

Department of Public Health  
University of Helsinki

# **LEISURE ACTIVITIES AND OBESITY IN ADOLESCENCE -**

## **A FOLLOW-UP STUDY AMONG TWINS**

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ACADEMIC DISSERTATION

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## ABSTRACT

The aims of this dissertation were 1) to investigate associations of weight status of adolescents with leisure activities, leisure activity patterns, and computer and cell phone use, and 2) to investigate environmental and genetic influences on body mass index (BMI) during adolescence.

A population-based sample of Finnish twins born in 1983–1987 was assessed at the ages of 11-12, 14, and 17 years by postal questionnaires. The twins' parents also responded at baseline. At 11-12 years, 5184 (92%) of the twins responded to the questionnaire and at 17 years, 4168 (74%) of the twins still participated. BMI (weight/height<sup>2</sup>) was computed from self-reported weight and height. Information was obtained by questionnaires on leisure activities including television viewing, video viewing, computer games, listening to music, board games, musical instrument playing, reading, arts, crafts, socializing, clubs, sports, and outdoor activities, as well as computer use hours, home computer ownership, and amount of a monthly cell phone bill. The relationship between individual leisure activities, as well as leisure activity patterns, and being overweight was investigated using multiple logistic and linear regression. Activity patterns were studied using latent class analysis. Genetic and environmental effects on BMI and BMI phenotypic correlations across adolescence were studied using twin modeling and quantitative genetic analysis methods based on structural equation modeling.

When individual leisure activities were analyzed, sports were associated with decreased risk of being overweight among boys in both cross-sectional and longitudinal analyses, but among girls only cross-sectionally. Many sedentary leisure activities, such as video viewing (boys/girls), arts (boys), listening to music (boys), crafts (girls), and board games (girls), had positive associations with being overweight in cross-sectional and/or longitudinal analyses. Time spent using a home computer was associated with higher prevalence of overweight and cell phone use had a weak positive correlation with BMI among both boys and girls in cross-sectional analyses. However, musical instrument playing, commonly considered as a sedentary activity, was associated with a decreased risk of overweight among adolescent boys. Some of the associations between leisure activities and overweight risk are thus probably not explained solely by direct effects of leisure activities on energy expenditure but also by different lifestyles related to them.

Four patterns of leisure activities were found: 'Active and sociable', 'Active but less sociable', 'Passive but sociable', and 'Passive and solitary'. The prevalence of overweight was highest among the 'Passive and solitary' boys at 11-12 and 14 years and girls at 11-12 years. Overall, leisure activity patterns did not predict the risk of being overweight later in adolescence. An exception were 14-year-old 'Passive and solitary' girls who had the greatest risk of becoming overweight by 17 years of age although the prevalence of overweight did not differ between leisure activity patterns in cross-sectional analyses.

Heritability of BMI was estimated to be high (0.58-0.83). Common environmental factors shared by family-members affected the BMI at 11-12 and 14 years but their effect was no longer discernible at 17 years of age. Additive genetic factors explained 90-96% of the BMI phenotypic correlations across adolescence and unique environmental factors explained the rest. Genetic correlations across adolescence were high, which suggests similar genetic effects on BMI throughout adolescence, while unique environmental effects on BMI appeared to vary at different phases of adolescence.

These findings suggest that family-based interventions hold promise for obesity prevention into early and middle adolescence, but that later in adolescence obesity prevention should focus on individuals rather than families. A useful target could be adolescents' leisure time, and our findings highlight the importance of versatility in leisure activities.

## TIIVISTELMÄ

Tämän väitöskirjatyön tavoitteina oli 1) selvittää harrastusten, harrastusprofiilien ja tietokoneen sekä matkapuhelimen käytön yhteyksiä nuorten painoon ja 2) selvittää ympäristötekijöiden ja perinnöllisten tekijöiden suhteellista vaikutusta painoindeksiin nuoruusiässä.

Väestöpohjainen otos vuosina 1983-1987 syntyneitä, suomalaisia kaksosia vastasi postikyselyihin 11-12-, 14- ja 17-vuotiaana. Myös heidän vanhempansa vastasivat kyselyyn tutkimuksen alussa. Kaksosista 5184 (92%) palautti kyselylomakkeen 11-12-vuotiaana ja vielä 17-vuotiaanakin mukana oli 4168 eli 74% kaksosista. Painoindeksi (paino/pituus<sup>2</sup>) laskettiin kaksosten itsensä ilmoittamien painojen ja pituuksien perusteella. Kyselylomakkeissa tiedusteltiin television katselun, videoiden katselun, tietokonepelien pelaamisen, musiikin kuuntelun, lautapelien pelaamisen, soittoharrastuksen, lukemisen, piirtämisen tai maalaamisen, kavereiden kanssa ajanvieton, kerhossa tai partiossa käymisen, urheilun ja ulkoilun yleisyyttä sekä tietokoneen käyttötunteja, tietokoneen omistamista ja kuukausittaisen puhelinlaskun suuruutta. Näiden sekä harrastusprofiilien yhteyksiä ylipainoisuuteen tutkittiin logistisilla ja lineaarisilla regressiomalleilla. Harrastusprofiileja tutkittiin käyttäen latenttiluokka-analyysiä. Ympäristötekijöiden ja perinnöllisten tekijöiden vaikutuksia painoindeksiin ja painoindexikorraatioihin eri ikäpisteiden välillä tutkittiin kaksosmallinnuksella lineaariseen rakenneyhtälömallinnukseen perustuvien kvantitatiivisen genetiikan menetelmien avulla.

Yksittäisiä harrastuksia tarkasteltaessa urheilu oli yhteydessä pienempään ylipainoisuuden riskiin pojilla sekä poikkileikkaus- että pitkittäisasetelmissä mutta tytöillä vain poikkileikkausasetelmassa. Useat fyysisesti passiiviset harrastukset, kuten videoiden katselu (pojat/tytöt), piirtäminen tai maalaaminen (pojat), musiikin kuuntelu (pojat), käsityöt (tytöt) ja lautapelien pelaaminen (tytöt) olivat yhteydessä suurempaan ylipainoisuuden riskiin poikkittäisissä ja/tai pitkittäisissä analyyseissä. Tietokoneen käyttö oli yhteydessä suurempaan ylipainoisuuden esiintyvyyteen ja kännykän käytöllä oli heikko positiivinen korrelaatio painoindexin kanssa tytöillä ja pojilla poikkileikkausasetelmassa. Yllättäen soittoharrastus, joka nähdään fyysisesti passiivisena ajanviettotapana, oli kuitenkin pojilla yhteydessä pienempään ylipainoisuuden riskiin. Tämä viittaa siihen, että kaikki harrastusten ja ylipainoisuuden väliset yhteydet eivät välttämättä selity ainoastaan harrastusten suorilla vaikutuksilla energian kulutukseen vaan myös erilaisilla harrastuksiin liittyvillä elämäntavoilla.



Analyyseissä löytyi neljä erilaista harrastusprofiilia: ‘Aktiivinen ja sosiaalinen’, ‘Aktiivinen mutta vähemmän sosiaalinen’, ‘Passiivinen mutta sosiaalinen’ ja ‘Passiivinen ja yksinäinen’. Ylipainoisuus oli yleisintä ‘passiivisilla ja yksinäisillä’ pojilla ja 11–12-vuotiailla tytöillä. Yleisesti ottaen eri harrastusryhmiin kuuluminen ei kuitenkaan ennustanut myöhempää ylipainoisuuden riskiä. Poikkeuksena olivat 14-vuotiaat tytöt, joilla ylipainoisuuden vallitsevuudessa ei ollut eroja eri harrastusryhmien välillä, mutta kaikkein passiivisimpaan ja yksinäisimpään ryhmään kuuluvilla tytöillä oli suurin ylipainoiseksi tulemisen riski 14–17-vuotiaana.

Painoindeksin periytyvyysaste arvioitiin korkeaksi (0.58-0.83). Yhteiset eli perheensisäiset ympäristötekijät vaikuttivat painoindeksiin 11–12- ja 14-vuotiaana, mutta eivät enää 17-vuotiaana. Additiiviset geneettiset tekijät selittivät 90-96% painoindeksikorrelaatioista eri ikäpisteiden välillä yksilöllisten ympäristötekijöiden selittäessä loput. Painoindeksin geneettiset korrelaatiot eri ikäpisteiden välillä olivat korkeita, mikä viittaa siihen, että painoindeksiin vaikuttavat geneettiset tekijät olivat samankaltaisia eri ikäpisteissä kun taas yksilölliset ympäristötekijät muuttuivat nuoruuden aikana.

Nämä löydökset viittaavat siihen, että perheisiin kohdistuvilla interventioilla on onnistumisedellytyksiä nuorten lihavuuden ehkäisyssä ainakin murrosiän keskivaiheeseen asti, mutta murrosiän loppuvaiheesta lähtien lihavuuden ehkäisyohjelmat kannattaisi suunnata nuoriin yksilöinä eikä heidän perheisiinsä. Yksi kohde voisi olla nuorten vapaa-ajan vietto: tutkimuksen tulokset korostavat monipuolisen vapaa-ajanvieton tärkeyttä.

## ABBREVIATIONS

A	Additive genetic effect
ACE	A model containing additive genetic, common and unique environmental effects
ADE	A model containing additive and dominant genetic and unique environmental effects
BMI	Body mass index
C	Common environmental effect
CI	Confidence interval
CT	Computerized axial tomography
D	Dominant genetic effect
DEXA	Dual-energy x-ray absorptiometry
d.f.	Degrees of freedom
DZ	Dizygotic
E	Unique environmental effect
FTO	Fat mass and obesity associated (gene)
GNPDA2	Glucosamine-6-phosphate deaminase 2 (gene)
GxE	Genotype-environment interaction
GWA	Genome-wide association (study)
KCTD15	Potassium channel tetramerisation domain containing 15 (gene)
LCA	Latent class analysis
LDL	Low-density lipoprotein
MZ	Monozygotic
MC4R	Melanocortin 4 receptor (gene)
MRI	Magnetic resonance imaging
MTCH2	Mitochondrial carrier homolog 2 (gene)
N (or n)	Number of participants
NEGR1	Neuronal growth regulator 1 (gene)
OS	Opposite-sex
OSDZ	Opposite-sex dizygotic
OR	Odds ratio
PCSK1	Prohormone convertase 1/3
PDS	Pubertal development scale
r	Correlation coefficient
rGE	Genotype-environment correlation
SD	Standard deviation
SES	Socio-economic status

SH2B1	SH2B adaptor protein 1 (gene)
TMEM18	Transmembrane protein 18 (gene)
WHO	World Health Organization
$\chi^2$	Chi-squared

## LIST OF ORIGINAL PUBLICATIONS

The thesis is based on the following original publications, which are referred to in the text by their Roman numerals (I-V).

I. Nuorten harrastukset ja niiden yhteydet ylipainoisuuteen 14- ja 17-vuotiailla. Lajunen H-R, Keski-Rahkonen A, Pulkkinen L, Rissanen A, Kaprio J. *Sosiaalilääketieteellinen aikakauslehti*. 2004;41:276-288.

II. Are computer and cell phone use associated with body mass index and overweight? A population study among twin adolescents. Lajunen H-R, Keski-Rahkonen A, Pulkkinen L, Rose RJ, Rissanen A, Kaprio J. *BMC Public Health*. 2007;7:24.

III. Leisure activity patterns and their associations with overweight: a prospective study among adolescents. Lajunen H-R, Keski-Rahkonen A, Pulkkinen L, Rose RJ, Rissanen A, Kaprio J. *J Adolesc*. 2009;32:1089-1103.

IV. Genetic and environmental effects on body mass index during adolescence: a prospective study among Finnish twins. Lajunen H-R, Kaprio J, Keski-Rahkonen A, Rose RJ, Pulkkinen L, Rissanen A, Silventoinen K. *Int J Obes*. 2009;33:559-567.

V. Genetic influences on the difference in variability of height, weight and body mass index between Caucasian and East Asian adolescent twins. Hur Y-M, Kaprio J, Iacono WG, Boomsma DI, McGue M, Silventoinen K, Martin NG, Luciano M, Visscher PM, Rose RJ, He M, Ando J, Ooki S, Nonaka K, Lin CCH, Lajunen H-R, Cornes BK, Bartels M, van Beijsterveldt CEM, Cherny SS, Mitchell K. *Int J Obes*. 2008;32:1455-1467.

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# 1 INTRODUCTION

About 10% of the world's school aged children were obese or overweight based on surveys conducted between 1990 and 2003, and the prevalence was on the rise in most countries (Lobstein et al., 2004). In Finland, the prevalence of overweight among 13-year-olds has increased from 6-7% to 12-17% in less than 20 years (Välilä & Ojala, 2004). This development has led to many health problems, including type 2 diabetes, previously considered an adults' disease, which has started to occur among youngsters. For instance, impaired glucose tolerance was found in 21-25% of obese American children and adolescents and 4% of the adolescents had previously undiagnosed type 2 diabetes (Sinha et al., 2002). Childhood obesity is also associated with other cardiovascular risk factors (Lobstein et al., 2004) and appears to have a direct association with increased risk of coronary heart disease in adulthood (Baker et al., 2007). In addition to its many somatic health risks, childhood and adolescent obesity also leads to psychological and social problems (Regan & Betts, 2006).

Although fundamentally obesity is a result of excess energy intake in relation to energy expenditure and that required for growth, the underlying mechanisms are complex. It is commonly thought that the process is initiated by increased energy intake or by decreased physical activity, but surprisingly this has proved difficult to substantiate. It has even been speculated that the process could be initiated by adipose tissue actively enhancing the amount of energy stored as fat, with increased energy intake and/or decreased physical activity being merely consequences of the actions of adipose tissue (Sørensen, 2009). However, this highly speculative theory could well prove even more difficult to substantiate.

Genetic factors have a significant role in the etiology of obesity: they explain much of the variation in relative weight during childhood and adolescence (Maes et al., 1997). The effect of genetic factors on body mass index was even shown to increase with age from 4 to 11 years in a British study (Haworth et al., 2008b). The sole longitudinal study of adolescents of both genders (Cornes et al., 2007) was unable to confirm that the increase in heritability continues beyond childhood. A meta-analysis of eight twin studies (both cross-sectional and longitudinal) conducted among children and adolescents estimated the heritability of BMI to be lowest in mid-childhood but to increase in adolescence (Silventoinen et al., 2009a).

Common environmental factors shared by family members have also affected BMI in childhood (Koeppen-Schomerus et al., 2001; van Dommelen et al., 2004; Silventoinen

et al., 2007a; Haworth et al., 2008a; Haworth et al., 2008b; Wardle et al., 2008a), but the effect has not been evident in adulthood (Maes et al., 1997). It is not clear when the common environmental effect disappears, although it decreased by age from 4 to 11 years (Haworth et al., 2008b) and the meta-analysis estimated that it would disappear after 13 years (Silventoinen et al., 2009a).

Despite the high heritability of BMI, environmental factors must also play a role in the obesity epidemic - based on current knowledge, gene distribution cannot have changed as rapidly as the obesity epidemic has spread. Some genetic factors may also act by predisposing people to certain environmental factors. Most of the discovered monogenetic defects leading to obesity appear to be neuroendocrine in nature and to affect feeding behavior (Blakemore & Froguel, 2008). *FTO*, the first gene found to affect BMI at a population level, has been hypothesized to affect food intake or satiety (Cecil et al., 2008; Timpson et al., 2008; Wardle et al., 2008b; Wardle, 2009), and six new loci preliminarily found to be associated with BMI are also highly expressed or known to act in the central nervous system (Willer et al., 2009). Thus, genetic and environmental factors affecting BMI cannot be considered as totally independent entities but they interact and correlate with each other.

If the relationship between genetic and environmental factors is complex, the actions and interactions of environmental factors are even more so. Television viewing has been hypothesized to increase body weight by displacing more physically active leisure interests and by increasing snacking and intake of energy-dense foods (Robinson, 2001). The protective effect of physical exercise (Reichert et al., 2009) is more straightforward, but what makes some people go to the gym and others to stay watching television is not known. At the individual level, explanations may lie in psychology, personal values, or a particular lifestyle. At the population level, the causes for different eating and exercise patterns may be cultural or related to common values and lifestyles in a society. Society also affects individuals' choices by offering or restricting options for healthy behavior. For instance, a parent cannot choose to take a child to a playground instead of letting a child to watch television indoors if there are no playgrounds and the streets are full of traffic. Similarly, healthy foods are not an option if local stores do not stock them, or if they are too expensive for most people to afford. The diversity of influences on the selection and pricing of foods or on the built environment and so on leads to the conclusion that the causes of obesity can also be economic, political, or environmental.

Our prospective, population-based sample of Finnish twins offered us a unique opportunity to concentrate on some specific environmental factors not extensively

studied in relation to obesity – leisure activities and leisure activity patterns thought to represent different lifestyles – as well as genetic and environmental factors affecting BMI in general. The findings of this study could be useful in the design of interventions to prevent obesity, by helping to evaluate the magnitude of their possible effects on BMI and to focus them on specific population groups particularly prone to obesity.

## 2 REVIEW OF THE LITERATURE

### 2.1 TWIN STUDIES IN MEDICAL RESEARCH

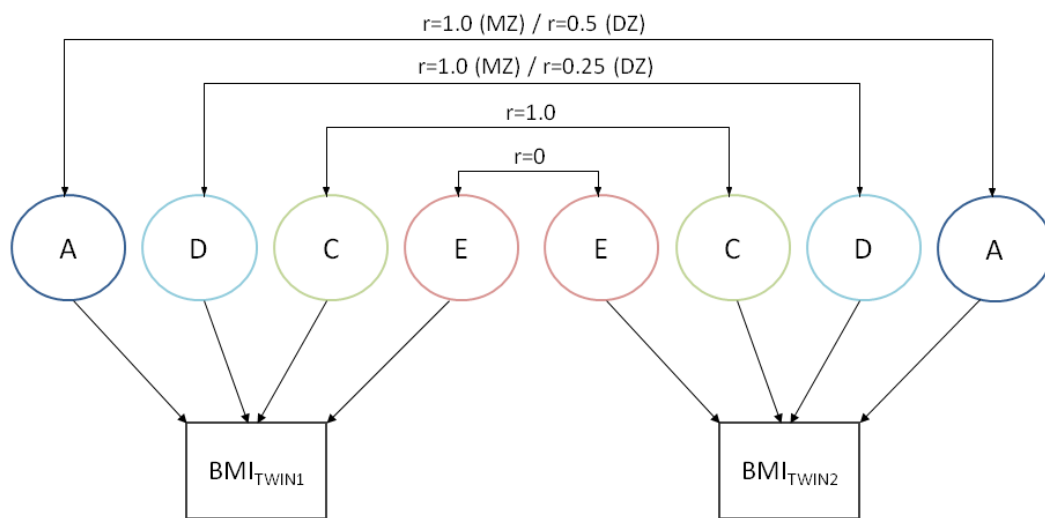
Twins offer many unique opportunities for medical research (Boomsma et al., 2002). The classical twin analysis estimates the proportions of phenotypic variation explained by genetic and environmental factors by comparing monozygotic (MZ) with dizygotic (DZ) twins.

A major difference between MZ and DZ twins is that MZ twins are genetically identical whereas DZ twins share, on average, half of their segregating genes. This means that if a trait is genetically determined, MZ twins within twin pairs will resemble each other more than DZ twins. Genetic effects can be divided into additive (A), dominant (D), and epistatic effects. An additive genetic effect means that the effect of the two individual gene alleles at a locus is simply the sum of their individual effects. A dominant genetic effect means that the effect of a heterozygotic allele combination deviates from the mean effect of the homozygotic allele combinations. Epistasis refers to interaction between alleles at different loci. A correlation for genetic effects is always 1.0 within MZ twin pairs, but within DZ twin pairs it is 0.5 if the genetic effects are purely additive and 0.25 if the genetic effects are purely dominant. (Posthuma et al., 2003). Epistatic effects are not parameterized in twin models but they are modeled as part of a dominance genetic effect if the loci are not linked, and as part of additive genetic factors if the loci inherit together due to a close linkage between them.

Members of a twin pair who are reared together resemble each other because they share their genes but also part of their environment. The part of the environment that is shared within twin pairs and makes co-twins similar to each other is called the common environment. Common environmental factors are assumed to affect both MZ and DZ twins to the same extent. The correlation of common environmental effects (C) between members of a twin pair is 1.0 in both MZ and DZ twin pairs. There are also environmental factors not shared by co-twins called unique environmental factors (E). This component also includes measurement error in twin analyses. The correlation for these effects is, by definition, 0 within both MZ and DZ pairs. In addition to an assumption of equality of C for MZ and DZ pairs, classical twin models assume random mating. The effects of gene-environment interactions and correlations cannot be estimated in classical twin models. (Posthuma et al., 2003), but it is possible to study them separately with special models.



In classical twin modeling the total variance of a phenotype is divided to four variance components caused by the above mentioned four different types of factors: additive genetic (A), dominant genetic (D), common environmental (C), and unique environmental (E) factors. The variance components of a phenotype (in this case BMI) and correlations between them within a twin pair are shown schematically in Figure 1 (adjusted from Neale & Cardon, 1992). The magnitude of variance components A, E, and either C or D can be estimated when employing a design including MZ and DZ twins reared together. When data from opposite-sex pairs are available, the presence of genetic effects specific to one gender can be tested (Neale & Cardon, 1992). Finding significant gender-specific genetic effects indicates that genetic factors are somewhat different between males and females. Opposite-sex (OS) pairs also enable estimation of gender differences in the magnitude of variance components or if the proportions of the total variance explained by genetic and environmental factors differ between males and females (Neale & Cardon, 1992).



Abbreviations:

MZ=monozygotic

A=additive genetic component

C=common environmental component

BMI<sub>TWIN1/2</sub>=body mass index in twin1 or twin2

DZ=dizygotic

D=dominant genetic component

E=unique environmental component

r=correlation

**Figure 1: Variance components of a phenotype (BMI) and the correlations between the components within MZ and DZ twin pairs.**

Classical twin studies can be extended to multivariate analyses which make it possible to explore causes of co-morbidity of two or more traits, to test if there is interaction between genotype and environment, and to analyze causes of phenotypic stability or change over time in longitudinal analyses (Boomsma et al., 2002).

There are also many other applications of twin studies. Co-twin control studies explore cases and controls of MZ twin pairs discordant for a trait or a disease. This can be very useful because MZ twins are perfectly matched for genes and family background. Studying gene expression in discordant MZ twins can, for example, reveal which changes in gene expression are consequences rather than causes of a disease (Boomsma et al., 2002).

Extended twin studies include twins and their families. Including parents, spouses, siblings, or offspring of MZ twins makes it possible to study cultural transmission, genetic and environmental stability, assortative mating, special twin effects, maternal effects, genotype-environment correlation, and imprinting (Boomsma et al., 2002).

Twins are valuable in molecular genetic studies, too. Genotyping of MZ twins can help detect variability genes and to estimate penetrance. Genotyping of DZ twins can help to estimate associations within and between families and to detect linkage with a quantitative trait loci. Selecting informative families can help to find quantitative trait loci of small effects (Boomsma et al., 2002).

## **2.2 PSYCHOSOCIAL DEVELOPMENT FROM 11 TO 17 YEARS**

Children change a lot both physically and psychologically during the period lasting from 11 to 17 years of age. Children at the age of 11-12 years are, according to Freud's theory of psycho-sexual development (Freud, 1940/1964), at the end of the 'latency period' lasting from 6 to 12 years. During this period sexual desires are hidden and psychic energy is channeled into constructive, both intellectual and social activities (Siegler et al., 2006). According to the theory of Erik H. Erikson (Erikson, 1963; Erikson, 1968) one of the main tasks at this stage is to develop a positive impression of one's own abilities at home, school and in peer groups (Siegler et al., 2006). Leisure activities may aid this development by strengthening both operational and social abilities as well as by nurturing the feeling of competence (Nurmi et al., 2006). Children still identify themselves with the same-sex parent, and the parents and school environment have an important role in the development (Dunderfelt, 1998).

Adolescence is a period from age 12/14 years to 20/25 years. According to the psycho-sexual development theory (Freud, 1940/1964) it is defined as the 'genital stage' of development. The sexual energy that has been hidden surfaces and gets to be directed toward opposite-sex peers. According to Erikson's theory (Erikson 1963, Erikson 1968) the main task during adolescence and early adulthood is to achieve a core sense of identity. Adolescents have to resolve who they really are and what they want to do in their lives. (Siegler et al., 2006). They have to gain independence from the parents, learn to get into more mature social relationships, and eventually start an independent life of their own. (Dunderfelt, 1998; Nurmi et al., 2006).

In early adolescence (13-16 years) main focus is in human relationships. Adolescents protest against the rules of their parents and other authorities and peers become very important. Peers may act as surrogate objects for parents and help in that way gaining independence from the parents. (Dunderfelt, 1998; Nurmi et al., 2006). In middle adolescence (16-19 years) a main focus is in finding one's own identity. Self-concept becomes clearer during this phase, youngsters look for their boundaries and may engage in their first serious relationships (Dunderfelt, 1998). Especially when moving from early to middle adolescence young people's independence in decision making increases (Nurmi et al., 2006). In late adolescence (19-20/25 years) a main task is to find one's own ideology. Young people hopefully calm down and find their own place in a society. (Dunderfelt, 1998).

## **2.3 OBESITY IN CHILDHOOD AND ADOLESCENCE**

### **2.3.1 Prevalence and assessment**

#### ***Measurement of body composition***

Obesity is defined as excess of body fat that presents a health risk (WHO, 2006). Unfortunately, adiposity is difficult to measure: even dual-energy x-ray absorptiometry (DEXA) and isotope dilution, which are among the most accurate measures, give slightly different results (Regan & Betts, 2006). Methods used to estimate body composition are listed in Table 1.

**Table 1: Methods for estimating body composition (Malina, 2004)**

Method	Basis
Dual-energy x-ray absorptiometry (DEXA)	Attenuation of a low-dose X-ray beam as it passes through different tissues of the body.
Isotope dilution	Differences in water content between specific tissues. Measurement of total body water content based on volume and concentration of an isotope tracer.
Underwater weighing or gas displacement	Density differences of specific body tissues and measured whole body density.
Bioelectrical impedance analysis	Differences in electrical conductivity between fat and fat-free mass.
Measurement of body potassium	Differences in potassium content between muscle and fat mass. Measurement of gamma emissions of potassium-40 isotope.
Magnetic resonance imaging (MRI)	Differences in water content between specific tissues. Hydrogen protons (of water molecules) align in a magnetic field. A specific radio frequency changes their alignment, and when they change back, they emit energy which can be detected.
Computerized axial tomography (CT)	Digitally processed large series of two-dimensional X-ray images taken around a single axis of rotation.
Anthropometry	Measurements of skin fold thickness as indicators of subcutaneous adipose tissue.

Most of these methods are too laborious, expensive, and time-consuming for population level screening or for epidemiological studies (Cole, 2006). Moreover, the application of these methods to children and adolescents is not straightforward because the assumptions underlying the methods are based on adults. Children's body density also varies during childhood and adolescence and there are gender differences (Malina et al., 2004). Males tend to have higher body densities because they have a lower percentage of body fat. This difference is clear from 5-6 years of age onwards (Malina et al., 2004). The percentage of body fat increases rapidly during infancy among both genders and then declines during early childhood. It increases gradually through adolescence among girls, whereas among boys relative fatness increases gradually until just before the adolescent growth spurt and then declines until about 16-17 years of age, followed by another increase (Malina et al., 2004).

### ***Definitions based on weight and height***

For practical reasons, obesity definitions based on weight and height are commonly used in population studies. To take into account the effect of height on weight several methods have been used. The simplest one is weight-for-height ratio, but because it is highly correlated with height it is not the best one (Michielutte et al., 1984).

The Benn index ( $\text{weight}/\text{length}^p$ ), where the exponent  $p$  varies with gestation or age, and the ponderal index ( $\text{weight}/\text{length}^3$ ) have been used mainly to estimate birth weight adjusted for length (Cole et al., 1997). Body mass index (BMI,  $\text{weight}/\text{height}^2$ ,  $\text{kg}/\text{m}^2$ ) is the most common measure of obesity in epidemiological studies among older children, adolescents, and adults. It is almost independent of height among adults (Malina et al., 2004) but among children BMI shows some residual correlation with height (Michielutte et al., 1984). Therefore the Benn index ( $\text{weight}/\text{height}^p$ ) with the exponent  $p$  varying from 2.0-3.5 could be more appropriate for children under 16 years of age (Franklin, 1999). A non-constant exponent of height varying with age would, however, be difficult and too complicated to use. Residual correlation between BMI and height means that taller children are more easily considered as obese (Franklin, 1999). True positive rates of BMI for a high percentage of body fat measured with DEXA varied between 0.67-0.83 and false positive rates between 0.03-0.13 among children and adolescents (Lazarus et al., 1996; Sardinha et al., 1999). Thus, the majority of children defined as overweight based on BMI are genuinely overweight, but some overweight children may not be detected when using BMI (Lobstein et al., 2004).

BMI increases from birth to 1 year of age and starts to decline thereafter. After reaching the nadir at 5 to 6 years, it increases steadily during childhood and then rapidly during adolescence, when sexual maturation and a physical growth spurt occur. The development of BMI is also different among boys and girls, particularly during puberty. Therefore, a single cut-off point is not feasible for defining overweight among children and adolescents. (Malina et al., 2004). A workshop on childhood obesity concluded that, regardless of its limitations, BMI may be an appropriate method for defining obesity among children because it has been validated against measurements of body density, and there is a pressing need for a consistent and pragmatic definition of childhood obesity (Bellizzi & Dietz, 1999).

Among adults, a BMI ( $\text{kg}/\text{m}^2$ ) of 25 or above is defined as overweight and a BMI of 30 or above as obesity. These are clinically significant figures because mortality has been found to be lowest at BMIs of 22.5-25 (Prospective Studies Collaboration,

2009), or at 25.3 among men and 24.3 among women (Pischon, 2008), and to increase at higher BMI levels (WHO, 1995; Pischon et al., 2008; Prospective Studies Collaboration, 2009) among adults.

Among children and adolescents health risks are not as easy to define because of low morbidity and mortality. Investigating associations with adult morbidity and mortality requires long follow-up times and is confounded by the tracking of BMI from adolescence to adulthood (Yang et al., 2007). Positive associations between adolescent overweight and risk of mortality among men (Must et al., 1992) as well as between the BMI of 7-13-year-olds and adult risk of coronary heart disease (Baker et al., 2007) and between the childhood BMI and the risk of young adult-onset diabetes (Lammi et al., 2009) have been found. Several overweight and obesity definitions (most based on BMI) have been used in the literature but they are not based on mortality or morbidity analyses. Some of them are presented in Table 2.

In Finland, the definitions for childhood overweight and obesity in clinical use are based on the weight-for-height measure. Pre-school-age children are defined as being overweight if they weigh over +10-+20% of the mean weight of children of the same age, height and gender in the Finnish reference data. School-age children are defined as being overweight if they weigh over +20-+40% of the mean weight in the reference data. Obesity is defined as weight-for-height over +20% for pre-school-age children and over +40% for children of school-age. After height growth has ceased, adult definitions based on BMI are recommended for defining adolescents as being overweight or obese (Salo et al., 2005).

Local definitions of overweight and obesity are not practical for scientific use because they do not allow comparison of results between different countries. International Obesity Task Force gender- and age-specific BMI cut-offs for overweight and obesity according to Cole et al. have been used increasingly since their release in 2000 (Cole et al., 2000). These values are based on an international sample of children and adolescents and the cut-off curves were mathematically fitted to pass the adult obesity and overweight cut-offs at 18 years of age. Their relation to long-term morbidity and mortality still waits to be established although their existence is a vast improvement on the earlier situation of various local definitions.

**Table 2: Various overweight and obesity definitions based on weight and height**

Reference	Age	Reference data	Overweight definition	Obesity definition
Must et al., 1991a & b	6 months-74 years	U.S. National Health and Nutrition Examination Survey I (NHANES I) collected in 1971-74 (Must et al, 1991 a & b).	'Obesity' 85-95th percentile of BMI for age, gender, and ethnicity.	'Superobesity' over 95th percentile of BMI for age, gender, and ethnicity.
Himes & Dietz, 1994	10-20 years	U.S. National Health and Nutrition Examination Survey I (NHANES I) collected in 1971-74 (Must et al., 1991 a & b).	BMI at or above the 95th percentile of BMI for age and gender or over 30 kg/m <sup>2</sup> . 'At risk for overweight' 85th-95th percentile and below 30 kg/m <sup>2</sup> .	...
Ogden et al., 2002	2-19 years	Year 2000 Centers for Disease Control and Prevention growth charts for the U.S (Kuczmarski et al., 2002).	BMI at or above the 95th percentile of BMI for age and gender. 'At risk for overweight' 85th-95th percentile.	...
WHO, 1995	10-18 years	U.S. National Health and Nutrition Examination Survey I (NHANES I) collected in 1971-74 (Johnson et al., 1981; Must et al. 1991 a & b) or a local reference data	'At risk for overweight' BMI at or above 85th percentile of BMI for age and gender.	BMI at or above 85th percentile and both subscapular and triceps skinfold thicknesses at or above 90th percentile for age and gender.
WHO, 1995	0-10 years	US National Center for Health Statistics – the NCHS/WHO reference (Waterlow et al., 1977; WHO, 1983)	Weight-for-height over + 2 SD.	...
WHO (de Onis et al., 2007)	5-19 years	Smoothed BMI for age SD curves based on U.S. National Health Examination Survey (NHES II and III) and U.S. National Health and Nutrition Examination Survey (NHANES I) data (Hamill, 1977)	No new definition for overweight but BMI +1 SD at 19 years is very close to adult definition of overweight (25 kg/m <sup>2</sup> ).	No new definition for obesity but BMI +2 SD at 19 years is very close to adult definition of obesity (30 kg/m <sup>2</sup> ).
Cole et al., 2000		Nationally representative samples from Brazil, Great Britain, Hong Kong, Netherlands, Singapore, United States (Cole, 2000)	Averaged age- and gender-specific BMI centiles corresponding to prevalence of adult overweight (BMI at or above 25 kg/m <sup>2</sup> )	Averaged age- and gender-specific BMI centiles corresponding to prevalence of adult obesity (BMI at or above 30 kg/m <sup>2</sup> )

### ***Prevalence of overweight and obesity***

The combined prevalence of overweight and obesity (defined according to Cole et al., 2000) among school aged children was 25.5% in Europe (Wang & Lobstein, 2006) but varied between countries (Jackson-Leach & Lobstein, 2006) in surveys between 1992 and 2003. It was 27.7% in Americas in 1988-2002 but only 1.6% in Africa at the same time (Wang & Lobstein, 2006). The prevalence of childhood obesity was 5.4% in European children and adolescents, 9.6% among Americans, and 0.2% in Africa (Wang & Lobstein, 2006). The prevalence increased in most countries from the 1970s to the end of the 1990s among school aged children (Lobstein et al., 2004; Wang & Lobstein, 2006). Even the rate of annual change in the prevalence of childhood overweight was found to be increasing when several European surveys were analyzed in 2006 (Jackson-Leach & Lobstein, 2006).

In Finland the development has been similar although obesity prevalence among children and adolescents has not been systematically monitored at the population level and most of the data available are based on self-report. Over the period 1979 to 2005 the combined prevalence of overweight and obesity (based on self-reported weight and height) increased among 12-18-year-old Finnish boys from 7-8% to 20-27% and among girls from about 4-6% to 13-18% based on the 'Adolescent Health and Lifestyle Survey' (Kautiainen et al., 2009). The youngest age cohorts (12-year-olds) had the highest prevalence of overweight and obesity throughout the whole time period (Kautiainen et al., 2009). According to the 'Health Behavior in School-aged Children Study' (HBSC), 7% of Finnish boys and 6% of girls aged 13 years were overweight in 1984 based on self-reported weight and height, while the corresponding figures were 17% and 12% in 2002, respectively. In 15-year-olds the prevalence increased from 8% to 18% among boys and from 3% to 9% among girls between 1984 and 2002 (Välimaa & Ojala, 2004). By 2006 the prevalence had increased further to 20% among boys and to over 10% among girls (Ojala et al., 2006). In the 1966 Northern Finland birth cohort, the prevalence of overweight (including obesity) based on self-report was 8% at 14 years among boys and 6% among girls, while the measured prevalence among children born 20 years later was 16% at 15-16 years among boys and 14% among girls (Laitinen & Sovio, 2005). It seems that the prevalence of overweight and obesity among adolescents has increased two-to-three fold in Finland over the last two or three decades. To inform of recent developments obesity prevalence should be constantly monitored and instead of merely weight and height, more data on children's and adolescents' body compositions should also be acquired.



### 2.3.2 Consequences of childhood obesity

Childhood obesity can cause problems in many organ systems during childhood and adolescence (Lobstein et al., 2004; Regan & Betts, 2006). Some of these are listed in Table 3. Obesity in adolescence has also been associated with increased adult coronary heart disease risk (Baker et al., 2007) and increased mortality in adulthood among men (Must et al., 1992). Higher BMI at the BMI rebound has been associated with increased risk of young adult-onset type 2 diabetes (Lammi et al., 2009).

**Table 3: Somatic consequences of childhood obesity**

Organ system	Consequences
Endocrine	insulin resistance/impaired glucose tolerance type 2 diabetes hypercortisolism polycystic ovary syndrome menstrual abnormalities earlier puberty in girls delayed puberty and gynecomastia in boys advanced bone age
Cardiovascular	increase in left ventricular mass hypertension raised cholesterol, LDL, triglycerides
Pulmonary	reduction in functional residual capacity impairment of diffusion capacity restrictive defect obstructive changes obstructive sleep apnea
Gastrointestinal	non-alcoholic fatty liver disease gallstones gastro-esophageal reflux
Orthopedic	Blount's disease (tibia vara) slipped capital femoral epiphysis tibial torsion flat feet ankle sprains
Neurological	idiopathic intracranial hypertension

Childhood obesity is also related to psychosocial problems. Obese children may be the object of weight-based stigmatization, teasing and bullying, not only by their peers but also by teachers and parents (Puhl, 2007). Obesity may also be associated with body dissatisfaction, lower self-esteem, and depression, but the findings are not unequivocal (Wardle, 2005). Some studies have shown inverse associations between cognitive/academic abilities and obesity (Li, 1995; Mo-suwan, 1999) but the causal

direction of the relationship is not clear (Puhl & Latner, 2007). A recent study of a large sample of 10-11-year-olds included academic performance, self-esteem and obesity status as well as other factors in a structural equation model and found that obesity was associated independently with lowered self-esteem. An association of obesity with lowered academic performance was detected but was mediated by other factors (Wang & Veugelers, 2008). The consequences of adolescent obesity may even carry into adulthood: weight status in adolescence was negatively correlated with earnings in young adulthood (Sargent & Blanchflower, 1994; Puhl & Latner, 2007) and obese 18-year-old men were more likely to move downwards and less likely to move upwards in the social hierarchy by age 30 than their normal weight peers (Karnehed et al., 2008).

## **2.4 FACTORS PREDISPOSING TO OBESITY**

### **2.4.1 Growth and developmental patterns**

Several studies suggest a relationship between birth weight and later obesity. Most report a direct, positive relationship (Oken & Gillman, 2003; Rogers, 2003; Adair, 2008) and some a U-shaped one (Rogers, 2003; Lobstein et al., 2004) with the highest risk among those with the lowest and the highest birth weights. Some studies suggest that while the relationship between birth weight and BMI may be direct, the relationship between birth weight and abdominal obesity is U-shaped (Rogers, 2003; Tian et al., 2006). Rapid weight gain during the first months of life also increases the risk of obesity (Baird et al., 2005), even independently of birth weight, gestational age, weight at 1 year, and maternal BMI and education (Stettler et al., 2002; Lobstein et al., 2004). Particularly infants with low birth weight who undergo early postnatal catch-up growth may be at risk for later obesity (Lobstein et al., 2004; Dunger & Ong, 2006).

The second increase of BMI at the age of 5-7 years is called adiposity rebound. Many studies have found a positive association between early adiposity rebound and increased risk of later obesity (Rolland-Cachera et al., 1984; Williams & Goulding, 2009). It has been suggested that it may be the increased BMI before or during adiposity rebound that really predicts later obesity, but some studies have found this association also while adjusting for prior or present BMI at adiposity rebound (Rolland-Cachera et al., 2006; Adair, 2008). Tracking of BMI is evident during childhood and adolescence, e.g. BMI at 6 and 7 years of age was significantly correlated with adolescent and young adult BMI (Fuentes et al., 2003; Magarey et al., 2003).

Girls who mature early have increased risk of being overweight as adults (Adair & Gordon-Larsen, 2001; Harris et al., 2008). It is unclear if this association is direct or dependent on pre-pubertal BMI because higher pre-pubertal BMI is associated with early maturation among girls (Davison et al., 2003) as well as with higher subsequent BMI (Adair, 2008). In one study, both early pubertal maturation and high pre-pubertal weight status increased the risk of being overweight in young adulthood among boys and girls (Mamun et al., 2009). Pubertal development and BMI also share a substantial proportion of their genetic effects (Kaprio et al., 1995).

#### **2.4.2 Genetic factors**

Heritability is defined as the proportion of phenotypic variation that is attributable to genetic variation in a population. Previous twin studies have estimated the heritability of BMI to be 0.31-0.85 at 1-12 years (Bodurtha et al., 1990; Koeppen-Schomerus et al., 2001; van Dommelen et al., 2004; Silventoinen et al., 2007a; Haworth et al., 2008a; Haworth et al., 2008b; Wardle et al., 2008a) and 0.81-0.90 at 12-19 years (Allison et al., 1994; Pietiläinen et al., 1999; Cornes et al., 2007; Hur, 2007) (Table 4).

Only a few longitudinal twin studies (Cornes et al. 2007; Silventoinen et al., 2007a & b; Haworth et al., 2008b) (Table 4) have explored age-changes in heritability of BMI or genetic and environmental influences on BMI trait correlations (or stability of BMI) during childhood and adolescence. Findings of cross-sectional studies at different ages may suggest how genetic and environmental influences change with age, but the results are not directly comparable to each other because heritability of a trait is always relative to the distribution of genetic and environmental factors in a population. Therefore, differences in estimates between cross-sectional studies of younger and older participants can also be attributed to population, cohort or some other effects rather than simply an effect of age. Longitudinal twin studies are needed to reliably investigate how genetic and environmental effects change with age. Only longitudinal twin studies can show which factors are responsible for a stability or change of traits with age and if genetic and environmental factors at different ages remain the same or differ.

**Table 4: Review of the twin studies estimating genetic and environmental effects on BMI and/or weight in childhood and adolescence**

Publication	Age	Country	Sample size	Model	Heritability	Common environment	Additional information
Van Dommelen et al., 2004	1-2 years	Holland	4649 pairs	ACE	0.55-0.64	0.17-0.31	Results for weight
Silventoinen et al., 2007a	3-12 years	Holland	7755 pairs	ACE	0.31-0.82	0.08-0.47	Longitudinal study
Koepfen-Schomerus et al., 2001	4 years	U.K.	3636 twins	ACE	0.61-0.64	0.24-0.25	Results reported for weight corrected for height, but results for BMI highly similar
Haworth et al., 2008b	4-11 years	U.K.	3148-4251 pairs	ACE	0.49-0.85	0.03-0.36	Longitudinal study
Haworth et al., 2008a	7-10 years	U.K.	2342 7- and 3526 10-year-old pairs	ACE	0.60-0.74	0.12-0.22	...
Wardle et al., 2008a	8-11 years	U.K.	5092 pairs	ACE	0.77	0.10	...
Bodurtha et al., 1990	11 years	USA	259 pairs	AE	...	...	Results reported for weight
Silventoinen et al., 2007b	1-18 years	Sweden	375 pairs	AE	0.83-0.92	...	Longitudinal study
Allison et al., 1994	12-18 years	USA	238 pairs	AE	0.89-0.90	...	...
Hur, 2007	13-19 years	South Korea	888 pairs	AE	0.82-0.87	...	South Korean twins
Pietiläinen et al., 1999	16-17 years	Finland	2111 pairs	AE	0.814-0.865	...	...
Cornes et al., 2007	12-16 years	Australia	1143 pairs	AE at 12-14 years and ADE at 16 years	0.87-0.89	...	Longitudinal study. D component found at 16 years was 0.59 and A 0.28

Abbreviations: ACE, a model containing additive genetic (A), common (C) and unique (E) environmental effects;

AE, a model containing additive genetic (A) and unique environmental (E) effects;

ADE, a model containing additive (A) and dominant (D) genetic and unique environmental (E) effects.

In the longitudinal studies, genetic factors accounted for 57-88% of BMI trait correlations (or stability of BMI) among Dutch children at 3 to 12 years (Silventoinen et al., 2007a), for 76-89% among British children at 4 to 11 years (Haworth et al., 2008b), and for 81-95% among Swedish males at 2 to 18 years (Silventoinen et al., 2007b). The heritability estimates in Dutch children at 3 to 12 years did not show a systematic age pattern (Silventoinen et al., 2007b), and were quite stable in Swedish boys at 2 to 18 years (Silventoinen et al., 2007b), but among British children the heritability estimates increased with age (Haworth et al., 2008b). The heritability estimates were stable between 12 and 16 years among Australian twins (Corney et al., 2007). It was found that the same set of genes accounted for most of the BMI variation at 12, 14, and 16 years, but some new genetic effects emerged at 14 years in girls and at 16 years in both genders (Corney et al., 2007).

Despite the high heritability of BMI, most of the underlying genes remain unknown: only 7% of rare, severe, early-onset obesity in children was a result of a monogenic defect. These genes coded leptin, leptin receptor, proopiomelanocortin, melanocortin-4-receptor (MC4R), prohormone convertase (PCSK1), and neurotrophin receptor. (Farooqi & O'Rahilly, 2006). These extremely rare monogenic defects do not explain the variation of BMI at a population level. Copy number variation has also been associated with severe, early-onset obesity and developmental delay and may play a role in human obesity (Bochukova et al., 2009). In the human obesity gene map constructed in 2006, based on studies published so far and conducted with many different methods, over 600 putative loci potentially affecting weight status were found on all chromosomes except Y (Rankinen et al., 2006). This finding reflects the complexity of genetic effects on obesity.

*Fat mass and obesity associated (FTO)* gene allele variants were found to have an effect on BMI at the population level in 2007. About 1% of the variability of BMI in adults was explained by *FTO* allele variation and the per risk allele effect on BMI was 0.08-0.12 z-score units among children aged 7-11 years and 0.05 z-score units among 14-year-old children (Frayling et al., 2007). There are also some common allele variants affecting BMI at a population level near the *MC4R* gene. The per risk allele effect in children aged 7-11 years was 0.13 BMI z-score units (Loos et al., 2008). When the effect of both *MC4R* and *FTO* was taken into account it was calculated that adolescents with 3-4 risk alleles would have on average 0.33 z-score units higher BMI and almost three times higher risk of obesity when compared to those with no risk alleles (Cauchi et al., 2009).

Other genes with a population level effect on BMI still remain to be found but recent genome-wide association (GWA) studies have identified some potential risk loci: *glucosamine-6-phosphate deaminase 2 (GNPDA2)*, *potassium channel tetramerisation domain containing 15 (KCTD15)*, *mitochondrial carrier homolog 2 (MTCH2)*, *neuronal growth regulator 1 (NEGR1)*, *SH2B adaptor protein 1 (SH2B1)*, *transmembrane protein 18 (TMEM18)* (Willer, 2009), and *prohormone convertase 1/3 (PCSK1)* (Benzinou, 2008). Four of these gene loci (*TMEM18*, *SH2B1*, *KCTD15*, *NEGR1*) came up also in another GWA study (Thorleifsson, 2009). When loci reported in previous studies were investigated, *SH2B1*, *MTCH2*, *NEGR1*, and *GNPDA2* in addition to *FTO* and *MC4R* were associated with weight status although the associations of the other loci were very weak when compared to those of *FTO* (Renström, 2009). These studies have been conducted mainly among adults. One study investigated 13 loci reported to be associated with BMI in previous GWAs in a pediatric population. Four loci (*FTO*, *TMEM18*, *GNPDA2*, *MC4R*) had a significant association with BMI in this study when alpha level correction for multiple testing was considered (Zhao et al., 2009).

While the exact mechanisms of genetic influences on BMI remain unknown, most of the discovered monogenetic defects leading to obesity are neuroendocrine in nature and affect weight via feeding behavior (Blakemore & Froguel, 2008). *FTO* gene variants have been found to be associated with satiety (Wardle et al., 2008b), measured food intake (Wardle et al., 2009), and energy (Cecil et al., 2008; Timpson et al., 2008) intake in most but not all (Hakanen et al., 2009) studies among children and *MC4R* allele variants were associated with eating behavior in both children and adults (Stutzmann et al., 2009). Seven new loci (*GNPDA2*, *KCTD15*, *MTCH2*, *NEGR1*, *SH2B1*, *TMEM18*, *PCSK1*) found to be preliminarily associated with BMI (Benzinou et al., 2008; Willer et al., 2009) are also highly expressed or known to act in the central nervous system (Benzinou et al., 2008; Willer et al., 2009).

### **2.4.3 Environmental factors**

#### ***Familial factors***

Studies in children have often (Koeppen-Schomerus et al., 2001; van Dommelen et al., 2004; Silventoinen et al., 2007a; Haworth et al., 2008a; Haworth et al., 2008b; Wardle et al., 2008a) but not always (Bodurtha et al., 1990; Silventoinen et al., 2007b) shown that common environmental effects, shared by family members, are of importance and account for 0.03-0.47 of the inter-individual variation of BMI (Table 4). Cross-sectional studies in adolescents (Allison et al., 1994; Pietiläinen et al., 1999;

Hur, 2007) (Table 4) and adults (Maes et al., 1997) do not show evidence for a persistent effect of this childhood common environment. Common environmental effects have been found to decrease but not disappear during childhood (Haworth et al., 2008b), but the two previous longitudinal studies in adolescents (Cornes et al., 2007; Silventoinen et al., 2007b) (Table 4) failed to substantiate that these effects would disappear during adolescence. This could be due to lack of statistical power (Silventoinen et al., 2007b) or to sample characteristics (Cornes et al., 2007). To find out how genetic and environmental factors impacting BMI change during adolescence longitudinal studies of adolescents in large, population-based twin samples are needed.

The magnitude of common environmental component is an approximation of the effect of non-genetic familial factors on a trait. Some of the real non-genetic familial influences may be modeled as part of 1) genetic effects if children respond differently to the same familial factors because of their genetic background, or 2) as part of unique environmental effects if parents do not treat each of their children in exactly the same way or if the children respond differently to the same within-family factors due to some unique environmental factors, e.g. different social networks. Additionally, twin models are able to measure the influences of only those factors that vary in the population and therefore influences of familial factors that affect BMI but do not vary between families are not seen in the estimates of the common environment. Common environmental variance component is thus not simply a sum of the influences of individual non-genetic familial factors on a trait.

Parental obesity is an important risk factor for childhood obesity because parents and their offspring share approximately half of their segregating genes but usually also live in the same environment. Shared environmental factors which may predispose a child to obesity include, for example, low socio-economic status of a family (Shrewsbury & Wardle, 2008) and neighborhood characteristics (Nelson et al., 2006; Grafova, 2008; Spence et al., 2008). Mother's weight can influence the child's weight by also affecting prenatal fetal conditions. Maternal smoking (Oken & Gillman, 2008) and diabetes during pregnancy (Lobstein et al., 2004; Adair, 2008) result in offspring with higher risk of later obesity. Breastfeeding may protect children from obesity (Cope & Allison, 2008) and other non-genetic familial factors shared by siblings and possibly associated with children's weight status are parenting styles (Wake et al., 2007; Ventura & Birch, 2008), eating family meals together (Yuasa et al., 2008) and school type (Procter et al., 2008)

### ***Behavioral factors***

Overweight results from over-intake of energy in relation to energy expenditure and that required for growth among children. The reasons for the energy imbalance have been surprisingly difficult to show in longitudinal epidemiological studies, probably due to measurement problems. Such difficulties are worsened by the tendency of obese people to under-report their dietary intake (Heitmann & Lissner, 1995; Lissner et al., 2007) and overestimate their physical activity (Irwin et al., 2001; Brown & Werner, 2008).

Some dietary factors, however, have been found to be associated with obesity. The World Health Organization (WHO) reported that there was convincing scientific evidence for high intake of dietary fiber to be negatively and high intake of energy-dense micronutrient-poor foods to be positively associated with obesity (WHO, 2003) and a recent study of dietary patterns found a positive association between an energy-dense, low-fiber, high-fat dietary pattern and fatness in childhood (Johnson et al., 2008). Very high intake of sugar-sweetened soft drinks and fruit juices was found to have a probable positive association with obesity (WHO, 2003), but it is debatable if reducing normal level use of sugar-sweetened drinks results in weight loss (Allison & Mattes, 2009).

### ***Leisure activities***

In most cross-sectional studies among children and adolescents physical activity has been negatively (Must, 2005; Reichert et al., 2009) and television viewing positively (Must & Tybor, 2005; Marshall et al., 2004) associated with childhood overweight, but the mixed results of prospective studies give a less clear picture (Must & Tybor, 2005). This may be due to low adherence to long-term changes (WHO, 2003), to measurement problems, or to bidirectional associations between obesity and physical activity (Petersen et al., 2004).

Finnish elementary school pupils reported 5.95 hours of daily leisure time during the week and 9.85 hours per day during weekends/holidays in 1999-2000. Television viewing took up 32% and sports/exercise 13% of the reported leisure time (Pääkkönen, 2002). Thus, about 55% of children's and adolescents' leisure time was devoted to something other than television viewing or sports/exercise. According to Statistics Finland (Statistics Finland, 2006c) 34-52% of 10-19-year-olds in 2002 were engaged in drawing or painting, 49-60% in crafts, 26-38% played an instrument, 33-



42% had read more than five books during the last six months, and 61-82% listened to music daily.

Despite their high frequency, leisure activities other than television viewing and physical activity have barely been studied in relation to overweight risk and prospective studies are almost non-existent. A positive association between use of electronic games and weight has been found in Canadian (O'Loughlin et al., 2000) and Swiss (Stettler et al., 2004) children but not in American (McMurray et al., 2000), Finnish (Kautiainen et al., 2005) or Australian (Burke et al., 2006) adolescents. Reading and doing homework were associated with higher BMI among American boys but not girls (Utter et al., 2003). Overweight adolescents were also more likely to be socially isolated than their normal-weight peers in the USA (Falkner et al., 2001; Strauss & Pollack, 2003).

In addition to the 'traditional' leisure activities mentioned above, adolescents spend time using information and communication technologies. Households with children were more likely than others to have electronic devices such as computers, wide-screen TVs, or video cameras in 1997-2002 (Kangassalo, 2002). In 1997, about 35% of Finnish households had a home computer and the percentage increased to 55% by 2002 (Kangassalo, 2002). Internet and computer use is very common among 15-19-year-olds in Finland (Statistics Finland, 2006b; Statistics Finland, 2007). Of the 16-29-year-olds, 99% had used the Internet during the past three months in 2008 and of all Internet-users between 16-74 years of age 80% had used it daily or almost daily (Statistics Finland, 2009). Of Finnish 15-year-olds, 58.5% communicated with their friends with cell phone or the Internet almost daily in 2002 and the number had increased to 69.6% by 2006 (Kuntsche et al., 2009). The use of cell phones started to spread rapidly in Finland in the mid 1990s. Cell phone subscriptions increased from about 1 million to 6 million over the period 1995-2007 (Statistics Finland, 2008), coinciding with the rise in adolescent obesity prevalence (Pietikäinen, 2007). Still, the role of information and communication technology use in the development of overweight is not clear.

The few studies on the use of these new technologies and obesity are conflicting. Computer time/video games were not associated with BMI among Australian boys and girls (Wake et al., 2003). On the other hand, computer use alone was positively associated with weight status among American (Utter et al., 2003) and Finnish girls (Kautiainen et al., 2005), and among both boys and girls in the USA (Lutfiyya et al., 2007), although other studies did not find any association among Canadian (Janssen et al., 2004), Australian (Burke et al., 2006) or European (te Velde et al., 2007) children.

One longitudinal study found that computer/video games were associated with a decreased risk of overweight 1 year later among Asian boys, while they were associated with an increased risk of overweight among Asian girls; there was no association between computer/video games and risk of overweight among other ethnic groups (Gordon-Larsen et al., 2002).

Thus, the role of leisure activities other than sports and television viewing in obesity development is unclear and should be studied further. Special attention should be paid to information and communication technology usage that forms an integral part of the leisure time of today's children and adolescents. A more holistic perspective when investigating the etiology of obesity is also essential. So far, studies have concentrated mainly on individual activities and their effects on weight status, whereas people's behavior is far more complex. To discover the lifestyles that predispose to weight gain studies of behavior patterns rather than individual behaviors could be useful.

### 3 AIMS OF THE STUDY

The aims of this study were 1) to explore associations of adolescents' weight status with individual leisure activities, leisure activity patterns and information and communication technology use, and 2) to estimate contributions of genetic and environmental factors to adolescent BMI.

The specific aims of the study were as follows:

1. To explore the prevalence of leisure activities, computer and cell phone use and ownership, and the cross-sectional associations of these with BMI and overweight during adolescence (I, II).
2. To determine if individual leisure activities predict weight gain during adolescence (III).
3. To explore leisure activity patterns and their cross-sectional and longitudinal associations with being overweight during adolescence (III)
4. To explore the relative contributions of genetic and environmental factors to adolescent BMI and to determine if there are gender differences in genetic and environmental effects on BMI (IV).
5. To compare BMI and variance components of BMI among Finnish 14-year-old twins to those among other Caucasian and East Asian twins of the same age (V).

## 4 METHODS

### 4.1 PARTICIPANTS

*FinnTwin12* is a longitudinal study of health-related behaviors among Finnish twins born in 1983-1987 (Kaprio et al., 2002). All twins in these birth cohorts were ascertained from the Population Register Center. Twins responded to postal questionnaires at 11-12 years (N=5184, participation rate 92%), 14 years (N=4643, 82% of the original sample), and 17 years (N=4168, 74% of the original sample). Separate questionnaires were sent also to children's both parents at baseline and 2736 mothers (94%) and 2636 fathers (88%), responded. Of particular interest in this study was their education level and occupational group. The questionnaires were mailed to twin individuals and their parents in the autumn of the year in which the twins reached 11 years of age. A minority (~10%) returned the questionnaires very early in the year in which their birth cohort turned 12. Mean age at response was 11.4 (SD 0.30) years. The twins were sent follow-up questionnaires in the month of their 14th birthday and the mean age at response was 14.1 (SD 0.08) years. The last follow-up questionnaires were mailed at average age 17.5 years in 2000-2005. Mean age at response was 17.6 (SD 0.26) years. The local ethics committee approved the study protocol; written informed consent was obtained from the participating families.

Numbers of participants in each study and gender ratios at each age are presented in Table 5. They differ somewhat between studies. Only data on three (1983-1985) out of the five birth cohorts of 17-year-olds were included in study I because data collection in this wave of the study (during 2000-2005) was still ongoing when study I was being conducted. The number of participants in study II excludes those with BMI z-score over 5 or under -5 and those with missing height or weight, but all twins who responded to the questionnaires are included in the participant numbers for study III. However, the number of participants at 14 years of age differs somewhat from the number reported in study I. This is because 96 subjects who had not responded to the 11-12-year-olds' questionnaire but to whom the 14-year-olds' questionnaire was erroneously sent, were included in study I but not in study III. The numbers reported for study IV include only complete twin pairs without missing or outlying BMIs. Not all Finnish twins were included into study V because samples from other countries were considerably smaller than the Finnish sample. Therefore only twin pairs from whom a response to the 14-year-olds' questionnaire was received from both co-twins during the same day were included in order to reduce age variability. Study V also included 13-15-year-old twins from Australia (N of twin pairs=739), China (N of twin

pairs=170), Japan (N of twin pairs=627), the Netherlands (N of twin pairs=797), South Korea (N of twin pairs=697), Taiwan (N of twin pairs=90), and the United States (N of twin pairs=621). The mean age was 14.1 years (SD 0.4) among Caucasians and 14.0 (SD 0.7) among East Asian twins.

**Table 5: Numbers of participants**

Original publication	N at 11-12 years	N at 14 years	N at 17 years
I	0	4739	2669 <sup>1</sup>
II	0	0	4098
III	5184	4643	4168
IV	4826	4350	3929
V	0	2572 <sup>2</sup>	0
% boys	51	50	48

<sup>1</sup> In this sample 47% were boys.

<sup>2</sup> The number includes only Finnish twins.

## 4.2 MEASURES

### 4.2.1 Outcome variables

#### *Body mass index*

BMI (weight/height<sup>2</sup>) was calculated using self-reported height and weight at 11-12, 14, and 17 years. At 11-12 years 4%, at 14 years 3%, and at 17 years 2% of the participants had a missing BMI. To eliminate outliers resulting from data errors, participants with z-scores over 5 or under -5 were excluded from the analyses in studies II and III (3 participants at 11-12 years, 1 participant at 14 years, and 3 participants at 17 years). Z-scores were created using the 1990 British Growth Reference data (Cole et al., 1998). In study IV 3 participants at 17 years were excluded because they had a z-score of log<sub>e</sub>-transformed BMI under -5 or over 5. Log<sub>e</sub>-transformed BMI was used in study IV to reduce positive skewness of the BMI distribution. In study II the analyses were conducted with both log-transformed and raw BMI and the results were similar either way. There were no differences in mean BMI and prevalence of overweight at 11-12 or at 14 years between adolescents who responded and did not respond to later questionnaires.

#### *Overweight*

In study I, participants with BMI higher than the 90th percentile were defined as overweight. In studies II and III, overweight was defined according to the

International Obesity Task Force age- and gender-specific BMI cut-off points (Cole et al., 2000), analogous to BMI cut-off points of 25 kg/m<sup>2</sup> and 30 kg/m<sup>2</sup> for adult overweight and obesity. The function *zbmicat* in Stata was used to categorize adolescents as normal weight, overweight, or obese based on the above-mentioned BMI cut-off points and the exact age at response. Participants who were 18 years or older when responding to the 17 year questionnaire (5%) were categorized using adult definitions of overweight and obesity (25 and 30 kg/m<sup>2</sup>, respectively). Because of low numbers, the last two categories (overweight and obesity) were merged.

#### **4.2.2 Exposure variables**

##### ***Leisure activities***

Participation in individual leisure activities was studied with a 15-item instrument (Pulkkinen & Narusk, 1987) at 11-12 and 14 years. Leisure activities included were: television viewing, video viewing, computer games, listening to music, board games, musical instrument playing, reading, arts, crafts, meeting peers at home, meeting peers at friends' home, meeting peers away from home, clubs or scouts, sports, and outdoor activities (Pulkkinen & Narusk, 1987). Arts were defined in the questionnaires as drawing or painting and crafts as handicrafts, woodwork, and building scale models.

The original frequency scale given for leisure activities in the 15-item instrument was: daily, 2-3 times a week, 2-3 times a month, 2-3 times half-yearly, and never. All the activities were dichotomized in the individual activity analyses by defining a frequency of daily and 2-3 times a week as high participation and less often as low participation. Television viewing, listening to music, and outdoor activities were, however, dichotomized, defining daily as high participation and less often as low participation because of the original distribution of the variables.

Leisure activities were also included in the 17 year questionnaire, but the items were somewhat different from those at 11-12 and 14 years. These data were only used in study I. The frequency scale was daily, 2-3 times a week, once a week, once a month, once half yearly, and never. Individual leisure activities were: television viewing, video viewing, computer games, musical instrument playing, reading, arts, crafts, meeting peers away from home, and clubs, which were also included in the 11-12 and 14 year questionnaires. High participation was defined as a frequency of 2-3 times a week or more often as at previous ages. In addition, the frequencies of going to theater or concerts, bars, nightclubs, and movies, and engaging in religious activities were

asked. Because the frequency distributions of these activities were totally different from the distributions of other activities, dichotomization was done by comparing those who never participated and those who participated sometimes (once half yearly or more often).

In study I three items on socializing (meeting peers at home, meeting peers at friends' home, meeting peers away from home) were analyzed separately in the analyses of the prevalence of leisure activities to enable comparison to 17-year-olds whose questionnaire was different from the one used at 11-12 and 14 years. In logistic regression analyses of study I a combined variable of the three items was used to reduce the number of models. In the later conducted study III the two variables, meeting peers at home and at friends' home, were again combined to one variable called socializing at home when analyzing individual leisure activities but meeting peers away from home was analyzed separately because it was thought to represent somewhat different aspect of leisure time than socializing at home. In leisure activity pattern analyses (study III) the number of leisure activity variables did not affect the number of tests conducted and therefore the three items on socializing were used separately. When describing leisure activity patterns in study III the term socializing referred to all three of the above mentioned activities.

The frequency of physical activity was not asked similarly at every age. At 11-12 years, the frequency of sports (for example team sports or sports training) and the frequency of outdoor activities were inquired in the 15-item leisure activity instrument described above. At 14 years, these two items were identical but in addition there was a specific item on any physical activity. The frequency scale for this item was: almost every day, 4-5 times a week, 2-3 times a week, once a week, 1-2 times a month, less than once a month, and never. At 17 years, this was the only item on physical activity and the frequency of 2-3 times a week was defined as high participation. In study I logistic regression models this item was also used to validate sports participation item at 14 years so that to be defined as highly active in sports, a participant had to pick the frequency of 2-3 times a week or more often for both sports and any physical activity. Combining the items also reduced the number of tests. This variable was called as sports/physical activity. In the analyses of leisure activity prevalences (study I) physical activity and sports had to be analyzed separately to enable comparison between 14- and 17-year-olds. In study III, to avoid problems of slightly different items at different ages, only data from the 15-item leisure activity instrument were used because the instrument was identical for both 11-12- and 14-year-olds from whom leisure activity information was used in this study.

### ***Computer use and ownership and cell phone use***

Participants were asked whether or not they had a computer at home and if it had an Internet connection. They were also asked how many hours a week they usually used a computer for school/work and recreation. A categorical variable of computer use hours was formed because the distribution was extremely skewed. Five quintile-based categories of computer use were therefore formed. Cell phone use was determined via the amount of the participants' monthly cell phone bill, with the following response options: no cell phone, monthly bill less than 10 euros, 10 – 20 euros, 20 – 35 euros, 35 – 85 euros, and over 85 euros. The two highest categories were combined, because there were too few observations in the top category.

### ***Zygosity***

Zygosity was determined by well-validated questionnaire items on physical similarity and confusability at school age supplemented by parental response to items developed for zygosity classification of twin children (Goldsmith, 1991). Additional information obtained from twins' mothers and school photographs was used to determine zygosity of same-sex twin pairs whose zygosity could not be determined by the above methods. After exclusion of those whose zygosity still remained uncertain (n=340) the final number of participants was 4844, and the final number of complete twin pairs at 11-12 years was 2413, including 796 monozygotic (MZ), 815 dizygotic (DZ), and 802 opposite-sex (OSDZ) twin pairs. Our method of determining zygosity has previously shown high reliability in Finnish twin data (Sarna et al., 1978), and in our data the zygosity definition based on questionnaire reports was confirmed among 93% of the 216 same-sex pairs whose DNA was tested.

#### **4.2.3 Confounding factors**

##### ***Pubertal development***

Pubertal development level was measured by the Pubertal Development Scale (PDS) (Petersen et al., 1988; Dick et al., 2001) at 11-12 and 14 years. PDS is based on responses given by adolescents to five questions concerning their physical maturation: growth spurt, skin changes, growth of body hair, and either breast development and age at menarche, or voice change and growth of beard. A missing pubertal



development level measure (2% of participants at 11-12 years and 3% at 14 years) was replaced by the mean of the PDS in the specific gender and age group.

### ***Self-reported health and physical fitness***

The items on self-reported health in the questionnaires at 14 and 17 years and on physical fitness in the 17-year-olds' questionnaires had five response options: very good, good, medium, fairly poor, and poor. Good or very good was defined as 'good' and medium, fairly poor, or poor as 'poor' health or fitness.

### ***Parental education level and occupational group***

The items on parental education level and occupation were included in the questionnaires sent to both parents at baseline when the twins were 11-12 years. Parents with the minimum nine years of mandatory education plus senior high school were classified as having 'high education', whereas those who had not graduated from senior high school were classified as having 'low education'. Missing answers (2% for mothers and 12% for fathers) were placed in a third category of education variables. Seven occupational categories were formed: 1) self-employed; 2) upper-level employees; 3) lower-level employees; 4) manual workers; 5) students; 6) pensioners, and 7) others (unemployed, not classified elsewhere) (Statistics Finland, 1989; Statistics Finland, 2006a). The last three categories were collapsed into one because there were too few observations.

### ***Parental body mass index***

Mothers' and fathers' height and weight were also asked in parents' questionnaires at baseline when the twins were 11-12 years, and body mass indices ( $\text{kg}/\text{m}^2$ ) were calculated.

### ***Age***

Exact ages at response were calculated from the twin's date of birth and the dates the questionnaires were returned to the study center.

### **4.3 DATA ANALYSIS**

#### **4.3.1 Prevalence of leisure activities**

Prevalences of leisure activities between boys and girls at 14 and 17 years were compared in study I using a chi-squared test developed for a complex data set such as ours, as co-twins are part of the same family and may resemble each other. Prevalences of leisure activities between 14- and 17-year-olds were compared with the Stuart Maxwell marginal homogeneity test (Maxwell, 1970). Tetrachoric correlations were used to study how well leisure activities at 14 and 17 years correlated. In study I the proportions of adolescents who continued their high participation in individual leisure activities from 14 to 17 years, the proportions who continued their low participation in these activities over the same period, and the proportions who changed their low participation to high participation in individual leisure activities from 14 to 17 years were also calculated.

#### **4.3.2 Cross-sectional associations of individual leisure activities with weight status**

Simple logistic regression was used to study cross-sectional associations of individual leisure activities with being overweight at 14 and 17 years in study I. The leisure activities which had an association with being overweight in simple logistic regression analyses were then entered into a multiple logistic regression model adjusted for mother's and father's BMI, mother's and father's education level, pubertal development level, and self-reported health and physical fitness. In the multiple logistic regression models of 17-year-olds the effect of BMI and pubertal development level at 14 years was also studied by including these variables in the models. Backward stepwise regression was used to eliminate variables that were not statistically significantly associated with overweight to reach the final model containing only variables that were associated with the outcome. All the analyses in study I described above were conducted separately for boys and girls.

Multiple logistic regression analysis was also used to study associations of computer ownership and use and cell phone use with being overweight among all five birth cohorts of 17-year-olds in study II. To study associations of these factors with BMI, multiple linear regression analysis was used in the same age group. A likelihood-ratio test, which determines whether a more complex model (with a study variable) fits data significantly better than a simpler one (without a study variable), was used to determine the overall significance of the study variables.

The association of cell phone bill with weight status was analyzed in two ways: 1) in a trend test where categories of monthly cell phone bill were numbered consecutively 1-5, and 2) as a categorical variable, with the most prevalent category chosen as the reference group. The most prevalent group was chosen as the reference group for statistical stability because the prevalence of the lowest group (no cell phone) was only 6% in the whole sample and in the 1987 cohort only 1%. The lowest category of computer use hours (0-1 h) was chosen as the reference category. The models were adjusted for gender, physical exercise (times a week), and mother's and father's education levels and occupational classes.

The effect of potential non-independence of observations (twins within twin pairs may resemble each other) was taken into account in regression models by computing robust estimators of variance and correcting for clustered sampling of families to obtain correct confidence intervals (Williams, 2000).

#### **4.3.3 Leisure activity patterns**

Latent class analysis (LCA) was conducted in study III using the software Latent Gold 4.0 to group the subjects into distinct classes based on their participation in the leisure activities measured with the 15-item instrument described earlier (4.2.2. Exposure variables). LCA treats ordinal leisure activity ratings as imperfect indicators of an otherwise unobserved discrete and categorical variable (Magidson & Vermunt, 2004; Vermunt & Magidson, 2005) and classifies participants with similar profiles of leisure activity participation into a same class. The optimal number of categories or classes can be determined in a variety of ways (Magidson & Vermunt, 2004; Dunn et al., 2006), but in study III the smallest number of classes that afforded adequate fit to the data (as measured by reduction of the likelihood-ratio goodness-of-fit value or  $L^2$ ) and that could be interpreted was selected.

Both cross-sectional and longitudinal associations of leisure activity classes were studied by multiple logistic regression models. The longitudinal models are described below and the cross-sectional models were similar but without adjustment for BMI at the outset (not necessary in cross-sectional analyses).

#### **4.3.4 Longitudinal associations of leisure activities with being overweight**

The associations of individual leisure activities with becoming overweight between 14 and 17 years of age were preliminarily studied in three (1983-1985) of the five birth cohorts in study I by including only normal weight 14-year-olds in simple logistic regression models and investigating the associations of their leisure activity participation with the risk of being overweight at 17 years.

Multiple logistic regression analysis was used to study the associations of individual leisure activities and leisure activity classes (formed by LCA, see the section above) with overweight in the whole sample at 11-12, 14, and 17 years of age. Either baseline age (11-12 years) or age at first follow-up (14 years) was used as the starting point for the prospective analyses and being overweight at either 14 or 17 years was defined as the outcome. The most passive and solitary pattern of leisure activities, the 'Passive and solitary' class (the class with the lowest frequency of participation in almost all leisure interests, sports, sedentary activities, and socializing) served as the reference class in leisure activity pattern analyses.

The models were adjusted for pubertal development level, parental education, and BMI at the outset. The analyses were also conducted in a subsample of adolescents who were all normal weight at the outset to examine the risk of becoming overweight during follow-up; these analyses were otherwise similar to the ones described above. Television viewing could not be reliably investigated as an independent predictor of later overweight risk, because daily television viewing was so common that there was no proper reference group and more accurate measures of daily television viewing hours were not available. All the analyses were corrected for clustered sampling within families to obtain correct confidence intervals (Williams, 2000).

#### **4.3.5 Genetic and environmental effects on BMI**

Twin modeling was used to estimate contributions of genetic and environmental factors to total variance of BMI at 11-12, 14, and 17 years of age. In the models the total variance of BMI was divided into variance components: additive genetic (A), dominant genetic (D), common environmental (C), and unique environmental (E). The significance and magnitude (the proportion of the total variance explained by each component) of these variance components were assessed to find out a model that fits into the co-variance patterns of the data best. This was done using methods of

quantitative genetic analysis based on structural equation modeling in Mx software (Neale, 1997).

Univariate models for variance of BMI were fitted separately at 11-12, 14, and 17 years of age in study IV to investigate how heritability and environmental effects differed between age groups and whether gender-specific genetic effects (different genetic factors affecting BMI in boys and girls) or gender differences in the magnitudes of variance components (A, C, D, E) existed. In study V separate univariate models for variance of BMI were fitted among East Asian and Caucasian twins to discover any differences between the two ethnic groups.

The basic assumptions of twin modeling (equal means and variances for MZ and DZ twins) were first tested by comparing saturated models, which make no such assumptions, to genetic models. If the fit of genetic models to the data is not significantly worse than the fit of saturated models it means that the basic assumptions are fulfilled.

After examining the intra-class or twin pair correlations of BMI among MZ and DZ twins, an ACE model (containing additive genetic, common and unique environmental effects) or an ADE model (containing additive and dominant genetic and unique environmental effects) was taken as the starting point for genetic modeling. Higher intra-class correlations among MZ than DZ twin pairs suggest a genetic effect (A or D). Intra-class correlations among DZ twin pairs that are above half of the correlations for MZ pairs suggest that there are also common environmental (C) factors that make co-twins to resemble each other, while intra-class correlations of DZ twins that are below half of the intra-class correlations of MZ twins suggest a dominant genetic (D) effect. The unique environmental (E) component is always incorporated in twin models because it includes measurement error in addition to the effect of environmental factors that make co-twins different from each other. After fitting the ACE or ADE model, it was tested whether it was possible to eliminate the C component from the ACE model or the D component from the ADE model without decreasing the fit of the model significantly.

Lower intra-class correlations of BMI among opposite-sex compared to same-sex DZ pairs suggest a gender-specific genetic effect on BMI, and its significance was tested by removing the gender-specific genetic effect from the model and comparing the fit of the two hierarchical models. By constraining the variance components (A, E, C or D) equal for both genders and comparing this model to one with parameter estimates not constrained it was tested whether the magnitudes of parameters differed

significantly between the genders. In study V, a parameter or an effect was removed from the model only if it could be removed from the models of both Caucasians and East Asians, in order to enable comparisons between the two groups.  $\chi^2$ -goodness-of-fit statistics and degrees of freedom (d.f.) were used for testing the relative fit of these hierarchical models. In studies IV and V we adjusted all the models for the participants' exact age at assessment and in study V for their country of residence.

Multivariate twin modeling with BMI at three ages included to the same model was used in study IV to estimate relative contributions of genetic and environmental factors on trait correlations of BMI over time (or stability of BMI) in a longitudinal setting and to examine how genetic and environmental factors affecting BMI correlate across ages. Cholesky decomposition was used for these multivariate analyzes. This procedure makes no assumptions about the underlying variance structure but simply decomposes the variation and co-variation in the data into a series of uncorrelated genetic and environmental factors. It is a useful method when the number of measurements is limited and the variance structure of a trait is not known and may even change during the follow-up.

## 5 RESULTS

### 5.1 BODY MASS INDEX AND PREVALENCE OF OVERWEIGHT

Mean BMI and combined prevalence of overweight and obesity at 11-12, 14, and 17 years among boys and girls are shown in Table 6. Of the normal weight 14-year-old boys 3.8% and of the girls 4.2% became overweight by 17 years as reported in study I. They represented 38% of the overweight boys and 39% of the overweight girls at 17 years (study I). When using the International Obesity Task Force criteria (Cole et al., 2000) for defining overweight in all the five birth cohorts, 5.8% of the normal weight 14-year-old boys and 2.9% of the girls became overweight by 17 years. Of the normal weight 11-12-year-old boys 4.1% and of the girls 3.2% became overweight by 14 years.

**Table 6: Mean BMI and prevalence of overweight and obesity among Finnish twins**

Age	Mean BMI (SD)				Prevalence of overweight and obesity <sup>1</sup>			
	boys	n	girls	n	boys (%)	n	girls (%)	n
11-12 years (in 1994-1999)	17.7 (2.6)	2527	17.6 (2.6)	2445	10.3	261	9.3	227
14 years (in 1997-2002)	19.3 (2.7)	2228	19.4 (2.7)	2273	10.2	228	7.9	180
17 years (in 2000-2005)	21.8 (3.0)	1981	21.0 (3.0)	2117	11.9	235	7.9	168

<sup>1</sup> Defined according to International Obesity Task Force age- and gender-specific BMI cut-offs (Cole et al., 2000).

There was no cohort effect on BMI, that is, the level of BMI did not differ between cohorts, but for combined prevalence of overweight and obesity there was a trend of increasing prevalence with cohort (OR 1.2, 95% CI 1.1-1.3) among 11-12-year-old girls, but not among boys and not among either gender at 14 or 17 years of age.

The mean BMI of Finnish 14-year-old twins (19.3-19.4 kg/m<sup>2</sup> among boys and 19.3 kg/m<sup>2</sup> among girls of same-sex pairs) was lower than among 14-year-old Australians and Americans, about the same level as among East-Asians, and a little higher among boys but at the same level among girls when compared to Dutch twins (Table 7).

**Table 7: Mean BMI (variance) among Caucasian and East Asian twins.**

Population	Country	N	BMI (kg/m <sup>2</sup> )				
			boys		girls		both
			MZ	DZ	MZ	DZ	OSDZ
Caucasians	Australia	1478	19.7 (8.4)	20.3 (13.7)	20.8 (15.2)	20.3 (11.6)	20.8 (11.6)
	Finland	2572	19.3 (6.8)	19.4 (8.4)	19.3 (7.3)	19.3 (6.8)	19.5 (8.4)
	Netherlands	1594	18.9 (5.8)	18.8 (4.8)	19.3 (6.8)	19.3 (6.8)	18.9 (4.8)
	USA	1242	21.4 (13.7)	21.6 (17.6)	21.8 (16.0)	22.9 (24.0)	...
	Total	7470	20.1 (10.2)	20.0 (12.3)	20.4 (12.3)	20.5 (14.4)	19.7 (9.0)
East Asians	East Asia <sup>1</sup> (total)	3168	19.5 (7.8)	19.0 (7.3)	19.3 (5.8)	19.3 (5.3)	19.2 (6.8)

<sup>1</sup>Including China, Japan, South Korea, Taiwan.

Abbreviations: MZ, monozygotic; DZ, dizygotic; OSDZ, opposite-sex dizygotic.

## 5.2 LEISURE ACTIVITIES AND WEIGHT STATUS

### 5.2.1 Prevalence of leisure activities and computer and cell phone use

High participation in leisure activities was more common overall at 14 than 17 years of age. The only exception was ‘meeting peers away from home’, which was more common at 17 than 14 years. Participation in most leisure activities varied with gender (I).

The proportion of 17-year-olds who did not have a computer at home decreased from 18% to 8% from 2000 to 2005. Weekly computer use hours varied between 0 and 115 hours a week. The median was 4 hours a week overall and it increased from 3 to 5 hours during 2000-2005. The proportion of adolescents without a personal cell phone decreased from 12% to 1% between 2000 and 2005 (II).

### 5.2.2 Individual leisure activities and overweight

The significant associations of individual leisure activities with being overweight among boys are presented in Table 8. At 14 years, the prevalence of overweight was lower among boys who engaged frequently in outdoor activities, sports/physical exercise, and spending time with peers compared to boys not doing so (I). Among those frequently engaged in arts/drawing and video viewing the prevalence of overweight was higher when compared to those not thus engaged (I). At 17 years, the prevalence of overweight was lower in boys frequently playing a musical instrument



(I). Video viewing had a positive and physical exercise a negative association with being overweight among 17-year-old boys in simple logistic regression models, but in the multivariate models they lost their significance. Poor self-reported physical fitness, however, had a significant, positive association with being overweight both in univariate (OR 4.8, 95% CI 3.2-7.3) and multivariate (OR 3.9, 95% CI 2.1-6.9) models. In prospective analyses (III) among boys, frequent sports activity at 11-12 years was associated with a decreased overweight risk at 14 years. Musical instrument playing and boys' clubs or scouts at 14 years were associated with a decreased overweight risk at 17 years. Listening to music at 11-12 years, arts, and socializing at home at 14 years were associated with an increased overweight risk at 17 years. (Table 8).

**Table 8: Cross-sectional and longitudinal associations of leisure activities with being overweight among boys<sup>1</sup>**

Leisure activity	Age (years)	Participation	Overweight at 14 years (OR, 95% CI)	Overweight at 17 years (OR, 95% CI)
Sports/ exercise	11-12	no	1.0	...
		yes	0.63 (0.41– 0.98) <sup>3</sup>	...
	14	no	1.0	...
		yes	0.58 (0.40 – 0.85) <sup>2</sup>	...
Listening to music	11-12	no	...	1.0
		yes	...	1.4 (1.0 – 2.1) <sup>3</sup>
Musical instrument playing	14	no	...	1.0
		yes	...	0.58 (0.38 – 0.90) <sup>3</sup>
	17	no	...	1.0
		yes	...	0.33 (0.14 – 0.77) <sup>2</sup>
Arts	14	no	1.0	1.0
		yes	1.9 (1.3 – 2.8) <sup>2</sup>	1.5 (1.0 – 2.3) <sup>3</sup>
Socializing <sup>4</sup>	14	no	1.0	1.0
		yes	0.50 (0.32 – 0.77) <sup>2</sup>	1.8 (1.2 – 2.7) <sup>3</sup>
Boys' clubs or scouts	14	no	...	1.0
		yes	...	0.66 (0.43 – 1.0) <sup>3</sup>
Outdoor activities	14	no	1.0	...
		yes	0.58 (0.40 – 0.84) <sup>2</sup>	...
Video viewing	14	no	1.0	...
		yes	1.6 (1.1 – 2.3) <sup>2</sup>	...

<sup>1</sup> Only significant associations shown.

<sup>2</sup> Overweight defined as BMI over 90th percentile. Study I.

<sup>3</sup> Overweight defined according to International Obesity Task Force (Cole et al., 2000). Study III.

<sup>4</sup> In cross-sectional analyses (study I) this was a composite measure of three socializing variables but in prospective analyses (study III) a composite measure of only two variables (called socializing at home) was used.

Girls who at 14 years participated frequently in sports/physical exercise were less likely to be overweight than girls not doing so, but other leisure activities had no significant associations with the prevalence of overweight at 14 years in the multivariate model (Table 9). Among 17-year-old girls the only leisure interest associated with the prevalence of overweight in the multivariate model was crafts: the prevalence of overweight was higher among girls doing crafts frequently (I). However, poor self-reported physical fitness had a significant association with being overweight both in univariate (OR 3.9, 95% CI 2.6-5.8) and multivariate (OR 2.8, 95% CI 1.7-4.7) models (I). In prospective analyses (III) among girls, video viewing at 11-12 years, and crafts and board games at 14 years, were associated with an increased overweight risk at 17 years. The results of cross-sectional and longitudinal analyses among girls are presented in Table 9.

**Table 9: Cross-sectional and longitudinal associations of leisure activities with being overweight among girls<sup>1</sup>**

Leisure activity	Age (years)	Participation	Overweight at 14 years (OR, 95% CI)	Overweight at 17 years (OR, 95% CI)
Video viewing	11-12	no	...	1.0
		yes	...	1.6 (1.0 – 2.5) <sup>3</sup>
Crafts	14	no	...	1.0
		yes	...	1.7 (1.0 – 2.9) <sup>3</sup>
	17	no	...	1.0
		yes	...	3.5 (1.3 – 9.6) <sup>2</sup>
Board games	14	no	...	1.0
		yes	...	2.0 (1.1 – 3.5) <sup>3</sup>
Sports/exercise	14	no	1.0	...
		yes	0.60 (0.40 – 0.89) <sup>2</sup>	...

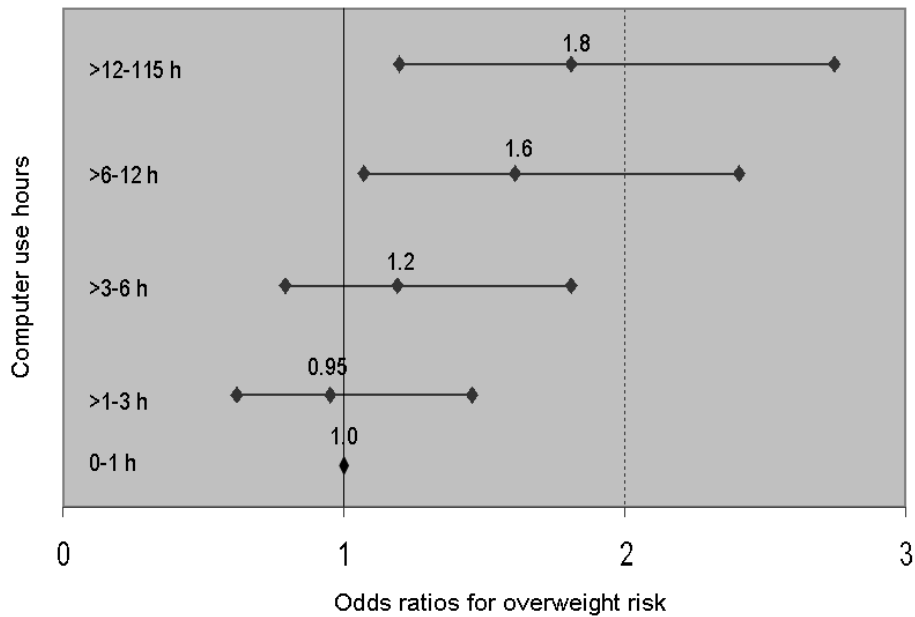
<sup>1</sup> Only significant associations shown.

<sup>2</sup> Overweight defined as BMI over 90th percentile. Study I.

<sup>3</sup> Overweight defined according to International Obesity Task Force (Cole et al., 2000). Study III.

### 5.2.3 Computer and cell phone use and ownership and weight status

Having a home computer (without an Internet connection) was associated with a higher BMI (beta 0.57, 95% CI 0.15-0.98) and prevalence of overweight (OR 2.3, 95% CI 1.4-3.8) when compared to 17-year-olds without a home computer. However, having a home computer with an Internet connection was not associated with weight status. Those belonging to the highest quintile (OR 1.8, 95% CI 1.2-2.8) and the second-highest quintile (OR 1.6, 95% CI 1.1-2.4) of weekly computer use were more likely to be overweight than those belonging to the lowest quintile (Figure 2).



**Figure 2: Overweight risk (OR, 95% CI) among 17-year-old boys and girls by weekly computer use hours. Reference group 0-1 hours.**

Weekly computer use hours were not statistically significantly associated with BMI. There was a trend of increasing BMI with rising computer use hours but it was not significant ( $p=0.106$ ) in the analysis adjusted for gender (Table 10).

**Table 10: Associations of weekly computer use hours with BMI among 17-year-old boys and girls**

Weekly computer use for school, work, and recreation (hours)	n (%) <sup>1</sup>	Mean BMI (SD)	Linear regression <sup>2</sup>	
			Beta coefficient, 95% confidence interval	p-value
0-1	689 (20)	21.1 (3.0)	(reference)	...
1-3	801 (23)	21.2 (2.9)	0.10 (-0.21 to 0.41)	0.52
3-6	731 (21)	21.3 (2.9)	0.12 (-0.20 to 0.44)	0.46
6-12	620 (18)	21.6 (3.0)	0.31 (-0.38 to 0.65)	0.081
12-115	620 (18)	21.7 (3.4)	0.25 (-0.14 to 0.65)	0.21

<sup>1</sup> number of participants who did not have missing values in any of the variables which were included in the model.

<sup>2</sup> adjusted for gender, physical exercise, and parents' socio-economic status.

There was a positive linear trend of increasing monthly phone bill with BMI (beta 0.18, 95% CI 0.06 to 0.30, p=0.003), but this association was very weak when one of the categories was chosen as a reference and the others were compared to it (Table 11). There was no association between cell phone bill and overweight.

**Table 11: Association of cell phone use with BMI at 17 years**

Cell phone bill for one month (euros)	n (%) <sup>1</sup>	Mean BMI (SD)	Linear regression <sup>2</sup>	
			Beta coefficient, 95% confidence interval	p-value
No cell phone	223 (6)	21.0 (3.4)	-0.53 (-1.09 to 0.04)	0.068
< 10	424 (12)	21.3 (3.6)	-0.20 (-0.60 to 0.21)	0.34
10 – 20	1204 (34)	21.3 (2.9)	-0.25 (-0.49 to -0.006)	0.045
20 – 35	1343 (38)	21.4 (2.9)	(reference)	...
35 – 85	369 (10)	21.7 (2.9)	0.29 (-0.04 to 0.63)	0.085

<sup>1</sup> number of participants without missing values in any of the variables that were included in the model.

<sup>2</sup> adjusted for gender, physical exercise, and parents' socioeconomic status.

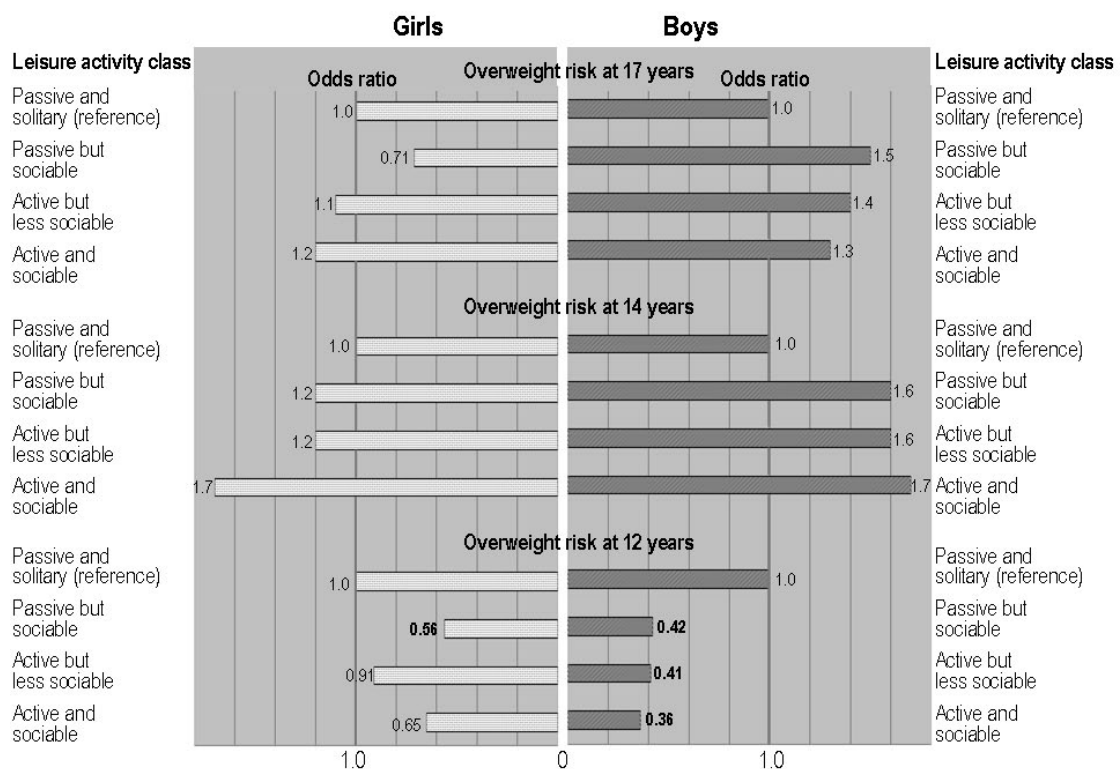
Computer and cell phone use (and ownership) had similar associations with weight status among both boys and girls and therefore separate analyses for the two genders were not conducted but the analyses were adjusted for gender. Although computer and cell phone use and ownership increased in 2000-2005, the analyses were not adjusted for the study year because the level of BMI and prevalence of overweight among 17-year-olds did not differ between the study years. Significance of the study year was anyway tested by adding it to the models: it did not have significant associations with dependent variables and adding it to the models did not change the interpretation of the results. When analyses were conducted stratified by the study year it was found that the association of computer ownership and BMI in linear regression models was stronger in the last cohort in which the computer ownership was more common than in the preceding cohorts (II, pre-publication history).

#### 5.2.4 Leisure activity patterns and overweight

Four different leisure activity patterns or classes were identified: "Active and sociable", 'Active but less sociable', 'Passive but sociable', and 'Passive and solitary' (III). The patterns with a low frequency of involvement in sports and outdoor activities but also in sedentary activities, such as computer games, musical instrument playing, reading, arts, crafts, and clubs, were classed as 'passive', while the profiles with a higher frequency of participation in these leisure activities were classed as 'active'. The adolescents in the different classes also differed in the level of

sociability. The classes in which adolescents had a high frequency of socializing (meeting peers at home, meeting peers at friends' home, and meeting peers away from home) were defined as 'sociable', those with a lower frequency of socializing as 'less sociable', and those with the lowest frequency of socializing as 'solitary'. Leisure activity patterns were quite similar among both 11-12- and 14-year-olds and they were called in a similar way in both age groups.

The associations of 11-12-year-olds' leisure activity patterns with overweight risk at 11-12, 14, and 17 years of age are shown in Figure 3. The proportion of overweight boys at 11-12 years was lower in the 'Active and sociable', 'Active but less sociable', and 'Passive but sociable' than in the 'Passive and solitary' class (the reference class), but belonging to a specific leisure activity class did not predict overweight risk later in adolescence. Among 11-12-year-old girls, the proportion of overweight was lower in the 'Passive but sociable' than in the 'Passive and solitary' class. Belonging to a specific leisure activity class at 11-12 years did not predict risk of overweight at 14 or 17 years.



**Figure 3: Associations of leisure activity classes at 11-12 years with overweight risk at 17, 14, and 11-12 years of age. Significant odds ratios in bold.**

The associations of 14-year-olds' leisure activity classes with overweight risk at 14 and 17 years of age are shown in Figure 4. Boys in the 'Passive but sociable', 'Active but less sociable', and 'Active and sociable' classes were less likely to be overweight than boys in the 'Passive and solitary' class at 14 years, but belonging to a specific class did not predict overweight risk at 17 years. Among 14-year-old girls (n=2273), leisure activity patterns had no cross-sectional associations with being overweight, but in the prospective analyses, 14-year-old girls in the 'Passive but sociable' leisure activity class had a smaller risk of overweight at 17 years than the girls in the 'Passive and solitary' class. When the analysis was limited to girls of normal-weight at 14 years (n=2045) in order to predict the risk of becoming overweight between 14 and 17 years of age, the girls in the 'Passive but sociable' (OR 0.12 95% CI 0.03-0.44), 'Active but less sociable' (OR 0.32 95% CI 0.14-0.76), and 'Active and sociable' (OR 0.36 95% CI 0.16-0.82) classes had a smaller risk of becoming overweight than the girls in the 'Passive and solitary' class (reference class).



**Figure 4: Associations of leisure activity classes at 14 years with overweight risk at 17 and 14 years of age. Significant odds ratios in bold**

## 5.3 GENETIC AND ENVIRONMENTAL EFFECTS ON BMI

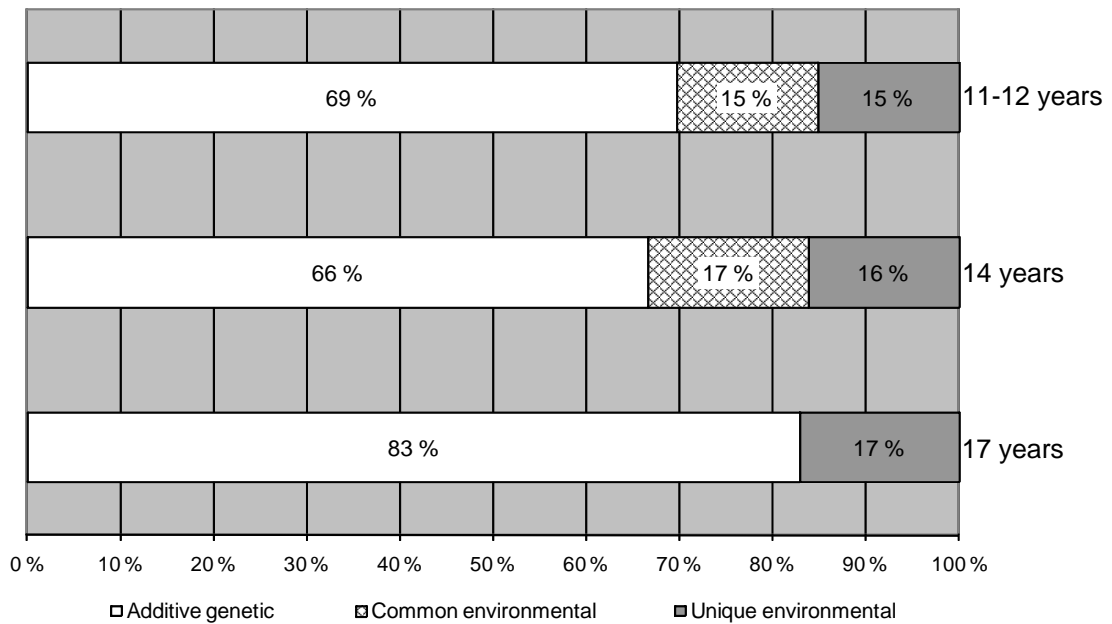
### 5.3.1 Cross-sectional analyses (univariate models)

Higher intra-class correlations of BMI within MZ than DZ pairs suggested additive genetic (A) effects on BMI. The intra-class correlations within DZ pairs were greater than half of the MZ correlations at 11-12 and 14 years and among 17-year-old girls, which suggested that there were also environmental factors that made co-twins similar to each other, that is, common environmental (C) factors. Unique environmental (E) factors are always included in twin models because they include also measurement error. Based on the intra-class correlations, an ACE model containing additive genetic (A), common environmental (C), and unique environmental (E) components was taken as the starting point of genetic modeling. An ADE model, containing A, E, and a dominant genetic (D) components, was also tested at 17 years because DZ correlations in relation to MZ correlations were lower than among younger twins. A lower intra-class correlation in opposite-sex than in same-sex DZ pairs suggested a gender-specific genetic effect on BMI and therefore importance of gender-specific genetic effects and different parameter estimates for boys and girls were tested.

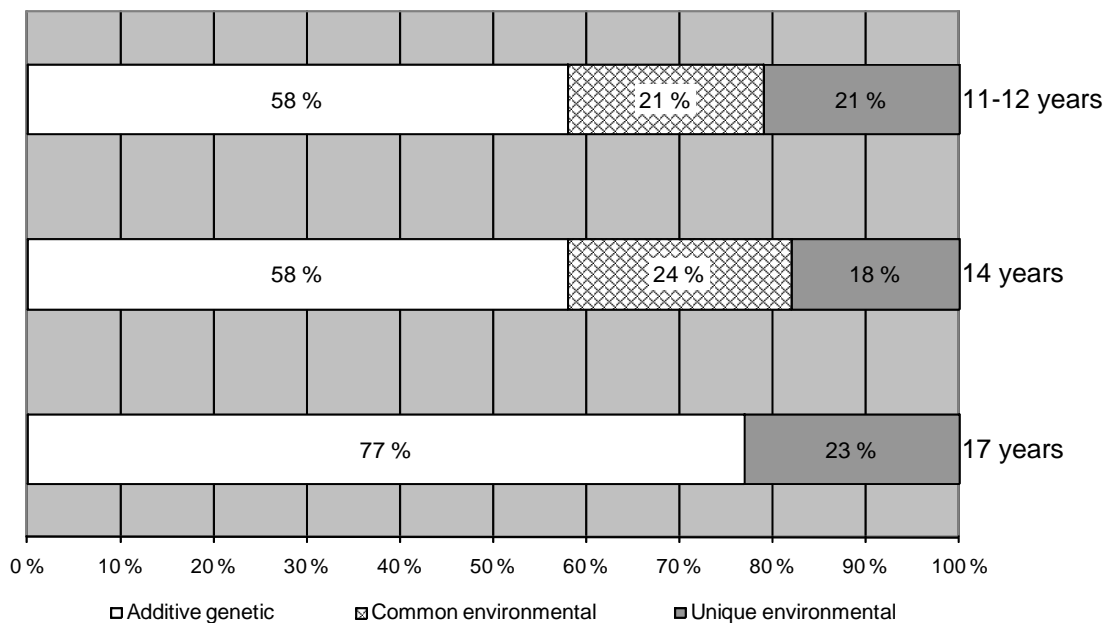
By comparing the fit of the saturated models to the ACE models at 11-12 and 14 years and to ACE and ADE models at 17 years, it was concluded that the assumptions of twin modeling (equality of means and variances in MZ and DZ twins and in the first and second twin of all pairs) were fulfilled. By comparing the fit of hierarchical models, it was found that the ACE model was the best fitting model at 11-12 and 14 years, while the AE model with only additive genetic (A) and unique environmental (E) component and without common environmental (C) or dominant genetic (D) component had the best fit at 17 years. Additive genetic correlation for OS pairs could not be fixed at 0.5 at any age without worsening the fit, indicating gender-specific genetic effects meaning that genetic factors affecting BMI among boys and girls were not all identical. Further, setting parameter estimates as equal between boys and girls worsened the fit of the model significantly except at 14 years, but for the sake of uniformity and because the sample size was sufficient, the parameter estimates were calculated separately for boys and girls at each age.

The results from cross-sectional analyses estimating genetic and environmental effects on BMI separately at 11-12, 14, and 17 years of age are presented in Figure 5 for boys and in Figure 6 for girls. Heritability of BMI among boys was 69% at 11-12 years, 66% at 14 years, and 83% at 17 years. Among girls it was 58% at 11-12 and 14 years, and 77% at 17 years. Common environmental factors contributed to BMI at 11-12 and at 14 years, but the effect disappeared by 17 years. Unique environmental effect

explained 15-23% of the inter-individual variance of BMI among adolescents. To show that disappearance of common environmental effects by 17 years was not due to decreasing statistical power (decreased number of participants), also ACE models were conducted at 17 years. From these results - C among boys 0% (95% CI 0-11%) and C among girls 3% (95% CI 0-20%) – it was obvious that C had indeed disappeared by 17 years.



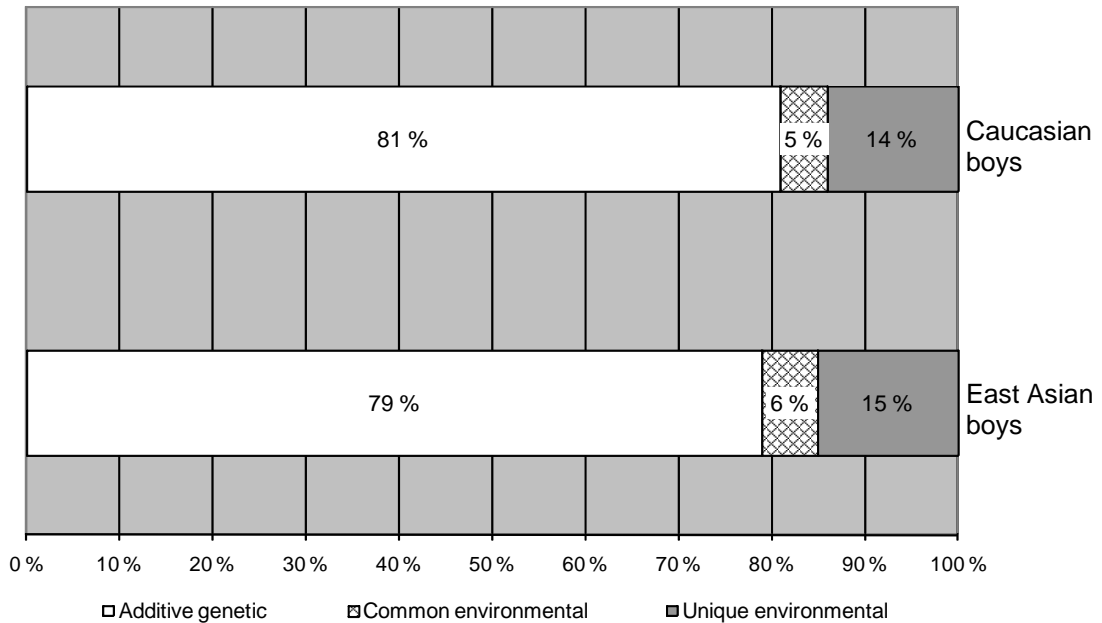
**Figure 5: Genetic and environmental effects on BMI at 11-12, 14, and 17 years of age among Finnish boys.**



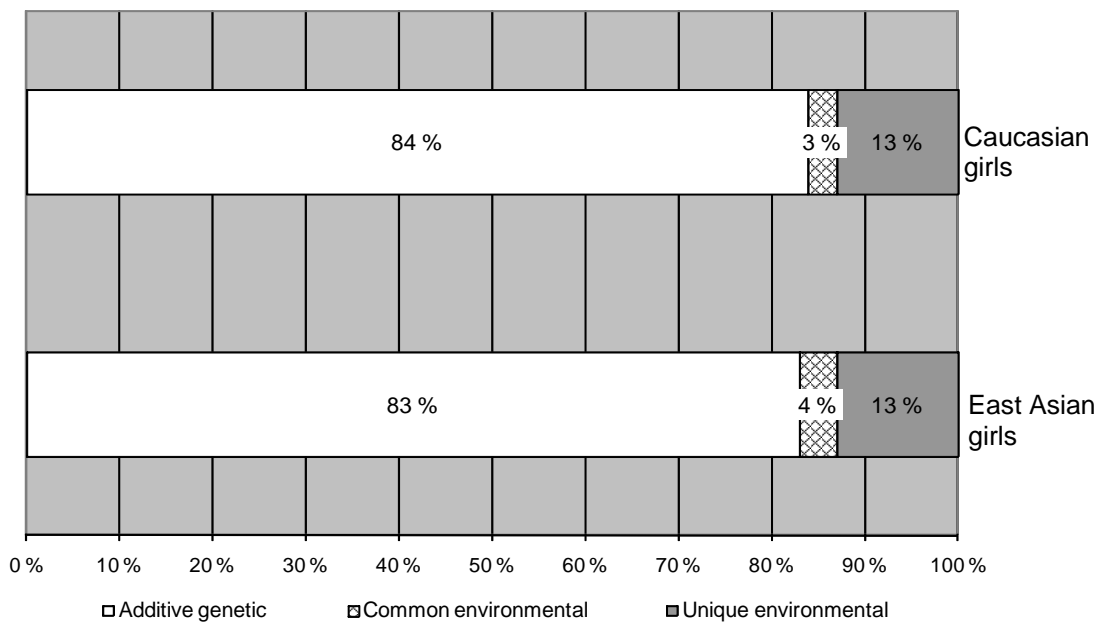
**Figure 6: Genetic and environmental effects on BMI at 11-12, 14, and 17 years of age among Finnish girls.**



In study V twin model fitting for BMI was done separately for East Asian and Caucasian 14-year-old boys and girls. Additive genetic and both common and unique environmental factors made a significant contribution to the total inter-individual variation of BMI. These relative contributions based on the best fitting models are presented in Figure 7 for boys and in Figure 8 for girls.



**Figure 7: Genetic and environmental effects on BMI among 14-year-old Caucasian and East Asian boys**



**Figure 8: Genetic and environmental effects on BMI among 14-year-old Caucasian and East Asian girls**

The relative contributions of genetic and environmental factors were similar among East Asian and Caucasian twins (Figures 7 and 8). However, total variance of BMI was slightly greater among Caucasian boys (38) than East Asian boys (35) and the difference was attributable to greater genetic variation among Caucasian boys. Among Caucasian girls, the total variation of BMI was clearly higher (42) than among East Asian girls (27). The majority (80%) of this difference was attributable to higher genetic variation, with 20% being due to higher unique environmental variation among Caucasian than East Asian girls.

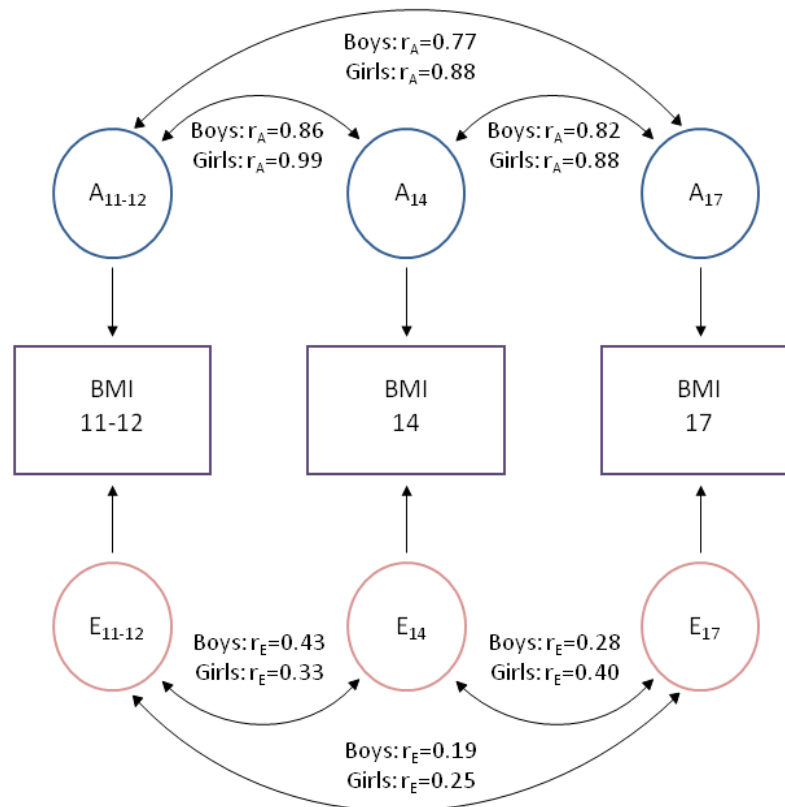
### **5.3.2 Longitudinal analyses (multivariate models)**

To model correlations of genetic and environmental factors affecting BMI between different ages Cholesky decomposition including BMI at 11-12, 14, and 17 years of age was used (Figure 9, adjusted from Neale & Cardon, 1992). By estimating genetic and environmental correlations across ages it was possible to study if genetic and environmental factors affecting BMI were mainly same or different at different ages and how much of the stability of BMI was explained by genetic and environmental factors. Based on univariate model fitting results presented before, A, C, and E components were included into the model at 11-12 and 14 years and A and E components at 17 years. Because the correlation between common environmental (C) factors at 11-12 years and 14 years was not significant, it was not included into the final model. Thus, only A and E components and their correlations across ages were in the final longitudinal model. Table 12 and Figure 9 present the results from the longitudinal analyses. The phenotypic correlations of BMI between different ages were 0.66-0.80 during the follow-up and additive genetic factors explained 90-96% of inter-individual variation of these correlations (Table 12). Correlations between additive genetic factors affecting BMI at different ages were rather high ( $r=0.77-0.99$ ) (Figure 9), suggesting that most of the genetic factors affecting BMI were the same at different ages. Unique environmental factors affecting BMI appeared to be mainly different at different ages because their correlations across adolescence were only modest ( $r=0.19-0.43$ ) (Figure 9).

**Table 12: Phenotypic correlations of BMI between 11-12 and 17 years and proportions of them explained by genetic and environmental factors<sup>1</sup>.**

BMI at	Phenotypic correlation		% of phenotypic correlation explained by additive genetic factors		% of phenotypic correlation explained by unique environmental factors	
	boys	girls	boys	girls	boys	girls
11-12 and 14 years	0.80	0.74	92	92	8	8
14 and 17 years	0.73	0.77	94	90	6	10
11-12 and 17 years	0.67	0.66	96	92	4	8

<sup>1</sup>Parameter estimates based on the trivariate Cholesky decomposition.



Abbreviations in Figure 9:

BMI 11-12, 14, 17 = body mass index at 11-12, 14, and 17 years of age

$A_{11-12, 14, 17}$  = additive genetic factors affecting BMI at 11-12, 14, and 17 years

$E_{11-12, 14, 17}$  = unique environmental factors affecting BMI at 11-12, 14, and 17 years

$r$  = correlation between factors affecting BMI at different ages

**Figure 9: Cholesky decomposition used for longitudinal twin analyses: genetic and environmental correlations among boys and girls.**

## 6 DISCUSSION

### 6.1 LEISURE ACTIVITIES, COMPUTER AND CELL PHONE USE, AND OVERWEIGHT

#### 6.1.1 Summary

Participation in most leisure activities decreased between 14 and 17 years of age (I). Physically active leisure interests were generally associated with a lower prevalence of overweight and sedentary leisure interests with a higher overweight prevalence in cross-sectional analyses. This was most striking among 14-year-old boys, whereas only sports were associated with a decreased prevalence of overweight among 14-year-old girls (I). Among 17-year-olds there were very few associations between prevalence of overweight and leisure interests (I).

In prospective analyses across adolescence some sedentary leisure interests were associated with increased risk of overweight, while sports and musical instrument playing were associated with decreased overweight risk among boys (III). Among girls, the 'Passive and solitary' leisure pattern at 14 years predicted an increased risk of becoming overweight by the age of 17 (III).

Computer ownership and use were associated with higher BMI and/or overweight prevalence among 17-year-olds, but there was only a weak trend of increasing BMI with larger cell phone bill and no association between being overweight and the size of the cell phone bill (II).

#### 6.1.2 Television and video viewing and physical exercise

Television and video viewing and physical exercise are the most studied leisure activities in relation to weight status among children and adolescents. Most cross-sectional studies confirm that television viewing is positively (Marshall et al., 2004) and physical exercise negatively associated with weight status, although the results of prospective studies are mixed (Must & Tybor, 2005). The effect size of television viewing on adiposity measurements is quite small (Marshall et al., 2004), although the results from intervention studies are more promising (Swinburn & Shelly, 2008). It has been suggested that the small effect size in population studies could be due to consistently high levels of television viewing among children, that is, small variation nowadays in time spent viewing television in most populations (Swinburn & Shelly, 2008). The measures of our study unfortunately failed to capture the true patterns of

television viewing. However, the measures were more suitable for video viewing, which may act in a similar way in relation to weight status. Although not fully consistently, there appeared to be a positive association between video viewing and overweight; in particular, video viewing at 11-12 years predicted later overweight risk among girls (III).

Our study confirmed that sports/exercise were associated with lower overweight prevalence in cross-sectional analyses but also in some prospective analyses among boys (III). Physical exercise is supposed to decrease weight by increasing energy expenditure. On the other hand, sedentary activities such as television and video viewing are supposed to increase weight by displacing more physically active leisure interests and possibly also by increasing energy intake due to snacking while viewing or, while television viewing, as a response to advertisements (Robinson, 2001). A negative relationship between television viewing and physical activity was found in a meta-analysis based mainly on cross-sectional studies (Marshall et al., 2004), and although video viewing was not directly associated with obesity it was inversely associated with physical activity, a negative correlate of obesity (Marshall et al., 2004). Increased snacking between meals was associated with television viewing while other dietary measures were not, in a review on correlates of television viewing (Gorely et al., 2004). There is also some evidence that television food advertisements could increase energy intake among children (Halford et al., 2007a; Halford et al., 2007b), and increased television viewing was associated with more positive attitudes towards junk food and higher reported junk food consumption (Dixon et al., 2007). Although a review on the matter, with special emphasis on Australian data, found that evidence for energy-intake-increasing effects of TV advertisements among children was equivocal and also that the link between television viewing and childhood obesity was weak (Carter, 2006), many countries have already restricted TV junk-food advertisements focused at children in order to prevent childhood obesity.

### **6.1.3 Other leisure activities**

Sedentary leisure activities such as computer and cell phone use or video games may replace more physically active leisure interests and therefore decrease total energy expenditure. In our study, having a home computer and increased computer use hours were positively associated with weight status. These findings are in line with another Finnish study (Kautiainen et al., 2005) as well as with some American studies (Utter et al., 2003;; Lutfiyya et al., 2007) conducted among children and adolescents and with one Australian study conducted among adults (Vandelanotte et al., 2009) but not

with all previous cross-sectional studies (Janssen et al., 2004; Burke et al., 2006; te Velde et al., 2007). Longitudinal studies are completely lacking, and it is still unclear whether increased computer use precedes overweight or is a consequence of becoming overweight. The same applies to cell phone use: a weak positive linear trend of increasing BMI with rising cell phone bill was found in our study but there was no association between cell phone bill amount and prevalence of overweight (II). In a previous study among Finnish adolescents cell phone use was associated with some health-compromising behaviors, such as tobacco, snuff, and alcohol use (Koivusilta et al., 2005).

In line with our findings, a previous Finnish study did not find any association between use of electronic games and weight (Kautiainen et al., 2005) and these findings have been confirmed by studies conducted in Australia (Burke et al., 2006) and in the USA (McMurray et al., 2000). Studies among Canadian (O'Loughlin et al., 2000) and Swiss (Stettler et al., 2004) children have however found a positive association between use of electronic games and weight. One longitudinal study on computer/video games found only ethnicity- and gender-specific positive and negative associations with overweight (Gordon-Larsen et al., 2002). Computer and video games have been considered as potential risk factors for obesity development, but today's activity-promoting video games such as dance games and Nintendo Wii, innovations that have spread rapidly among young people, may be able to reverse the effect of video games on weight. At least energy expenditure was significantly greater among both children and adolescents while they played such games in one study (Lanningham-Foster et al., 2009), and access to them reduced sedentary screen time among children and may have facilitated slight increases in vigorous physical activity in another study (Maloney et al., 2008).

Reading and doing homework were associated with higher BMI among American adolescent boys contrary to our findings. In girls reading was not related to weight status in the same study (Utter et al., 2003) which is in line with our results. The cross-sectional and longitudinal associations of arts (boys) and crafts (girls) with increased risk of overweight found in our study are novel. It was also found that musical instrument playing was associated with decreased overweight risk (boys) in both prospective and cross-sectional analyses. In prospective analyses only, listening to music daily (boys) and playing board games (girls) increased the risk of overweight, while participating in boys' clubs decreased the risk (III). These associations have not been investigated before. The above leisure activities which had positive associations with overweight (arts, crafts, listening to music, playing board games) are sedentary in nature and do not normally include social intercourse with

peers (except for playing board games). Such activities can displace more physically active leisure interests but may also be associated with the kind of lifestyles that increase weight. Negative association of musical instrument playing with overweight risk could be explained by many things, e.g. it does not leave hands free for eating, is time-consuming and demands a lot of practice, and therefore may be associated with an overall regular life style. Residual confounding effect of parental socioeconomic status is also possible although the models were adjusted for parental education level. The risk-reducing effect of boys' clubs/scouts could be explained by its partially physically active nature and possibly also its sociability-promoting effects in addition to life-style differences.

#### **6.1.4 Leisure activities in relation to lifestyle**

Active involvement in a leisure activity can reflect a certain lifestyle that affects weight status via health habits. For instance, American students who participated in extracurricular activities and/or sports were more likely to meet exercise guidelines and consume milk and fruits/vegetables and less likely to consume alcohol, tobacco, and marijuana than students who did not participate in any activities. The students not participating in any activities had the lowest rates for measures of family and school connectedness and self-esteem, and the highest rates for emotional distress and suicidal behavior. (Harrison & Narayan, 2003). Active involvement in school clubs was associated with a lower level of externalizing problem behavior, and among boys with a lower alcohol and marijuana use in another study (Fredricks & Eccles, 2006). Sports participation was related to a lower level of depression, internalizing problem behavior, higher self-esteem, lower alcohol use (Fredricks & Eccles, 2006), better self-reported physical health status, quality of life, and quality of family and peer relationships (Iannotti et al., 2009). Television and computer use were, however, negatively associated with physical health status, quality of life, and family relationships but positively associated with quality of peer relationships (Iannotti et al., 2009). Also higher use of electronic media communication was associated with increased time spent with friends (Kuntsche et al., 2009). Youngsters in different groups formed based on their participation in out-of-school activities have been found to differ in their attitudes and perceptions about school, the level of truancy and delinquency, (Nelson & Gastic, 2009), level of academic achievement (Bartko & Eccles, 2003; Nelson & Gastic, 2009), engagement in problem behavior, depressive symptoms, as well as internalizing and externalizing problems (Bartko & Eccles, 2003).

To obtain a more comprehensive view of associations of leisure activities with being overweight, latent class analysis was used to group subjects based on their leisure activity profiles (III). Among boys and 11-12-year-old girls, these leisure activity profiles did not predict becoming overweight, but the prevalence of overweight was higher in the 'Passive and solitary' group. This suggests that instead of leisure activity profiles affecting weight status, adolescents' weight status may affect their leisure activity profiles, or that leisure activity profiles have already exerted their effect on weight earlier in childhood. Overweight adolescents have been previously shown to be socially isolated (Falkner et al., 2001; Strauss & Pollack, 2003) and when studied as an individual leisure activity in this study, 14-year-old boys who spent time with their peers frequently were less likely to be overweight than boys who did not do so (I). However, in prospective analyses adjusted for initial BMI level, socializing was associated with an increased risk of later overweight (III). Thus, while it seems likely that boys who are overweight do not spend time with peers as often as boys of normal weight, social isolation does not increase the risk of later overweight among boys, which is in line with the results of leisure activity patterns analyses.

Among 14-year-old girls, however, the 'Passive and solitary' cluster carried the greatest risk of becoming overweight later in adolescence (III). During adolescence peers become more important as adolescents gain independence from their parents (Dunderfelt, 1998; Nurmi et al., 2006). Girls' relationships with their friends are more intimate and provide more caring, help, and guidance than boys' relationships (Siegler et al., 2006) which could explain why belonging to the "Passive and solitary" class predicted weight gain in 14-year-old girls but not in boys. The level of involvement in organized activities has been associated with depressive symptoms (Fredricks & Eccles, 2006; Randall & Bohnert, 2009) and depressive symptoms have increased the risk of later obesity among girls but not boys (Richardson et al., 2003; Anderson et al., 2006) which could also explain gender differences. Among boys more longitudinal associations between individual leisure activities and weight status were found than among girls. It seems that leisure activity profiles among girls and individual leisure activities among boys may help to estimate the risk of later overweight in early adolescence.

Only a few previous studies have considered patterns of leisure activities instead of individual activities as risk factors for being overweight. When cluster analysis was used to study patterns of television viewing, computer use, and physical exercise in a cross-sectional setting among 11-year-old European children, clusters with high levels of television viewing/computer use and low levels of physical activity were associated with a higher overweight prevalence when compared to a cluster with low levels of



television viewing/computer use and high levels of physical activity (te Velde et al., 2007).

Associations of behavior patterns with obesity have been investigated before in a longitudinal setting in only two studies: a study involving American 11-22-year-olds (Boone-Heinonen et al., 2008) and another among Chinese 6-18-year-olds (Monda & Popkin, 2005). The method used was cluster analysis rather than latent class analysis as in this study (III). Cluster input variables among Americans included diet, independence in decisions (about foods consumed and television viewing), alcohol use, smoking, dieting or exercising to lose weight, and various leisure activities (television and video viewing, computer/video games, housework, hobbies, skating, sports, exercise, hanging out, school clubs, physical education, and use of community recreation centers) (Boone-Heinonen et al., 2008). Among Chinese children and adolescents (Monda & Popkin, 2005) the input variables included four physical activities and two variables composed of sedentary activities (television/video viewing and reading/writing/drawing).

It is difficult to compare the cluster solution approach used by Boone-Heinonen et al. and Monda & Popkin with the latent class approach (III) because the behaviors on which they were based were only partly overlapping, due to the subjects' age differences and a wide age range of both studies, high number (35%) of subjects excluded in one study (Boone-Heinonen et al., 2008) and because only 51% of the subjects attended the follow-up assessment in another study (Monda & Popkin, 2005), and because behavior patterns may be culture-specific. In any case, a common finding in our study (III) and in a study of Boone-Heinonen et al. was that behaviour patterns in males did not predict the risk of overweight but among girls behaviour patterns predicted incidence of obesity. The girls who belonged to a cluster defined by active participation in school clubs and sports had a lower prevalence of overweight than other girls. Belonging to the 'School clubs & sports' cluster was also associated with a decreased 5-year-incidence of obesity when compared to girls who belonged to the 'Average diet & activity', 'Sedentary behaviors', and 'Restrictive dieting & smoking' clusters (Boone-Heinonen, 2008). The results among Chinese children (Monda & Popkin, 2005) were also somewhat consistent with our results (III): in incident longitudinal models youngsters in the high activity/high inactivity cluster had the lowest odds of overweight when compared to those in the low activity/no inactivity group (Monda & Popkin, 2005).

## **6.2 GENETIC AND ENVIRONMENTAL EFFECTS ON BMI**

### **6.2.1 Summary**

Additive genetic as well as unique and common environmental factors affected BMI in early adolescence (IV). Common environmental effects disappeared by the age of 17 years while heritability of BMI increased (IV). BMI trait correlations across adolescence were largely explained by additive genetic factors (IV). Genetic effects were largely similar at each age while environmental effects changed during the follow-up (IV). Genetic factors affecting BMI were somewhat different among boys and girls (IV). Total variation of BMI was higher among Caucasian than East Asian 14-year-olds and the difference was mainly due to higher genetic variation among the Caucasians (V).

### **6.2.2 Genetic and environmental effects on the level of BMI**

As several previous studies have shown (Koeppen-Schomerus et al., 2001; van Dommelen et al., 2004; Silventoinen et al., 2007a; Haworth et al., 2008a; Haworth et al., 2008b; Wardle et al., 2008a) BMI of children is affected by common environmental factors in addition to unique environmental and additive genetic factors, although there are some divergent results, too (Bodurtha et al., 1990; Silventoinen et al., 2007b). The longitudinal British twin study (Haworth et al., 2008b) showed that heritability of BMI increased while the common environmental effect decreased during childhood from 4 to 11 years of age and a recent meta-analysis on childhood twin studies found that common environmental effects start to decrease at school age and are evident until the age of 13 years, after which they disappear and heritability estimates increase (Silventoinen et al., 2009a). These findings are in line with our results (IV). The two previous longitudinal twin studies conducted among Swedish boys (Silventoinen et al., 2007b) and among both genders in Australia (Cornes et al., 2007) did not however show that decline in common environmental influence and increase in heritability would continue in adolescence.

In one of the studies with divergent results, BMI was found to be influenced only by additive genetic and unique environmental but not by common environmental factors (Silventoinen et al., 2007b) but this was probably due to insufficient statistical power. In the other study (Cornes et al., 2007) BMI was affected by unique environmental and additive genetic factors at 12 and 14 years, but at 16 years a large dominant genetic effect was found. Dominant genetic effects were not found in our study (IV)

and have not been usually found in other previous studies among adolescents either (Allison et al., 1994; Pietiläinen et al., 1999, Hur, 2007; Silventoinen et al., 2007b). The Australian study of Cornes et al. is the only longitudinal twin study on adolescent BMI among both genders in addition to ours (IV).

It is possible that real differences in the type of factors influencing BMI between Australian and Finnish adolescents exist. These could be based on differences in family or school environments, such as in frequency of family meals, school catering, or school class placement of co-twins, which might affect the number of shared environmental factors and thus the magnitude of the common environmental component. Differences in genetic background are also possible and genetic diversity is actually suggested to be lower among Finns than other European populations (Peltonen et al., 1999), and may also be lower than among the Australian population. Finns were also genetically distinct when whole genome polymorphisms from several Northern European, European-Australian, and European-American populations were examined (McEvoy et al., 2009). However, significant differences in variance structure of BMI between Finland and Australia were not found when genetic and environmental effects on BMI were estimated in young adults aged 20-39 years from eight countries (Schousboe et al., 2003). Study V showed that when Caucasian 14-year-old twins from Australia, Finland, Netherlands, and USA were studied in one group, the results were quite similar to the results of Finnish twins only, but the common environmental component was considerably smaller. However, the common environmental component varied by country from 2 to 17% in Caucasian and from 2 to 24% in East Asian 14-year-olds (V), which corresponds to Finnish estimates of 15-24% (IV).

Study V showed that mean BMI and also the total variance of BMI were somewhat higher among 14-year-old Australian compared to Finnish twins. This can be also seen by comparing the whole Finnish (IV) and Australian (Cornes et al., 2007) samples at 14 years of age, when the twins were about the same age in both studies. The percentage of overweight and obesity was also higher among Australian 14-year-olds (17.1% for boys and 17.2% for girls) (Cornes et al., 2007) than among Finnish 14-year-olds (10.2% for boys and 7.9% for girls). One possible explanation for the divergent findings between Australian (Cornes et al., 2007, V) and Finnish (IV, V) twins could therefore be different BMI distributions among adolescents from the two countries, although when genetic and environmental influences were studied among 7- and 10-year-old British twins the influences were found to be quantitatively and qualitatively similar among obese and normal weight children (Haworth et al., 2008a).

Although Australian study (Cornes et al., 2007) was longitudinal, only 39% of 1143 twin pairs were measured at every age point, compared to 72% of 2251 twin pairs in our study (IV). Further, the Australian study (Cornes et al., 2007) was not population-based, leading to the possibility of some selection bias. In our study self-report may have biased the results while in Australian study (Cornes et al., 2007) measured weight and height were used. Due to these matters it cannot be resolved without more studies in population-based samples from different countries with measured BMI whether divergent findings from Australians and Finns reflect real differences between the two countries.

A slight discrepancy between the previous literature and our study (IV, V) may be seen in the fact that common environmental influence on BMI was found at 14 years although in previous studies it has not been found among adolescents older than 12 years (Allison et al., 1994; Cornes et al., 2007; Hur, 2007; Silventoinen et al., 2007b). Two of the studies and their characteristics were discussed above (Cornes et al., 2007; Silventoinen et al., 2007b) and in the two other studies adolescents aged 12-18 years (Allison et al., 1994) and 13-19 years (Hur, 2007) were analyzed as a single group and it is therefore impossible to say if the factors contributing to BMI were different in younger than in older adolescents.

### **6.2.3 Gene-environment interaction and correlation**

In study V it was found that the genetic variation of BMI was slightly greater among Caucasians than East Asians. Larger genetic variation of BMI among Caucasians could be due to increased number of BMI-affecting genes, increased variation of the allele variants of the same BMI-affecting genes or larger impact of the same genetic factors among Caucasians. Genetic and environmental variations are population- and time-specific and depend on the prevailing environmental conditions. For this reason the last of the three explanations would appear to be the most plausible one. For instance, among people with similar genetic background the absolute genetic variance of BMI was about four times bigger in the United States than Nigeria, although heritability estimates were of the same magnitude due to an environmental variance that was also bigger in the USA. For height, heritability was clearly smaller in Nigeria than in the USA. (Luke et al., 2001). These differences could be due to gene-environment interaction (GxE), which means that the magnitude of genetic variation is dependent on the type of environment the individual is exposed to, probably because of changing gene expression. For instance, high physical activity has been

shown to decrease the genetic contribution to BMI among adults (Silventoinen et al., 2009b; Mustelin et al., 2009).

Another possible explanation for different genetic variances in different environments is gene-environment correlation (rGE), which means that a correlation exists between a genotype and environmental conditions. If rGE is active, individuals select their environments based on their genotype (Jaffee & Price, 2007). For instance diet and food use patterns (Hur et al., 1998; Breen et al., 2006; Teucher et al., 2007; Keskitalo et al., 2008) and physical activity (Beunen & Thomis, 1999; Eriksson et al., 2006; Stubbe et al., 2006) are partly genetically determined and genes could affect weight status via them. Genetic variation of BMI may be higher in environments, such as ours, where individuals are free to choose a diet or a level of physical activity that suits their genotype. Alcohol use among adolescents, for example, was more genetically determined in urban than rural areas (Rose et al., 2001), possibly because adolescents in urban areas had greater choice as to whether or not to use alcohol, and their decisions were also based partly on their genetic background. Genes can thus act on phenotypes via environmental factors too, and environmental factors can modify the extent of variation explained by genetic factors.

GxE or rGE may also have affected the results of study IV. In classic twin analyses GxE effects are modeled as part of additive genetic effects if the environmental factors are shared by siblings, and as part of unique environmental effects if they are not shared. GxE could therefore explain the disappearing common environmental effect in study IV only if there were some genes whose expression was turned on only later in adolescence and these genes would interact with the common environmental factors whose effect was detected earlier. However, the high correlation between genetic effects at 14 and 17 years, suggesting that most of the genetic factors affecting BMI were similar at 14 and 17 years, makes this option unlikely.

Active rGE effects are modeled as part of additive genetic effects: they make MZ twins resemble each other more than DZ twins, as twins choose environments that suit their genotypes. Adolescents' independence in decision making increases especially when moving from early (13-16 years) to middle (16-19 years) adolescence (Nurmi et al., 2006) and therefore also rGE may increase in importance and explain the disappearing effect of common environmental factors on BMI by 17 years and the increasing heritability found in study IV, particularly if adolescents decide more independently about their eating habits and other important weight-related behaviors that are partly genetically determined.

#### 6.2.4 Genetic and environmental effects on stability of BMI

Genetic and environmental effects on BMI trait correlations, or stability of BMI, have been previously explored in only a few studies during childhood and adolescence. Among Dutch children aged 3 -12 years, genetic factors accounted for 57-88% of the variance in BMI trait correlations (Silventoinen et al., 2007a), among British children aged 4 - 11 years for 76-89% (Haworth et al., 2008b), and among Swedish males aged 2 - 18 years for 81-95% (Silventoinen et al., 2007b). The last study is the only one that included adolescents and it was not reported how percentages varied with age (Silventoinen et al., 2007b). If it is assumed that the higher percentages were from adolescents, the numbers were very close to our estimates of 90-96% of the variance in BMI trait correlations to be explained by additive genetic factors (IV).

In line with our findings, transmission coefficients of genetic effects among Australian adolescents were large, suggesting that the same set of genes accounted for most of the BMI variation at 12, 14, and 16 years, although some new genetic effects also emerged at 14 years in girls and at 16 years in both genders (Cornes et al., 2007). In a study among Swedish males a similar model as in our study was used and genetic correlations between BMI at 18 years and 12-17 years ranged from 0.78 to 0.93 (Silventoinen et al., 2007b) which is comparable to the correlations found in study IV ( $r= 0.77-0.99$ ). The high genetic correlations suggest that most of the genetic factors affecting BMI at different ages were the same and therefore the increase in heritability of BMI reported above (IV) is more likely to be attributed to the increasing effects of the same genetic factors rather than to new ones emerging later in adolescence.

Contrary to our findings, transmission coefficients of unique environmental effects among Australian adolescent twins were quite large during adolescence, but at each age (12, 14, 16 years) some new environmental effects also emerged (Cornes et al., 2007). Correlations between unique environmental factors affecting BMI at 18 years and at 12-17 years ranged from 0.33 to 0.85 and increased with age among Swedish males (Silventoinen et al., 2007b) while correlations between unique environmental effects in study IV were only modest (0.19-0.43), suggesting differing unique environmental factors between ages. However, it must be taken into consideration that the E component in twin analyses also includes measurement error which is larger when using self-reported than measured BMI. Correlations between common environmental factors at 11-12 and 14 years of age were not significant in study IV, but it has been found that among younger children such correlations can significantly contribute to BMI trait correlations across ages (Silventoinen et al., 2007a; Haworth et al., 2008b).

### **6.2.5 Assortative mating**

Assortative mating means that individuals choose spouses who are to some extent similar to themselves. This may confound the results of family studies because it makes the offspring more similar than in the case of random mating. Correlations between BMIs of Finnish twins and their spouses were 0.18-0.27 (Silventoinen et al., 2003), mainly because of social homogamy (choosing a mate based on a more similar environmental background, which has created similarity in BMI) rather than phenotypic assortment (choosing a mate based on a more similar phenotype). Only phenotypic assortment can result in genotypically more similar offspring. Phenotypic assortment may increase phenotypic correlations between DZ twins (Posthuma et al., 2003) and overestimate the common environmental component (Evans, 2002) or conceal the presence of dominant genetic effects and increase the possibility of observing additive genetic effects (Posthuma et al., 2003). Assortative mating cannot, however, explain our findings of diminishing effects of common environmental factors later in adolescence, because assortative mating would influence all age groups in a similar way. In our study sample the correlation between BMIs of mothers and fathers at baseline (when their children were 11-12 years old) was 0.15, which is slightly lower than among couples born in 1930–1957 (Silventoinen et al., 2003). The correlations between BMIs of parents at baseline and the BMIs of their children at 11-17 years were higher ( $r=0.19-0.26$ ) despite the two to four decades of age difference between parents and their children.

## **6.3 METHODOLOGICAL CONSIDERATIONS**

### **6.3.1 Cross-sectional study setting and causation**

In studies I, II, and partly III a cross-sectional study setting was used. When there is no information about the timing of events, an association does not necessarily imply causation. In the case of leisure activities and overweight the associations are very likely to be bidirectional: individuals of normal weight are, for example, more likely to participate in sports than their overweight peers (Petersen et al., 2004) and sports can also decrease the risk of future overweight (Gordon-Larsen et al., 2002).

The situation is made more complicated by BMI tracking or a very high correlation of initial BMI with the BMI later in life. Previous sports participation could therefore have an association with later decreased BMI, although sports would not really decrease BMI but vice versa. This problem was tried to overcome in this study by

adjusting for BMI level at the outset in the longitudinal analyses. This could have led to some confusing results, such as in the case of socializing among 14-year-old boys. Socializing was negatively associated with being overweight in the cross-sectional analyses (I), but positively associated with later overweight when the initial BMI was taken into account (III). Computer and cell phone use were measured at 17 years of age and only cross-sectional analyses were possible at that age. Therefore, it is not possible to draw the conclusion that computer or cell phone use increases BMI or the risk of overweight.

### **6.3.2 Self-report and measurement bias**

Using self-reported weight and height in assessing overweight can lead to underestimation of overweight prevalence among adolescents (Crawley & Portides, 1995; Elgar et al., 2005). However, self-report bias of weight and height varying with leisure activity participation, which could create spurious associations between overweight risk and leisure activities, is unlikely to rise. On the contrary, self-report bias may attenuate the associations because underestimation of weight is more common among heavier than normal weight and underweight adolescents (Crawley & Portides, 1995; Elgar et al., 2005). Weight concerns are less common among adolescent boys than girls (Kaltiala-Heino et al., 2003) and boys may even associate being heavier with a positive image of being stronger (Adams et al., 2000) and therefore self-report bias of weight could also differ between genders.

Self-report bias of weight and height can also lead to decreased variation of BMI, because tall, thin adolescents underestimate their height while shorter and heavier adolescents overestimate their height and underestimate their weight (Crawley & Portides, 1995). However, in this study, we concentrated mainly on proportions of the total variance explained by genetic and environmental factors. Self-report bias could also lead to an increased E component in twin analyses because it includes measurement error in addition to unique environmental factors. Weight and height measurements were available from the school health records of a random sample of Finnish twins born in 1975-79. Their mean BMI and SD of BMI at 11-12 and 14 years were very close to the self-reported values of our sample (IV).

Self-report bias may concern reporting leisure activities, too. Obese adults have been shown to overestimate their physical activity more than adults of normal weight (Irwin et al., 2001; Brown & Werner, 2008), further attenuating the associations between physical exercise and overweight. Self-report bias was even more



pronounced among adolescents and varied by gender, education, and weight status (Slootmaker et al., 2009). In our study, physical activity variables were not exactly the same in every age group but at 11-12 and 14 years sports and not any kind of physical activity were investigated. Participation in sports is usually more organized than participation in ordinary physical activity and it could therefore be easier to report the frequency of sports truthfully. In study I an item on any physical activity was also used to validate the sports question at 14 years. The questionnaire at 11-12 years did not include the item on any physical activity and to keep the variables of 11-12- and 14-year-olds similar the item was not used in study III. At 17 years the item on sports was not included and therefore only any kind of physical activity could be investigated. Anyway, the physical activity measurements of this study were not precise and were prone to bias and this may explain why longitudinal associations with weight status were found only among boys.

Television or video viewing (and maybe playing computer games) could also be reported in different ways depending on weight status, because they are commonly considered to have an undesirable effect on weight. Other leisure activities studied are commonly considered as more neutral in relation to weight and may therefore not be susceptible to weight-dependent self-report bias. Studies investigating self-report bias of leisure activities (other than physical activity) according to weight status do not to our knowledge exist.

The questionnaire used in this study was a very crude method to measure leisure activity participation. The frequency options were the same for all the 15 leisure activities with very different frequency distributions because the questionnaire had to be simple enough for children and adolescents. Therefore it was impossible to design frequency options that would have been optimal for every activity. For instance, association of television watching with weight status could unfortunately not be reliably assessed in this study as the highest frequency option available in the questionnaire was 'daily'. The real television watching patterns were not captured because almost all adolescents watched television daily: there was not enough variation in the distribution of the variable to conduct reliable statistical analyses. Measuring daily television viewing hours would have been a better method to capture variation in television watching. Large inter-individual variation in temporal patterns of leisure activities complicated measurements still further. Measuring leisure activities directly and accurately (e.g. using videotaping) is unfortunately not possible in large, epidemiological studies without disturbing subjects' behavior. It would also require unrealistic resources and could not be assessed over long periods.

### **6.3.3 Defining weight status**

Categorical overweight classification rather than continuous BMI was used as a main outcome in leisure activity analyses (I, III). This approach was chosen to identify associations between leisure interests and excess fat mass, and more exact measures of body composition were not feasible for this large, population-based sample. BMI is a problematic measure because it is poor at differentiating fat from muscle mass. Among normal-weight and underweight children and adolescents, fat-free muscle mass explained a large part of the inter-individual variation of BMI, while among children and adolescents with BMI at or over the 85th percentile it was a good indicator of adiposity (Freedman et al., 2005). Indeed, it has been found that although physical activity decreased BMI in overweight boys, it increased BMI in normal-weight boys (Berkey et al., 2003). To study possible differences between continuous and categorical BMI as an outcome, the analyses were conducted using both of them in study II and some differences in the results were found. It was particularly surprising to find that physical activity frequency had a strong negative association with being overweight but no significant association with BMI (II, results for variables, such as physical activity, that were used to adjust the analyses not reported in the article).

### **6.3.4 Twinship**

Twins may differ in some ways from singletons. At 16.5 years twins, especially boys, had lower mean BMI than singletons (Pietiläinen et al., 1999). Twins were rated higher than singletons in adaptive behaviors but no evidence was found that individual twins differ from singletons in externalizing or internalizing problem behaviors (Pulkkinen et al., 2003). When twins and singletons born in 1966 were followed from birth to adolescence it was found that sports were slightly more common among twins than singletons (Moilanen & Rantakallio, 1990), but responses to the intensity of physical activity item were very similar among Finnish twins born in 1974-77 and among Finnish singletons born in 1974 (Aarnio et al., 1997). The effect of twinship on social interactions is not straightforward but depends on the level of co-twin dependence. For some pairs the relationship between co-twins is similar to the relationship between normal siblings and unlikely to affect their social interactions with peers while twins who have a very close relationship with their co-twins may spend more time with their co-twins and less time with other friends (Penninkilampi-Kerola, et al., 2005). Twinship may diminish computer use time at home because many families own only one computer, but the situation is the same for singletons

who have siblings of about the same age. Differences particular to twinship are relatively minor and unlikely to affect the relationship of leisure activities or computer and cell phone use with the risk of overweight.

Twin analyses on genetic and environmental factors impacting BMI are based on variation and co-variation of BMI and are not affected by differences in mean BMI between twins and singletons. However, non-twin family studies have usually yielded heritability estimates lower than twin studies (Maes et al., 1997; Silventoinen et al., 2008), although differences in methods can also produce these differences. Twin studies can yield higher heritability estimates because of perfect age matching in twins, but also because environmental effects are assumed to be equal within MZ and DZ pairs. If MZ pairs have more similar environments and resemble each other more because of this, genetic effects are overestimated because any excess similarity of MZ pairs is regarded as a genetic effect (Evans, 2002). Larger heritability estimates in twin studies can also be due to participation bias. It was found that variance of weight was lower in twins who participated in a survey than among those who did not or whose zygosity could not be determined (Silventoinen et al., 2008). There is, however, no perfect method for determining genetic and environmental effects on certain traits; despite its limitations classic twin modeling remains one of the best.

### **6.3.5 Strengths**

The sample of this study was large and population-based and included twins of each zygosity: monozygotic, and both same-sex and opposite-sex dizygotic pairs. All twins born in Finland in 1983-87 were ascertained and the participation rates were high. Both cross-sectional and longitudinal analyses could be conducted with the data. Follow-up covered the whole period of adolescence and adolescents were assessed at every phase of puberty: pre-puberty, puberty, and post-puberty. Age at baseline and at each follow-up point was standard, which enabled studying how leisure activities and their associations with overweight and genetic and environmental effects on BMI changed with age. Information was available about a wide range of leisure activities, which enabled, with the help of advanced statistical methods, using them as markers of different life styles. Information was also available on several potential confounding factors, including pubertal development level and parental education and occupational group, which allowed adjusting the analyses for these.

## **6.5 CONCLUSIONS**

Sports had cross-sectional associations with lower overweight prevalence among both boys and girls, and sports also decreased the later risk of being overweight among boys. Many sedentary leisure activities had positive associations with being overweight, and 17-year-olds who were overweight used a computer more than their peers of normal weight. The prevalence of overweight was highest among 12-year-olds and 14-year-old boys whose leisure activity pattern was 'passive and solitary'. Among girls aged 14, this kind of a leisure activity pattern increased the risk of becoming overweight later in adolescence.

Despite the high heritability of BMI, common environmental factors shared by siblings also had an effect on BMI until 14 years of age, but the effect disappeared by 17 years. Genetic factors accounted for the stability of BMI during adolescence and unique environmental factors had only a minor impact. Genetic factors affecting BMI were quite similar at each age, but environmental factors changed during adolescence. It was also found that genetic factors affecting BMI differed somewhat between boys and girls during adolescence. Total variance of BMI of 14-year-olds was greater among Caucasians than East Asians. The difference was mainly attributable to higher genetic variation among Caucasians.

## **6.6 IMPLICATIONS FOR HEALTH PROMOTION STRATEGIES**

The findings of this study highlight the importance of creating a versatile leisure time environment for adolescents. Sedentary leisure time may predispose adolescents to overweight. Physical activity and healthy eating should be encouraged especially among adolescents who have mainly sedentary hobbies. Internet-based prevention campaigns may be a useful approach given that overweight adolescents used computers more than their peers. On the other hand, longitudinal studies are needed to explore whether increased computer use predicts the risk of later overweight.

Low sports participation and a passive and solitary leisure activity pattern were more common among adolescents who were overweight. These results highlight the importance of also creating opportunities for overweight adolescents to enjoy participation in sports and other leisure activities. Stopping discrimination related to overweight as early as possible is crucial for preventing psychological problems and social marginalization of overweight adolescents.

Family-based interventions hold the key to controlling obesity until middle adolescence. Later in adolescence interventions should concentrate on individuals rather than families. These conclusions are based on our finding of disappearance of the common environmental effect on BMI by the age of 17 years. To confirm this finding requires longitudinal studies of genetic and environmental effects on BMI during adolescence, using measured weight and height in large, population-based samples. Studies of genetic and environmental effects on body composition measured in more accurate ways than BMI are also needed. To disentangle the complex interplay of genetic and environmental factors affecting BMI will also require more studies among various ethnic groups and among children with similar genetic backgrounds living in different environments as well as studies investigating interactions of individual environmental factors with individual genetic factors.

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