opposite-sex twins. Altogether, 241 twins were excluded from the present study as it was not possible to determine their zygosity, and 311 persons were excluded because of pregnancy or a medical condition that could clearly prevent engagement in leisure-time physical activity such as motor disability, chronic diseases (angina pectoris, myocardial infarction, diabetes mellitus, cardiovascular disease other than hypertension or venous diseases, chronic obstructive pulmonary disease, asthma, chronic intense pain, neurological diseases), malignant disease or mental disability (e.g. anorexia, depression, schizophrenia). Persons eating prescribed drugs for selected chronic diseases other than hypertension were also excluded. The sample dropout was low: 73.8% percent of the participants had provided leisure-time physical activity data on all four occasions, 16.2% on three occasions, and only about 10% on at most two occasions. Although the hypothesis would be that the least active participants would more likely have dropped out, this was complicated to verify, because all the data available at any time point were used. A person might have participated randomly at any of the four time points.

Only the fourth and the fifth waves (participants' mean ages 24.5–33.9 years) of the data collection of the FinnTwin16 study were used in study III, which examined the motives for leisure-time physical activity among active and inactive men and women in their mid-thirties. Each of the twin individuals of the consecutive birth cohorts (1974–1979) was included as a potential study participant. All the twin individuals who answered the fifth survey on monthly frequency, mean duration and mean intensity of their leisure-time physical activity, the daily duration of commuting-related physical activity and their motives for engaging in leisure-time physical activity (N=3 874) were included. The response rate was 71.6%. However, since pregnancy can reduce the ability to be physically active in women, pregnant women were excluded from the analysis (n=186). Finally, the twin individuals were divided into three groups: active persons (N=1 202), moderately active persons (N=1 380), and inactive persons (N=1 106) based on cross-sectional physical activity levels. The relationship between longitudinal physical activity behavior and motivation factors was also examined. Although the motivation data were only available from the ongoing wave five of the cohort, physical activity habits were also available from wave four. First, the consistently active (N=617) and inactive (N=532) persons were compared, as motives related to consistent leisure-time physical activity and inactivity were of interest. In addition, it was studied whether those who had reported increased physical activity (changed from inactive to active, N=238) differed from those who were consistently inactive (N=532).

4.2 Assessment of descriptive variables

Most of the descriptive variables in the studies in the thesis were based on the questionnaire data. The participants of the twin cohorts had answered medical-social questionnaires with items on current body height, body weight, chronic diseases and symptoms and physical fitness. Chronic diseases were assessed as a dichotomous variable (yes/no). Some participants, however, had described their disease in more detail; this was taken into account when deciding if the chronic disease affected physical activity behavior. Subjective physical fitness was a categorical variable assessed on a five-point scale from very good to very poor. Body mass index (BMI) was calculated from body weight and height as kg/m^2. Height and weight were collected from the questionnaire data. Occupation (Studies II, IV), work-related physical activity (Studies III, IV), subjective self-reported health status (Study III), pregnancy (Studies I, III) financial standing (Study III), and marital status (Study IV) were taken into account in some of the studies. Participants' occupations were divided into the six categories: upper white-collar, clerical work, skilled workers, unskilled workers, farmers and others. Work-related physical activity was used as a categorical variable: sedentary, standing or walking at work, light manual work, heavy manual work. Subjective health status and financial standing were categorical variables with a five-point scale from very good to very poor. All the items were self-reported.

In addition to these questionnaire-based characteristics, descriptive characteristics were obtained to the twin pairs discordant over 30 years for leisure-time physical activity (Study IV) in laboratory measurements. These additional descriptive characteristics were maximal oxygen uptake (VO_{2peak}), fat percent and fat mass, all of which were assessed using the specific measurement procedures (Leskinen et al. 2009b). A symptom-limited maximal clinical exercise test with a cycle ergometer was performed for the assessment of $VO_{2peak,}$ representing cardiorespiratory fitness, using a slightly modified WHO protocol. Fat percent and fat mass were assessed using an InBody (720) (Biospace Co., Seoul, Korea) eight-point tactile electrode multifrequency impedance plethysmograph body composition analyzer with subjects wearing only undergarments and having had a ten-hour fast. Lookin'Body software (Biospace) was used for the output of the fat percent and fat mass measures (Leskinen et al. 2009a).

4.3 Assessment of leisure-time physical activity

Leisure-time physical activity was also based on the questionnaire data in all the studies. In studies II, III and IV the main outcome was measured as leisure-time metabolic equivalent units (MET index). The MET indexes were based on a series of structured questions on leisure-time physical activity: monthly frequency, mean duration and mean intensity of leisure-time physical activity sessions, and physical activity during journeys to and from work (Appendix 1). All types of leisure-time and commuting-related physical activity were taken into account. The indexes were calculated by assigning a multiple of the resting metabolic rate (MET score) to each activity and by calculating the product of activity, defined as intensity × duration × frequency. The MET indexes were expressed as the sum score of leisure-time MET hours/day. The MET values (physical activity metabolic rate divided by resting metabolic rate) for leisure-time physical activity intensity were: 4 for intensity corresponding to walking, 6 for intensity corresponding to vigorous walking to jogging, 10 for intensity corresponding to jogging, and 13 for the intensity corresponding to running. MET value 4 (walking) was used for intensity of commuting-related physical activity. Further, it was assumed that commuting-related physical activity is done on 5 days per week.

In study III, which examined the motives for leisure-time physical activity among twin individuals in their mid-thirties the calculation of MET hours/day was somewhat modified compared to that used in studies II and IV, because response alternatives of the leisure-time physical activity questions deviated slightly for the younger twins in this study, although the questions were same. In this study, the raw MET indexes were not used. The MET indexes from wave five of the data collection were divided into thirds (active persons, moderately active persons, and inactive persons). In the cross-sectional analyses, the extremes of the distribution, namely active persons (N=1 202) and inactive persons (N=1 106) were used. The MET index for active persons was >5.3 MET hours/day and for inactive persons <2.3 MET hours/day. In addition, the relationship between leisure-time physical activity behavior and the motivation factors were studied longitudinally. The cross-sectional time point in the study was the wave five of the cohort. A longitudinal 10-year follow-up time for leisure-time physical activity was compiled from the fourth (participants' mean age 24.4 years, standard deviation, SD, 0.94 years) to fifth wave (participants' mean age 33.9 years, SD 1.19 years). Thus, the fifth wave was shared by both designs. Motivation data were only available from wave five, but data on leisure-time physical activity behavior were available from both wave four and five. Thus, MET hours/day was also analyzed longitudinally. Despite the fact that the motivation factors were not available from both time points in the longitudinal design, the combination of two different study designs gives us a unique opportunity to compare the results of those two designs. At the baseline (wave four) of the longitudinal design, age-specific MET index thirds were again formed, with only the extremes included in the analyses. The persons in the highest thirds, i.e. at least 6.1 MET hours/day, were defined as active, and those in the lowest thirds, i.e. less than 2.6 MET hours/day, were defined as inactive. Based on self-reported longitudinal leisure-time physical activity behavior for the last 10 years, four groups were formed: 1) those who were active at both baseline and follow-up (consistently physically active persons), 2) those who were physically active at baseline but physically inactive at follow-up, 3) those who were physically inactive at baseline but physically active at follow-up, and 4) those who were physically inactive at both baseline and follow-up (consistently physically inactive persons). The consistently physically active (N=617) and physically inactive (N=532) persons were compared, as the motives of persons who have been consistently physically active or inactive were of main interest. Moreover, it was studied whether those who had reported increased physical activity (changed from physically inactive to physically active) (N=238) differed from those who were consistently physically inactive (N=532).

In study IV, among twin pairs discordant for physical activity over 30 years, the raw MET indexes were not used either. The analyses were based on leisure-time physical activity discordance. The discordance was based on MET hours/day. The baseline cut-off point for discordance was 2 MET hours/day. During the follow-up period from 1980 to 2007 the mean MET difference in leisure-time physical activity between the co-twins was 8.8 MET hours/day (inactive 2.2 ± SD 2.3 vs. active 11.0 ± SD 4.1 MET hours/day, $p<0.001$), which is the equivalent of, for example, a 2-hour walk daily. Details on the persistent discordance in the co-twins leisure-time physical activity behavior are given by Leskinen et al. (2009b).

In study I, unlike in the other studies of the present thesis, leisure-time physical activity was assessed as physical activity frequency when longitudinal genetic influences were analyzed from adolescence to young adulthood. For the purpose of this investigation, the answers to the following question were analyzed: “How often do you exercise or do sports during your leisure-time?” The possible answers were: 1) not at all, 2) less than once a month, 3) one or two times a month, 4) about once a week, 5) two or three times a week; 6) four or five times a week; 7) just about every day. The participants’ answers were further recoded as follows: 1) inactive, if exercising less than once a week, 2) moderately active, if exercising one to three times per week; and 3) very active, if exercising four or more times per week. The item was asked in exactly the same form at all time points.

Earlier analyses have shown high correlations between the leisure-time physical activity items used in the present study and physical activity data obtained by interview (Waller et al. 2008). Moreover, a detailed assessment of leisure-time physical activity volume over the previous 12 months (12-month MET index) and a questionnaire-based leisure-time physical activity MET index showed a good correlation ($r=0.73$, $p<0.001$, N=36) when the assessment and the questionnaire were administered at the same time point (Leskinen et al. 2009b).

4.4 Assessment of motivation for leisure-time physical activity

To evaluate participants’ motives for leisure-time physical activity the Recreational Exercise Motivation Measure (REMM) created by Rogers & Morris

(2003) was used. The measure is designed to assess adults' physical activity motivation. As stated earlier, the Self-Determination Theory, a well-constructed motivational theory, provides a strong foundation for understanding the goals and motives for leisure-time physical activity behavior. When the creators of the REMM measure constructed the questionnaire on motivational factors, the motives that they used fitted the theoretical framework of the Self-Determination Theory (Rogers et al. 2008). Thus, the intrinsic-extrinsic motivation framework is shared by the REMM and the Self-Determination Theory.

In the present thesis, the original 73-item version of the REMM measure (Appendix 2) was used (Study IV), and a modified 8-item measure (Appendix 3) was also used (Study III). The 73 items of original measure form eight sub-dimensions, of 8 to 13 items each. The space available for the questions assessing motivation for physical activity in study III was restricted, and hence each sub-dimension was represented by only one item. Although the sub-dimensions of the modified REMM questionnaire are exactly the same as those used in the original version of the REMM questionnaire, it is obvious that this may have consequences for the validity and the reliability of the measure. The sub-dimensions of the original and modified REMM measures were: 1) mastery ("improve my skills and/or get better at an activity"), 2) physical fitness ("be physically fit"), 3) affiliation ("be with friends and/or do activity with others"), 4) psychological state ("improve psychological health"), 5) appearance ("maintain/improve appearance and body shape"), 6) others' expectations ("conform to others' expectations"), 7) enjoyment ("have a good time and I enjoy exercising"), and 8) competition/ego ("be fitter and/or look better than others"). The sub-dimensions represent aspects of extrinsic motivation, except for mastery and enjoyment, which represent intrinsic motivation. More precisely, affiliation, others' expectations, and competition/ego indicate social motives whereas appearance, physical fitness, and psychological state indicate body/mind motives. The grouping of the sub-dimensions fits neatly into the framework of the Self-Determination Theory.

Participants were asked to rate each item on a 5-point Likert scale: 1=strongly disagree, 5=strongly agree. In study IV, in which the original long version of the REMM measure was used, the sum scaled scores were constructed from the items of the sub-dimensions. All the items were introduced by the stem "I exercise…". In addition, the original version of the measure included an additional open item, number 74, where the participants could give any reasons for engaging in exercise not mentioned in the scale. The open answers were excluded, as there were only 7 responses (Study IV). The modified version of the REMM measure used in study III did not include an open item.

The developers of the REMM have validated the measure (Rogers & Morris 2003). They assessed 750 men and women in gyms and fitness centers. Cronbach alpha coefficients for internal consistency of the sub-dimensions were acceptable, ranging from 0.77 (others' expectations) to 0.92 (competition/ego).

Furthermore, the test-retest reliabilities were examined among 82 exercisers. The exercisers completed the questionnaire a second time two weeks later. The reliabilities for the sub-dimensions between these two completed questionnaires ranged from 0.58 (psychological state) to 0.84 (competition/ego). The values for psychological state and for physical fitness, both 0.64 were the only ones below 0.70 (Rogers & Morris 2003). The Finnish version of the REMM has been analyzed with 756 adult members of private fitness clubs in six large cities in Finland (Pajunen 2004). Among the Finns, the internal consistencies of the sub-dimensions were rather similar to those cited by Rogers and Morris (Rogers & Morris 2003). The lowest Cronbach alpha coefficient was 0.76 (others' expectations) and the highest was 0.89 (affiliation). The other Cronbach alpha coefficients were 0.88 for the sub-dimension of enjoyment and competition/ego, 0.85 for the sub-dimensions of mastery and appearance, 0.83 for the sub-dimension psychological state, and 0.81 for the sub-dimension of physical fitness (Pajunen 2004).

4.5 Assessment of barriers to leisure-time physical activity

The questionnaire used for the measurement of barriers to leisure-time physical activity consisted of 25 items. The questionnaire is shown in Appendix 4. As there are no gold standards or high-level validation studies on questionnaires combining barriers to physical activity, items describing possible barriers in the form of statements were selected with the purpose of creating an instrument for identifying barriers to leisure-time physical activity. The present questionnaire is based to a slight extent on the questions in the PRECEDE-PROCEED model used by Sörensen (2005 and 2008) to identify factors hindering physical activity. However, the possible barriers for the present questionnaire were mostly derived from other studies in this area (Zunft et al. 1999, Sörensen 2005, Allender et al. 2006, Reichert et al. 2007, Ebben & Brudzynski 2008). Participants were asked to state which of a list of barriers they perceived to hinder their leisure-time physical activity. There was also an open item, in which participants could freely report barriers, which were important for them, but not included in the questionnaire as a response alternative. Each of the barrier items were answered on a dichotomized scale, yes or no. The number of yes answers was not restricted. At the end of the questionnaire it was also possible for participants to mention the three most important barriers out of the 25 listed. The assessment of possible barriers to leisure-time physical activity was restricted to middle-aged and older twin pairs meeting the 32-year physical activity discordance criterion (Study IV).

4.6 Ethics of the study

All the studies were conducted according to the accepted ethical standards and the Declaration of Helsinki. The ethics committee of the Department of Public Health of the University of Helsinki (Finland), and the Institutional Review Board of Indiana University (United States of America) approved the FinnTwin16 study protocol. In both the Finnish Twin Cohort and the FinnTwin16 study, the participating twins and families were provided with information about the study at baseline and were given regular feedback during follow-up in the form of personal letters. In TWINACITVE study, all the participants gave their written informed consent and the ethics committee of the Central Finland Health Care District (August 15, 2006) approved the study design.

4.7 Statistical methods

Data were analyzed using SPSS 15.0 (SPSS Inc. Chicago, IL), IBM SPSS statistics 19.0 (SPSS, Inc., an IBM Company) and Stata versions 10.0 and 12.0 (Stata Corp., College Station, TX). Quantitative genetic modeling was developed with the Mx program, and with R-CRAN statistical software utilizing the specialized packages "psych" and "OpenMx" (Boker et al. 2011, R Development Core Team R 2011, Revelle 2011). In each of the analyses, the level of significance was set at $p<0.05$. Variable distributions and normality were examined. The normality of variables was assessed by the Kolmogorov-Smirnov test and by the Shapiro-Wilk test. The equality of means and the variances of the descriptive variables were assessed by ANOVA, the *t* test and the Mann-Whitney U test. For normally distributed variables, paired t-tests were used to test for significant differences between co-twins discordant for leisure-time physical activity (Study IV). For non-normally distributed variables, the Wilcoxon signed rank test was used. The symmetry test (Stata) was used for categorical variables (Stata 2005). The symmetry test is equivalent to a McNemar's test for matched data for categorical variables that are applicable to more than two categories. When the twins were analyzed as individuals, the Wald test for the analysis of the descriptive variables was used (Study III).

In the quantitative genetic analysis examining changes in the contribution of genetic and environmental influences to leisure-time physical activity over a 6-year follow-up (Study II) the initial MET index variables showed non-normality with high kurtosis and positive skewness. Thus, the variables were normalized using rank transformation methods. The transformation procedures successfully corrected the initial non-normality of the data substantially improving both skewness and kurtosis while stabilizing variances in the data. Preliminary information on the within-pair resemblances was obtained by estimating intraclass correlation coefficients (ICCs) or polychoric correlation coefficients (PCCs) separately for MZ and DZ twin pairs. Polychoric correlations are computed if a trait is treated as a categorical level variable in modeling using a threshold model, assuming that a normally distributed standardized liability function underlies the observed measures.

In the biometric modeling methods, additive genetic (A), shared environmental (C) and specific environmental influences (E) were estimated on the basis of the information available on the twin and co-twin covariance structure and comparison of observed and expected variance-covariance matrices. Biometric model-fitting analyses were started by computing a series of univariate models to determine whether A, C and E conclusively influenced leisure-time physical activity at each time point. Finally, a series of longitudinal Cholesky decompositions were fitted in order to evaluate stability and change in the genetic and environmental influences across the follow-up periods. In the younger twin study, in which genetic and environmental influences were estimated by analyzing the categorical variable on the longitudinal evolution of leisure-time physical activity habits (Study I), the twin data were analyzed with biometric methods in a "multifactorial liability threshold" approach (Neale & Cardon 1992). Accordingly, it is assumed that the liability underlying the categories in the phenotype of interest is normally distributed and holds different thresholds, generally defining the z-value in the liability distribution separating the different categories. In the present study, two thresholds were assumed, as three different leisure-time physical activity categories were defined.

All the models were fitted to the raw data using maximum likelihood algorithms and treating unobserved data as missing-at-random, including the individual's age as a definition variable in study II (Little & Rubin, 2002). Among the younger twins (Study I), the drop-out patterns were very random and unpredictable, and the inclusion of co-twins without information on their birth partner at any of the data collection waves were allowed. For the sake of parsimony and analyzability, missing data were considered to be "missing-at-random". The significance of estimates and path coefficients were tested by removing them sequentially in different subsequent models. Their fit was compared against the fit of the unconstrained initial model, in which a higher number of possible paths of relations and estimates was present. This comparison was done by applying likelihood-ratio tests, LRT (Studies I, II), the Akaike's information criterion, AIC (Studies I, II), the Bayesian information criterion, BIC (Study II) and the deviance information criterion, DIC (Study II). Initially, smaller AIC, BIC or DIC values normally indicate a better fit to the data. Thus, when a discrepancy was noticed between these criteria, preference was given to the models achieving best fit with these AIC, BIC and DIC values, as they are thought to perform better than the other criteria in more complex models with relatively large sample sizes (Markon & Krueger 2004).

In addition, because the samples used in the genetic analyses were composed of men and women, the significance of potential gender differences in the estimates was tested by comparing model fit statistics from a model that constrains the A, C, and E parameters to be equal for men and women with models where these parameters are allowed to differ by gender. Afterwards, among the younger twins (Study I) potential gender-specific genetic influences underlying leisure-time physical activity were tested by comparing the model fit statistics from a model, in which the genetic covariance between opposite-sex DZ twins was constrained to be equal (at a 0.5 level, the expected genetic correlation for full siblings) with those from a less-constrained model where the genetic covariance between opposite-sex DZ twin was freely estimated.

When studying differences in leisure-time physical activity motivation between co-twins discordant for leisure-time physical activity over 30 years (Study IV), pairwise analyses were used. For normally distributed variables, paired t-tests were used to test for significant differences between consistently active and inactive co-twins. For non-normally distributed variables, the Wilcoxon signed rank test was used. Confidence intervals (95% CI) were calculated for the absolute mean differences between consistently active and inactive co-twins. Effect sizes were calculated as Cohen's d, which illustrates the strength of a phenomenon. Specifically, Cohen's d is the difference between means divided by the standard deviation. Twins from the FinnTwin16 study were analyzed as individuals rather than as pairs when the motivation factors were examined (Study III). In situation like this, it is possible that the observations and their error terms between the co-twins of a pair may be correlated. Hence, twin clustering was controlled for and the Wald test used for equality of means to derive the proper values. Again, effect sizes were calculated as Cohen's d. The Stata symmetry test (Stata 2005) was used to analyze perceived barriers to leisure-time physical activity among the co-twins of twin pairs discordant for leisure-time physical activity over 30 years (Study IV), as these variables were categorical.

5 RESULTS

5.1 Participant characteristics

The present thesis is based on several data sets. Participants' basic characteristics, both baseline and follow-up, are gathered together and shown in Table 1. In addition, study by study, a few more detailed descriptive statistics are also presented.

Study I In this study, designed to estimate the genetic and environmental influences on leisure-time physical activity from adolescence to young adulthood, the mean ages of the participants at the four data collection waves were: 16.2 (SD 0.1), 17.1 (SD 0.1), 18.6 (SD 0.2), and 24.5 (SD 0.9) years. At baseline, 30.7% of the participants (34.6% of the boys, and 27.6% of the girls) were very active. However, the percentage of very active persons decreased to 26.8% by young adulthood (25.3% of the men, and 27.9% of the women). In contrast, the percentage of moderately active participants increased from 47.8% (43.5% of the boys, and 51.3% of the girls) to 52.5% (49.8% of the men, and 54.8% of the women) during the follow-up. The percentage of inactive participants remained relatively stable over the follow-up, except for a slight decrease observed at the mean age of 17.1 years (Table 2).

TABLE 1 Basic characteristics of the participants in the four studies.

Studies	Age (mean±SD)	Height (cm; mean±SD)	Weight (kg; mean±SD)	BMI (kg/m²; mean±SD)	Leisure-time MET index (hours/day; mean)
BASELINE					
FinnTwin16 study (Study I)					
Active (N=1 603)	16.2±0.1	170.7±8.1	59.6±8.7	20.4±2.1	NR
Moderately active (N=2 493)	16.2±0.1	169.3±8.1	58.5±9.5	20.3±2.5	NR
Inactive (N=1 120)	16.2±0.1	169.2±8.2	58.2±10.0	20.3±2.7	NR
Finnish Twin Cohort (Study II)					
MZ (N=4 280)	29.4±9.0	168.5±8.7 (N=4 266)	63.8±11.4 (N=4 258)	22.3±3.0 (N=4 250)	3.1±3.6
DZ (N=9 276)	29.8±9.1	169.5±8.7 (N=9 242)	65.4±11.6 (N=9 237)	22.7±3.0 (N=9 206)	2.8±3.1
FinnTwin16 study (Study III) §					
Active (N=1 202)	33.9±1.2	173.0±9.7	73.0±14.2	24.3±4.5	9.0±3.9
Inactive (N=1 106)	33.9±1.2	171.5±9.4	74.6±17.0	25.2±4.8	1.1±0.6
TWINACTIVE study (Study IV)					
Active (N=16)	28.4±6.3	172.9±10.1 (N=15)	65.9±9.4	22.3±2.0 (N=15)	4.0±2.3
Inactive (N=16)	28.4±6.3	173.0±9.8	69.3±16.4	23.0±4.2	0.5±0.3
FOLLOW-UP					
FinnTwin16 study (Study I)					
Active (N=1 212)	24.5±0.9	172.4±9.3	68.5±13.8	22.9±3.2	NR
Moderately active (N=2 382)	24.5±1.0	171.9±9.0	68.1±12.8	22.9±3.2	NR
Inactive (N=937)	24.5±0.9	172.9±9.3	70.0±15.3	23.3±4.1	NR
Finnish Twin Cohort (Study II)					
MZ (N=4 383)	35.4±9.0	168.7±8.8 (N=4 367)	66.0±12.0 (N=4 372)	23.1±3.1 (N=4 360)	3.1±3.3 (N=4 383)
DZ (N=9 439)	35.7±9.1	169.6±8.8 (N=9 398)	67.7±12.2 (N=9 394)	23.4±3.2 (N=9 368)	3.1±3.3 (N=9 439)
FinnTwin16 study (Study III) †					
Active (N=1 107)	24.4±1.0	173.5±9.3 (N=1 106)	69.0±12.6	22.8±2.8 (N=1 106)	11.0±4.7
Inactive (N=1 107)	24.4±1.0	171.8±9.4 (N=1 106)	69.1±14.9 (N=1 105)	23.3±3.9 (N=1 104)	1.3±0.8
TWINACTIVE study (Study IV)					
Active (N=16)	60.4±6.3	171.1±9.9	72.9±11.9	24.8±2.6	8.4±4.1
Inactive (N=16)	60.4±6.3	171.8±10.4	79.5±18.4	26.7±3.5	1.6±1.4

BMI=body mass index, MET=metabolic equivalent, MZ=monozygotic, DZ=dizygotic, NR=not reported, leisure-time physical activity was assessed as physical activity frequency, §=wave five of the FinnTwin16 study, †=wave four of the FinnTwin16 study

TABLE 2 Physical activity levels of the participants at each measurement wave (Study I).

Physical activity group	Zygosity/Sex	Baseline Mean age 16.2 years N=5 216 N (%)	Follow-up 1 Mean age 17.1 years N=4 949 N (%)	Follow-up 2 Mean age 18.6 years N=4 930 N (%)	Follow-up 3 Mean age 24.5 years N=4 531 N (%)
Inactive					
	MZ men	128 (2.5%)	112 (2.3%)	122 (2.5%)	125 (2.8%)
	MZ women	185 (3.5%)	149 (3.0%)	171 (3.5%)	130 (2.9%)
	DZ men	190 (3.6%)	166 (3.4%)	190 (3.9%)	182 (4.0%)
	DZ women	201 (3.9%)	165 (3.3%)	167 (3.4%)	151 (3.3%)
	DZ opp-sex men	213 (4.1%)	174 (3.5%)	193 (3.7%)	203 (4.5%)
	DZ opp-sex women	203 (3.9%)	159 (3.2%)	187 (3.8%)	146 (3.2%)
	Total (N)	1120 (21.5%)	925 (18.7%)	1030 (21.0%)	937 (20.7%)
Moderately active					
	MZ men	250 (4.8%)	208 (4.2%)	230 (4.7%)	244 (5.4%)
	MZ women	486 (9.3%)	479 (9.7%)	486 (9.9%)	477 (10.5%)
	DZ men	394 (7.6%)	372 (7.5%)	380 (7.7%)	377 (8.3%)
	DZ women	456 (8.7%)	459 (9.3%)	453 (9.2%)	417 (9.2%)
	DZ opp-sex men	414 (7.9%)	372 (7.5%)	388 (7.9%)	401 (8.9%)
	DZ opp-sex women	493 (9.5%)	508 (10.2%)	484 (9.9%)	466 (10.3%)
	Total (N)	2493 (47.8%)	2398 (48.5%)	2421 (49.2%)	2382 52.5%)
Very active					
	MZ men	223 (4.3%)	224 (4.5%)	188 (3.8%)	140 (3.1%)
	MZ women	319 (6.1%)	339 (6.9%)	303 (6.1%)	256 (5.7%)
	DZ men	306 (5.9%)	299 (6.0%)	256 (5.1%)	187 (4.1%)
	DZ women	217 (4.2%)	218 (4.4%)	227 (4.6%)	210 (4.6%)
	DZ opp-sex men	303 (5.8%)	310 (6.3%)	275 (5.6%)	192 (4.2%)
	DZ opp-sex women	235 (4.5%)	236 (4.8%)	230 (4.7%)	227 (5.0%)
	Total (N)	1603 (30.7%)	1626 (32.8%)	1479 (29.8%)	1212 (26.8%)

MZ=monozygotic, DZ=dizygotic

Study II In this study of changes in the genetic and environmental influences on leisure-time physical activity in adult men and women twins, the mean age of the participants was 29.6 years (SD 9.0) at baseline and 35.6 years (SD 9.1) at the 6-year follow-up. The participants' average volume of leisure-time physical activity increased from 2.9 MET hours/day (SD 3.3) at baseline to 3.1 MET hours/day (SD 3.3) ($p<0.001$) at follow-up. However, their BMI also increased from baseline (22.6±3.0) to follow-up (23.3±3.2) ($p<0.001$) (Table 3). The intra-class correlation coefficients for the MZ and DZ twins are shown in Table 3.

TABLE 3 Body mass index, volume of leisure-time physical activity expressed as MET hours/day and intraclass correlation coefficients at baseline and at follow-up among MZ and DZ adult twins (Study II).

Variable	N	Mean±SD	ICC (95% CI)
Baseline			
BMI, kg/m^2	13 456	22.6±3.0	
MZ	4 250	22.3±3.0	0.79 (0.77–0.80)
DZ	9 206	22.7±3.0	0.52 (0.50–0.55)
MET hours/day	13 556	2.9±3.3	
MZ	4 280	3.1±3.6	0.54 (0.51–0.58)
DZ	9 276	2.8±3.1	0.24 (0.20–0.27)
Follow-up			
BMI, kg/m^2	13 728	23.3±3.2	
MZ	4 360	23.1±3.1	0.78 (0.76–0.80)
DZ	9 368	23.4±3.2	0.47 (0.44–0.50)
MET hours/day	13 822	3.1±3.3	
MZ	4 383	3.1±3.3	0.43 (0.39–0.47)
DZ	9 439	3.1±3.0	0.15 (0.11–0.18)

BMI=body mass index, MET=metabolic equivalent, MZ=monozygotic, DZ=dizygotic, SD=standard deviation, ICC=intraclass correlation coefficient, CI=confidence intervals

Study III The results of the study on the motives for leisure-time physical activity among active and inactive men and women in their mid-thirties showed that relatively more women than men were physically inactive, and therefore the characteristics of the sample are presented by gender. The following characteristics are based on the fifth data wave of the study that was the time point in the cross-sectional design and the follow-up time point in the longitudinal design. There were no differences in height between the active and inactive persons (men p=0.27, women p=0.10). Active men had a lower body weight (p=0.003) and lower BMI (p=0.002). The same was seen among women; active women had a lower body weight (p<0.001), and lower BMI (p<0.001). As expected, active persons reported better subjective health status (both men and women p<0.001) and subjective physical fitness (both men and women p<0.001) than inactive ones. On the other hand, inactive persons reported significantly poorer financial standing (men p=0.002, women p<0.001) than active persons, and inactive men had significantly more chronic diseases (p=0.007) than active men. Among both sexes active persons had significantly more sedentary work than inactive persons (men p=0.008, women p<0.001).

Study IV This study examined motives for and barriers to leisure-time physical activity in twins discordant for leisure-time physical activity over 30 years. For the active co-twins the mean volume of leisure-time physical activity at baseline was 4.0 MET hours/day (SD 2.3) and for the inactive co-twins 0.5 MET hours/day (SD 0.3) (p<0.001). At follow-up, the average volume of leisure-time physical activity for the active co-twins was 8.4 MET hours/day (SD 4.1) and for the inactive co-twins 1.6 MET hours/day (SD 1.4) (p<0.001)

(Table 1). Furthermore, among the twins in this unique sub-sample, Leskinen et al. (2009a and 2009b) found no statistical differences in the descriptive variables between the consistently active and inactive co-twins either at baseline in 1975 or at follow-up in 2007, other than those related to physical activity, fitness and body-composition. At follow-up, the inactive co-twins were less fit, when fitness was measured as $VO_{2peak,}$ than their active co-twins ($p<0.001$). In addition, at follow-up, after 30 years leisure-time physical activity discordance, statistically significant differences between the active and inactive co-twins were observed in fat percent ($p=0.004$), fat mass ($p=0.02$), abdominal area ($p=0.01$), visceral adipose tissue area ($p=0.01$), liver fat score ($p=0.03$), mid-thigh intramuscular adipose tissue area ($p=0.002$), and mid-thigh subcutaneous adipose tissue area ($p=0.05$) (Leskinen et al. 2009a).

5.2 Genetic influences on leisure-time physical activity (Studies I and II)

Study I In this study, which focused on the genetic and environmental influences on leisure-time physical activity from adolescence to young adulthood, the analyses of the polychoric correlations revealed that the MZ twins were more likely to have a similar leisure-time physical activity level than the DZ twins, suggesting the presence of A in the phenotype (Table 4). Further, both the univariate biometric models and the modeling of the Cholesky decompositions confirmed that models with additive genetic, shared environmental and specific environmental influences (ACE model) fitted best to the data (Table 5). Additional tests revealed not only that the estimates of genetic and environmental influences were different in men and women, but also the presence of gender-specific genetic influences (Table 6).

TABLE 4 Within-pair polychoric correlations for participants at each measurement wave from adolescence to young adulthood (Study I).

Zygosity/Sex	**Baseline** **Mean age** **16.2 years** **N=5 216** **PCC (95% CI)**	**Follow-up 1** **Mean age** **17.1 years** **N=4 949** **PCC (95% CI)**	**Follow-up 2** **Mean age** **18.6 years** **N=4 930** **PCC (95% CI)**	**Follow-up 3** **Mean age** **24.5 years** **N=4 531** **PCC (95% CI)**
MZ men	0.72 (0.66–0.77)	0.71 (0.65–0.76)	0.69 (0.63–0.74)	0.79 (0.74–0.83)
MZ women	0.77 (0.74–0.81)	0.77 (0.73–0.80)	0.76 (0.72–0.80)	0.80 (0.77–0.83)
DZ men	0.48 (0.41–0.55)	0.48 (0.41–0.55)	0.51 (0.44–0.57)	0.64 (0.59–0.69)
DZ women	0.50 (0.43–0.57)	0.54 (0.47–0.60)	0.31 (0.23–0.39)	0.69 (0.64–0.73)
DZ opp-sex	0.24 (0.18–0.29)	0.23 (0.17–0.29)	0.25 (0.20–0.31)	0.58 (0.54–0.62)

MZ=monozygotic, DZ=dizygotic, PCC=polychoric correlation coefficient, CI=confidence intervals

TABLE 5 Model-fitting statistics using raw data, assuming unequal thresholds (Study I).

Physical activity at mean age 16.2 years	**-2LL**	**df**	**ΔLL**	**Δdf**	**AIC**	**p-value**
1. ACE allowing gender differences	8437.78	4300	-	-	-162.22	-
2. ACE same genes in men and women	8443.60	4301	5.82	1	-158.40	0.02
3. ACE equating men and women	8457.25	4304	19.47	4	-150.75	<0.001
4. AE allowing gender differences	8446.69	4302	8.91	2	-157.31	0.01
5. AE same genes in men and women	8455.78	4303	18.01	3	-150.22	<0.001
6. AE equating men and women	8457.55	4305	19.77	5	-152.45	<0.001
7. CE, allowing gender differences	8538.30	4303	100.52	3	-67.70	<0.001
8. CE equating men and women	8545.11	4305	107.33	5	-64.89	<0.001
Physical activity at mean age 17.1 years	**-2LL**	**df**	**ΔLL**	**Δdf**	**AIC**	**P-value**
1. ACE allowing gender differences	7906.50	4093	-	-	-279.50	-
2. ACE same genes in men and women	7911.79	4094	5.29	1	-276.21	0.02
3. ACE equating men and women	7923.36	4097	16.86	4	-270.64	<0.001
4. AE allowing gender differences	7919.94	4095	13.44	2	-270.06	<0.001
5. AE same genes in men and women	7924.72	4096	18.23	3	-267.28	<0.001
6. AE equating men and women	7925.81	4098	19.31	5	-270.19	<0.001
7. CE allowing gender differences	7978.39	4096	71.89	3	-213.61	<0.001
8. CE equating men and women	7986.03	4098	79.54	5	-209.97	<0.001
Physical activity at mean age 18.6 years	**-2LL**	**df**	**ΔLL**	**Δdf**	**AIC**	**P-value**
1. ACE allowing gender differences	7990.29	4068	-	-	-145.71	-
2. ACE same genes in men and women	7990.44	4069	0.15	1	-147.56	0.7
3. ACE equating men and women	8004.20	4072	13.92	4	-139.80	0.01
4. AE allowing gender differences	7998.11	4070	7.82	2	-141.89	0.02
5. AE same genes in men and women	8003.67	4071	13.38	3	-138.33	<0.001
6. AE equating men and women	8004.20	4073	13.92	5	-141.80	0.02
7. CE allowing gender differences	8087.06	4071	96.77	3	-54.94	<0.001
8. CE equating men and women	8087.09	4073	96.81	5	-58.91	<0.001
Physical activity at mean age 24.5 years	**-2LL**	**df**	**ΔLL**	**Δdf**	**AIC**	**P-value**
1. ACE allowing gender differences	6567.04	3742	-	-	-916.96	-
2. ACE same genes in men and women	6567.91	3743	0.86	1	-918.09	0.35
3. ACE equating men and women	6568.36	3746	1.31	4	-923.64	0.86
4. AE allowing gender differences	6606.90	3744	39.86	2	-881.10	<0.001
5. AE same genes in men and women	6617.94	3745	50.89	3	-872.06	<0.001
6. AE equating men and women	6617.97	3747	50.93	5	-876.03	<0.001
7. CE allowing gender differences	6580.99	3745	13.95	3	-909.01	<0.001
8. CE equating men and women	6582.01	3747	14.97	5	-911.99	0.01

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

TABLE 6 Multivariate longitudinal model fitting statistics (Study I).

Model	-2LL	df	ΔLL	Δdf	AIC	p-value
1. ACE allowing gender difference	33778.53	19498	-	-	-5217.47	-
2. ACE same genes in men and women	33820.48	19502	41.95	4	-5183.52	<0.001
3. ACE equating men and women	33912.34	19532	133.81	34	-5151.66	<0.001
4. AE allowing gender differences	33851.26	19518	72.73	20	-5184.74	<0.001
5. AE same genes in men and women	34045.29	19522	266.76	24	-4998.71	<0.001
6. AE equating men and women	33912.35	19542	133.82	44	-5171.65	<0.001
7. CE allowing gender differences	34283.43	19522	504.90	24	-4760.57	<0.001
8. CE equating men and women	34098.71	19542	350.18	44	-4985.29	<0.001

LL=log-likelihood, df=degrees of freedom, ΔLL=log-likelihood difference (chi-squared) between the initial model and fitted sub model, Δdf=increment in degrees of freedom with respect to the initial model, AIC=Akaike's information criterion

The results of the final models for leisure-time physical activity between ages 16.2 and 24.5 years have been presented in Figure 5. Among both men and women, the heritability of leisure-time physical activity remained relatively stable during adolescence at 43%–52%, finally declining to approximately 30% in young adulthood. In contrast, shared environmental influences also showed relative stability during adolescence at 18%–26%, finally increasing to 43% in men and 49% in women in young adulthood. Specific environmental influences remained relatively stable at all the follow-ups, ranging approximately between 20% and 30% in both men and women.

Baseline additive genetic and environmental influences had a residual effect in the subsequent waves, showing a tendency to decrease with age. The additive genetic correlation (r_a) between the first and second waves was 0.78 for men and 0.67 for women, while the corresponding estimates between the first and the last waves were 0.44 for both sexes. This suggests that only approximately 19% of the additive genetic influences detected at the mean age of 16.2 years were present at the mean age of 24.5 years. The shared environmental correlations (r_c) between the first and second waves was 0.76 for men and 0.81 for women, while the corresponding estimates between the first and the last waves were 0.57 for men and 0.41 for women. The observed values for the specific environmental correlation (r_e) between the first and the second waves was as high as 0.44 for men and 0.36 for women, while the corresponding estimates between the first and the last waves were 0.10 for men and 0.19 for women.

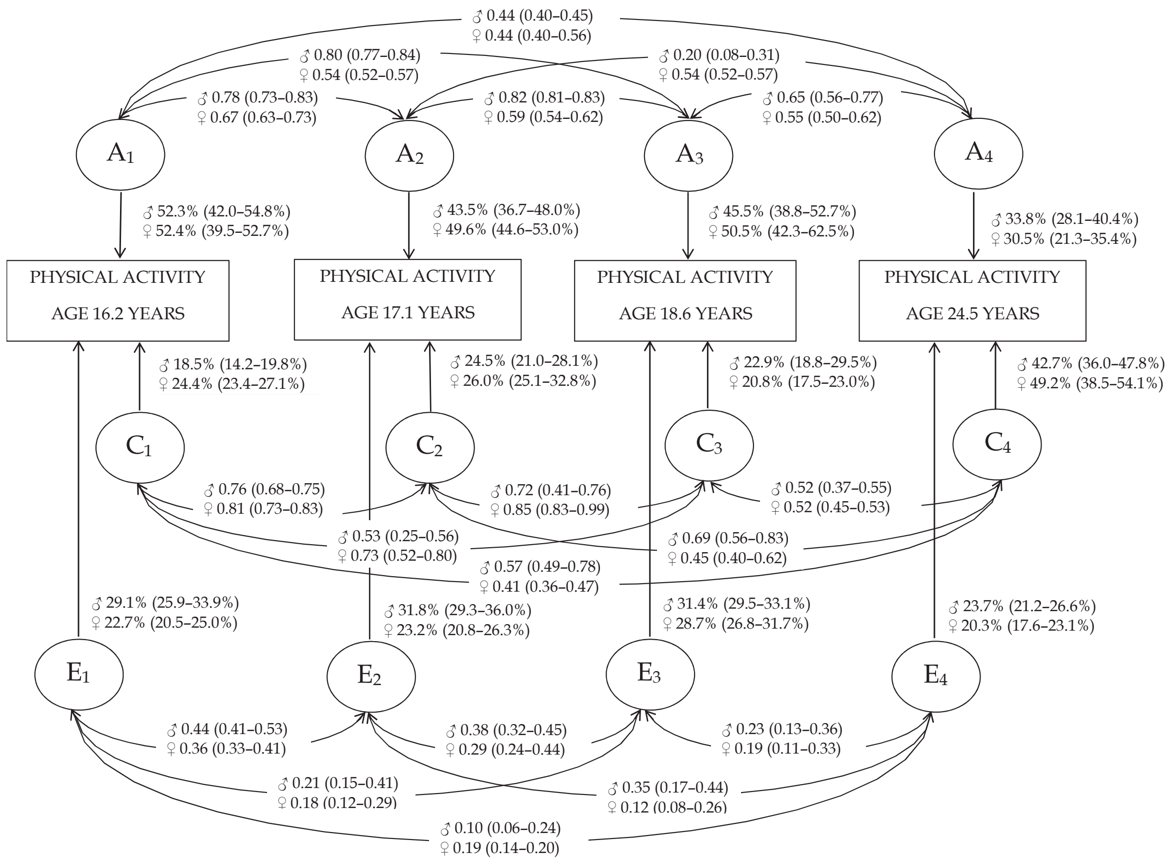

FIGURE 5 Summary of the final model for leisure-time physical activity between ages 16.2 and 24.5 years. Additive genetic, shared environmental and specific environmental correlations between the baseline and follow-up results are shown as curved arrows (Study I).

Study II At all times the adult MZ twin individuals resembled each other more than did the adult DZ twin individuals when the changes over 6 years in influences on leisure-time physical activity were examined. This is indicative of the greater importance of genetic influences on the leisure-time physical activity phenotype (Table 7). Based on the longitudinal bivariate Cholesky decomposition, the model of additive genetic influences and specific environmental influences (AE model) was the best-fitting model for (Table 7). The genetic modeling was started with the full ACE model. After dropping the weakest parameters, the model with the best fit to the data according to the DIC contained additive genetic (A) and specific environmental (E) influences with equal estimates in men and in women. Because the model with gender differences may also provide the best fit according to the AIC and BIC, it is preferable to report the results from both models, with and without gender differences in the parameter estimates (Markon & Krueger 2004).

TABLE 7 Bivariate longitudinal model fitting statistics (Study II).

Model	-2LL	df	χ^2	Δdf	p-value	AIC	BIC	DIC
ACE gender differences	74317.63	27356	--	--	--	19605.63	-44546.60	-62874.64
ACE no gender differences	74347.15	27365	29.52	9	0.001	19617.15	-44558.72	-62892.79
ACE men–AE women	74318.20	27359	0.57	3	0.904	19600.20	-44555.28	-62885.33
AE men–ACE women	74317.63	27359	0.00	3	1.000	19599.63	-44555.56	-62885.61
AE gender differences	74318.20	27362	0.57	6	0.997	19594.20	-44564.24	-62896.30
AE no gender differences	74347.35	27368	29.72	12	0.003	19611.35	-44567.59	-62903.66
CE gender differences	74422.10	27362	104.48	6	0.000	19698.11	-44512.28	-62844.34
CE no gender differences	74450.72	27368	133.09	4	0.000	19714.72	-44515.90	-62851.97

LL=log-likelihood, df=degrees of freedom, χ^2=chi-squared goodness-of-fit statistic, Δdf=increment in degrees of freedom with respect to the initial model, AIC=Akaike's information criterion, BIC=Bayesian information criterion, DIC=deviance information criterion

In the overall sample model for both sexes, the additive genetic influences on leisure-time physical activity declined from 44% of the total variance at baseline to 34% at follow-up (Figure 6). The remaining variance at each time point was explained by specific environmental influences. The additive genetic correlation (r_a) between the time points was high 0.72. This suggests that a considerable proportion of the additive genetic influences at baseline were still present at follow-up. Conversely, the environmental correlation (r_e) between the two time points was modest 0.23. The longitudinal phenotypic correlation (r_p) between the baseline and follow-up measures was moderate 0.42, of which 67% was due to longitudinal additive genetic influences.

In the model allowing gender differences a similar pattern of declining additive genetic influences from baseline to follow-up in both men (from 47% to 38%) and women (from 42% to 31%) was observed. The remaining percentages at each time were accounted for by specific environmental influences. The additive genetic correlation (r_a) for leisure-time physical activity was greater for men 0.79 than for women 0.64 (Figure 7). However, the environmental correlation (r_e) between the two time points did not differ substantially between the sexes (men 0.21 vs. women 0.24). The longitudinal phenotypic correlation (r_p) in men was 0.45, of which 74% was due to longitudinal additive genetic influences, while in women the longitudinal phenotypic correlation (r_p) was 0.38, of which 60% was due to longitudinal additive genetic influences.

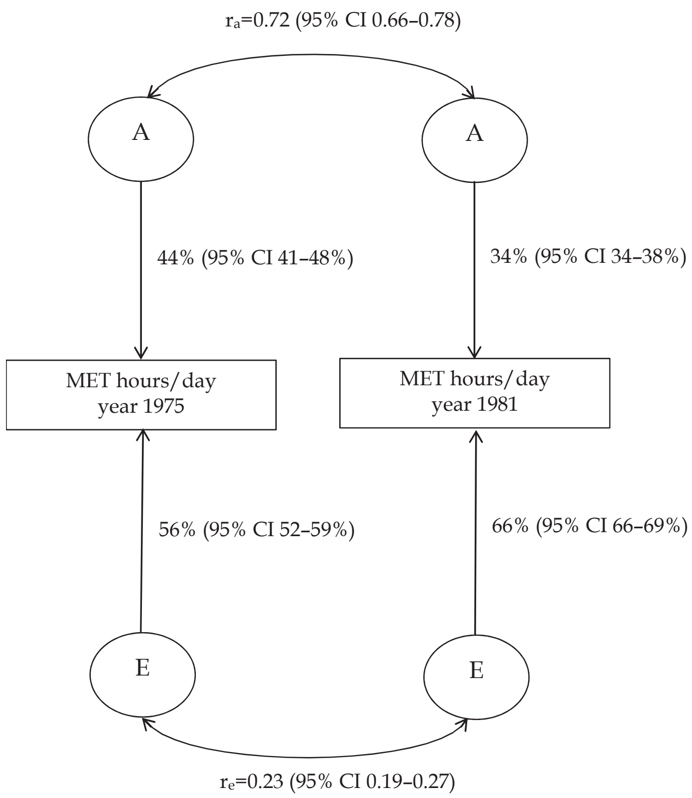

FIGURE 6 Summary models of the changes over 6 years in influences on leisure-time physical activity. Additive genetic and specific environmental correlations between the baseline and follow-up results are shown as curved arrows (Study II).

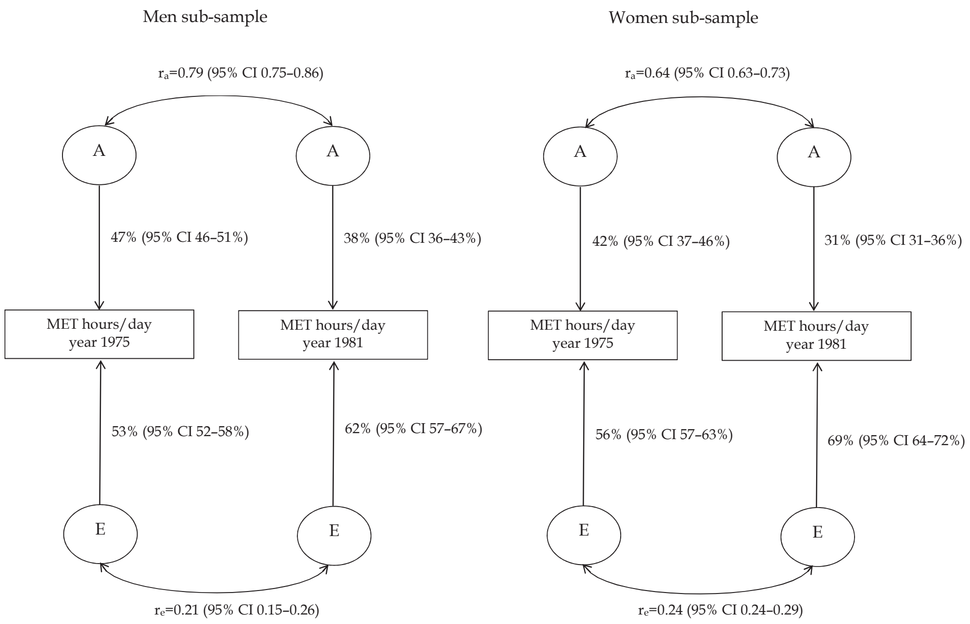

FIGURE 7 Summary models of the changes over 6 years in influences on leisure-time physical activity among men and women. Additive genetic and specific environmental correlations between the baseline and follow-up results are shown as curved arrows (Study II).

Thus, the results indicated that the drop detected in the heritability of leisure-time physical activity over the 6-year follow-up was produced by a decline in the genetic variance and an increase in the environmental variance, with no substantial change in the overall variance. These results were consistent in both men and women (Table 8).

TABLE 8 Raw variance estimates for leisure-time physical activity (MET hours/day) at baseline and at follow-up (Study II).

	Baseline		**6-year follow-up**	
	Men (95% CI)	**Women (95% CI)**	**Men (95% CI)**	**Women (95% CI)**
Total variance	1.02 (0.98–1.06)	0.97 (0.93–1.00)	1.02 (0.98–1.06)	0.96 (0.96–1.00)
Genetic variance	0.48 (0.43–0.53)	0.40 (0.35–0.45)	0.39 (0.33–0.45)	0.30 (0.26–0.35)
Environmental variance	0.54 (0.50–0.59)	0.56 (0.55–0.61)	0.63 (0.62–0.69)	0.67 (0.62–0.72)
Heritability	0.47 (0.46–0.51)	0.42 (0.37–0.46)	0.38 (0.36–0.43)	0.31 (0.31–0.36)

CI=confidence intervals

5.3 Motives for leisure-time physical activity (Studies III and IV)

Study III The mean values for each sub-dimension of the REMM based on the total twin participant population in their mid-thirties are presented in Table 9. As expected, the values for the moderately active participants were between the values scored by the active and inactive participants in their mid-thirties.

TABLE 9 Differences in the sub-dimensions of the REMM measure among active, moderately active and inactive men and women in their mid-thirties (Study III).

Sub-dimension	**Active Mean±SD N=1 202**	**Moderately active Mean±SD N=944**	**Inactive Mean±SD N=1 106**
Mastery	4.16±0.94	3.71±1.07	3.26±1.23
Physical fitness	4.76±0.59	4.64±0.65	4.42±0.76
Affiliation	3.58±1.22	3.13±1.23	2.95±1.21
Psychological state	4.72±0.63	4.55±0.73	4.35±0.82
Appearance	3.66±1.14	3.49±1.19	3.42±1.20
Others' expectations	1.75±0.96	1.74±0.98	1.79±1.01
Enjoyment	4.61±0.68	4.16±0.89	3.65±1.09
Competition/ego	3.44±1.23	3.15±1.23	3.09±1.27
Men	**N=602**	**N=411**	**N=473**
Mastery	4.23±0.91	3.78±1.05	3.46±1.16
Physical fitness	4.69±0.69	4.51±0.75	4.31±0.86
Affiliation	3.72±1.18	3.17±1.18	2.99±1.17
Psychological state	4.63±0.72	4.39±0.83	4.17±0.93
Appearance	3.36±1.17	3.11±1.19	3.06±1.21
Others' expectations	1.82±0.97	1.87±1.02	1.86±1.04
Enjoyment	4.57±0.70	4.01±0.95	3.63±1.05
Competition/ego	3.50±1.18	3.22±1.02	3.07±1.22
Women	**N=600**	**N=533**	**N=633**
Mastery	4.09±0.97	3.66±1.08	3.12±1.25
Physical fitness	4.83±0.46	4.75±0.54	4.51±0.67
Affiliation	3.45±1.24	3.09±1.26	2.92±1.23
Psychological state	4.80±0.52	4.67±0.61	4.48±0.69
Appearance	3.96±1.04	3.78±1.09	3.68±1.11
Others' expectations	1.67±0.95	1.64±0.93	1.74±0.99
Enjoyment	4.65±0.65	4.27±0.82	3.66±0.98
Competition/ego	3.38±1.28	3.10±1.30	3.11±1.30

SD=standard deviation

Among both the active (N=1 202) and inactive (N=1 106) twin participants in their mid-thirties, the motive "be physically fit" was the most frequently reported motivation sub-dimension of the REMM, followed by "improve psychological state". Next in order of frequency was the sub-dimension "enjoyment of physical activity", followed by the sub-dimensions cultivation of skills ("mastery") and willingness to improve appearance and body shape ("appearance"), highlighted in particular by the active group. The active participants scored higher on all the motivation items except one, viz. "conform to other peoples' expectations". The sub-dimension of conform to others' expectations was the least reported motivation sub-dimension among all the participants. These findings were similar in both men and women (Figure 8).

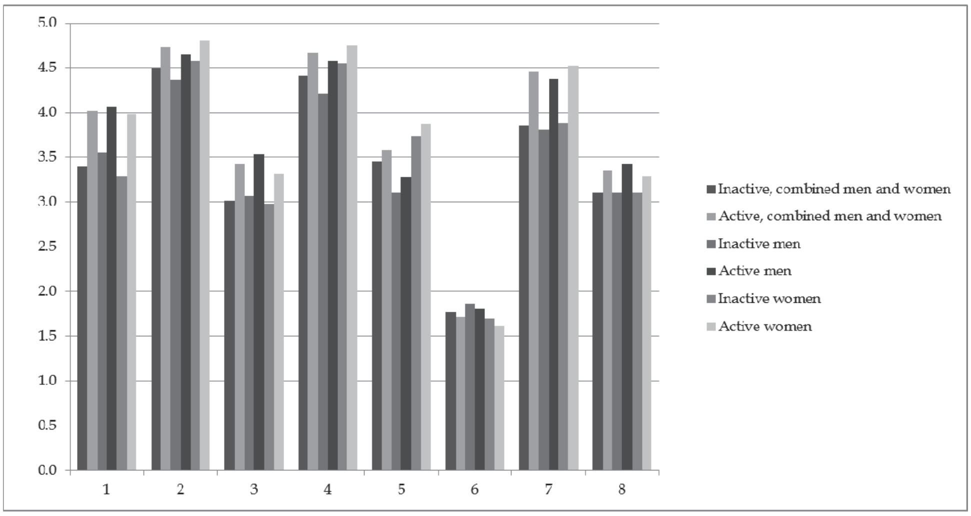

FIGURE 8 Differences in the sub-dimensions of the REMM measure among physically active and inactive men and women in their mid-thirties. Physical activity level was based on leisure-time physical activity frequency. 1=Mastery, 2=Physical fitness, 3=Affiliation, 4=Psychological state, 5=Appearance, 6=Others' expectations, 7=Enjoyment, 8=Competition/ego (Study III).

When all the active participants were compared to all the inactive participants, the motivation sub-dimensions mastery ($p<0.001$, Cohen's d=0.82), physical fitness ($p<0.001$, Cohen's d=0.49), the social aspect of physical activity ($p<0.001$, Cohen's d=0.52), psychological state ($p<0.001$, Cohen's d=0.51), appearance ($p<0.001$, Cohen's d=0.20), and enjoyment ($p<0.001$, Cohen's d=1.07) were found to be significantly more important for the active than inactive participants (Table 10). Also, willingness to be fitter or look better than others ($p<0.001$, Cohen's d=0.28) was highlighted significantly more by the active than the inactive participants. Conforming to others' expectations was the only sub-dimension that was scored slightly higher by the inactive than active participants. However, the between-group difference was not statistically significant (p=0.3, Cohen's d=-0.04). The results of the separate-sex analysis were nearly identical to those for both sexes combined, and almost the same differences in all the sub-dimensions were found (Table 10). The results remained unchanged after excluding the participants with poor financial standing, poor subjective health status, or one or more chronic disease.

TABLE 10 Differences in the sub-dimensions of the REMM measure among physically active and inactive men and women in their mid-thirties (Study III).

Sub-dimension	**Active Mean±SD N=1 202**	**Inactive Mean±SD N=1 106**	**Mean difference (95% CI)**	**p-value**	**Effect size Cohen's d**
Combined men and women					
Mastery	4.16±0.94	3.26±1.23	-0.89 (-0.99 to -0.80)	<0.001	0.82
Physical fitness	4.76±0.59	4.42±0.76	-0.33 (-0.39 to -0.28)	<0.001	0.49
Affiliation	3.58±1.22	2.95±1.21	-0.64 (-0.73 to -0.53)	<0.001	0.52
Psychological state	4.72±0.63	4.35±0.82	-0.37 (-0.43 to -0.31)	<0.001	0.51
Appearance	3.66±1.14	3.42±1.20	-0.24 (-0.34 to -0.14)	<0.001	0.20
Others' expectations	1.75±0.96	1.79±1.01	0.04 (-0.04 to 0.12)	0.3	-0.04
Enjoyment	4.61±0.68	3.65±1.09	-0.96 (-1.04 to -0.88)	<0.001	1.07
Competition/ego	3.44±1.23	3.09±1.27	-0.35 (-0.45 to -0.24)	<0.001	0.28
Men	**N=602**	**N=473**			
Mastery	4.23±0.91	3.46±1.16	-0.77 (-0.90 to -0.64)	<0.001	0.75
Physical fitness	4.69±0.69	4.31±0.86	-0.38 (-0.47 to -0.28)	<0.001	0.49
Affiliation	3.72±1.18	2.99±1.17	-0.73 (-0.87 to -0.58)	<0.001	0.62
Psychological state	4.63±0.72	4.17±0.93	-0.47 (-0.57 to -0.36)	<0.001	0.57
Appearance	3.36±1.17	3.06±1.21	-0.30 (-0.44 to -0.15)	<0.001	0.25
Others' expectations	1.82±0.97	1.86±1.04	0.04 (-0.08 to 0.17)	0.47	-0.05
Enjoyment	4.57±0.70	3.63±1.05	-0.94 (-1.05 to -0.83)	<0.001	1.08
Competition/ego	3.50±1.18	3.07±1.22	-0.43 (-0.58 to -0.29)	<0.001	0.36
Women	**N=600**	**N=633**			
Mastery	4.09±0.97	3.12±1.25	-0.97 (-1.10 to -0.84)	<0.001	0.86
Physical fitness	4.83±0.46	4.51±0.67	-0.32 (-0.38 to -0.25)	<0.001	0.55
Affiliation	3.45±1.24	2.92±1.23	-0.53 (-0.67 to -0.39)	<0.001	0.43
Psychological state	4.80±0.52	4.48±0.69	-0.32 (-0.39 to -0.25)	<0.001	0.52
Appearance	3.96±1.04	3.68±1.11	-0.27 (-0.40 to -0.15)	<0.001	0.25
Others' expectations	1.67±0.95	1.74±0.99	0.06 (-0.05 to 0.17)	0.28	-0.14
Enjoyment	4.65±0.65	3.66±0.98	-0.98 (-1.09 to -0.88)	<0.001	1.05
Competition/ego	3.38±1.28	3.11±1.30	-0.27 (-0.41 to -0.12)	<0.001	0.21

SD=standard deviation, CI=confidence intervals

Among the twin participants in their mid-thirties, the motivation factors for longitudinal physical activity were also analyzed during the 10-year follow-up. The consistently active participants were compared to the consistently inactive participants (Figure 9). It should be borne in mind that motivation data were only available from the follow-up time point (the ongoing wave five of the cohort). The results of the longitudinal study design were parallel to the results of the cross-sectional study design: motives related to all the sub-dimensions except one were significantly more important for the participants who had been consistently active over the last decade than for those consistently inactive during the same time period (Table 11). Again, conforming to others' expectations was the least meaningful motivation sub-dimension for the participants. Furthermore, conforming to others' expectations was the only sub-dimension of the REMM measure more important for the consistently inactive than consistently active participants (p=0.01, Cohen's d=-0.16). When men and women were analyzed separately, the results revealed that the motivation dimension of other's expectations differed significantly between the groups only in the women, not men (Table 11). Otherwise, the analysis conducted among men and women separately did not substantially change the results.

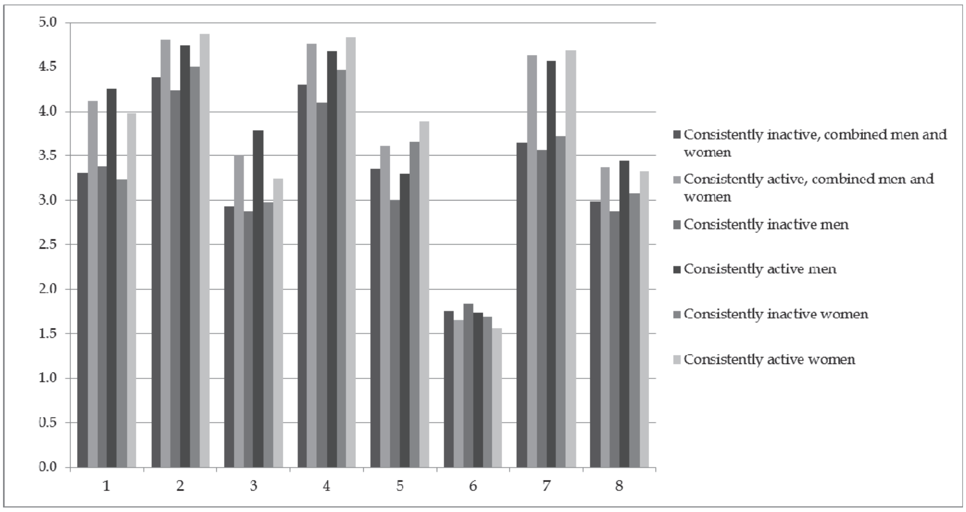

FIGURE 9 Differences in the sub-dimensions of the REMM measure among consistently physically active and consistently inactive men and women in their mid-thirties. Physical activity level was based on leisure-time physical activity frequency. 1=Mastery, 2=Physical fitness, 3=Affiliation, 4=Psychological state, 5=Appearance, 6=Others' expectations, 7=Enjoyment, 8=Competition/ego (Study III).

TABLE 11 Differences in the sub-dimensions of the REMM measure among consistently physically active and consistently inactive men and women in their mid-thirties (Study III).

Sub-dimension	**Consistently active Mean±SD N=617**	**Consistently inactive Mean±SD N=532**	**Mean difference (95% CI)**	**p-value**	**Effect size Cohen's d**
Combined men and women					
Mastery	4.21±0.90	3.15±1.23	-1.06 (-1.20 to -0.93)	<0.001	1.00
Physical fitness	4.81±0.49	4.30±0.82	-0.51 (-0.59 to -0.43)	<0.001	0.76
Affiliation	3.70±1.19	2.83±1.21	-0.87 (-1.01 to -0.73)	<0.001	0.73
Psychological state	4.76±0.59	4.23±0.84	-0.53 (-0.62 to -0.45)	<0.001	0.74
Appearance	3.61±1.10	3.30±1.20	-0.30 (-0.44 to -0.17)	<0.001	0.26
Others' expectations	1.69±0.92	1.85±1.05	0.15 (0.04 to 0.27)	0.01	-0.16
Enjoyment	4.75±0.54	3.39±1.13	-1.36 (-1.47 to -1.25)	<0.001	1.57
Competition/ego	3.47±1.22	3.02±1.26	-0.45 (-0.60 to -0.31)	<0.001	0.36
Men	**N=334**	**N=240**			
Mastery	4.29±0.83	3.33±1.19	-0.96 (-1.14 to -0.79)	<0.001	0.97
Physical fitness	4.73±0.60	4.20±0.90	-0.53 (-0.66 to -0.39)	<0.001	0.71
Affiliation	3.93±1.06	2.80±1.19	-1.13 (-1.32 to -0.94)	<0.001	1.01
Psychological state	4.66±0.69	4.05±0.96	-0.61 (-0.75 to -0.46)	<0.001	0.76
Appearance	3.34±1.14	3.05±1.22	-0.28 (-0.48 to -0.09)	0.004	0.25
Others' expectations	1.78±0.93	1.94±1.07	0.16 (-0.01 to 0.33)	0.07	-0.16
Enjoyment	4.71±0.58	3.33±1.12	-1.38 (-1.54 to -1.23)	<0.001	1.64
Competition/ego	3.52±1.19	3.00±1.24	-0.52 (-0.72 to -0.32)	<0.001	0.43
Women	**N=283**	**N=292**			
Mastery	4.13±0.97	3.01±1.25	-1.12 (-1.31 to -0.93)	<0.001	1.05
Physical fitness	4.90±0.30	4.38±0.74	-0.52 (-0.61 to -0.43)	<0.001	0.91
Affiliation	3.43±1.28	2.85±1.23	-0.57 (-0.79 to -0.36)	<0.001	0.46
Psychological state	4.87±0.43	4.37±0.70	-0.50 (-0.60 to -0.41)	<0.001	0.87
Appearance	3.93±0.96	3.52±1.14	-0.42 (-0.59 to -0.24)	<0.001	0.39
Others' expectations	1.59±0.90	1.77±1.03	0.18 (0.02 to 0.34)	0.03	-0.19
Enjoyment	4.79±0.49	3.44±1.15	-1.35 (-1.50 to -1.21)	<0.001	1.53
Competition/ego	3.41±1.27	3.03±1.30	-0.38 (-0.59 to -0.17)	<0.001	0.30

SD=standard deviation, CI=confidence intervals

When we compared the participants who changed from inactive to active during the 10-year follow-up period and those who were consistently inactive, the results of the motivation sub-dimensions changed slightly. In this analysis, the motivation sub-dimension of others' expectations (p=0.47, Cohen's d=-0.06) did not differ significantly between the two groups (Table 12).

TABLE 12 Differences in the sub-dimensions of the REMM measure among consistently physically inactive persons and persons who changed from inactive to active during the 10-year follow-up (Study III).

Sub-dimension	**Change from inactive to active Mean±SD N=228**	**Consistently inactive Mean±SD N=532**	**Mean difference (95% CI)**	**p-value**	**Effect size Cohen's d**
Mastery	4.00±1.12	3.15±1.23	-0.85 (-1.03 to -0.67)	<0.001	0.71
Physical fitness	4.63±0.82	4.30±0.82	-0.33 (-0.45 to -0.20)	<0.001	0.40
Affiliation	3.42±1.30	2.83±1.21	-0.59 (-0.78 to -0.39)	<0.001	0.48
Psychological state	4.59±0.75	4.23±0.84	-0.36 (-0.48 to -0.24)	<0.001	0.44
Appearance	3.64±1.26	3.30±1.20	-0.34 (-0.53 to 0.15)	0.006	0.28
Others' expectations	1.79±1.01	1.85±1.05	0.06 (-0.10 to 0.21)	0.47	-0.06
Enjoyment	4.32±0.83	3.39±1.13	-0.93 (-1.08 to -0.79)	<0.001	0.89
Competition/ego	3.45±1.24	3.02±1.26	-0.43 (-0.63 to -0.24)	<0.001	0.34

SD=standard deviation, CI=confidence intervals

Study IV When studying the motives for leisure-time physical activity among the twin pairs discordant for physical activity over 30 years, the original REMM motivation measure was used. The factor "stay in shape" was the most frequently (71.9%) reported "strongly agree" answer of the 73 REMM motivation items. It was followed by "willingness to improve cardiovascular function" (68.8%) and "feel good afterwards" (65.5%). Furthermore, the active co-twins also highlighted management of a medical condition as an important motivation factor (81.3%). Of the 73 REMM motivation items, keeping healthy was one of the main motivation factors for the inactive co-twins (62.5%). There were statistically significant differences in the items "exercise helps me relax" (p=0.01) and "be physically fit" (p=0.03) between the active and inactive co-twins. A tendency to differences was also seen in the items "exercise helps improve my psychological health" (p=0.06), "it is fun" (p=0.06) and "I like physical challenges" (p=0.06). In all these items the active co-twins reported higher values than their inactive co-twins.

The top four sub-dimensions of the REMM measure with which the participants, both active and inactive, most frequently expressed agreement were physical fitness, enjoyment, psychological state and mastery. Finally, the eight REMM sub-dimensions were sum-scaled and tested for differences between the co-twins discordant for leisure-time physical activity over 30 years, in order to identify whether there were any differences in the major motivation dimensions. Significant differences for the mastery (p=0.02, Cohen's d=0.76), physical fitness (p=0.03, Cohen's d=0.69), and psychological state (p=0.04, Cohen's d=0.65) sub-dimensions were found (Table 13). Interestingly, these were the sub-dimensions in which both groups most frequently expressed agreement.

TABLE 13 Differences in the sub-dimensions of the REMM measure among consistently physically active and inactive co-twins (Study IV).

Sub-dimension	Active Mean±SD	Inactive Mean±SD	Mean difference (95% CI)	p-value	Effect size Cohen's d
Mastery	3.54±0.66	2.94±0.89	-0.60 (-1.08 to -0.12)	0.02*	0.76
Physical fitness	4.49±0.32	4.20±0.50	-0.29 (-0.55 to -0.03)	0.03*	0.69
Affiliation	3.06±0.74	2.98±1.02	-0.78 (-0.72 to 0.57)	0.80*	0.09
Psychological state	4.05±0.48	3.72±0.50	-0.32 (-0.62 to -0.02)	0.04*	0.65
Appearance	3.12±0.83	2.98±0.73	-0.14 (-0.48 to 0.20)	0.40*	0.18
Others' expectations	2.54±0.71	2.85±0.58	0.30 (-0.14 to 0.75)	0.14+	0.47
Enjoyment	4.40±0.40	3.95±0.68	-0.44 (-0.83 to 0.05)	0.11+	0.80
Competition/ego	2.00±1.03	1.85±0.85	-015 (-0.70 to 0.40)	0.62+	0.16

SD=standard deviation, CI=confidence intervals, *=paired t-test, +=Wilcoxon signed rank test

5.4 Barriers to leisure-time physical activity (Study IV)

Study IV Among the middle-aged and older twin pairs discordant for physical activity over 30 years, barriers to leisure-time physical activity were also examined. Interestingly, approximately 62% both the active and inactive co-twins, reported having no reasons for not participating in physical activity. However, if barriers were reported, the most cited were pain and different health problems or diseases, lack of time, and weather conditions. When the active and inactive co-twins were examined separately, the most often mentioned barriers were largely the same, except that different health problems or diseases and lack of time were slightly more important barriers for the inactive than active co-twins. Overall, no differences emerged between the active and inactive co-twins in perceived barriers (Table 14).

TABLE 14 Differences in barrier items among consistently physically active and inactive co-twins (Study IV).

Item	Active (N)	Inactive (N)	p-value
Pain interferes with my exercise.	3	3	1.00
Poor health and/or disease make it difficult for me to be physically active.	2	4	0.41
Poor eyesight makes it difficult for me to be physically active.	-	-	-
Fear of falling makes it difficult for me to be physically active.	-	-	-
Fear of injuries makes it difficult for me to be physically active.	-	-	-
I feel uncomfortable to be physically active.	0	1	0.32
I feel too old to be physically active.	-	-	-
Health care workers have told me not to be physically active.	1	1	1.00
I do not have time to be physically active.	2	4	0.41
I am not interested to be physically active.	-	1	0.32
I have other pleasant hobbies.	-	1	0.32
I do no like to be physically active alone.	1	-	0.32
I feel unsafe when I am physically active outdoors.	-	-	-
I am not used to be physically active.	0	2	0.16
I do not know why should I be physically active.	-	-	-
I do not know where to go to exercise.	-	-	-
Poor weather conditions rule out to be physically active.	4	2	0.32
Places for me to be physically active are not very pleasant.	-	-	-
Places for me to be physically active are too far away.	1	1	1.00
Being physically active tires me.	0	1	0.32
I do not have skills to be physically active.	-	-	-
Exercising is too expensive.	-	-	-
Lack of proper equipment makes it difficult for me to be physically active.	-	-	-
Some other reason not mentioned earlier.	2	2	1.00
There is no reason not to engage in exercise.	10	10	1.00

6 DISCUSSION

The present study estimated genetic and environmental influences on the longitudinal evolution of leisure-time physical activity behavior among twins from adolescence to young adulthood, and among adult twins from around age thirty to around age thirty-five. In addition, motives for and barriers to engagement in leisure-time physical activity among consistently active and inactive twins were examined using a co-twin control design. Motives were further longitudinally examined among active and inactive twin individuals in their mid-thirties.

The results confirmed the existence of age-specific changes in the genetic and environmental influences on leisure-time physical activity by revealing a change in the pattern of genetic and environmental influences in the progress of leisure-time physical activity from adolescence to adulthood. The relative role of additive genetic influences remained rather stable during adolescence changing from 43% to 52%. At around age thirty additive genetic influences were also moderate, at 44%. However, the heritability estimate declined from adolescence to young adulthood to around 30%, while a slight decline was also seen in the mid-thirties, when additive genetic influences were estimated to be 34%. Shared environmental influences, in turn, also showed relative stability during adolescence, but in contrast to genetic influences, increased markedly in young adulthood, especially in women. Both shared and specific environmental influences affected leisure-time physical activity up to adulthood, but only specific environmental influences were further present in adulthood in the thirties and mid-thirties. In contrast to the consistent expression of an important group of genes observed in adulthood, new additive genetic, shared and specific environmental influences emerged at each follow-up point in adolescence and in young adulthood. Furthermore, a major result of this research was confirmation of the importance of motivation factors in separating leisure-time physical activity behavior. The motivation factors of mastery, physical fitness and psychological state were sub-dimensions that differed significantly between the consistently physically active participants and the consistently physically inactive participants. Pain, health problems, diseases and lack of time were the most often cited barriers to physical activity. However, no differences between the consistently physically active and inactive middle-aged and older co-twins in perceived barriers were observed.

6.1 Genetic influences on leisure-time physical activity

A longitudinal genetic model of leisure-time physical activity has not been implemented in many earlier studies. Although several cross-sectional twin studies have explored the genetic influences on physical activity, the results have been somewhat conflicting (de Vilhena e Santos et al. 2012). The present study of the contribution of the genetic influences on leisure-time physical activity produced results, which corroborate the findings of much of the previous work in this field, suggesting that the heritability of leisure-time physical activity behavior ranges between 27% and 71% (Kaprio et al. 1981, Aarnio et al. 1997, Beunen & Thomis 1999, Maia et al. 2002, Carlsson et al. 2006, Stubbe et al. 2006, Stubbe & de Geus 2009, Mustelin et al. 2012, Carlsson et al. 2013). In the present study, the heritability estimate of leisure-time physical activity ranged between 30% and 52% among adolescents and adults. This lends important support to the idea that leisure-time physical activity levels are moderately accounted for by genetic influences. The present results also support previous cross-sectional findings suggesting that genetic influences are relatively more prominent during adolescence than in young adulthood (van der Aa et al. 2010, Vink et al. 2011, Mustelin et al. 2012). In the present study, based on the two data sets from the younger and the older twin cohorts, genetic influences decreased as early as after the age of 18 years, but, interestingly, increased again at around age thirty, only to decrease yet again in the mid-thirties. Of course, it should be noted that the participants in these studies were not the same and the data collections took place at different time periods.

Longitudinal genetic models of leisure-time physical activity have previously been examined in only a few studies (Stubbe et al. 2005, Turner et al. 2005, Eriksson et al. 2006, van der Aa et al. 2010, Vink et al. 2011). However, the findings for genetic influences on the progress of leisure-time physical activity in these studies are also largely consistent with each other: they all reveal that the contribution of genetic influences changes with age. In particular, the findings corroborate the suggestion of Eriksson et al. (2006) that the heritability of leisure-time physical activity is reduced in young adulthood. An animal model also showed that genetic background has a highly significant influence on physical activity level, which in turn changes as a function of time (Turner et al. 2005).

In the present study, genetic influences tended to remain stable during adolescence, while fluctuations in the overall leisure-time physical activity level across time period were mostly determined by changes in environmental influences. In young adulthood, the slight decline in the heritability of leisure-time physical activity was produced by a fall in the genetic variance and an increase in the environmental variance. This might suggest a complex longitudinal mechanism, in which genetic influences are mostly sustained while environmental influences gain in strength, but with highly inconsistent effects across time. It has been shown that, before adolescence, shared family environmental influences seem to play an important role (Stubbe & de Geus 2009). In the present study, both shared and specific environmental influences were present among adolescents and young adults. However, the contribution of the shared environmental influences on leisure-time physical activity appealed to increase with age, and their contribution to leisure-time physical activity peaking by young adulthood. Among adults from around age thirty to thirty-five specific environmental influences alone gained in importance. Consequently, the present study seems to be the first to emphasize not specific but shared environmental influences on leisure-time physical activity in young adulthood. Further, some contradictory findings emerged between the studies of the present thesis. The study on adolescents and young adults showed that only a small proportion of the additive genetic influences detected at baseline were present at the last follow-up point, while among the adults in other study most of the genetic influences were sustained over time. The latter mentioned study was conducted from 1975 to 1990, while the first mentioned study data were collected between 1991 and 2002, and consequently it is possible social change over a period of 30 years altogether may have had an effect on the comparability of the two studies, even within a single country.

The estimates of additive genetic influences on leisure-time physical activity differed by gender. In particular, a clear difference was noticed among adults: the estimates were higher for men than for women at both baseline and follow-up during the 6-year study period. The additive genetic correlation for this phenotype was also greater for men than for women. In this case, genetic influences seemed to be more important in keeping men physically active in adulthood. There is also evidence to suggest that genetic influences overall may play a somewhat more important role in men's leisure-time physical activity behavior. This is explained by the fact that the genetic contribution may be higher for vigorous activity than for nonvigorous activity, as found in several studies (Kaprio et al. 1981, Lauderdale et al. 1997, Beunen & Thomis 1999), while it is known that men exercise more vigorously than women (Barnekow-Bergkvist et al. 1996). Generally, adolescence and young adulthood are periods of multiple changes in health-related behaviors. In the present study, the number of very active persons decreased during the 8-year follow-up, also confirming the earlier results of physical activity changes in adolescence and in young adulthood (Kimm et al. 2002, Dumith et al. 2011). Thus, among adolescents and young adults, we found a decrease both in genetic influences on leisure-time physical activity and in the proportion of very active participants during the 8-year follow-up. This may suggest a connection between these two factors. On the other hand, the decrease in physical activity observed during the follow-up may have other explanations. For instance, it is a known fact that a low level of physical activity and obesity are related to each other, although it is not clear which comes first. Recently, it has been suggested that obesity may be a driver of physical inactivity (Bauman et al. 2012). In general, people, including the present twins, gain in weight as they get older (Nooyens et al. 2009), which may explain the decrease in physical activity. The study by Pietiläinen et al. (2008) demonstrated that a physically inactive lifestyle triggers the development of obesity, which in turn may lead to less activity, low energy expenditure and increasing obesity again. All this may create a self-perpetuating and possibly never-ending, deleterious circle.

The gender specific analyses in the present study showed a decrease in both the number of very active men and the number of inactive women during the follow-up from adolescence to young adulthood. Probably due to this phenomenon, the sexes converged in their physical activity behavior, increasing the polychoric correlations for the DZ opposite-sex twin pairs from adolescence to young adulthood. Furthermore, differences between the sexes were observed in the genetic analyses on leisure-time physical activity. In young adulthood, the role of environmental influences was more important for women than for men. This greater role may partly be connected with the fact that the onset of adulthood brings with it different role expectations for women than for men. Although egalitarian gender role attitudes are generally prevalent, providing models for negotiating family and work, family responsibilities and childrearing nevertheless continue to be mainly performed by women (Davis & Greenstein 2009). This may partially explain the differences between physical activity behavior among men and women. Moreover, in Finland women seem to move out of the parental home earlier than men (Nikander 2009). This may also impact the role of environmental influences. The idea that environmental influences have more effect on leisure-time physical activity as people get older is not a finding from genetic studies alone. Several life events may decrease leisure-time physical activity behavior (Engberg et al. 2012), and it is generally known that major life transitions such as moving out of the parental home, starting work, entering tertiary education and the formation of new interpersonal relationships are very common in young adulthood. Such changes were not analyzed in the present thesis.

In addition to the possible connections between the proportions of very active persons, heritability of leisure-time physical activity and obesity, the heritability estimates of leisure-time physical activity obtained in the present study seem to share a tendency similar to that for heritability of self-rated health. Silventoinen et al. (2007) found that the heritability of self-rated health also declined from adolescence to young adulthood. A connection between these factors may be assumed, as the twins in both studies were originally from the same cohort. De Moor et al. (2007) confirmed that genetic influences on leisure-time exercise participation and self-rated health seem to partially overlap. According to them the association between leisure-time exercise and self-rated health can be explained by genes predisposing to both traits.

Overall, during the past decades much more information has become available on the genetics of physical activity in humans. Genetic epidemiology has moved from quantitative analyses of family data to more complex DNA analyses. Quantitative analyses have consistently showed familial and genetic influences on physical activity and related traits. The next step has been to identify the genetic loci associated with physical activity. Recently, de Vilhena e Santos et al. (2012) published a review in which they gathered together all the studies on the genetics of physical activity, also summarizing the existing literature on the genome-wide linkage studies and association studies. Linkage studies try to identify regions within the genome responsible for the variation in the physical activity phenotype and association studies test candidate genes associated with the physical activity phenotype. According to de Vilhena e Santos et al. (2012), neither the linkage studies nor the association studies have been consistent. Markers in common have not been detected across the linkage studies, but suggestive linkages have been found with markers near to several activity-related genes. In the association studies, dispersed results have shown different genes to be associated with physical activity phenotype but strong evidence focusing on a few specific genes does not exist. This is probably due to inadequate sample sizes and the variability of the phenotype in the studies to date, as large association studies in other traits have discovered thousands of genotype-phenotype links (Visscher et al. 2012). The challenge is carefully to characterize the underlying biology and functional genomics. Thus, for the reasons just mentioned, inconsistent results on the genetic variants that are putatively associated with physical activity continue to be seen.

6.2 Motives for leisure-time physical activity

In the present study, physical fitness, psychological state and enjoyment were the highest scored reasons for engaging in leisure-time physical activity. In this Finnish study, the same factors seem to be important for engagement in leisure-time physical activity among both younger and older adults in Finland. These were also the factors that the physically active participants rated higher than the physically inactive participants. In addition, the results did not substantially differ by gender. The findings of the importance of physical and psychological health as motivation factors are also in agreement with earlier findings by other researchers. Basically, health seems to be the most important motivator, regardless of age, gender or level of physical activity, of participation in physical activity (Ashford et al. 1993, Kolt et al. 2004, Dacey et al. 2008, Murcia et al. 2008, Caglar et al. 2009). It is somewhat surprising that appearance was not cited as a leading motivation factor for persons in their mid-thirties, although previous studies have indicated that appearance and body image are linked to physical activity among younger adults (Kilpatrick et al. 2005, Brudzynski & Ebben 2010).

Comparison of the physically active and physically inactive co-twins and twin individuals produced results which also corroborate the findings of the previous work in this field. Based on the literature, active persons have rated health, fitness and stress management as more meaningful motivation factors than inactive persons (Reid & McGowan 1986, Zunft et al. 1999, Trembath et al. 2002, Dacey et al. 2008). In the present study the same factors emerged, but with the addition that enjoyment, appearance, skill improvement, affiliation and competition were more important for the active than for inactive twin participants, and that skill improvement was more important for the active co-twins than inactive co-twins discordant for physical activity over 30 years. Although enjoyment was also a major motive for leisure-time physical activity, and although it has been rated differently by active and inactive persons in earlier studies (Reid & McGowan 1986, Zunft et al. 1999, Trembath et al. 2002, Dacey et al. 2008), it did not differ between the active and inactive co-twins in the present study. This is interesting, as there is evidence that people continue to engage in physical activity if they find it enjoyable (Dacey et al. 2008). According to the present study, the inactive co-twins also reported finding leisure-time physical activity enjoyable, although they had been consistently inactive for several decades.

In the present study, all the participants scored conforming to others' expectations as the least meaningful motive for leisure-time physical activity. Furthermore, the inactive co-twins and the inactive twin individuals in their mid-thirties emphasized compliance with other peoples' expectations slightly more than the active. However, the difference was statistically significant only between the consistently active and consistently inactive participants and between the consistently active and consistently inactive women, both in their mid-thirties. The measure of effect size also revealed that the difference between the groups was of low magnitude. The sub-dimension of conforming to others' expectations strongly represents the extrinsic type of motivation.

There are several theories of motivation which have relevance for participation in leisure-time physical activity. The differences between these theories are notable (Soós et al. 2007). However, after examining the association between motivation and physical activity behavior, a number of researchers have adopted a two-dimensional approach, comprising both extrinsic and intrinsic motivation (Iso-Ahola & St. Clair 2000). The Self-Determination Theory, the theoretical framework of the motivation studies in the present thesis, distinguishes between these motivational aspects. Intrinsic motivation represents the highest level of self-determinism; people pursue activities that interest them and, in which they can freely participate (Deci & Ryan 1985). Intrinsic motives are those that cause a person to be sufficiently interested in a physically active lifestyle, and value its outcomes enough to make it important in their lives (Teixeira et al. 2012). This is well in line with the present results while both the sub-dimensions of the REMM measure representing intrinsic motives, mastery and enjoyment, were significantly more important for the active than inactive twin individuals, and mastery was significantly more important for the consistently active than inactive co-twins. Extrinsic motivation refers to motivation that comes from outside the individual. These rewards provide satisfaction and pleasure that the physical activity itself may not provide. The findings of the present study corroborate the idea that chronically ill individuals, who are often advised to increase their level of physical activity, may consider external motives important. Also, while extrinsic motives may dominate during the early stages of physical activity adoption, intrinsic motives seem to be important for maintaining activity (Ryan et al. 1997, Ingledew et al. 1998, Buckworth et al. 2007).

In study III, in which twins were analyzed as individuals, the motives reported by those who remained inactive and those who changed from inactive to active during the 10-year follow-up period were compared. The results showed that the consistently physically active persons gave higher ratings for most of the motivation sub-dimensions than those who changed their leisure-time physical activity level during the follow-up. In addition, the consistently active persons gave higher ratings when they were compared to those who were physically active at the cross-sectional time point. The results also supported the view that intrinsic motivation factors are needed to induce people to be physically active, as those who increased their physical activity during the 10-year follow-up scored higher on intrinsic motivation factors at the follow-up measurement than those who were consistently inactive. All in all, the motivation factors among the groups seemed to be highly parallel, which suggests that the cross-sectional design may hint at the longitudinal results.

It is assumed that this is the first time that the REMM measure has been used in study of family members who were dissimilar for leisure-time physical activity. However, the findings revealed the same trend as the results of the other study related to REMM conducted among twin individuals. The minor difference between the results of these studies may partly be explained by the participants and partly by the study design. Also, the motives for physical activity change in their relative importance as people age. The participants of the studies are widely different in age. The genetic studies of the present thesis indicated that environmental influences on leisure-time physical activity increase with age, which may in turn influence motives. The estimation of leisure-time physical activity was based on metabolic equivalent in the present studies on motivation for leisure-time physical activity. However, for the additional analyses, physical activity and inactivity were also estimated using the frequency, intensity and duration of physical activity (results not shown). No matter which estimator of physical activity was used, the same tendency to differences in motivation factors among the different groups of participants was seen.

The difference in leisure-time physical activity between active and inactive persons in their mid-thirties (Study III) may partly be explained by the fact that the inactive persons significantly more often had poorer financial standing than the active persons. It is obvious that poor economic circumstances can restrict a person’s opportunities to be physically active in leisure-time. Because a chronic disease may also restrict the ability to engage in exercise, we excluded all persons reporting a current chronic disease; however the results remained unchanged. Surprisingly, no differences were observed in the environmental or socio-demographic factors between the active and inactive co-twins in this study, which is contrary to earlier findings (Gordon-Larsen et al. 2000) and contrary to the findings of the other study, on active and inactive persons, in the present thesis. This discrepancy may be explained by the fact that childhood socioeconomic status and family environment were the same among the active and the inactive co-twins discordant for physical activity over 30 years, suggesting that family background is not an important causal contributor to some aspects of motivation to engage in leisure-time physical activity, but rather that these motivational factors arise and are maintained after leaving the childhood home environment.

All in all, cause and effect, and the origin and background of the various phenomena related to motives and leisure-time physical activity, including the results of the present study, can only be speculated. From a broader perspective, this may have something to do with the need to feel that one has comprehensive control over one’s life and it may therefore be difficult to isolate which parts of the phenomenon are actually meaningful for leisure-time physical activity. The concept of sense of coherence has been used to explain the association between control over life and physical activity (Endler et al. 2008, Ahola et al. 2012). However, studies have also been published on the role of psychophysical influences on the motives for physical activity. Psychophysical influences may also act as a key motivator for leisure-time physical activity. For example, exercise-induced changes in mood, such as high happiness ratings, have been reported in relation to endurance training (Boecker et al. 2008). The phenomenon seems to be a consequence of alterations in endogenous opioid release (Lauenberger 2006). Opioid release has a close correlation, for example, to the euphoria reported by runners (Lauenberger 2006, Boecker et al. 2008), and thus may motivate people to engage in exercise. It can be assumed that perceived euphoria may be related to feelings of enjoyment, which was one of the main reasons for leisure-time physical activity reported by the participants in the present study. Unfortunately, the pursuit of euphoria can sometimes lead to harmful states such as exercise addiction (Lauenberger 2006, Landolfi 2013), which is one of the regrettable sides of leisure-time physical activity.

6.3 Barriers to leisure-time physical activity

The major perceived barriers mentioned among Europeans are work or study commitments and the belief that one is not a sporty type (Zunft et al. 1999). However, these factors were not found to differ between the active and inactive co-twins discordant for physical activity over 30 years in the present study. In addition, lack of time has been one of the main barriers in several studies (Reichert et al. 2007, Ebben & Brudzynski 2008). This was also noted in the present study among the middle-aged and older twins. The inactive co-twins did not find lack of time a significantly greater hindrance to their activity level than did their active co-twins, which is in line with previous findings among active and inactive participants (Ebben & Brudzynski 2008). Interestingly, Leyk et al. (2012) suggested that the lack of time may be the most frequently reported barrier as it is a simple, straightforward and socially acceptable answer.

Furthermore, and surprisingly, the results of the present study indicate that barriers to leisure-time physical activity do not explain the differences between persistent activity levels. Previous studies have shown that perceived barriers to physical activity differ between inactive and active persons, and hence it was hypothesized in the present study that barriers would differ between twins discordant for leisure-time physical activity behavior for 30 years as well. However, these results might also be interpreted as emphasizing the importance of the role of the motives for engaging in persistent physical activity reported by active vs. inactive persons. It should also be noted, in relation to barriers, that the twins examined in the present study were middle-aged and older, which may have had an effect on the results. Among younger twins, the results may have been different, as in younger age groups there are more potential work and family commitments to hinder leisure-time physical activity than in older age groups.

6.4 Methodological considerations

Comparison between the studies that have been published in the topic area of the present thesis may be difficult because of the many differences in study designs and study parameters. Both the discrepancies between heritability estimates of leisure-time physical activity and the differing results of the existing studies on the motives for and barriers to leisure-time physical activity may partially be explained by differences in the samples used. Both human and animal studies have been conducted, sample sizes vary widely, samples comprise different age, sex and ethnic groups, and the possibility of genetic differences between the populations investigated should also be noted. Socio-cultural background may also have an influence on study results. Further, studies differ in the methods used to capture physical activity, in the type of activities studied, and in the definitions of physical activity applied, such as daily physical activity, leisure-time physical activity, sports participation, and exercise participation. The terms physical activity and exercise are often used interchangeably even though the term exercise is a subcategory of the concept of physical activity. These definitions may assess slightly different aspects of self-chosen physical activity and may have an effect on the study results, mainly because the genetic contribution may be different for different intensity levels of physical activity (Kaprio et al. 1981, Lauderdale et al. 1997, Beunen & Thomis 1999), and that motives and barriers may differ by level of physical activity as well. The comparability of studies with slightly different definitions of physical activity is neither reliable nor valid and it may be confusing. Nevertheless, the number of the studies in the research area of this thesis, especially studies concerning genetic influences on leisure-time physical activity, is relatively few, and for this reason the results of all the relevant studies on leisure-time physical activity, even where the precise definition of physical activity is unknown, are reported and compared in the thesis. With respect to the present study, it is important to know that in Finnish, which is the language used in the physical activity questionnaires, the word "liikunta" translates equally as both physical activity and exercise.

All the present studies, except for one study, are based on twin analyses. This raises the issue of whether twins are representative of the general population. It is known that twins are often born premature and hence lower in weight than average singleton newborns (Phillips 1993, Buckler & Green 2004, Loos et al. 2005), but catch up on growth quickly and show at most only minor differences in their anthropometric characteristics by the end of puberty compared to singletons. Twins share the same womb and are thus exactly the same age, and because they are the same age they tend to be in the same school, maybe in the same class, and share many of the same peers. Twins may be even dressed similarly. Thus, this may cause twins to be more alike than non-twin siblings. Moreover, there is a moderate volume of published studies on the role of the relationship between birth weight and leisure-time physical activity (Andersen et al. 2009, Kajantie et al. 2010, Kaseva et al. 2012). These studies have shown that low birth weight is associated with lower levels of physical activity in adulthood. All these factors may potentially limit the generalizability of twins on the population level.

In the present study, subjects with overt chronic diseases were excluded, which should have minimized the possibility of the influence on diseases on the level of leisure-time physical activity reported by the participants. Thus, the results of the present research can be generalized only to healthy people. In the main analysis of study III, only the extremes of the study population were taken into account. This may affect the generalizability of these results. In addition, loss of participants is a concern, as this can affect the generalizability of the findings. In the older Finnish Twin Cohort, 89% of the invited twins answered the questionnaire in 1975 and 84% in 1981. Among the twin participants in the FinnTwin16 study, the response rate was not lower than 72% in any of the five waves. Hence, the loss of participants in the present research seems to be within reasonable bounds.

A key strength of the present study is the use of longitudinal designs, especially the longitudinal co-twin control design. Longitudinal studies are useful for investigating the predictors of physical activity as they may capture a true aging effect (Vink et al. 2011). Although many previous studies have examined genetic and environmental influences on leisure-time physical activity, longitudinal data have been used on only a few occasions. However, a longitudinal design is strongly recommended due to the possibly limited period of time during which genetic influences that vary over the course of an individual's life can be detected (Boomsma et al. 2002). In addition, the study of the longitudinal evolution of leisure-time physical activity behavior from adolescence to young adulthood yielded new information on genetic and environmental influences during a specific part of the life course. The fact that data on specific age groups were available presented a first-class opportunity to investigate age-specific influences on change in leisure-time physical activity. Several previous studies have examined both motives for and barriers to leisure-time physical activity. Nevertheless, this issue has not previously been examined among twins, and longitudinal data have not been used either, not to mention a longitudinal study design among consistently physically active or inactive participants. Few studies, in fact, have compared motives between active and inactive persons. In the present study, both the examination of physical activity-inactivity among twin pairs and the 30-year duration of activity monitoring provided new information on motivational dimensions and barriers. A longitudinal design offers a unique opportunity to examine the relationship between these factors.

A further strength of the present studies, except for the co-twin control design study, concern the adequacy of the size of the study samples. The sample sizes were big enough to capture differences between the genetic and environmental influences in the studies using quantitative genetic methods, and also between the groups of active and inactive persons in the study on motivation for leisure-time physical activity. In study IV, which used a co-twin control design, sample size was small, which meant relatively low statistical power to detect small differences between the active and inactive co-twins. This small sample size is explained by the strict criterion for activity discordance: the extremely rare situation of twin pairs discordant for leisure-time physical activity behavior over 30 years. Despite the fact that consistently different leisure-time physical activity levels are common, they are less commonly found among co-twins of a twin pair, even in adulthood. Furthermore, the fact that it was difficult to locate a substantial numbers of twin pairs significantly discordant for leisure-time physical activity itself speaks for a genetic or familial basis for lifetime activity patterns. No data from population-level samples have previously been published that describe how a big a proportion of singletons are consistently physically active or inactive during leisure-time over a period as long as 30 years.

Among the main potential limitations of the present study is the use of self-reported questionnaire data to estimate leisure-time physical activity level and motives for and barriers to leisure-time physical activity, as these may be unreliable and lack validity. A recent systematic review revealed that only very few physical activity questionnaires show good results on reliability and validity (Helmerhorst et al. 2012). Although the validity of the physical activity questionnaire used has been demonstrated (Kaprio et al. 1978, Sarna et al. 1978, Kujala et al. 1998, Waller et al. 2008), the possibility of errors cannot be avoided when using such a non-objective instrument. It should be noted that the purpose of the questions related to physical activity was to reflect voluntary leisure-time physical activity as a lifestyle, not objectively to assess the total level of physical activity. However, the fact that all self-reports are prone to various kinds of reporting and social desirability bias means that measurement errors may also explain a small part of the results. In genetic models, measurement error is subsumed into the specific environmental component of the variance.

A further limitation may be the wide age range of the sample used in the genetic modeling study among adults (Study IV). If the data set had been divided into different age groups, this may have produced some age-specific results, but there are no natural ages at which to divide adults according to overall leisure physical activity. In addition, the questionnaire used to determine the level of leisure-time physical activity was not specific to any age group; instead, the results described a general level of leisure-time physical activity irrespective of age. The key limitation of the genetic study among younger twins was related to the outcome measure. Physical activity is a complex trait, and limiting the assessment of physical activity to frequency is not the most optimal way to measure physical activity behavior. However, frequency of physical activity was the only variable for which longitudinal data were available to assess leisure-time physical activity in the present study. The use of MET values to measure the intensity of leisure-time physical activity can also be criticized. It is reasonable to assume that the MET value for the intensity of walking, for example, may be very different for a young healthy man than for an elderly women with a chronic disease. Thus, the use of non-interchangeable MET values for every participant may be productive of bias caused by for over- or underestimation (Jetté et al. 1990, Byrne et al. 2005, Kozey et al. 2010). Ideally, the characteristics of an individual should be taken into consideration when describing physical activity based on MET intensity classifications (Kozey et al. 2010). However, the questionnaire for every participant was exactly the same, giving each the same opportunity to self-rate the intensity of their physical activity. Thus, the results can be considered comparable.

The reliability and validity of the original REMM questionnaire and the Finnish version of the original measure have been demonstrated (Rogers & Morris 2003, Pajunen 2004). However, this has not been done for the modified version of the REMM used in study III. The use of eight single-item sub-dimensions instead of the original 73-item REMM questionnaire may limit validity and induce bias, even though the single item sub-dimensions used are the larger sub-dimensions of the original REMM questionnaire. Thus, the modified measure is very close to the original questionnaire, and it may be assumed that the validity of the measure used is reasonable, although it has not been proven. Furthermore, the modified version of the REMM may not be as sensitive as the original version of the REMM to the differences between the groups of active and inactive persons. Although no differences between the sexes were found using the modified version of the REMM, it is possible that used of a more multifaceted and a more sensitive questionnaire may have revealed differences between men and women. Unfortunately, the use of the modified version of the measure was forced, because the space available for the question was restricted by the multi-item online questionnaire used. Furthermore, comparison between the original and modified versions of the REMM measure may be questionable. The questionnaire on barriers included items that were relevant on the basis of earlier studies (Zunft et al. 1999, Sörensen 2005, Allender et al. 2006, Reichert et al. 2007, Ebben & Brudzynski 2008), but the questionnaire was not validated. The non-validated questionnaire may not be sensitive enough to show differences in barriers between physically active and physically inactive co-twins. The stem “I exercise…” was used in the REMM to introduce the items. It is also questionable how appropriate this stem is for inactive participants who are not exercising. Thus, phrasing of the stem may have an effect on results of the REMM presented in the present thesis.

6.5 Implications and future directions

Overall, the present study contributes to the evidence on age-specific genetic and environmental influences on leisure-time physical activity. It deepens understanding of why some people fail to engage in regular, consistent leisure-time physical activity. The outcomes indicate that variations in environmental factors are the key element in understanding the deterioration observed in leisure-time physical activity levels. The results of this thesis also revealed differences in motivation factors for leisure-time physical activity between consistently physically active and inactive persons, supporting the view that intrinsic motivation factors are needed to induce people to be physically active in their leisure-time. In addition to the importance of the role of motives, evidence on the relatively minor role of barriers to engagement in physical activity was found in middle-aged and older persons.

Many important factors thought to predispose people to be physically active or inactive were clarified or strengthened by the present studies. However, more research is needed. Because physical activity seems to be regulated by environmental, genetic and biological aspects, both individual factors and multilevel ecological models should be used when leisure-time physical activity or physical inactivity are studied. In general, future studies should focus on the interaction of genes, family environment, and later developmental factors, using large samples. Genetic studies should consider more precisely the age of the sample when investigating genetic variants mediating longitudinal leisure-time physical activity. Clinically, understanding the relative role of stable genetic and changing environmental influences on leisure-time physical activity is a key to better focused health promotion. Measures promoting leisure-time physical activity may be even more important for women than for men, because of the greater role of environmental influences in women. A prerequisite for better focused health promotion is an understanding of the role of increasing environmental influences and the role of actions targeted at promoting physical activity during critical periods of life. Public health promoters and health policy makers should see the transitional period from adolescence to young adulthood as a strategic point to stimulate leisure-time physical activity that would also lead to an active lifestyle in later adulthood. Earlier physically active lifestyle during leisure-time has been shown to be an important predictor of later leisure-time physical activity (Borodulin et al. 2012).

Generally, in future studies sports and behavioral sciences research should be linked. For example, the identification of signs that may be important predictors of the implementation of a physically active lifestyle would be worthwhile. To achieve successful physical activity interventions, it would be important to find out what, if any, indicators predict the adoption of a physically active lifestyle. Furthermore, motivation studies should clarify how peoples' motives, especially intrinsic motives can be influenced, and whether these influences are different for physically active and inactive persons. Extrinsic motives, such as other peoples' expectations, may be temporarily important for physically inactive persons, but in the long term, intrinsic motives need to be present to induce a consistent physical activity habit. This was shown in the present study, where those who increased their physical activity level during the 8-year follow-up scored higher on intrinsic motivation factors at the follow-up measurement than those who were consistently inactive. Thus, research on how to arouse intrinsic motivation among inactive persons, and how to encourage inactive persons to exercise consistently would be welcomed. This would be important area of future research, since while we know that increasing one's level of physical activity has beneficial effects on cardio-metabolic risk, only a small proportion of the individuals who are a focus of clinical interventions actually do this (Kujala et al. 2011). Moreover, care should be taken in generalizing the present findings on motives and barriers to consistently active and inactive persons who are not twins.

Clinically, the suggestion of the present research that intrinsic motivation factors are needed to induce people to be physically active should be taken into account in health education situations and in physical activity guidance where inactive people are counseled to be physically active. Instead of the traditional advice-based health education individuals should be helped to clarify their personal values and to take action on them, giving reasons and making their behavior more meaningful. In short, counseling methods, which are able to promote intrinsic motivation, are needed.

7 CONCLUSIONS

The main findings and conclusions of the present thesis are:

1. Genetic influences on leisure-time physical activity were rather stable during adolescence (ages from ~16 to ~18 years), finally declining in young adulthood. In contrast, shared environmental influences increased by young adulthood, especially in women. Only a small proportion of the genetic influences detected at baseline in adolescents were present at the last follow-up point in young adults at age ~25 years.

2. In healthy adults in their thirties, genetic influences on leisure-time physical activity were moderate. These influences declined somewhat during the 6-year follow-up among both sexes. Genetic influences between the time points were highly correlated, suggesting that a relatively small proportion of new effects emerged with age.

3. Greater importance was attributed to mastery, physical fitness, and psychological state as motives for leisure-time physical activity by the consistently physically active co-twins and twin individuals than their consistently physically inactive co-twins and twin individuals. Moreover, motives related to appearance, enjoyment, willingness to be fitter or look better than others and the social aspect of physical activity were more important for the consistently physically active than consistently physically inactive twin individuals in their mid-thirties. Gender-specific differences were not revealed.

4. Conforming to others’ expectations as a motive for leisure-time physical activity was the least meaningful motive for all the participants.

YHTEENVETO (FINNISH SUMMARY)

Vapaa-ajan liikunta-aktiivisuuden yhteys geneettisiin ja ympäristötekijöihin sekä motivaatioon kaksosilla

Liikkuminen ylläpitää ihmiselimistön fyysistä ja psyykkistä terveyttä monin tavoin. Liikunnalla on osoitettu olevan positiivisia vaikutuksia esimerkiksi useiden pitkäaikaissairauksien ehkäisyssä ja hoidossa sekä ennenaikaisen kuoleman riskin alentamisessa. Näiden positiivisten vaikutusten saavuttamiseksi liikunnan tulisi olla määrältään riittävää ja säännöllisesti toistuvaa. Vaikka monet edellä mainituista liikunnan eduista ovat yleisesti tiedossa, useat ihmiset liikkuvat aivan liian vähän. Viimeisten vuosikymmenten aikana ihmisten päivittäisen fyysisen aktiivisuuden määrä on laskenut erityisesti työssä tapahtuvan fyysisen aktiivisuuden vähennyttyä. Tästä syystä vapaa-ajalla tapahtuvan liikunnan merkitys terveyttä edistävänä ja ylläpitävänä tekijänä korostuukin nykypäivänä.

Useat eri tekijät määrittävät ihmisten liikunta-aktiivisuuden tasoa, minkä vuoksi liikunta-aktiivisuutta kutsutaankin monitekijäiseksi ominaisuudeksi. Ainakin perimän, ympäristötekijöiden ja biologisten ominaisuuksien tiedetään vaikuttavan yksilön liikunta-aktiivisuuden tasoon. Myös näiden tekijöiden yhteisvaikutuksella saattaa olla ratkaiseva merkitys liikunta-aktiivisuuteen. Vaikka liikunta-aktiivisuuden taustalla vaikuttavia tekijöitä ja niiden selitysosuuksia selvittäviä tutkimuksia on tehty paljon, toistaiseksi ei ole yksiselitteisesti pystytty määrittämään mistä yksilöiden väliset erot liikunta-aktiivisuudessa johtuvat. Perimän ja geenien osuutta on tutkittu yhä enenevässä määrin. On tärkeää huomioida, että liikkumattomuus ei aiheuta yksilöille ainoastaan terveydellisiä ongelmia vaan myös yhteiskunnallisesti merkittäviä taloudellisia kustannuksia, jotka näkyvät lisääntyneinä sairaudenhoito- ja lääkemenoina. Tämän vuoksi olisi ensiarvoisen tärkeää saada lisätietoa siitä miksi toiset ihmiset liikkuvat ja toiset eivät.

Vaikka liikunta-aktiivisuuteen yhteydessä olevia tekijöitä on kaiken kaikkiaan pyritty selvittämään varsin kattavasti, ei pitkittäisseurantoihin tai kaksosaineistoihin perustuvia tutkimuksia ole tehty juurikaan. Pitkittäistutkimusten etuna ovat sekä iän vaikutuksen huomiointi että mahdollisten syy-seuraus -suhteiden havaitseminen. Kaksostutkimus sen sijaan mahdollistaa liikunta-aktiivisuuteen vaikuttavien taustatekijöiden kuten perimän ja ympäristötekijöiden osuuksien erittelyn luonnon omaa tutkimusasetelmaa, kahdenlaista kaksosuutta, hyväksikäyttäen. Kaksostutkimuksen periaatteisiin perustuvat myös kvantitatiivisen genetiikan tutkimusmenetelmät. Kvantitatiivinen genetiikka tutkii kuinka paljon yksilöiden väliset erot geneettisissä ja ympäristötekijöissä selittävät väestöllistä vaihtelua liikunta-aktiivisuudessa.

Myös motivaatiolla on todettu olevan suuri merkitys yksilön liikuntakäyttäytymiselle. Liikunnallisesti aktiivisten ja liikkumattomien henkilöiden välisistä eroista liikuntamotivaatiotekijöissä tiedetään kuitenkin toistaiseksi varsin vähän, vaikka liikuntamotivaatio saattaa olla yksi merkittävä avaintekijä selittämään ihmisten vapaa-ajan liikunta-aktiivisuutta. Lisätieto sekä pitkittäisaineistoilla tutkituista geneettisten ja ympäristötekijöiden vaikutuksista vapaa-ajan liikunta-aktiivisuuteen että mahdollisista säännöllisesti liikkuvien tai liikkumattomien välillä olevista liikuntamotivaatioiden eroista on tarpeen, jotta ymmärrettäisiin miksi toiset ihmiset epäonnistuvat säännöllisen liikuntaharrastuksen omaksumisessa.

Tämän väitöskirjatutkimuksen tarkoituksena oli valottaa liikunta-aktiivisuuden ja liikkumattomuuden taustalla piileviä tekijöitä. Tutkimus pyrki selvittämään geneettisten ja ympäristötekijöiden osuuksia vapaa-ajan liikunta-aktiivisuuden vaihtelua selittävinä tekijöinä kahden pitkittäisseurannan avulla. Lisäksi väitöskirjatutkimus käsittelee useita vuosia jatkuneen vapaa-ajan liikunta-aktiivisuuden tai liikkumattomuuden ja motivaatiotekijöiden välisiä yhteyksiä sekä kaksoskohortista valituilla yksilöillä että kaksospareilla. Kaksosparien jäsenet ovat eronneet liikunnan harrastamisen suhteen yli 30 vuoden ajan. Lisäksi yhdessä väitöskirjan osatyössä tutkittiin liikuntaa rajoittavia tekijöitä kaksospareilla.

Aineistoina tässä tutkimuksessa käytettiin sekä Nuorten Kaksosten Terveystutkimusta että vanhempaa Suomen Kaksoskohorttia. Geneettisten ja ympäristötekijöiden osuuksia selvitettäessä tutkittavina oli alkutilanteessa 5 216 nuorten kohorttiin kuulunutta tervettä kaksosta (keski-ikä 16,2 vuotta) ja 13 556 vanhempaan kohorttiin kuulunutta tervettä kaksosta (keski-ikä 29,6 vuotta). Seurantajaksojen päättyessä 4 531 nuorta (keski-ikä 24,5 vuotta) ja 13 822 aikuista (keski-ikä 35,6 vuotta) geneettisesti identtistä ja ei-identtistä kaksosta olivat mukana tutkimuksessa. Liikuntaan liittyviä motivaatiotekijöitä tutkittiin Nuorten Kaksosten Terveystutkimukseen osallistuneella 2 308 kaksosella (keski-ikä 33,9 vuotta). Motivaatiotekijöitä tutkittiin myös 16 kaksosparilla (keski-ikä 60,4 vuotta), jotka oli rekrytoitu vanhemmasta kaksoskohortista TWINACTIVE-alatutkimukseen heillä ilmenneen yli 30 vuoden liikunnan harrastuksen eroavaisuuden vuoksi. Näillä TWINACTIVE-tutkimukseen osallistuneilla tutkittiin myös liikunnan harrastamista rajoittavia tekijöitä. Vapaa-ajan liikunta-aktiivisuutta arvioitiin joko liikunnan energiankulutusta kuvaavalla MET-arvolla (MET tuntia/päivä) tai vapaa-ajan liikunnan useutena. Vapaa-ajan liikuntamotivaatiota arvioitiin REMM-kyselyn (Recreational Exercise Motivation Measure) avulla. Liikuntaa rajoittavia tekijöitä puolestaan arvioitiin 25-kohtaisella strukturoidulla kyselyllä. Tilastolliset analyysit perustuivat kvantitatiivisen genetiikan mallinnuksiin sekä parittaisiin ja yksilötason analyyseihin.

Geneettisten tekijöiden osuus väestötasolla vapaa-ajan liikunta-aktiivisuuden vaihtelua selittävänä tekijänä vaihteli 43 %:n ja 52 %:n välillä nuoruudessa (16 vuodesta 18 vuoteen) laskien nuoressa aikuisiässä noin 30 %:iin (ikä noin 25 vuotta). Geneettisten tekijöiden havaittiin olevan kolmenkymmenen ikävuoden tietämillä lähes samalla tasolla kuin nuoruudessa; väestön liikunta-aktiivisuudesta 44 % selittyi yksilöiden välisillä geneettisillä eroilla. Tämä osuus kuitenkin laski seuranta-ajan kuluessa ja oli kuuden vuoden kuluttua 34 %. Ainoastaan pieni osuus niistä geneettisistä tekijöistä, jotka selittivät liikunta-aktiivisuuden vaihtelua 16 vuoden iässä, selittivät sitä myös nuoressa aikuisiässä. Kolmenkymmenen ikävuoden kohdalla liikunta-aktiivisuutta selittävät geneettiset tekijät puolestaan korreloivat voimakkaasti 36 ikävuoden seuranta-aikaan. Sisaruksille yhteisten ympäristötekijöiden merkitys liikunta-aktiivisuuden vaihtelua selittävänä tekijänä pysyi vakaana nuoruudessa, mutta niiden osuus kasvoi nuoressa aikuisiässä, erityisesti naisilla. Ilmiö on päinvastainen kuin geneettisillä tekijöillä. Sekä yhteiset että yksilölliset (ei sisaruksen kanssa jaettavat) ympäristötekijät selittivät nuoreen aikuisikään asti liikunta-aktiivisuuden vaihtelua. Kolmenkymmenen ikävuoden jälkeen enää vain yksilölliset ympäristötekijät selittivät geneettisten tekijöiden kanssa liikunta-aktiivisuuden vaihtelua kvantitatiivisen genetiikan mallissa.

Omien taitojen kehittämiseen, fyysiseen kuntoon, ja psyykkiseen hyvinvointiin liittyvät motivaatiotekijät olivat säännöllisesti yli 30 vuoden ajan liikkuneille kaksosparien jäsenille tilastollisesti merkitsevästi tärkeämpiä motivaatiotekijöitä kuin saman ajan liikkumattomina olleille kaksosparien jäsenille. Näiden lisäksi ulkonäköön, liikunnasta nauttimiseen, sosiaaliseen kanssakäymiseen ja muiden kanssa kilpailuun liittyvät liikuntamotivaatiotekijät olivat tilastollisesti merkitsevästi tärkeämpiä motivaatiotekijöitä 34-vuotiaille noin 10 vuoden ajan säännöllisesti liikkuneille henkilöille kuin saman ajan pysyvästi liikkumattomina olleille henkilöille. Muiden ihmisten odotusten mukaisesti toimiminen oli vähiten tärkeä motivaatiotekijä kaikille tutkittaville. Se oli myös ainut vapaa-ajan liikuntaan motivoiva tekijä, jonka pysyvästi liikkumattomat arvioivat hieman tärkeämmäksi motivaatiotekijäksi kuin säännöllisesti liikkuvat, vaikkei ero aina ollut tilastollisesti merkitsevä. Kipu, sairaudet ja ajanpuute olivat tutkittavien esille nostamista vapaa-ajan liikuntaa rajoittavista tekijöistä tärkeimpiä. Nämä tekijät eivät kuitenkaan eronneet keski-ikäisillä ja vanhemmilla yli 30 vuoden ajan eri tavalla liikkuneiden kaksosparien jäsenillä.

Tämän tutkimuksen tulosten perusteella voidaan päätellä, että vapaa-ajan liikunta-aktiivisuuteen yhteydessä olevien geneettisten ja ympäristötekijöiden selitysosuudet vaihtelevat iän myötä. Tämä vaihtelu geneettisten ja ympäristötekijöiden osuuksissa näyttäisi selittävän myös seurannan aikana havaittua vapaa-ajan liikunta-aktiivisuuden vaihtelua. Liikuntamotivaatio-tekijöihin liittyvät tulokset puolestaan vahvistivat aiempia käsityksiä siitä, että sisäisillä motivaatiotekijöillä olisi tärkeä merkitys säännöllisen ja pitkään jatkuvan vapaa-ajan liikunta-aktiivisuuden toteutumisessa.

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APPENDIX 1

Original leisure-time physical activity questions. Questions are translated from Finnish.

How much of your daily journey to work/study is spent in walking, cycling, running and/or cross-country skiing? (Finnish Twin Cohort and FinnTwin16 study)
1 less than 15 min
2 15 min to less than half an hour
3 half an hour to less than one hour
4 one hour or more
5 I am presently not at work/studying

How often do you exercise/engage in physical activity during your leisure time? (FinnTwin16 study)
1 not at all
2 less than once a month
3 1–2 times a month
4 once a week
5 2–3 times a week
6 4–5 times a week
7 about every day

How often do you exercise/engage in physical activity during your leisure time? (Finnish Twin Cohort)
1 less than once a month
2 1–2 times a month
3 3–5 times a month
4 6–10 times a month
5 11–19 times a month
6 more than 20 times a month

Is your physical activity during leisure time about as tiring on average as: (Finnish Twin Cohort and FinnTwin16 study)
1 walking
2 alternatively walking and jogging
3 jogging (light run)
4 running

How long does one session of the physical activity last on average? (Finnish Twin Cohort)
1 less than 15 min
2 15 min to less than half an hour
3 half an hour to less than one hour
4 one hour to under two hours
5 two hours or more

How long does one session of physical activity last on average? (FinnTwin16 study)
1 less than 30 min
2 half an hour to less than one hour
3 one hour to less than two hours
4 two hours or more

APPENDIX 2

Recreational Exercise Motivation Measure (REMM)

In responding to the following statements, think of the motives you have for the exercise activities you do. Try not to spend time pondering over your responses There are no right or wrong answers. Indicate how much your motives correspond with each of the statements by circling one of the numbers one to five on the scale beside each statement. In each case 1 indicates strongly disagree and 5 indicates strongly agree.

I exercise…	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
1. to maintain current skill level.	1	2	3	4	5
2. because I like activities that are challenging.	1	2	3	4	5
4. because I get rewarded for doing it.	1	2	3	4	5
5. because it is something I have in common with my friends.	1	2	3	4	5
6. because exercise helps keep my mind healthy.	1	2	3	4	5
7. to meet new people.	1	2	3	4	5
8. to do more for my fitness than other people.	1	2	3	4	5
9. because friends want me to.	1	2	3	4	5
10. because the activities I do are exciting.	1	2	3	4	5
11. because I want to cope better with stress.	1	2	3	4	5
12. because doing exercise helps me maintain a healthy body.	1	2	3	4	5
13. to improve my appearance.	1	2	3	4	5
14. to improve my strength.	1	2	3	4	5
15 to make my muscles look better.	1	2	3	4	5
16. because I like the physical challenges.	1	2	3	4	5
17. to perform well compared to my own past performance.	1	2	3	4	5
18. to obtain new skills or try new activities.	1	2	3	4	5
19. because it keeps me healthy.	1	2	3	4	5
20. because exercise is stimulating.	1	2	3	4	5
21. because after exercise I feel good about myself.	1	2	3	4	5
22. because doing exercise helps me achieve other things in life.	1	2	3	4	5
23. because it acts as a stress release.	1	2	3	4	5
24. because exercise helps improve my mental health.	1	2	3	4	5
25. to make new friends.	1	2	3	4	5
26. to achieve an exercise goal I have set myself.	1	2	3	4	5
27. because someone close to me approves	1	2	3	4	5
of my exercise activities.	1	2	3	4	5
28. to improve my body shape.	1	2	3	4	5
29. because it helps me gain status or recognition.	1	2	3	4	5
30. because exercise helps me take my mind off other things.	1	2	3	4	5
31. to be physically fit.	1	2	3	4	5
32. because it helps me relax.	1	2	3	4	5
33. because doing exercise stops me from feeling depressed.	1	2	3	4	5
34. to improve cardiovascular fitness.	1	2	3	4	5

35. because I like to win.	1	2	3	4	5
36. because it makes my physical appearance better than others.	1	2	3	4	5
37. to talk with friends while I exercise.	1	2	3	4	5
38. because I am required to stay fit for my job.	1	2	3	4	5
39. because it helps me manage a medical condition.	1	2	3	4	5
40. to do an activity with others.	1	2	3	4	5
41. to improve existing skills.	1	2	3	4	5
42. to have more energy.	1	2	3	4	5
43. to be attractive to others.	1	2	3	4	5
44.. to compete with others around me.	1	2	3	4	5
45. because it is fun.	1	2	3	4	5
46. to earn a living.	1	2	3	4	5
47. to beat my friends.	1	2	3	4	5
48. because I enjoy exercising.	1	2	3	4	5
49. to be the best in the group.	1	2	3	4	5
50. to work harder than others when I exercise.	1	2	3	4	5
51. because it helps me maintain a trim, toned body.	1	2	3	4	5
52. because it is interesting.	1	2	3	4	5
53. to improve my skill or technique.	1	2	3	4	5
54. to achieve the looks/figure others expect of me.	1	2	3	4	5
55. because I have a goodtime.	1	2	3	4	5
56. because it helps me stay in shape.	1	2	3	4	5
57. to be with friends.	1	2	3	4	5
58. to lose weight to look better.	1	2	3	4	5
59. because it makes me happy.	1	2	3	4	5
60. because I get paid to do it.	1	2	3	4	5
61. to be fitter than others.	1	2	3	4	5
62. because exercise lessens the physical effects of ageing.	1	2	3	4	5
63. to make my muscles look more toned than other people's.	1	2	3	4	5
64. to make my body look better than other people’s.	1	2	3	4	5
65. to get away from pressures at work/home.	1	2	3	4	5
66. because people tell me I need to exercise.	1	2	3	4	5
67 because I enjoy spending time with others doing exercise.	1	2	3	4	5
68. because I like the excitement of participation.	1	2	3	4	5
69. to maintain strength.	1	2	3	4	5
70. to maintain physical health.	1	2	3	4	5
71. to get better at an activity.	1	2	3	4	5
72. because it is prescribed by my doctor, physiotherapist.	1	2	3	4	5
73. to perform better than others.	1	2	3	4	5

Do you have any motives for exercise that are not included in the above statements? Please write them here.

APPENDIX 3

Recreational Exercise Motivation Measure (REMM) modified version

In responding to the following statements, think of the motives you have for the exercise activities you do. Try not to spend time pondering over your responses There are no right or wrong answers. Indicate how much your motives correspond with each of the statements by circling one of the numbers one to five on the scale beside each statement. In each case 1 indicates strongly disagree and 5 indicates strongly agree.

I exercise…	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
1. to improve my skills and/or get better at an activity.	1	2	3	4	5
2. to have a good time and I enjoy exercising.	1	2	3	4	5
3. to be with friends and/or do activity with others.	1	2	3	4	5
4. because I get rewarded for doing it.	1	2	3	4	5
5. to conform to others' expectations.	1	2	3	4	5
6. to be physically fit.	1	2	3	4	5
7. to improve my psychological state.	1	2	3	4	5
8. to maintain/improve my appearance and body shape.	1	2	3	4	5

APPENDIX 4

Questionnaire for barriers to leisure-time physical activity

Which of the possible factors described below hinder your leisure-time physical activity (such as walking, jogging, gymnastic, swimming etc.)? Please, answer by circling all of the alternatives you find as a barrier to being physically active in your leisure time.

1. I feel in too much pain to exercise.
2. Poor health and/or disease make it difficult for me to exercise.
3. Poor eyesight makes it difficult for me to exercise.
4. Fear of falling makes it difficult for me to exercise.
5. Fear of injuries makes it difficult for me to exercise.
6. It feels uncomfortable to exercise.
7. I feel too old for exercise.
8. Health care workers have told me not to exercise.
9. I do not have time to exercise.
10. I am not interested in exercise.
11. I have other pleasant hobbies.
12. I dislike exercise alone.
13. I feel unsafe when I exercise outdoors.
14. I am not used to exercise.
15. I do not know why I should exercise.
16. I do not know where to go to exercise.
17. Poor weather conditions rule out exercise.
18. Places for me to exercise are not very pleasant.
19. Places for me to exercise are too far away.
20. Exercise tires me.
21. I do not have skills to exercise.
22. Exercising is too expensive.
23. Lack of proper equipments makes it difficult for me to exercise.
24. Some other reason not mentioned earlier_______________________________
25. There is no reason for me not to engage in exercise.

Now we ask you to choose and write the numbers of the most important barriers to physical activity on the following lines. Do not list more than the three most important barriers.

______________ ______________ _____________