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Secular trend, tracking and familial resemblance in physical activity and physical fitness:

The Leuven Longitudinal Study on Lifestyle, Fitness and Health

1969-2004

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Lynn Matton,

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ABBREVIATIONS

BAQ	Baecke Questionnaire
BIA	Bio-electrical Impedance Analysis
BMI	Body Mass Index
CDC	Centers for Disease Control and Prevention
CFS	Canada Fitness Survey
CI	Confidence Interval
DXA	Dual-energy X-ray Absorptiometry
EEactl	Total energy expenditure related to active leisure time activities during a usual week (including household and garden activities, sports participation and active transportation (cycling and walking))
EEocc	Total energy expenditure related to the the main or additional occupation during a usual week (including time spent working and time spent on transportation by bike, on foot or motorized to and from the workplace)
EEsport	Total energy expenditure related to sports participation during a usual week
EEtotal	Total energy expenditure during a usual week
FLOS	Flemish Longitudinal Offspring Study
FPACQ	Flemish Physical Activity Computerized Questionnaire
h^2	Heritability
Iactl	Average energy expenditure related to active leisure time activities during a usual week (including household and garden activities, sports participation and active transportation (cycling and walking))
ICC	Intraclass Correlation Coefficient
Iocc	Average energy expenditure related to the the main or additional occupation during a usual week (including time spent working and time spent on transportation by bike, on foot or motorized to and from the workplace)
IOS	Interuniversitair Onderzoekscentrum voor Sportbeleid
IPAQ	International Physical Activity Questionnaire
Isport	Average energy expenditure related to sports participation during a usual week

LGSBB	Leuven Growth Study of Belgian Boys
LGSFG	Leuven Growth Study of Flemish Girls
LLSLFG	Leuvense Longitudinale Studie over Levensstijl, fysieke Fitheid en Gezondheid
LLSLFH	Leuven Longitudinal Study on Lifestyle, Fitness and Health
LLTS	Leuven Longitudinal Twins Study
MET	Metabolic Equivalent Task
PAL	Physical Activity Level
QFS	Québec Family Study
QTDT	Quantitative Transmission Desiquilibrium Test
r	Correlation coefficient
RT3	RT3 Tri-axial Research Tracker
SD	Standard Deviation
SPAH	Sport, Physical Activity and Health
Tactl	Time spent on active leisure time activities during a usual week (including household and garden activities, sports participation and active transportation (cycling and walking))
Tatransl	Time spent on active transportation (cycling and walking) in leisure time during a usual week
TCQ	Tecumseh Community Health Questionnaire
Teat	Time spent eating during a usual week
Tocc	Time spent on the main or additional occupation during a usual week (including time spent working and time spent on transportation by bike, on foot or motorized to and from the workplace)
Tsleep	Time spent sleeping during a usual week
Tsport	Time spent on sports participation during a usual week
Ttv	Time spent watching TV/video or playing computer games during a usual week
Vc	Proportion of the total variance explained by common environmental factors
Ve	Proportion of the total variance explained by unique environmental factors
Vg	Proportion of the total variance explained by genetic factors
Vtot	Total variance

ENGLISH SUMMARY

The importance of regular physical activity and of physical fitness for health has been widely accepted and extensively documented. However, before developing and implementing strategies to encourage physical activity and improve physical fitness, it is important to 1) be able to accurately assess physical activity and physical fitness, 2) be well informed about the status and (generation- or age-related) change of physical activity and physical fitness and 3) have clear insight into the causes underlying the phenotypic variation in physical activity and physical fitness. The purpose of this thesis was to document each of these aspects in the Flemish population using data from the Leuven Longitudinal Study on Lifestyle, Fitness and Health (LLSLFH) 1969-2004. Therefore this thesis was divided into a methodological, a longitudinal epidemiological and a genetic epidemiological part each consisting of two chapters addressing one specific research question.

In the first chapter of the methodological part, three difficulties associated with longitudinal research, i.e. the "imperfect" design, the evolution of data collection methods and the representativeness of the ongoing study sample, were documented by means of findings from the LLSLFH. The LLSLFH provides unique research opportunities, especially in studying longitudinal and genetic epidemiological aspects of physical activity and physical fitness, but is also faced with several limitations. However, when aware of these possible "pitfalls" several measures (e.g., thorough planning, appropriate sampling procedures, reimbursement of travel expenses, personal results, newsletters, telephone interviews with dropouts) should be taken to prevent or limit them as much as possible and to interpret the results in the right perspective. In the second chapter two-week test-retest reliability and concurrent validity of the Flemish Physical Activity Computerized Questionnaire (FPACQ) developed for employed/unemployed and retired people was investigated. The FPACQ was used in the most recent phase of the LLSLFH. The RT3 Tri-axial Research Tracker, in combination with a written seven-day activity record was used as objective criterion measure. Particularly in employed/unemployed people and slightly less in retired people, the FPACQ was a reliable and reasonably valid questionnaire for the assessment of different dimensions of physical activity and sedentary behaviour.

In the first chapter of the longitudinal epidemiological part the secular trend in physical activity and physical fitness was investigated in adolescents from 1969 to 2005. Several anthropometric characteristics in both sexes and skeletal age in boys demonstrated a positive secular trend, while a negative secular trend was observed for most physical fitness tests. No

secular trend was apparent for sports participation. In the second chapter tracking of physical activity and physical fitness was studied from adolescence to middle adulthood in females. Most anthropometric and physical fitness characteristics were relatively stable from adolescence to adulthood. On the other hand, sports participation was not a stable characteristic.

In the first chapter of the genetic epidemiological part the familial aggregation in physical activity and physical fitness was studied and the proportion of the variability attributable to genetic, common and unique environmental factors was quantified. The observed familial aggregation was explained by genetic factors for body mass index, sum of five skinfolds, trunk-extremity skinfold index, flexibility and muscular endurance and by common environmental factors for balance and sports participation, while both factors were important for waist circumference and explosive strength. However, for all variables at least about half of the variance was explained by unique environmental factors. In the second chapter parent-offspring resemblance in physical activity and physical fitness was compared between adolescent chronological age-matched parent-offspring pairs and date-of-exam-matched (adult parent-adolescent offspring) parent-offspring pairs. Only for height, weight, trunk-extremity skinfold index and vertical jump in males, the stated hypothesis of higher adolescent chronological age-matched parent-offspring correlations could be confirmed.

The findings of this thesis have important implications with regard to the necessity and the efficacy of strategies to improve physical activity and physical fitness. From the longitudinal epidemiological studies it can be concluded that 1) during adolescence measures are necessary to encourage physical activity and improve physical fitness and 2) during adulthood constant efforts should be made to keep people active and to reactivate those who have shifted from an active to a more sedentary lifestyle. Moreover, the identification of environmental factors, viewed against the background of genetic susceptibility, as major causes of the phenotypic variance in physical activity and physical fitness in the genetic epidemiological studies emphasizes the potential efficacy of such strategies.

DUTCH SUMMARY/SAMENVATTING

Het belang van regelmatige fysieke activiteit en van fysieke fitheid voor de gezondheid wordt algemeen aanvaard en is reeds uitvoerig aangetoond. Alvorens strategieën te ontwikkelen en toe te passen om fysieke activiteit aan te moedigen en fysieke fitheid te verbeteren is het echter noodzakelijk om 1) fysieke activiteit en fysieke fitheid nauwkeurig te kunnen meten, 2) goed geïnformeerd te zijn omtrent de toestand en de (generatie- of leeftijdsgebonden) verandering van fysieke activiteit en fysieke fitheid en 3) een duidelijk inzicht te hebben in de factoren die aan de grondslag liggen van de fenotypische variatie in fysieke activiteit en fysieke fitheid. Het doel van dit doctoraat was elk van deze aspecten te bestuderen in de Vlaamse bevolking gebruik makend van gegevens van de Leuvense Longitudinale Studie over Levensstijl, fysieke Fitheid en Gezondheid (LLSLFG) (1969-2004). Dit doctoraat is daarom onderverdeeld in een methodologisch, een longitudinaal epidemiologisch en een genetisch epidemiologisch deel. Elk deel bevat twee hoofdstukken die elk dieper ingaan op één specifieke onderzoeksvraag.

In het eerste hoofdstuk van het methodologisch deel werden drie moeilijkheden geassocieerd met longitudinaal onderzoek, meerbepaald het "imperfecte" design, de evolutie van de methodologie en de representativiteit van de longitudinale steekproef, gedocumenteerd met behulp van bevindingen van de LLSLFG. De LLSLFG verschaft unieke onderzoeks-mogelijkheden, vooral met betrekking tot het bestuderen van longitudinaal en genetisch epidemiologische aspecten van fysieke activiteit en fysieke fitheid, maar wordt ook geconfronteerd met verscheidene beperkingen. Wanneer men echter weet heeft van deze mogelijke "valkuilen" moeten verschillende maatregelen (bv. nauwgezette planning, aangepaste steekproeftrekking, vergoeding van verplaatsingsonkosten, persoonlijke resultaten, nieuwsbrieven, telefonische interviews met uitvallers) getroffen worden om deze tot een minimum te beperken en om de resultaten in een juist perspectief te interpreteren. In het tweede hoofdstuk werd de betrouwbaarheid met een test-retest interval van twee weken en de gelijktijdige validiteit van de Flemish Physical Activity Computerized Questionnaire (FPACQ) ontwikkeld voor werkenden/werklozen en gepensioneerden onderzocht. De FPACQ werd gebruikt in de meest recente fase van de LLSLFG. De RT3 Tri-axial Research Tracker, in combinatie met een schriftelijk zevendaags activiteitendagboek werd gebruikt als objectieve criterium meting. Vooral voor werkenden/werklozen en in iets mindere mate voor gepensioneerden kon de FPACQ als een betrouwbare en valide vragenlijst beschouwd worden voor het kwantificeren van verschillende dimensies van fysieke activiteit en sedentair gedrag.

In het eerste hoofdstuk van het <u>longitudinaal epidemiologisch deel</u> werd de seculaire trend in fysieke activiteit en fysieke fitheid nagegaan bij adolescenten tussen 1969 en 2005. Verscheidene antropometrische kenmerken bij beide geslachten en skeletale leeftijd bij jongens vertoonden een positieve seculaire trend, terwijl een negatieve seculaire trend genoteerd werd voor de meeste fysieke fitheidstests. Voor sportparticipatie werd geen seculaire trend waargenomen. In het tweede hoofdstuk werd de tracking van fysieke activiteit en fysieke fitheid bestudeerd van adolescentie naar midden volwassenheid bij vrouwen. Antropometrische kenmerken en fysieke fitheid konden beschouwd worden als vrij stabiele kenmerken. Sportparticipatie daarentegen vertoonde geen stabiliteit.

In het eerste hoofdstuk van het <u>genetisch epidemiologisch deel</u> werd de familiale samenhang in fysieke activiteit en fysieke fitheid onderzocht en werd het aandeel van de variabiliteit dat kon toegeschreven worden aan genetische, gemeenschappelijke en unieke omgevingsfactoren bepaald. De waargenomen familiale samenhang werd verklaard door genetische factoren voor body mass index, som van vijf huidplooien, romp-ledematen huidplooien ratio, lenigheid en krachtuithouding en door gemeenschappelijke omgevingsfactoren voor evenwicht en sportparticipatie, terwijl beide factoren van belang waren voor lendenomtrek en explosieve kracht. Voor alle variabelen werd echter ten minste de helft van de variantie verklaard door unieke omgevingsfactoren. In het tweede hoofdstuk werd de ouder-kind gelijkenis in fysieke activeit en fysieke fitheid tussen ouder-kind paren met dezelfde adolescente chronologische leeftijd vergeleken met de ouder-kind gelijkenis tussen ouder-kind paren gemeten op hetzelfde tijdstip (volwassen ouder-adolescent kind). Enkel voor gestalte, gewicht, romp-ledematen huidplooien ratio en explosieve kracht kon de hypothese van hogere correlaties tussen ouder-kind paren gemeten op dezelfde adolescente chronologische leeftijd bevestigd worden.

De bevindingen van dit doctoraat hebben belangrijke implicaties met betrekking tot de noodzaak en de doeltreffendheid van strategieën om fysieke activiteit aan te moedigen en fysieke fitheid te verbeteren. Uit de longitudinaal epidemiologsche studies kan besloten worden 1) dat tijdens de adolescentie maatregelen noodzakelijk zijn om fysieke activiteit en fysieke fitheid te bevorderen en 2) dat tijdens volwassenheid voortdurend moeite moet gedaan worden om mensen actief te houden of weer actief te krijgen. Het feit dat, uitgaande van de genetisch epidemiologische studies, omgevingsfactoren, te beschouwen in het licht van genetische vatbaarheid, als belangrijkste oorzaken van de fenotypische variatie in fysieke activiteit en fysieke fitheid mogen beschouwd worden, benadrukt bovendien de mogelijke doeltreffendheid van dergelijke strategieën.

SECTION 1

GENERAL INTRODUCTION AND OUTLINE

Abundant scientific evidence demonstrates that regular physical activity and physical fitness reduce the risk of morbidity and mortality from a number of chronic diseases (Biddle et al., 2004; Blair et al., 2001; Bouchard et al., 1990, 1994; Kesaniemi et al., 2001; Strong et al., 2005). The recognition of the importance of regular physical activity and physical fitness for optimal health has led to an increased interest in the study of different aspects of physical activity and physical fitness. This thesis aims to contribute to the available knowledge concerning the assessment of physical activity and physical fitness, the status and (generation- or age-related) change of the level of physical activity and physical fitness and the factors underlying the phenotypic variation in physical activity and physical fitness in the Flemish population using data from the Leuven Longitudinal Study on Lifestyle, Fitness and Health (LLSLFH) 1969-2004.

The purpose of this introduction is fourfold. First, fundamental terminology related to physical activity, physical fitness and health, frequently used in this thesis, is defined and different assessment methods are specified. Subsequently, the reference frame of this thesis, consisting of the "Toronto consensus model" and the Flemish Policy Research Centre Sport, Physical Activity and Health (SPAH) is addressed. Third, longitudinal aspects of the study samples used for this thesis are described. Finally, the specific research questions and further outline of this thesis are presented.

1. Physical activity, physical fitness and health: definitions and assessment methods

The terms physical activity, physical fitness and health are widely used, although the underlying assumption that readers share a common understanding of their meaning is often not justified. Therefore, a clear definition of those terms and a brief mentioning of their possible assessment methods seem appropriate. However, it should be noted that these definitions and assessment methods are still evolving and discussion is ongoing about their exact content and use.

Physical activity

"Physical activity" is a broad term defined as 'any bodily movement produced by skeletal muscles resulting in caloric expenditure'. It is a complex behaviour encompassing physical activity on the job, self-care, household chores, home and yard maintenance, transportation, and discretionary leisure-time activities including exercise and sports. Physical activity is often categorized by duration, frequency, intensity, and circumstances or purpose of the activity. The related term "exercise" is viewed more narrowly and has been defined as 'physical activity that is planned, structured, repetitive and purposive in the sense that improvement or maintenance of physical fitness or health is an objective'. "Habitual physical activity" refers to 'the overall level of regular engagement in physical activity' (Bouchard and Shepard, 1994; Caspersen et al., 1985).

The variety of available methods to assess physical activity can be subdivided into three categories: 1) criterion methods including direct calorimetry, direct observation, indirect calorimetry and doubly labelled water; 2) objective methods encompassing heart rate monitoring and motion sensors (i.e. pedometers, accelerometers); and 3) subjective methods consisting of paper-and-pencil or computerized self-report or interview-administered questionnaires, proxy-reports, and diaries. Each of these measurement techniques has specific strengths and weaknesses that need to be considered when selecting an appropriate instrument for specific research applications (Vanhees et al., 2005; Welk, 2002).

Physical fitness

"Physical fitness" has been defined as 'the ability to carry out daily tasks with vigour and alertness, without undue fatigue and with ample energy to enjoy leisure-time pursuits and to meet unforeseen emergencies'. In keeping with this definition, physical fitness implies 'a set of attributes people have or achieve that relate to the ability to perform physical activity'. These attributes are either related to performance or to health (Caspersen et al., 1985). "Performance-related fitness" refers to abilities associated with optimal athletic performance and encompasses components such as motor skills, cardiorespiratory power and capacity, muscular strength, power or endurance, body size, body composition, motivation, and nutritional status. "Health-related fitness" refers to those components of physical fitness that are affected favourably or unfavourably by habitual physical activity and relate to health. It has been defined as 'a state characterized by the ability to perform daily activities with vigour and the demonstration of traits and capacities associated with a low risk of premature development of hypokinetic diseases (i.e. those associated with physical inactivity)'. Health-related fitness comprises five major components: 1) a morphological component (body mass for height, body composition, subcutaneous fat distribution, abdominal visceral fat, bone density, flexibility); 2) a muscular component (muscular power, muscular strength, muscular endurance); 3) a motor component (agility, balance, coordination, speed of movement); 4) a cardiorespiratory component (submaximal exercise capacity, maximal aerobic power, heart functions, lung functions, blood pressure); and 5) a metabolic component (glucose tolerance, insuline sensitivity, lipid and lipoprotein metabolism, substrate oxidation characteristics). It is clear that performance-related and health-related fitness are not mutually exclusive (Bouchard and Shepard, 1994; Pate, 1988).

A number of laboratory and field methods can be distinguished to assess the different components of physical fitness. Laboratory tests are generally conducted in standardized test room conditions, using cycle ergometers, dynamometers, and other types of sophisticated equipment specially designed to measure, analyse, monitor, and record information. Field tests are usually conducted in gymnasia, large multipurpose rooms, or outside with equipment available and familiar to the general population. The selection of appropriate fitness tests should be based on the particular physical fitness component being measured, the population being studied and the reasons for testing (Shepard, 1986; Skinner and Oja, 1994; Vanhees et al., 2005).

Health

"Health" is probably the most general term and therefore also the most difficult to define. It has been defined as 'a human condition with physical, social, and psychological dimensions, each characterized on a continuum with positive and negative poles'. Positive health is associated with the capacity to enjoy life and to withstand challenges; it is not merely the absence of disease. Negative health is associated with morbidity and, in the extreme, with premature mortality (Bouchard and Shepard, 1994).

The measurement of health status as a reflection of the concept called health is a particularly complex endeavour. Traditionally, health status measures have focused on the assessment of negative health, while more recently there has been a growing emphasis on characterizing and measuring positive health. Several measurement categories can be identified, including mortality, morbidity, risk factor prevalence, use of medical care, disability, function (physical, mental, functional activities), well-being (bodily, emotional, self-concept, global perceptions of well-being), and healthy lifestyle (Caspersen et al., 1994; Kemm, 1992).

2. Frame of reference: the "Toronto consensus model" and the Flemish Policy Research Centre Sport, Physical Activity and Health (SPAH)

The "Toronto consensus model"

In 1988 and 1992 an international conference was held to establish a consensus statement about the complex relationships between physical activity, physical fitness and health (Bouchard et al., 1990, 1994). Bouchard and Shepard (1994) described the resulting, still widely accepted and frequently used, consensus model presented in Figure 1. This model specifies that physical activity, physical fitness and health influence each other in a reciprocal manner. Moreover, other lifestyle behaviours (e.g., smoking, diet, alcohol, stress), personal attributes (e.g., age, gender, socioeconomic status), physical (e.g., temperature, air quality) and social (e.g., family members, friends) environmental conditions, and genetic characteristics also affect these three major components of the model and their interrelationships.

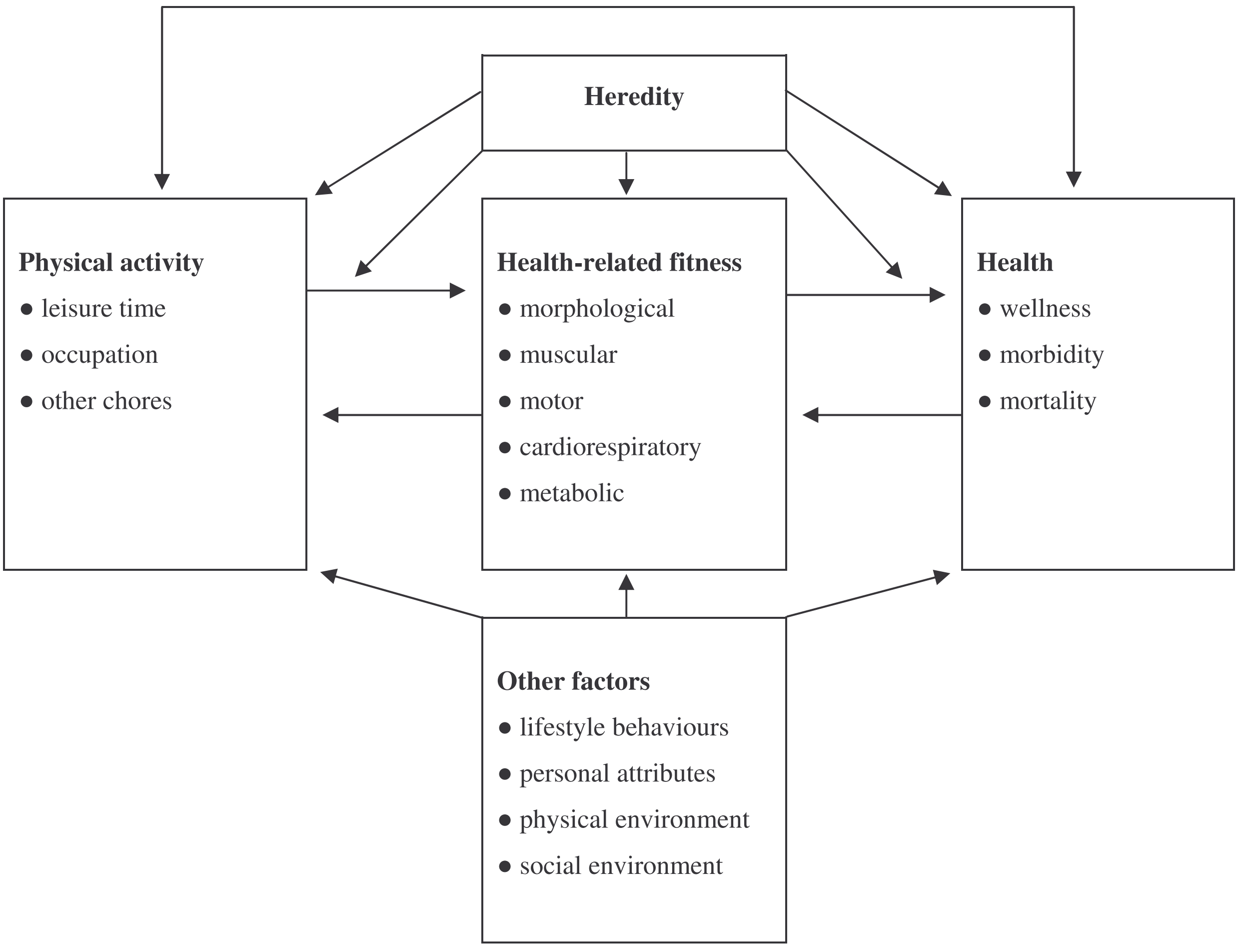

Figure 1. Toronto consensus model on relationships between physical activity, health-related fitness and health (Bouchard and Shepard, 1994).

Ever since, many studies have been published supporting the hypothesis that lack of physical activity and physical fitness increases the risk of morbidity and mortality from a number of chronic diseases. In adults, a physically active and fit way of life protects against the development of coronary heart disease, stroke, hypertension, obesity, non-insulin-dependent diabetes mellitus and some cancers. It also appears to reduce depression and anxiety, improve mood and is important for the health of muscles, bones and joints (Blair et al., 2001; Kesaniemi et al., 2001). So far, the established causal links between physical activity and physical fitness on the one hand and health on the other hand in adults are yet to be further confirmed in children and adolescents. However, growing research evidence identifies at least modest positive effects. Moreover, it is often assumed that physical activity and physical fitness during childhood and adolescence have a positive influence on adult health and that levels of physical activity and physical fitness track from childhood over adolescence into adulthood (Biddle et al., 2004; Blair et al., 1989; Strong et al., 2005). A conceptual model, proposed by Blair et al. (1989), on how childhood exercise may affect health throughout life is shown in Figure 2. In this model childhood exercise may affect adult health in three ways: a) directly, b) through its effect on youth health (which in turn affects adulth health), or c) through its effect on adult exercise (which in turn affects adulth health).

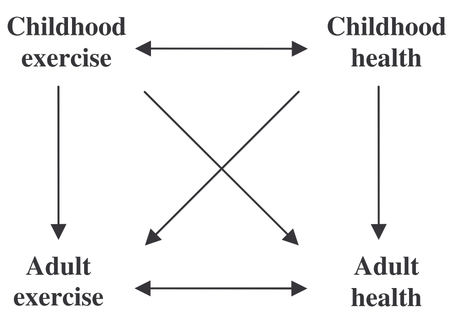

Figure 2. Conceptual model on how childhood exercise habits may affect health throughout life (Blair et al., 1989).

A variety of recommendations have been published regarding the duration, frequency, intensity and type of physical activity required for optimal physical fitness and health (Blair et al., 2004).

The Flemish Policy Research Centre Sport, Physical Activity and Health (SPAH)

In March 2002, the Flemish Government installed the Flemish Policy Research Centre SPAH, as one of 12 policy research centres. It falls under the jurisdiction of the Flemish minister for

Culture, Youth, Sport and Brussels Affairs and consists of a consortium of researchers from the Faculty of Kinesiology and Rehabilitation Sciences of the Katholieke Universiteit Leuven, the Department of Movement and Sports Sciences of the Ghent University, and the Faculty of Physical Education and Physical Therapy of the Vrije Universiteit Brussel. The first aim of the Flemish Policy Research Centre SPAH, is to obtain insight into the relationships between physical activity on the one hand and physical fitness and health on the other hand in the Flemish population by means of scientific research. With the "Toronto consensus model" as a reference frame, this aim was operationalized by identifying four major research themes:

1. Epidemiology of the present status of physical activity, physical fitness and health in the Flemish population: field tests in a random sample (n = 5170) of the Flemish population between 18 and 75 years of age.
2. Association between physical activity, physical fitness and health in the Flemish population:
   - 2.1 Cross-sectional: more detailed laboratory tests in a random subsample (n = 858) of the random sample of Theme 1.
   - 2.2 Longitudinal: Follow-ups of the Leuven Longitudinal Study on Lifestyle, Fitness and Health (LLSLFH) (originating from the Leuven Growth Study of Belgian Boys (LGSBB) and the Leuven Growth Study of Flemish Girls (LGSFG)) and the Longitudinal Ecological and Experimental Growth Study (LEGS) (field and laboratory tests).
3. Interventions to promote physical activity in the Flemish population including different age groups and several settings:
   - 3.1 Promotion of good body mechanism in elementary school children.
   - 3.2 Promotion of healthy food intake and physical activity in secondary school children.
   - 3.3 Promotion of physical activity through the Internet in adults.
   - 3.4 Promotion of physical activity in sociocultural associations.
   - 3.5 Effect of commuter cycling on physical fitness and health.
   - 3.6 Effect of different exercise programs on physical fitness and health of seniors.
4. Prevalence of injuries and health's hazards in Flanders due to physical activity.

Parallel with this first aim, the Flemish Policy Research Centre SPAH wants to be an information point collecting available know-how concerning physical activity, physical fitness and health. The second aim of the Flemish Policy Research Centre SPAH is to translate the scientific results into appropriate policy advice for the Flemish minister for

Culture, Youth, Sport and Brussels Affairs (Steens, 2006; Steunpunt Sport, Beweging en Gezondheid, 2006).

3. Description of the general sample

Because this thesis is primarily situated within the follow-up of LLSLFH of Theme 2.2 of the Flemish Policy Research Centre SPAH, it seems useful to give a description of this study and its follow-ups before the specific research questions are addressed. The LLSLFH originated from two earlier studies: the LGSBB and the LGSFG. The LGSBB, 1969-1974, was a mixed cross-sectional and longitudinal study designed to provide information concerning growth, maturity, physical activity and physical fitness of a large representative sample of Belgian secondary school boys. A total of 21175 assessments were made in 8963 boys. The majority of the boys were tested only once but 588 boys were followed longitudinally at yearly intervals between 12 and 18 years. A more detailed description of the LGSBB is given elsewhere (Beunen et al., 1988; Ostyn et al., 1980). The LGSFG, 1979-1980, was a cross-sectional study designed to provide information concerning growth, maturity, physical activity and physical fitness of a representative sample of Flemish primary and secondary school girls (6-18 years, n = 9954: 4738 primary school girls, 5216 secondary school girls). A more detailed description of the LGSFG is given elsewhere (Simons et al., 1990). In 1986 the LGSBB was extended in the LLSLFH. Of the 588 boys followed longitudinally during adolescence, 441 were Flemish speaking and were considered for further enrollment in the study. With the intention of five-yearly follow-ups, these males were re-examined in 1986 (30 years, n = 174), 1991 (35 years, n = 176), and in 1996 (40 years, n = 166). In 2002-2004, within the scope of the Flemish Policy Research Centre SPAH, these longitudinally followed males were tested again (47 years, n = 154). In addition, a subsample of the oldest girls (14-18 years) previously participating in the LGSFG, 37-43 years of age with at least two offspring older than 10 years of age, was also contacted. A sample of 138 women agreed to participate and was re-examined for the first time. Different from the previous follow-ups, spouses and offspring older than 10 years of age of the longitudinally followed men and women were also included in the study (follow-up males: 106 spouses, 111 sons, 78 daughters; follow-up females: 120 spouses, 153 sons, 132 daughters). The age of the offspring was similar to that of their fathers/mothers tested during adolescence in 1969-1974 and 1979-1980 respectively. This particular project within the LLSLFH was called the Flemish Longitudinal Offspring Study (FLOS). An overview of the sample of the LLSLFH from 1969 to 2004 is presented in Table 1.

Table 1. Overview of the sample of the Leuven Longitudinal Study on Lifestyle, Fitness and Health from 1969 to 2004

LEUVEN LONGITUDINAL STUDY ON LIFESTYLE, FITNESS AND HEALTH (LLSLFH)					
Follow-up males	**1969-1974**	**1986**	**1991**	**1996**	**2002-2004**
	Leuven Growth Study of Belgian Boys (LGSBB)				Theme 2.2 Policy Research Centre Sport, Physical Activity and Health (SPAH) = Flemish Longitudinal Offspring Study (FLOS)
	Annual assessments between 12-18 years				
Men	n = 8963 (21175 assessments) longitudinal n = 588 of which 441 were Dutch speaking	Complete data n = 174	Complete data n = 176 (150* + 26)	Complete data n = 166 (130* + 36)	Complete data n = 154 (112* + 42)
Spouses (women)					n = 106
Offspring (≥ 10 years)					Sons: n = 111 Daughters: n = 78
Follow-up females	**1979-1980**				**2002-2004**
	Leuven Growth Study of Flemish Girls (LGSFG)				Theme 2.2 Policy Research Centre Sport, Physical Activity and Health (SPAH) = Flemish Longitudinal Offspring Study (FLOS)
	1 assessment between 6-18 years				
Women	n = 9954 4738 primary school 5216 secondary school				n = 138 Subsample of the oldest girls (14-18 years in LGSFG) with at least 2 offspring ≥ 10 years of age
Spouses (men)					n = 120
Offspring (≥ 10 years)					Sons: n = 153 Daughters: n = 132

* : Longitudinal since 1969

4. Research questions and outline of the thesis

Before developing and implementing health strategies to improve physical activity and physical fitness it is important to 1) be able to accurately assess physical activity and physical fitness, 2) be well informed about the status and (generation- or age-related) change of the levels of physical activity and physical fitness and 3) have clear insight into the causes underlying the phenotypic variation in physical activity and physical fitness. In accordance with this, the research articles in Section 2 of this thesis are divided into 3 parts: 1) a methodological part (Part 1), 2) a longitudinal epidemiological part (Part 2), and 3) a genetic epidemiological part (Part 3). Each part consists of two chapters each addressing one specific research question. An overview of the exact content of each of the six research questions is given below.

Section 2, Part 1: Methodological issues

Research question 1 (Section 2, Part 1, Chapter 1): What are the methodological issues associated with longitudinal research? Findings from the Leuven Longitudinal Study on Lifestyle, Fitness and Health (1969-2004).

Despite the unique opportunities they provide, longitudinal studies are relatively scarce (Kemper, 1997; Kemper et al., 1997; Malina et al., 2004; Roche, 1992; Tanner, 1962). This can be attributed to the fact that they are also faced with a number of limitations that must be taken into account (Goldstein, 1979; Kemper et al., 1997; Malina et al., 2004; Nesselroade and Baltes, 1979; Schaie, 1965; Roche, 1992;). The purpose of this first research question is to gain insight into three of these difficulties in the LLSLFH before using data from this study in the longitudinal epidemiological and genetic epidemiological part of this thesis. First, the “imperfect” design is illustrated by describing the change in design associated with the different phases and evolving research questions throughout the LLSLFH. Second, the evolution of the selection of tests and measurements in the LLSLFH is situated within the framework of the changing ideas on physical fitness, body composition and physical activity, the continuing search for new and better measurement techniques over the past decades and the need for adaptations with age. Third, the representativeness of the subjects still involved in the most recent phase of the LLSLFH is investigated. With regard to body composition, physical fitness and physical activity, this is done by comparing adolescent values of ongoing study participants with those of subjects not participating in the follow-up and by comparing adult values of ongoing participants with those of participants in Theme 1 of the Flemish

Policy Research Centre SPAH. With regard to socio-economic status, ongoing participants are compared with a representative sample of the Belgian population from the Belgian Socio-Economic Survey in 2001.

Research question 2 (Section 2, Part 1, Chapter 2): Is the Flemish Physical Activity Computerized Questionnaire (FPACQ) a reliable and valid instrument to assess different dimensions of physical activity and sedentary behaviour in Flemish adults?

A variety of methods can be used to assess physical activity. Questionnaires are the most widely used type of physical activity measure in large scale epidemiological studies. This traditional method of data collection is very labour- and time-consuming (Kriska and Caspersen, 1997; Sallis and Saelens, 2000; Welk, 2002). Technology is now available to develop computerized questionnaires. The use of computerized questionnaires has several advantages compared to written surveys (Crawley et al., 2000; Schmitz et al., 2000; Turner et al., 1998; Vereecken, 2001; Wijndaele et al., in press). Literature only reveals three studies in children or adolescents (McMurray et al., 1998; Ridley et al., 2001; Philippaerts et al., 2006) and one study in adults (Vandelanotte et al., 2005) concerning the reliability and validity of computerized physical activity questionnaires. In 2002, within the framework of the Flemish Policy Research Centre SPAH, the Flemish Physical Activity Computerized Questionnaire (FPACQ), developed in the IOS-project 2001 to assess detailed information on several dimensions of physical activity and sedentary behaviour during a usual week, was further refined (Lefevre et al., 2002). To account for the different structure in the lifestyle of students, employed/unemployed and retired people, three different versions of the questionnaire were constructed. The FPACQ was used in the most recent phase of the LLSLFH. The reliability and validity of the version for students has already been investigated and reported in a previous study (Philippaerts et al., 2006). The purpose of this second research question is to investigate the two-week test-retest reliability and concurrent validity of the FPACQ developed for employed/unemployed and retired males and females. Different activity variables are calculated from the FPACQ. A tri-axial accelerometer, the RT3 Tri-axial Research Tracker (RT3), in combination with a written seven-day activity record, is used as objective criterion measure. This makes it possible to divide the RT3-output in the same dimensions as calculated from the FPACQ, allowing a more comprehensive investigation of concurrent validity compared to most studies only using broad sub-categories of light, moderate and high intensity activity based on predetermined cut-points. The study sample is a voluntary subsample of Theme 2.1 of the Flemish Policy Research Centre SPAH.

Section 2, Part 2: Longitudinal epidemiological studies

Research question 3 (Section 2, Part 2, Chapter 1): Is there a secular trend in anthropometric characteristics, physical fitness, physical activity, and biological maturation in Flemish adolescents?

Secular trends refer to changes over time, usually between successive generations (Malina, 1978, 2004; Malina et al., 2004; Roche, 1979). Secular change data for physical fitness and physical activity are relatively scarce and the time span across which comparisons can be made is generally not extensive (Craig et al., 1994; Dawson et al., 2001; Dollman et al., 2005; Duvigneaud et al., 2006; Eisenmann et al., 2004; Malina, 1978, 2004; Malina et al., 2004; Nishijima et al., 2003; Westerstahl et al., 2003a, 2003b;). Moreover, although physical fitness is, in part, related to biological maturity and body size, most studies do not take this into account (Beunen et al., 1981, 1983, 1994, 1997; Jones et al., 2000; Malina, 1975, 1978, 2004; Malina et al., 2004; Roche, 1979). Observations of secular changes are most commonly derived from cross-sectional independent population samples. However, the constantly changing demographic composition may hamper valid cross-sectional analyses. Family studies offer another interesting approach. Although they are generally less representative and more small-scaled compared to population-wide cross-sectional studies, they have the advantage of a greater control over time-specific genetic and environmental variation. Only a limited amount of studies have been published in which height, weight or physical ability has been assessed in like-sexed pairs of parents and offspring at approximately the same age during adulthood and no such studies are available during adolescence (Bock and Sykes, 1989; Cratty, 1960; Damon, 1968). The purpose of this third research question is to investigate secular trends in anthropometric characteristics, physical fitness, physical activity and biological maturation in Flemish adolescents using both a cross-sectional and parent-offspring approach. In addition, in the parent-offspring analysis secular trends are also investigated after adjustment for the secular trend in skeletal age. Data for the first time point of the cross-sectional analysis are from the cross-sectional part of the LGSBB for males (1969-1974) and from the LGSFG for females (1979-1980). Data for the second time point of the cross-sectional analysis are from the Eurofit-Barometer 2005 (Duvigneaud et al., 2006). The specific sample from the LLSLFH used for the parent-offspring analysis is shown in Figure 3 (red line). An overview of the included anthropometric, physical fitness and physical activity variables is presented in Table 2.

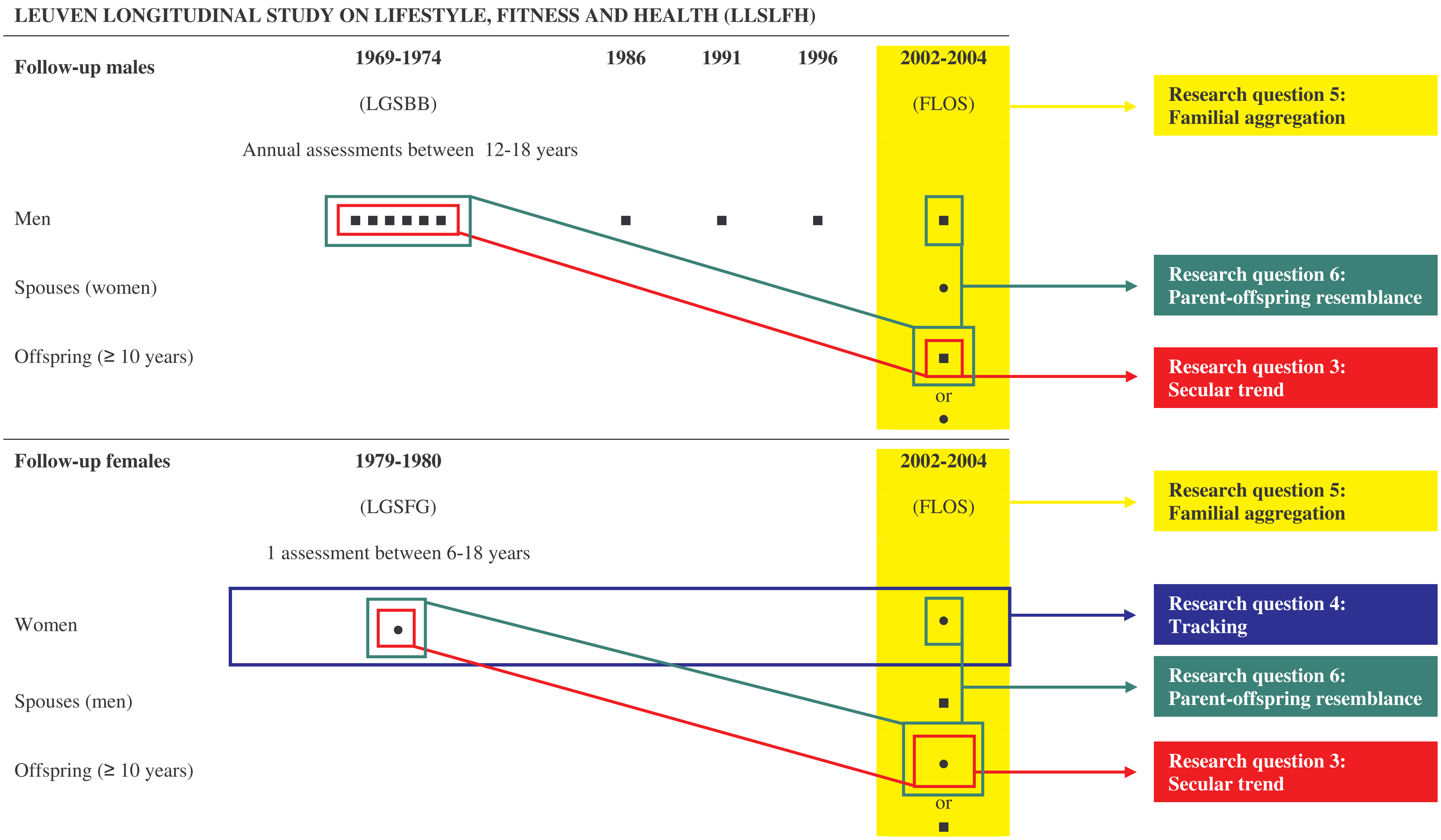

Figure 3. Samples of the Leuven Longitudinal Study on Lifestyle, Fitness and Health used for research questions 3 through 6
■: male; ●: female

Table 2. Overview of the anthropometric, physical fitness and physical activity variables included in research questions 3 through 6.

Variables	Research question 3 Secular trend				Research question 4 Tracking	Research question 5 Familial aggregation	Research question 6 Parent-offspring resemblance	
	Cross-sectional		Parent-offspring				males	females
	males	females	males	females				
Anthropometric characteristics								
Height (cm)	x	x	x	x	x		x	x
Weight (kg)	x	x	x	x	x		x	x
BMI (kg/m^2)	x	x	x	x	x	x	x	x
Waist (cm)						x		
Skinfold biceps (mm)		x		x	x			
Skinfold triceps (mm)	x	x	x	x	x			
Skinfold subscapula (mm)	x	x	x	x	x			
Skinfold suprailiac (mm)	x	x	x	x	x			
Skinfold medial calf (mm)		x		x	x			
Skinfold calf popliteus (mm)			x					
Sum 3 skinfolds (mm)	x							
Sum 4 skinfolds (mm)			x		x†		x‡	
Sum 5 skinfolds (mm)		x		x		x‡		x§
Trunk-extremity index††	x	x	x	x	x	x	x	x
Physical fitness								
Vertical jump (cm)			x	x	x		x	x
Standing broad jump (cm)						x		
Bent arm hang (sec)	x	x	x	x	x	x	x	x
Arm pull (kg)			x	x	x			x
Leg lifts (n/20 sec)			x	x	x			x
Sit and reach	x	x	x	x	x	x	x	x
10 x 5 m shuttle run (sec)	x	x	x	x	x			x
Plate tapping (n/20 sec)			x	x	x			x
Flamingo balance (n/min)		x		x	x	x		x
Physical activity								
Sports participation (h/week)‡‡			x	x	x	x	x	x

† Sum 4 skinfolds = biceps + triceps + subscapula + suprailiac
‡ Sum 4 skinfolds = triceps + subscapula + suprailiac + calf popliteus
§ Sum 5 skinfolds = biceps + triceps + subscapula + suprailiac + medial calf
†† Research question 3 cross-sectional females and parent-offspring females, research question 5, research question 6 females: trunk-extremity index = [(subscapula + suprailiac) / triceps + medial calf)]; research question 3 cross-sectional males: trunk-extremity index = [(subscapula + suprailiac) / triceps]; research question 3 parent-offspring males, research question 6 males: trunk-extremity index = [(subscapula + suprailiac) / (triceps + calf popliteus)]
‡‡ Assessed with a standardized questionnaire with retrospective approach (Renson et al., 1990) or with the Flemish Physical Activity Computerized Questionnaire (Philippaerts et al., 2006; Matton et al., in press)

Research question 4 (Section 2, Part 2, Chapter 2): Do anthropometric characteristics, physical fitness and physical activity track from adolescence to adulthood in Flemish females?

Tracking refers to 1) the stability of relative rank or position within a group over time or 2) the predictability of a measurement early in life for the value of the same variable later in life. There is a paucity of longitudinal data regarding measures of physical fitness and physical activity. Moreover, most studies concerning tracking of physical fitness and physical activity from childhood and adolescence into adulthood largely focus on young adulthood, the 20s and early 30s. Tracking of physical fitness and physical activity from adolescence to older ages in adulthood is less well studied and data are more available for males than for females (Malina, 2001a, 2001b, 2001c). Therefore, the purpose of this fourth research question is to investigate the tracking of physical fitness and physical activity from adolescence into middle adulthood in females. The specific sample from the LLSLFH used for this research question is presented in Figure 3 (blue line) and an overview of the included anthropometric, physical fitness and physical activity variables is given in Table 2.

Section 2, Part 3: Genetic epidemiological studies

Research question 5 (Section 2, Part 3, Chapter 1): 1) Do anthropometric characteristics, physical fitness and physical activity aggregate within Flemish nuclear families and 2) what proportion of the variability in these traits can be explained by genetic (Vg), common environmental (Vc) and unique environmental (Ve) factors?

In the basic genetic model, the total variation (Vtot) in complex, multifactorial traits can be partitioned into genetic (Vg), common environmental (Vc) and unique environmental (Ve) factors (Vtot = Vg + Vc + Ve). Heritability (h^2) refers to the proportion of the total variation attributable to genetic factors (Vg / Vtot) (Bouchard et al., 1997). Given the broad range of study designs, methodologies, sample sizes and populations in the literature, the large variability in the heritability estimates for anthropometric, physical fitness and physical activity variables is not unexpected. Moreover, traditional family studies cannot disentangle the effects of genes and common environment (Allison et al., 1996; Beunen and Thomis, 1999, 2000; Beunen et al., 2003; Bouchard et al., 1988, 1997; Katzmarzyk et al., 2000; Koopmans et al., 1994; Maes et al., 1996, 1997; Maia et al., 2002; Okuda et al., 2005; Peeters et al., 2003; Pérusse et al., 1987, 1988a, 1988b, 1989, 2000; Stubbe et al., 2005). Nevertheless, an accurate estimation of the variability within a population is important to get an idea of the magnitude of the influence of non-genetic factors and the potential impact of genotype-environment interactions on the phenotype. In addition, the power of studies searching for genes contributing to anthropometric characteristics, physical fitness and physical activity is largely affected by the heritability estimate (Allison et al., 1996). Therefore, the aim of this fifth research question is 1) to investigate the familial aggregation in anthropometric characteristics, physical fitness and physical activity by calculating correlations between different family members and 2) to determine the proportion of the variability in these traits that can be explained by genetic (Vg), common (Vc) and unique environmental (Ve) factors by decomposing the total variance in variance components in QTDT (Abecasis et al., 2000). A combined family and twin design is used. The family data from the LLSLFH used for this research question are indicated in yellow in Figure 3. Data for the twins and their parents are from the Leuven Longitudinal Twins Study (LLTS) (Maes et al., 1996; Peeters et al., 2003). In Table 2 the included anthropometric, physical fitness and physical activity variables are shown.

Research question 6 (Section 2, Part 3, Chapter 2): Is the parent-offspring resemblance in anthropometric characteristics, physical fitness and physical activity higher in adolescent chronological age-matched compared to date-of-exam-matched Flemish parent-offspring pairs?

Although time-point-matched parent-offspring correlations might be disturbed by generation-specific genetic and/or environmental factors, familial aggregation in anthropometric, physical fitness and physical activity variables is usually investigated using intra-pair correlations between family members measured at the same time-point (Beunen and Thomis, 1999; Beunen et al., 2003; Bouchard et al., 1988, 1997; Maes et al., 1996, 1997; Peeters et al., 2003; Pérusse et al., 1987, 1988a, 1988b, 1989; Stubbe et al., 2005). To prevent the disturbance of parent-offspring correlations by generation-specific factors, parents and offspring should be tested at the same age during adolescence or adulthood. Only two studies have been published in which correlations for BMI or physical ability have been calculated between parents and offspring at similar adult ages (Cratty, 1960; Trudeau et al., 2003). No studies are available during adolescence. The LLSLFH provides unique data on anthropometric characteristics, physical fitness and physical activity of parents at adolescent and adult age and of their adolescent offspring. Therefore, the purpose of this sixth research question is to compare sex-specific correlations for anthropometric characteristics, physical fitness and physical activity between parents and offspring measured at approximately the same adolescent chronological age (age-matched) with those measured at the same date-of-exam (date-of-exam-matched: adult parents-adolescent offspring). In addition, tracking and the variability in secular trends are investigated as possible explanations for the observed parent-offspring correlations. It is hypothesized that adolescent chronological age-matched parent-offspring correlations will be higher than date-of-exam-matched parent-offspring correlations in case of changing genetic and/or environmental factors over the life span. This will probably be more clearly reflected in traits with a small variability in within-family secular trends and low tracking. The specific sample of the LLSLFH and the anthropometric, physical fitness and physical activity variables included in this research question are presented in Figure 3 (green line) and Table 2 respectively.

The different research questions of this thesis can be situated within the model of Bouchard and Shepard (1994) described in Figure 1, with the longitudinal aspects situated within the model of Blair et al. (1989) described in Figure 2. While the methodological and longitudinal epidemiological part primarily focus on different aspects of the physical activity and physical fitness components itself, the emphasis of the genetic epidemiological part further lies on the extend to which the genetic and environmental factors – modelled as latent factors – influence the observed interindividual differences in these components. The direct study of health and the identification of specific genes or environmental factors (e.g., dietary intake) influencing physical activity and physical fitness is beyond the scope of this thesis. Furthermore, the unique combination of longitudinal follow-up and familial structure of the LLSLFH is explored in the last research question.

In Section 3 of this thesis a summary of the main findings of the six research questions in Section 2 is provided and a general discussion, including implications, limitations and possible opportunities for future research, is given.

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SECTION 2
RESEARCH ARTICLES

PART 1. Methodological issues

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Journal of Sports Sciences, accepted for publication

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PART 1. Methodological issues

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Journal of Sports Sciences, accepted for publication

Chapter 2. Reliability and validity of the Flemish Physical Activity Computerized Questionnaire (FPACQ) in adults
Research Quarterly for Exercise and Sport, accepted for publication

CHAPTER 1

Methodological issues associated with longitudinal research: Findings from the Leuven Longitudinal Study on Lifestyle, Fitness and Health (1969-2004)

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Abstract

Longitudinal studies provide unique opportunities but are also faced with several limitations. The purpose of this manuscript was to document three of these issues ("imperfect" design, evolution of data collection methods, representativeness) by means of the Leuven Longitudinal Study on Lifestyle, Fitness and Health (LLSLFH). The LLSLFH (1969-2004) comprises observations in males between 12 and 18 years, at 30 years, 35 years, 40 years and 47 years and in females at 16 years and 40 years. In the most recent phase of the study spouses and offspring were also included. The different phases and evolving research questions throughout the LLSLFH required an appropriate adaptation of the research design. The associated evolution of data collection methods largely reflects the changing ideas about physical fitness, body composition and physical activity, the continuing search for new and better measurement techniques and the need for adaptations with age. Ongoing study participants are representative with regard to body composition and, except for adolescence in males, also for physical activity. No straightforward answer can be given concerning physical fitness. In both sexes socio-economic status is above average. When informed about the possible "pitfalls" of longitudinal research in advance, several measures could be taken to prevent or limit them as much as possible.

Key words

longitudinal research, design, methodology, representativeness

Introduction

A longitudinal study involves repeated observations on the same individuals at specific intervals over a period of time. Until the mid-20th century the longitudinal design was primarily viewed as the ideal method to study the natural course of human growth, development and aging. These studies basically were descriptive, providing information not only on status but also on change and progress and allowing construction of individual growth curves. As methods of analysis evolved, the value and utility of longitudinal studies increased. Today, they also permit answering questions concerning tracking over time, the relationship between the development of lifestyle factors (e.g., physical activity, nutrition) on the one hand and biological factors (e.g., blood pressure, cholesterol) on the other hand and the impact, over a larger age span, of lifestyle and biological factors on health (Tanner, 1962; Roche, 1992; Kemper, 1997; Kemper et al., 1997; Malina et al., 2004).

Historically, most longitudinal studies have focussed primarily on growth and maturation with follow-ups at very regular intervals spanning the entire growth period from birth to maturity or parts of it. Some of these studies also extend into adulthood (e.g., the Fels Study (Roche, 1992), the Harvard Growth Study (Must, 1992)). Later, a number of longitudinal studies additionally included measurements of motor performance and assessments of physical activity (e.g., the Leuven Growth Study of Belgian Boys (Ostyn et al., 1980; Beunen et al., 1988), the study of Growth and Health of Teenagers in Amsterdam (Kemper, 1995)). Besides these classical designs, several studies also investigated the long-term effects of the prenatal and early postnatal environment on later health (developmental origins hypothesis) (Barker et al., 1989; Loos et al., 2001a, 2001b). A more detailed overview of longitudinal studies on growth, maturation, physical performance and physical activity is given by Malina et al. (2004). From this overview it is clear that, despite the aforementioned possibilities, longitudinal studies are relatively scarce.

This can be attributed to the fact that they are also faced with a number of limitations (Schaie, 1965; Goldstein, 1979; Nesselroade and Baltes, 1979; Roche, 1992; Kemper et al., 1997; Malina et al., 2004). Practical problems associated with longitudinal studies include: 1) the great effort needed to achieve long-term commitment of staff and subjects, 2) the high cost requiring continued search for new funding to prevent premature ceasing of the study, 3) the adequate replacement of staff over time, and 4) the need for regularly published papers based on preliminary results from the ongoing study to cope with the constantly increasing publication pressure. In addition to these practical issues, methodological concerns should also be taken into account. According to Schaie (1965), results of pure longitudinal studies could be influenced by the confounding of age (growth) and time-of-measurement effects. To solve this problem, he suggested other research strategies (cohort-, time- and cross-sequential model) which, under certain assumptions, make it possible to separate the three sources of developmental change. However, other researchers do not entirely agree with his formulations (Baltes, 1968; Buss, 1973). Another possible confounding factor, especially for motor tests, is the learning or testing effect. Further, attention should be paid to the representativeness of the sample both at the beginning and during the study. Subsequently, no matter how well a study is planned, it will never be perfect and adaptations will be inevitable to answer changing or new research questions. In addition, as the study proceeds, knowledge, techniques and procedures also change and improve. Finally, appropriate analytical techniques are required. In order to, at least partly, overcome some of the limitations associated with pure longitudinal studies, mixed-longitudinal studies used in conjunction with appropriate analytic techniques could offer a valuable solution.

The purpose of this manuscript is to document three of the aforementioned difficulties of longitudinal research by means of the Leuven Longitudinal Study on Lifestyle, Fitness and Health (LLSLFH). First the "imperfect" design will be illustrated by describing the change in design associated with the different phases and evolving research questions throughout the LLSLFH. Second, the evolution in the selection of tests and measurements in the LLSLFH will be situated within the framework of the changing ideas on physical fitness, body composition and physical activity, the continuing search for new and better measurement techniques over the last decades and the need for adaptations with age. Third, the representativeness of the subjects still involved in the most recent phase of the LLSLFH will be investigated. With regard to physical fitness, body composition and physical activity, this will be done by comparing adolescent values of ongoing participants with those of subjects not participating in the follow-up and by comparing adult values of ongoing participants with those of a random sample of the Flemish population. With regard to socio-economic status, ongoing participants will be compared with a representative sample of the Belgian population.

First issue: The evolving design of the Leuven Longitudinal Study on Lifestyle, Fitness and Health 1969-2004

The LLSLFH originated from two existing studies: 1) The Leuven Growth Study of Belgian Boys (LGSBB) and 2) the Leuven Growth Study of Flemish Girls (LGSFG).

The Leuven Growth Study of Belgian Boys 1969-1974

During the late 1960's, the lack of available information concerning the individual growth patterns in a variety of fitness components together with the lack of well-documented growth and fitness characteristics of the Belgian population led to the initiation of the LGSBB. The LGSBB was a mixed cross-sectional and longitudinal study of a nationally representative sample of secondary school boys. Measurements included physical growth, biological maturity, motor performance, sports practice and sociocultural characteristics. The aim of the LGSBB was twofold: 1) to describe the state of physical fitness of Belgian boys at each age between 12 and 18 years and 2) to gather longitudinal information on the growth of a variety of somatic, skeletal and motor characteristics, and the pattern of sports practice.

Tests and measurements

In 1967 a pilot study was initiated on a group (n = 707) of boys 12 to 19 years of age. The purpose of this pilot study was to select reliable and valid tests and measurements for the LGSBB. Based on the factor structure identified by Fleishman (1964), age-specific factor analytic and reliability analyses were conducted to detect the underlying dimensions of motor fitness and body structure and to select the best measurements for the different dimensions in adolescent boys. This resulted in nine motor ability tests and 17 anthropometric measures. It was also decided to include several other variables in the main study such as somatotype, skeletal age, sports practice and sociocultural characteristics. An overview of the measurements of physical fitness, body composition and physical activity operationalized in the LGSBB is shown in Tables 1 and 2.

Sample

At the initiation of the LGSBB, the educational system in Belgium did not offer co-education. Consequently it was decided to study only boys. Considering the need of an adequate sampling frame, a multistage cluster sampling procedure was chosen. In the first stage, a proportionate stratified sample with schools as the primary sampling units was selected. The following four stratification factors were operationalized: language group (Dutch (Flemish) or French), type of schooling (vocational or humanities), school body (private (i.e. Roman Catholic) or state) and geographic distribution of the school population over the nine Belgian provinces. The first sampling stage resulted in the selection of 59 schools. In the second stage of the sampling, entire classes were randomly selected from one grade of the secondary school starting with the first grade in 1969, the second in 1970, and finally the sixth grade in 1974. The same schools were visited each year which made it possible for boys previously enrolled in the study to be reselected in the following years.

From Table 3 it can be seen that from the original sample of 4278 boys observed in 1969, 588 were followed throughout the six years. This selection was part of the design and could be considered random. Furthermore, no selective dropout was observed during this study. However, it should be noted that boys who were followed on successive occasions were those who had succeeded in their year of school. This may have possibly introduced a systematic bias into the longitudinal sample.

Table 1. Evolution in the assessment methodology of physical fitness in males of the Leuven Longitudinal Study on Lifestyle, Fitness and Health (LLSLFH) (1969-2004)

	Adolescence (12-18 years): Leuven Growth Study of Belgian Boys (LGSBB)						Adulthood: Leuven Longitudinal Study on Lifestyle, Fitness and Health (LLSLFH)					
	Secondary school grades						30 years	35 years	40 years	45-49 years: Flemish Longitudinal Offspring Study (FLOS)		
PHYSICAL FITNESS[#]	1st	2nd	3rd	4th	5th	6th				man	spouse	offspring
Morphological component												
Body mass for height	x	x	x	x	x	x	x	x	x	x	x	x
Waist-hip ratio								x	x	x	x	x
Skinfolds[†]	x	x	x	x	x	x	x	x	x	x	x	x
BIA								x	x	x	x	x
DXA									x	x		
Muscular component												
Vertical jump	x	x	x	x	x	x	x	x	x	x	x	x
Standing broad jump								x		x	x	x
Counter movement jump (standing/hopping)										x	x	x
Bent arm hang[‡]	x	x	x	x	x	x	x	x	x	x	x	x
Arm pull	x	x	x	x	x	x	x	x				x
Handgrip								x	x	x	x	x
Leg lifts	x	x	x	x	x	x	x	x				x
Dynamic sit-ups									x	x	x	
Sit-ups								x	x	x	x	x
Cybex (knee and trunk extension/flexion, torso rotation)									x			
Biodex (quadriceps/hamstrings)										x	x	x
Motor component												
Sit and reach	x	x	x	x	x	x	x	x	x	x	x	x
Side bending trunk									x	x	x	
Shoulder abduction									x			
10 x 5 m shuttle run	x	x	x	x	x	x	x	x				x
Plate tapping[§]	x	x	x	x	x	x	x	x	x	x	x	x
Stick balance	x	x	x	x	x	x	x	x				
Flamingo balance							x	x	x	x	x	x
Single leg balance									x	x	x	
Neurocom: postural control										x	x	
Cardiorespiratory component												
1 minute step test	x	x	x	x	x	x	x	x				
Bicycle ergometer test with analysis of expired air							x	x	x	x	x	x
Heart rate at rest	x	x	x	x	x	x	x	x	x	x	x	
Blood pressure at rest									x	x	x	
Metabolic component												
Glucose									x	x	x	x
Total cholesterol									x	x	x	x
Triglycerides									x	x	x	x
HDL-cholesterol									x	x	x	x
LDL-cholesterol									x	x	x	x

[#] Physical fitness components according to Bouchard and Shephard (1994)
[†] Adolescence: triceps, subscapula, suprailiac, calf popliteus; 30 years: + biceps, medial calf, calf popliteus; 35 years: + thigh
[‡] Adolescence + adulthood 30 years-35 years-47 years + offspring: knuckle grip; adulthood 40 years: palm grip
[§] Adolescence + adulthood 30 years: Leuven plate tapping test (number of cycli in 20 sec); adulthood 35 years + offspring: Leuven and Eurofit plate tapping test; adulthood 40-47 years + spouse: Eurofit plate tapping test

Table 2. Evolution in the assessment methodology of physical activity in males of the Leuven Longitudinal Study on Lifestyle, Fitness and Health (LLSLFH) (1969-2004)

	Childhood and adolescence (12-18 years): Leuven Growth Study of Belgian Boys (LGSBB)						Adulthood: Leuven Longitudinal Study on Lifestyle, Fitness and Health (LLSLFH)					
	Secondary school grades						30 years	35 years	40 years	45-49 years: Flemish Longitudinal Offspring Study (FLOS)		
PHYSICAL ACTIVITY#	1st	2nd	3rd	4th	5th	6th				man	spouse	offspring
Sports practice preceding year	x	x	x	x	x	x	x	x	x	x		x
Former and present sports practice parents	x	x	x	x	x	x						
Former and present sports practice spouse							x	x				
Present sports practice spouse									x			
Present sports practice offspring									x			
Sports career							x	x	x			
Leisure Time Profile							x	x	x			
Attitudes towards physical activity in leisure time							x	x	x			
Prior experience with physical education at school							x					
Tecumseh Community Health Questionnaire							x	x	x	x		
Five City Questionnaire								x	x			
Baecke Questionnaire									x	x		
Tracmor (triaxial accelerometry)†									x			
Doubly labeled water‡									x			
Flemish Physical Activity Computerized Questionnaire (FPACQ)										x	x	x
Retrospective physical activity questionnaire										x	x	

Except for the FPACQ, the questionnaires are in self- or interview-administered paper-pencil format
† For the validation of the Tecumseh Community Health Questionnaire, the Five City Questionnaire and the Baecke Questionnaire
‡ For the validation of the Tecumseh Community Health Questionnaire, the Five City Questionnaire and the Baecke Questionnaire on a subsample of 19 males

Table 3. Number of boys enrolled in the Leuven Growth Study of Belgian Boys (LGSBB)

Measuring period	Number of examinations						
	1	2	3	4	5	6	
1969 (January 13 – May 10)	4278						
1970 (January 12 – March 14)	1404	2921					
1971 (January 11 – March 19)	1287	832	1863				
1972 (January 10 – March 16)	1033	727	529	1177			
1973 (January 29 – March 22)	629	604	379	366	783		
1974 (January 28 – March 22)	332	442	482	239	280	588	
Total	8963	5526	3253	1782	1063	588	21175

Procedures

The boys were examined at yearly intervals during the same period of the year. The whole testing period lasted about three months each year and was always organized in the same way. The number of variables to be tested necessitated the creation of two separate test teams of well trained instructors. One team was charged with the anthropometric measures, the standardized photographs for somatotyping and the step test. The other team assessed the motor tests and the X-rays of the hand-wrist for the estimation of skeletal age. During this visit, all subjects were also submitted to a control-interview concerning the answers given by their parents on the questionnaire about sports practice and sociocultural background. The sequence of the physical fitness tests was always the same with the most strenuous tests at the end. The two teams visited the schools within a one-week interval: subjects tested by one team the first week, were revisited by the other team the subsequent week. Before participation in the study, written informed consent was given by the boys and their parents.

In-field reliability was evaluated by re-examining a subgroup of 100 boys in each birth cohort. The re-measurement was done by the same test instructor and took place about three weeks after the initial measurement. For the anthropometric measures, test-retest correlation coefficients varied between 0.99 (height) and 0.73 (bicondylar femur diameter, skinfold calf popliteus). For the physical fitness tests, test-retest correlation coefficients varied between 0.91 (sit and reach, arm pull) and 0.62 (sum of the pulse rate taken one and two minutes after the one minute step test).

More detailed descriptions of the LGSBB and reference data for the Belgian population have been published by Ostyn et al. (1980) and Beunen et al. (1988).

The Leuven Growth Study of Flemish Girls 1979-1980

Until the initiation of the LGSFG, few multidisciplinary studies had been conducted to assess physical fitness of Belgian youth and no data were available concerning physical fitness of 6- to 18-year-old girls.

The aim of the LGSFG was to draw up a separate assessment of the state of Flemish schoolgirls between 6 and 18 years. In contrast to the LGSBB a cross-sectional design was chosen given the limited financial and human resources. Furthermore, only Flemish girls were studied since at that time the Belgian constitution was changed and education became a responsibility of the communities.

Tests and measurements

With the intention to investigate the physical fitness of Flemish girls aged 6 to 18 years, the problem of the existing basic dimensions of motor fitness and body structure and the selection of appropriate tests and measurements was raised again.

Therefore, in 1974 a new pilot study was carried out. Starting from the boys' study and recent literature on the subject, new factor analytic and reliability analyses were conducted on a group of girls (n = 402) aged 11 to 19 years. From these analyses it was concluded that the motor characteristics and body structure of boys and girls was highly similar and that the relevant factors could be assessed using the same tests. It was accordingly decided to retain the battery of tests and measurements from the boys' study for use in the growth study on girls. Only a limited number of adaptations were carried out, mainly because the youngest girls were not able to perform some of the tests included in the boys' test battery.

In comparison with the boys' study, the number of anthropometric indicators was somewhat expanded. Apart from the measures of physical fitness and anthropometry mentioned above, data on somatotype rating, biological maturity, sociocultural correlates, sport skill, sports practice, hygiene and eating habits were also collected.

In Tables 4 and 5 an overview is given of the measurements of physical fitness, body composition and physical activity in the LGSFG.

Sample

As in the LGSBB, a multistage proportional cluster sampling was chosen. In the first stage, a proportionate sample with schools as the primary cluster was selected. The following three stratification factors were operationalized: school level (primary or secondary), geographic distribution of the schools over the five Flemish provinces and school body (private (i.e.

Table 4. Evolution in the assessment methodology of physical fitness in females of the Leuven Longitudinal Study on Lifestyle, Fitness and Health (LLSLFH) (1979-2004)

	Childhood and adolescence (6-18 years): Leuven Growth Study of Flemish Girls (LGSFG)		Adulthood: Leuven Longitudinal Study on Lifestyle, Fitness and Health (LLSLFH)		
			37-43 years: Flemish Longitudinal Offspring Study (FLOS)		
PHYSICAL FITNESS[#]	1^{st} till 3^{rd} grade primary school	starting from 4^{th} grade primary school	woman	spouse	offspring
Morphological component					
Body mass for height	x	x	x	x	x
Waist-hip ratio			x	x	x
Skinfolds[†]	x	x	x	x	x
BIA			x	x	x
Muscular component					
Vertical jump		x	x	x	x
Standing broad jump	x		x	x	x
Counter movement jump (standing/hopping)			x	x	x
Bent arm hang	x	x	x	x	x
Arm pull	x	x	x		x
Handgrip			x	x	x
Leg lifts		x	x		x
Sit-ups	x		x	x	x
Dynamic sit-ups			x	x	
Biodex (quadriceps/hamstrings)			x	x	x
Motor component					
Sit and reach	x	x	x	x	x
Side bending trunk			x	x	
10 x 5 m shuttle run	x	x	x		x
Plate tapping[‡]	x	x	x	x	x
Flamingo balance[§]	x	x	x	x	x
Single leg balance			x	x	
Neurocom: postural control			x	x	
Cardiorespiratory component					
1 minute step test		x			
24 x 20 m shuttle run		x			
Bicycle ergometer test[† †]	x	x	x	x	x
Spirometry	x	x			
Heart rate at rest[‡ ‡]	x	x	x	x	
Blood pressure at rest[§ §]	x	x	x	x	
Metabolic component					
Glucose			x	x	x
Total cholesterol			x	x	x
Triglycerides			x	x	x
HDL-cholesterol			x	x	x
LDL-cholesterol			x	x	x

[#] Physical fitness components according to Bouchard and Shephard (1994)
[†] Adolescence: biceps, triceps, subscapula, suprailiac, medial calf; adulthood + spouse + offspring: + calf popliteus, thigh
[‡] Adolescence: Leuven plate tapping test (number of cycli in 20 sec); adulthood + offspring: Leuven and Eurofit plate tapping; adulthood spouse: Eurofit plate tapping test
[§] Adolescence 1^{st} till 3^{rd} grade: wider foot support
[† †] Adolescence: without analysis of expired air, only administered to a random sample of the total group of subjects at each age level instead of the step test; adulthood + spouse + offspring: with analysis of expired air
[‡ ‡] Adolescence: in girls who performed the step test or the ergometer bicycle test
[§ §] Adolescence: in girls who performed the ergometer bicycle test

Table 5. Evolution in the assessment methodology of physical activity in females of the Leuven Longitudinal Study on Lifestyle, Fitness and Health (LLSLFH) (1979-2004)

	Childhood and adolescence (6-18 year): Leuven Growth Study of Flemish Girls (LGSFG)		Adulthood: Leuven Longitudinal Study on Lifestyle, Fitness and Health (LLSLFH)		
			37-43 years: Flemish Longitudinal Offspring Study (FLOS)		
PHYSICAL ACTIVITY[#]	primary school	Secondary school	woman	spouse	offspring
Sports practice preceding year		x			x
Environmental Stimulus for Physical Activity Questionnaire	x				
Flemish Physical Activity Computerized Questionnaire (FPACQ)			x	x	x
Retrospective physical activity questionnaire			x	x	

[#] Except for the FPACQ, the questionnaires are in self- or interview-administered paper-pencil format

Roman Catholic), state or community). The first sampling stage resulted in the selection of 43 primary and 45 secondary schools. Additionally, after this first selection, factors such as size of the school and population density of the location of the school were taken into account. Moreover, for secondary schools, the proportional representation of technical, vocational and general humanity schools in the sample was verified. A few corrections were made in order to match the required proportions.

In the second stage of the sampling, classes of school girls were selected from the six primary and the six secondary school grades. The total sample consisted of 9954 girls, 4738 at primary and 5216 at secondary school.

Procedure

Each school was visited twice, generally within two successive weeks, by two different well trained research teams. The test session in the first week comprised anthropometric measurements, somatotyping and exercise physiology. Half of the girls performed the 24 x 20 m endurance shuttle run, while the other half underwent a control interview of the questionnaire on sports practice and sociocultural background completed in advance by their parents. A random sample of one fourth of the girls was asked to perform the bicycle ergometer test instead of the step test. During the visit in the subsequent week, the test session consisted of the questionnaire of hygiene and eating habits, spirometry, an X-ray of the hand-wrist, motor tests and the ball skill test. The 24 x 20 m shuttle run and the control-interview for the questionnaire on sports practice and sociocultural background were carried out for the other half of the girls. The sequence of the physical fitness tests was always the same with the most strenuous tests at the end. Before participation in the study, written informed consent was given by the girls and their parents.

To assess in-field reliability of the anthropometric measurements, three percent of the girls were re-examined during the same day by the same anthropometrist. Test-retest correlation coefficients for the anthropometric measures varied between 1.00 (body weight, height, sitting height, acromial height, upper arm circumference relaxed, upper arm circumference flexed) and 0.84 (bicondylar femur diameter). For the physical fitness tests, the abovementioned procedure could not be followed. However, information about the test-retest reliability for 12- to 19-year-old girls, using the same testing procedures, was available from the pilot study. Test-retest correlations varied between 0.94 (sit and reach) and 0.36 (heart rate rest before the one minute step test). For the 6- to 13-year-old girls a separate test-retest reliability study was set up again using the same testing procedures. In this study 283 girls from two primary schools were tested twice within a one-week interval by the same testing team that conducted the main study. Test-retest correlations varied between 0.96 (vertical jump) and 0.56 (24 x 20 m shuttle run).

More detailed information on the LGSFG and growth curves, norm scales and profile charts for all tests and measurements have been published by Simons et al. (1990).

The Leuven Longitudinal Study on Lifestyle, Fitness and Health 1986-2004

In 1986 the LGSBB was extended in what is called the Leuven Longitudinal Study on Lifestyle, Fitness and Health. Of the 588 boys followed over six years during adolescence, 441 were Flemish speaking and were considered for further enrollment in the study. With the intention of five-yearly follow-ups, the males were re-examined in 1986 (30 years, n = 174), 1991 (35 years, n = 176), and in 1996 (40 years, n = 166).

In 2002-2004, within the scope of the Flemish Policy Research Centre Sport, Physical Activity and Health, the longitudinally followed males were tested again (47 years, n = 154). In addition, a subsample of the oldest girls (14-18 years) previously participating in the LGSFG, now 37-43 years with at least two offspring older than 10 years of age, was also contacted. A sample of 138 women agreed to participate and was re-examined for the first time (response rate: 32.9%). Different from the previous follow-ups, spouses and offspring older than 10 years of the longitudinally followed men and women were also included in the study. Offspring were approximately the same age as their fathers/mothers tested during adolescence in 1969-1974 and 1979-1980 respectively, and the assessment of physical fitness and physical activity was very comparable (see Tables 1, 2, 4 and 5). This particular project within the LLSLFH was called the Flemish Longitudinal Offspring Study (FLOS). An overview of the sample of the LLSLFH from 1969 to 2004 is presented in Figure 1.

In the LLSLFH the study design did not allow re-examining a subset of the participants to check in-field reliability. However, high quality of measuring techniques during adulthood was aimed at by careful selection of test instructors (M.Sc. in Physical Education or Physiotherapy), thorough training by experienced kinanthropometrists (staff members of the LGSBB and LGSFG) and regular supervision throughout the entire testing period.

The major aims to expand the LLSLFH and to conduct a follow-up of the LGSFG were: 1) to investigate tracking of physical fitness and physical activity in both genders, 2) to study generation differences in physical fitness and physical activity with corresponding data of parents and offspring at approximately the same age during adolescence, and 3) to conduct

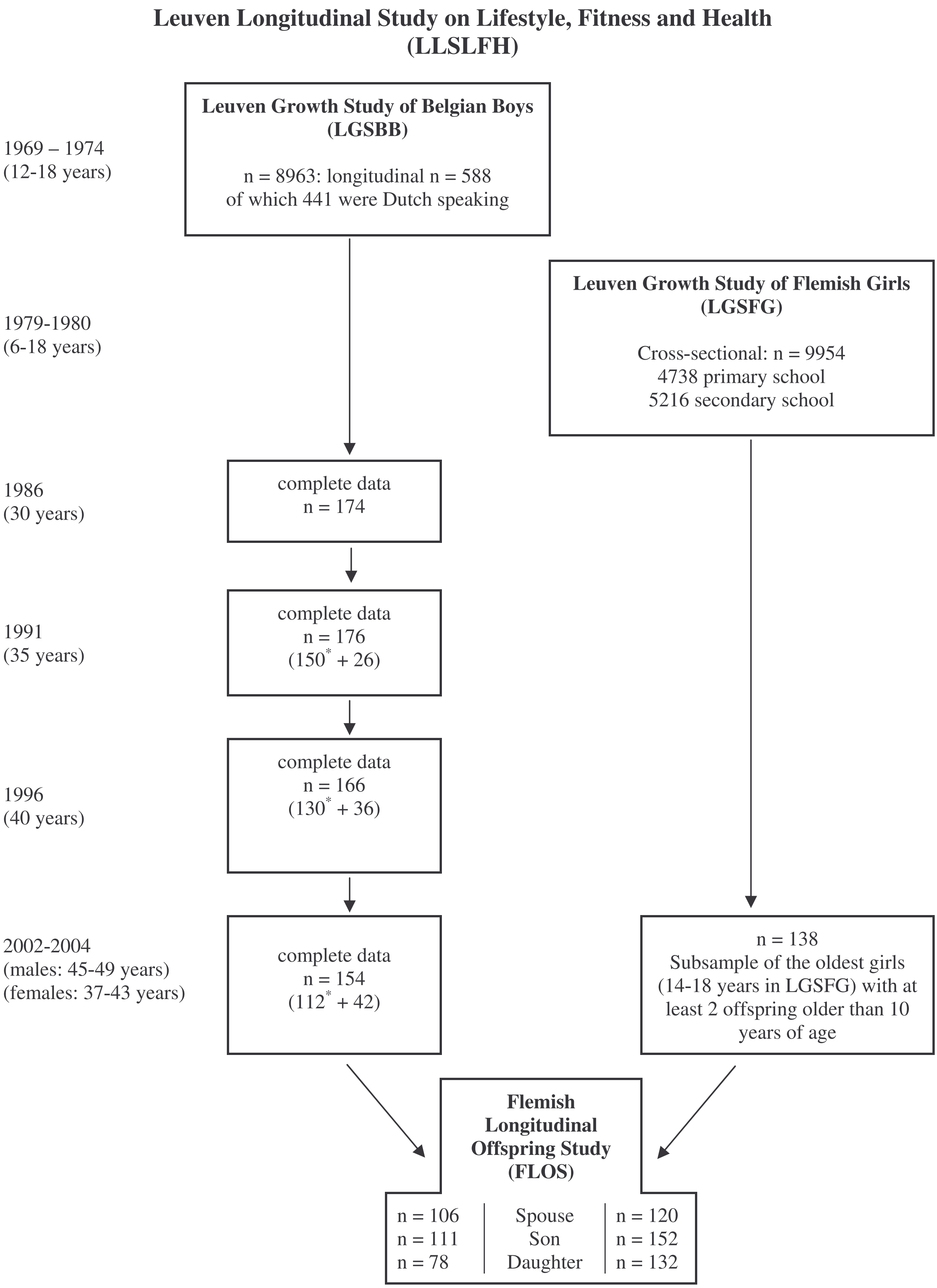

Figure 1. Overview of the sample of the Leuven Longitudinal Study on Lifestyle, Fitness and Health from 1969 to 2004

*: Longitudinal since 1969

family studies to investigate the effect of genetic, common and specific environmental factors on physical fitness and physical activity.

With the start of the LLSLFH, participants were no longer visited in the field by the test teams but were asked to come themselves to the laboratories in Leuven. Some staff members of the LGSBB en LGSFG were still involved in the study and were responsible for the training of new staff members. Previously conducted tests and measures were kept as similar as possible. Tests needing more sophisticated laboratory equipment and tests from Eurofit for Adults were added (Oja and Tuxworth, 1995).

An overview of the measurements of physical fitness, body composition and physical activity is given in Tables 1 and 2 for the follow-up males and in Tables 4 and 5 for the follow-up females.

Before participation in the study, written informed consent was given by all subjects 18 years and older. Written informed consent for offspring under the age of 18 was given by the parents.

Second issue: The evolving definition and changes in the assessment of physical fitness, body composition and physical activity

Physical fitness

At present, the model proposed by Bouchard and Shephard (1994) is well accepted and frequently used. For this reason it was also used in Tables 1 and 4 to give an overview of the evolution in assessment methodology of physical fitness in males and females from the LLSLFH from 1969 till 2004.

Before the start of the LGSBB and the LGSFG, a major issue was the selection of reliable and valid fitness tests. Since Sargent (1921) proposed the vertical jump as a physical performance test for men, considerable change has taken place both in our thinking about physical fitness and in its measurement. This evolution parallels the evolution in factor analytic methodology.

In the 1920's and 1930's the expression "general motor ability" was used to indicate one's "general" skill. This "general motor performance factor" was similar to the "general intelligence factor" proposed by Spearman (1904). However, with the evolution of factor analytic methodology and primarily under the influence of the work of Brace (1930) and McCloy (1934) increased interest emerged in the identification of different components of motor ability, and a multiple motor ability concept replaced the general ability concept (Fleishman, 1964).

In the psychometric tradition, two pilot studies were conducted prior to the initiation of the LGSBB and the LGSFG, using a factor analytic approach to detect the underlying dimensions of motor fitness and body structure and to select the best measurements for the different dimensions. This led to the development of the Leuven Physical Fitness Test battery used during the childhood and adolescent phase of the LLSLFH. Since the identified fitness components and selected tests for the Leuven Physical Fitness Test Battery served in part as the basis for the development of the Eurofit test battery (Adam and Klissouras, 1988) and to enhance international comparison, in 1986 (males 30 years) and 1991 (males 35 years), it was decided to add the missing tests of the Eurofit test battery. Until then, emphasis was still primarily on performance-related fitness. In 1996 (males 40 years), because of increasing concerns for the safety of the physical fitness tests with aging, several tests from Eurofit for Adults were adopted (Oja and Tuxworth, 1995). In addition, metabolic fitness components were included. This shift from a primary focus on performance-related fitness to more emphasis on health-related fitness is in agreement with the changing ideas about physical fitness extensively described in the international literature over the past decades (Caspersen et al., 1985; Shephard, 1986; Pate, 1988; Bouchard and Shephard, 1994; Oja, 2001; Vanhees et al., 2005).

In the adult phase of the LLSLFH, field tests were also replaced by a laboratory setting, allowing the use of more sophisticated and accurate apparatus (e.g., Cybex and Biodex (isokinetic dynamometers), Neurocom (balance testing device), bicycle ergometer test with analysis of expired air).

Body Composition

In both sexes, during childhood and adolescence, only skinfolds were taken to assess body composition. This was still the case in 1986 (males 30 years), but from 1991 onward (males 35 years) Bio-electrical Impedance Analysis (BIA) was added. In males, 40 years and older, Dual-energy X-ray Absorptiometry (DXA) was also used (Tables 1 and 4).

Physical Activity

Tables 2 and 5 show the evolution in assessment methodology of physical activity in males and females of the LLSLFH from 1969 till 2004.

To account for the change in physical activity habits with age, from adolescence to adulthood and in adulthood a shift occurred from questionnaires only assessing sports involvement in different contexts (i.e. in a club, in a youth organization, at school, with friends, with family, alone) to questionnaires also including a broad range of activities of daily life (e.g., occupation, home and garden activities, transportation). This is in line with accumulating research evidence in the 1990's on the relationship between physical fitness, physical activity and health resulting in new exercise recommendations expanding the traditional emphasis on formal exercise prescriptions to include a broader public health perspective on physical activity (Caspersen et al., 1985; Oja, 2001; Blair et al., 2004; Vanhees et al., 2005). Prior to administration, reliability of the Tecumseh Community Health Questionnaire, the Five City Questionnaire and the Baecke questionnaire was investigated and they were evaluated for validity against triaxial accelerometry (Tracmor) and doubly labeled water (Philippaerts and Lefevre, 1998; Philippaerts et al., 1999; Philippaerts et al., 2001). In the last phase of the study, evolution of computer technology made it possible to replace paper-and-pencil questionnaires by a computerized questionnaire, the Flemish Physical Activity Computerized Questionnaire (FPACQ). The reliability and validity of the FPACQ has been investigated in students (Philippaerts et al. 2006) and in employed/unemployed and retired people (Matton et al., in press).

Third issue: Representativeness of the ongoing study sample

Due to the possibility of selective dropout, before making inferences to the entire population based on results from longitudinal studies, it is important to verify the representativeness of the ongoing study participants.

First, ongoing study participants were compared with subjects not participating in the follow-up with regard to physical fitness tests, body composition and physical activity assessed in both groups during adolescence (Flemish speaking males, 18 years and females, 14-18 years). Since the majority of the variables were not normally distributed, the non-parametric Wilcoxon rank-sum test was used. Results for males and females are shown in Tables 6 and 7. In males, no differences were found for body composition and physical fitness. Sports practice at the age of 18 was higher ($p < 0.01$) in ongoing study participants compared to non-follow-ups. In females, no differences were found for body composition and sports practice. Ongoing females needed less time for the 10 x 5 m ($p < 0.01$) and the 24 x 20 m ($p < 0.05$) shuttle run during adolescence compared to non-follow-ups. However, although statistically significant, these differences are very small and can be considered irrelevant. Despite the fact that there was no or little difference in key variables between ongoing study participants and dropouts during adolescence, it should be mentioned that the difference might have been larger at the time dropouts decided not to take part anymore. Unfortunately, this could not be investigated in the present study since data were only available on the reasons for dropout in adulthood but not on the key variables at the time of dropout.

Table 6. Comparison of adolescent (18 years) physical fitness, body composition and physical activity values between ongoing males of the LLSLFH (2002-2004) and non-follow-up males

	Ongoing study participants (n = 142-154)		Non-follow-up males (n = 259-287)		p-value
	Mean	SD	Mean	SD	
BMI (kg/m^2)	21.2	1.9	21.1	2.4	0.136
Sum 4 skinfolds (mm)†	29.1	8.2	30.7	12.4	0.968
Vertical jump (cm)	49.7	6.6	49.1	7.0	0.782
Bent arm hang (sec)	31.6	17.9	30.5	17.0	0.611
Arm pull (kg)	75.6	12.6	74.4	13.2	0.388
Leg lifts (n/20 sec)	17.4	1.9	17.4	2.2	0.886
Sit and reach (cm)	26.1	7.4	25.0	6.8	0.068
10 x 5 m shuttle run (sec)	20.6	1.2	20.7	1.4	0.703
Plate tapping (n/20 sec)	96.6	9.0	97.1	9.4	0.783
Stick balance (sec)	53.6	169.9	28.0	96.2	0.112
1 minute step test (n/min)‡	116.0	15.5	117.6	16.2	0.566
Heart rate at rest (n/min)	75.3	10.6	76.2	11.0	0.536
Sports practice (h/week)	6.0	6.0	4.6	4.3	0.005

† triceps + subscapula + suprailiac + medial calf
‡ Heart rate immediately after the step test

Table 7. Comparison of adolescent (14-18 years) physical fitness, body composition and physical activity values between ongoing females of the LLSLFH (2002-2004) and non-follow-up females

	Ongoing study participants (n = 106-138)		Non-follow-up females (n = 1708-2803)		p-value
	Mean	SD	Mean	SD	
BMI (kg/m^2)	20.7	2.3	20.7	2.7	0.812
Sum 5 skinfolds (mm)†	63.5	20.2	65.0	21.7	0.162
Vertical jump (cm)	34.3	6.7	33.6	5.9	0.364
Bent arm hang (sec)	14.1	10.9	13.1	11.6	0.090
Arm-pull (kg)	42.4	8.3	42.2	8.7	0.818
Leg lifts (n/20 sec)	15.8	3.2	16.0	3.6	0.349
Sit and reach (cm)	26.1	6.9	26.4	7.0	0.748
10 x 5 m shuttle run (sec)	21.3	1.3	21.7	1.4	0.003
Plate tapping (n/20 sec)	83.0	9.9	82.1	9.5	0.256
Flamingo balance (n/min)	12.0	5.2	12.6	5.9	0.339
1 minute step test (n/min)‡	154.4	14.1	154.2	16.3	0.905
24 x 20 m shuttle run (sec)	156.1	10.8	159.4	13.1	0.010
Spirometry: FVC (l)§	3.4	0.7	3.3	0.7	0.930
Spirometry: FEV_1 (l)† †	3.0	0.7	3.1	0.7	0.203
Heart rate at rest (n/min)	89.0	16.1	89.0	14.8	0.911
Sports practice (h/week)	4.3	3.0	4.2	3.3	0.496

† biceps + triceps + subscapula + suprailiac + medial calf
‡ Heart rate immediately after the step test
§ Forced vital capacity
† † Forced Expiratory Volume after one second

Since selective dropout could have occurred between adolescence and adulthood, physical fitness, body composition and physical activity of participants in the most recent phase of the follow-up (2002-2004) was also compared to 45-49-year-old males and 37-43-year-old females from a random sample of the Flemish population voluntary participating in an epidemiological study to investigate the pattern of physical activity, physical fitness and health conducted by the Flemish Policy Research Centre Sport, Physical Activity and Health (2002-2004). Results from the Wilcoxon rank-sum test for males and females are shown in Tables 8 and 9. In both sexes, no differences were found for body composition and physical activity between ongoing participants and the random sample of the Flemish population. For physical fitness, results are more variable. Still participating males perform better ($p < 0.01$) on handgrip but worse ($p < 0.01$) on sit-ups, side bending trunk and single leg balance and they have a higher resting heart rate ($p < 0.01$) and blood pressure (systolic blood pressure $p < 0.01$, diastolic blood pressure $p < 0.05$) compared to the random sample of Flemish males. In females, study participants perform better ($p < 0.01$) on sit-ups and sit and reach, but worse ($p < 0.01$) on balance and they have a higher resting heart rate ($p < 0.01$) compared to the random sample of Flemish females.

Table 8. Comparison of adult (45-49 years) physical fitness, body composition and physical activity values between ongoing males of the LLSLFH (2002-2004) and a random sample of Flemish males

	Ongoing males (n = 124-154)		Flemish males (n = 158-263)†		p-value
	Mean	SD	Mean	SD	
BMI (kg/m^2)	26.2	3.3	25.8	3.2	0.436
Sum 6 skinfolds (mm)‡	85.3	32.9	86.2	34.0	0.729
Handgrip (kg)	49.1	10.0	46.4	10.7	0.005
Dynamic sit-ups (n)	14.7	1.4	14.7	1.7	0.638
Sit-ups (n/30 sec)	16.6	5.0	18.3	5.3	0.005
Sit and reach (cm)	20.7	8.8	19.5	9.8	0.180
Side bending trunk (cm)	20.5	4.5	21.9	4.6	0.002
Single leg balance (n/30 sec)	4.7	4.0	3.3	3.2	< 0.001
Heart rate at rest (n/min)	71.1	10.4	61.6	9.6	< 0.001
Systolic blood pressure at rest (mmHg)	131.6	12.9	128.8	13.6	0.007
Diastolic blood pressure at rest (mmHg)	84.0	9.9	81.8	8.9	0.014
Sports practice (h/week)§	3.9	4.7	3.1	3.4	0.353

† 45-49-year-old males from a random sample of the Flemish population voluntary participating in an epidemiological study to investigate the pattern of physical activity, physical fitness and health conducted by the Flemish Policy Research Centre Sport, Physical Activity and Health (2002-2004)
‡ biceps + triceps + subscapula + suprailiac + thigh + medial calf
§ FPACQ

Finally, with regard to socio-economic status, representativeness was investigated by comparing level of education and employment between ongoing males and females of the LLSLFH (2002-2004) and a representative sample of 45-49-year-old males and 37-43-year-old females from the Belgian Socio-Economic Survey of 2001. P-values associated with the calculated chi-squares are shown in Table 10. In both sexes, level of education and employment of the LLSLFH sample is higher ($p < 0.01$) compared to the Belgian population. Due to different categorizations, no exact comparisons could be made for socio-professional status. However, in men, the very low percentage of laborers (4.7%) compared to employees (23.5%), teachers (20.1%) and executive staff (30.2%) points to a high socio-professional level. On the other hand, in women, the high percentage of employees (53.2%) and teachers (20.6%) compared to laborers (14.3%) and executive staff (4%) is rather indicative for an intermediate socio-professional status.

Table 9. Comparison of adult (37-43 years) physical fitness, body composition and physical activity values between ongoing females of the LLSLFH (2002-2004) and a random sample of Flemish females

	Ongoing females (n = 96-138)		Flemish females (n = 120-425)†		p-value
	Mean	SD	Mean	SD	
BMI (kg/m^2)	24.1	3.8	23.9	3.9	0.375
Sum 6 skinfolds (mm)‡	128.2	46.3	126.6	45.9	0.777
Standing broad jump (cm)	139.6	21.9	141.2	24.4	0.747
Handgrip (kg)	31.7	8.2	33.4	5.4	0.044
Dynamic sit-ups (n)	14.3	2.4	13.7	2.7	0.002
Sit-ups (n/30 sec)	14.6	5.1	12.0	5.8	< 0.001
Sit and reach (cm)	25.2	7.9	22.3	9.6	0.003
Side bending trunk (cm)	21.0	4.2	21.2	3.6	0.775
10 x 5 m shuttle run (sec)	23.5	2.2	23.8	2.0	0.192
Plate tapping (sec)§	11.8	2.6	11.8	2.6	0.666
Flamingo balance (n/min)	14.6	7.4	12.2	6.5	0.003
Single leg balance (n/30 sec)	3.5	2.8	3.0	3.3	0.004
Heart rate at rest (n/min)	72.8	9.6	64.8	9.6	< 0.001
Systolic blood pressure at rest (mmHg)	119.6	12.7	120.3	14.8	0.993
Diastolic blood pressure at rest (mmHg)	75.5	8.3	76.1	9.0	0.620
Sports practice (h/week)† †	2.3	2.8	1.8	2.1	0.117

† 37-43-year-old females from a random sample of the Flemish population voluntary participating in an epidemiological study to investigate the pattern of physical activity, physical fitness and health conducted by the Flemish Policy Research Centre Sport, Physical Activity and Health (2002-2004)
‡ biceps + triceps + subscapula + suprailiac + thigh + medial calf
§ Eurofit plate tapping test
† † FPACQ

In summary, ongoing study participants are representative for body composition and, except for adolescence in males, also for physical activity. No straightforward answer can be given concerning physical fitness. In both sexes socio-economic status is above average. Especially men and women with a higher socio-economic background seem to continue participating in the adult phases of the LLSLFH. This might somewhat hamper the generalizability of results. However, because longitudinal studies inevitably rely on volunteers, the question should be raised if they could be representative and should be generalized to the total population. If a representative sample is needed, it will be better to select a new cohort. This does by no means reduce the value of longitudinal studies since they provide the opportunity to answer different questions compared to cross-sectional studies. Moreover, for many analyses the representativeness of the study sample is of less importance.

Table 10. Comparison of adult socio-economic status between ongoing males and females of the LLSLFH (2002-2004) and a representative sample of Belgian males and females

	Males (45-49 years)			Females (37-43 years)		
	Belgian Population (2001)†	LLSLFH (2002-2004)	p-value‡	Belgian population (2001)†	LLSLFH (2002-2004)	p-value‡
Level of education						
Primary school (%)	10.4	0.0		6.8	0.7	
Secondary school (%)	62.7	20.7	< 0.001	60.3	37.8	< 0.001
College (%)	26.9	79.3		32.9	61.5	
Employment						
Working (%)	90.4	99.3	< 0.001	77.0	93.3	< 0.001
Not working (%)	9.6	0.7		23.0	6.7	

† Representative sample of 45-49-year-old males and 37-43-year-old females from the Belgian Socio-Economic Survey 2001
‡ p-value associated with the calculated chi^2

Conclusions

It is clear that longitudinal research provides unique opportunities but is also faced with a number of difficulties that must be taken into account. In this manuscript three of these concerns were documented by means of findings from the LLSLFH, more specifically the "imperfect" design, the evolution of data collection methods and the representativeness of the study sample. When informed about these possible "pitfalls" in advance, several measures could be taken to prevent or limit them as much as possible. Before the initiation of the study all aspects should be planned thoroughly with the necessary creativity in anticipating or incorporating possible future trends. During the course of the study new research questions and new data collection methods will inevitably occur. However, these should only be added after careful attention has been given to the possible consequences (e.g., staff and participant burden). In addition, when previous methods are replaced by new ones, for comparability, a period of overlap with regard to the use of both methods should be provided. Finally, to ensure the representativeness of the sample, appropriate sampling procedures should be applied and special measures should be taken (e.g., reimbursement of travel expenses, personal results, newsletters) to enhance retention of subjects. If dropout does occur, telephone interviews or mailed questionnaires could be used to gather information on the reasons for dropout and the key variables at the time of dropout to be able to assess the selectiveness of this group.

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CHAPTER 2

Reliability and Validity of the Flemish Physical Activity Computerized Questionnaire (FPACQ) in Adults

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Abstract

The purpose of this study was to investigate the test-retest reliability and concurrent validity of the Flemish Physical Activity Computerized Questionnaire (FPACQ) in employed/unemployed and retired people. The FPACQ was developed to assess detailed information on several dimensions of physical activity and sedentary behaviour over a usual week. A tri-axial accelerometer, the RT3 Tri-axial Research Tracker, in combination with a written seven-day activity record, was used as the objective criterion measure. In employed/unemployed people, two-week test-retest reliability for several activity variables calculated from the FPACQ was good to excellent with *ICC*s ranging from .67 to .99. In retired people, lower but, except for time spent eating, still fair to excellent *ICC*s were found ranging from .57 to .96. Except for the time spent in active leisure time for men and the average energy expenditure related to sports participation in women, correlations between the RT3 and the FPACQ generally supported the relative validity of the FPACQ for employed/unemployed people (*r* ranging from .37 to .88). In retired people somewhat lower values were found (*r* ranging from .15 to .85) but most variables still reached at least moderate correlations. Concerning absolute validity, the FPACQ generally overestimated physical activity and underestimated sedentary behaviour compared to the RT3. From this study it can be concluded that the FPACQ is a reliable and reasonably valid questionnaire for the assessment of different dimensions of physical activity and sedentary behaviour.

Key words

accelerometer, assessment, activity record, sedentary behaviour

Introduction

In today's technological society, an increasing amount of people do not meet current physical activity recommendations. Due to mechanization and automation, few occupations today require significant physical activity. Moreover, most people use motorized transportation and even leisure time is increasingly filled with sedentary behaviour (Pate et al., 1995; U.S. Department of Health and Human Services [USDHHS], 1996). However, scientific evidence demonstrates that regular physical activity reduces the risk of morbidity and mortality from a number of chronic diseases (Bouchard, Shepard, & Stephens, 1994). The recognition of the importance of physical activity for optimal health has led to an increased interest in the assessment of physical activity.

A variety of methods can be used to assess physical activity (Welk, 2002). Although questionnaires have several limitations, given their ease of administration and distribution, low cost and low participant burden, they continue to be the most widely used type of physical activity measure in large scale epidemiological studies (Sallis & Saelens, 2000). Until now, these questionnaires generally consist of a simple written self- or interview-administered inquiry of physical activity spanning a time frame of one day to one year (Kriska & Caspersen, 1997). This traditional method of data collection is very labour- and time-consuming since, before data analysis, the completed questionnaires first have to be cleaned, coded and entered into a statistical program. Technology is now available to develop computerized questionnaires, enabling respondents to directly enter their answers into the computer. The use of computerized questionnaires has several advantages compared to written surveys. As is true of a written questionnaire, an electronic survey can be standardized easily but at the same time is very flexible including explanatory material, prompts, error correction, menus, branches and skips. A computerized questionnaire also has enormous cost and time saving potential due to the immediacy of data entry, elimination of coding errors and possibility of immediate scoring, reporting and interpretation of the results. Furthermore, clinicians, researchers and respondents seem to prefer the computerized mode, resulting in a more attentive, involved test-taking approach. Moreover, because no written records exist, respondents also have a greater feeling of privacy and anonymity, giving rise to more honest reporting of sensitive information or a reduction of the amount of social desirability in the answer. Finally, computer networks and the Internet allow large numbers of individuals to undertake the questionnaire at the same time (Crawley, Kleinman, & Dominitz, 2000; Schmitz, Hartkamp, Brinschwitz, Michalek, & Tress, 2000; Turner et al., 1998; Vereecken, 2001). Despite the enormous possibilities computerized questionnaires offer in large scale epidemiological studies, literature only reveals three studies in children or adolescents (McMurray, Harrell, Bradley, Webb, & Goodman, 1998; Philippaerts et al., 2006; Ridley, Dollman, & Olds, 2001) and one study in adults (Vandelanotte, De Bourdeaudhuij, Philippaerts, Sjörström, & Sallis, 2005) concerning the reliability and validity of computerized physical activity questionnaires.

A number of methods exist against which physical activity questionnaires can be validated. The doubly labelled water method is emerging as the preferred criterion measure of free-living energy expenditure. However, this method is complicated and expensive and provides no information on types of activities and time devoted by individuals to specific activities (Welk, 2002). For this reason, in epidemiological studies motion sensors (i.e. pedometers or accelerometers) are often used to validate physical activity questionnaires (Craig et al., 2003; Philippaerts, Westerterp, & Lefevre, 2000; Vandelanotte et al., 2005).

In 2002, within the framework of the Flemish Policy Research Centre Sport, Physical Activity and Health (SPAH), the Flemish Physical Activity Computerized Questionnaire (FPACQ) was developed to assess detailed information on several dimensions of physical activity and sedentary behaviour during a usual week. To account for the different structure in the lifestyle of students, employed/unemployed and retired people, three different versions of the questionnaire were constructed. The reliability and validity of the version for students has already been investigated in a previous study. (Philippaerts et al., 2006). The purpose of the present study was to investigate the test-retest reliability and concurrent validity of the FPACQ developed for employed/unemployed and retired men and women. A tri-axial accelerometer, the RT3 Tri-axial Research Tracker (RT3), in combination with a written seven-day activity record, was used as the objective criterion measure.

Materials and methods

Participants

Sixty-eight employed/unemployed people (33 men, 35 women) between 22 and 61 years of age and 49 retired people (30 men and 19 women) between 48 and 78 years of age participated in this study. They were all recruited from a larger community sample in Flanders (Belgium), randomly selected by the National Institute of Statistics (NIS) for a large scale epidemiological study to investigate physical activity, physical fitness and health of the Flemish population. This study was conducted by the Flemish Policy Research Centre SPAH. The study was approved by the Medical Ethics Committee of the Ghent University and of the Katholieke Universiteit Leuven. Individuals volunteered to participate in the study and they all provided informed consent prior to participation.

Due to technical problems with some accelerometers or with the saving of some computerized questionnaires, data on both reliability and validity were not available for all participants. Reliability analyses were conducted on 66 employed/unemployed people (31 men, mean age = 39.23 ± 11.65 years; 35 women, mean age = 41.46 ± 12.62 years) and 36 retired people (20 men, mean age = 63.65 ± 6.05 years; 16 women, mean age = 63.31 ± 3.94 years). Validity analyses were conducted on 62 employed/unemployed people (32 men mean age = 39.28 ± 11.72 years; 30 women, mean age = 39.13 ± 11.96 years) and of 49 retired people (30 men, mean age = 64.47 ± 5.48 years; 19 women, mean age = 65.37 ± 4.98 years).

Procedures

As part of the large scale epidemiological study on physical activity, physical fitness and health, participants completed the FPACQ in a municipal or sports hall in their neighbourhood. Before completion, they were instructed on the use of the FPACQ and during completion staff members stayed available to answer any possible questions. At the end of this session, they were asked to take part in a second, more extensive investigation in the laboratory of the Flemish Policy Research Centre SPAH. All individuals willing to visit the lab were asked to participate in an additional study on physical activity. The subsample of individuals agreeing to participate in this specific reliability and validity study were instructed on the use of the accelerometer and the written seven-day activity record. They were also provided with written instructions to take home. No further specifications concerning the link with the FPACQ, reliability or validity were given.

Participants were asked to maintain their usual activity pattern. During seven consecutive days, starting the next day, they wore an accelerometer clipped to the waistband on the right hip for all awakening hours except water activities. At the same time, in order to be able to interpret the accelerometer data in a more comprehensive way, they were also asked to keep a written seven-day activity record. In this activity record, participants were requested to report as detailed as possible all activities 24 hours a day for the seven days they wore the RT3. They reported the exact time of going to bed, getting up, having breakfast, transportation to work (by bike, on foot, motorized), occupation,…, so that all 24 hours of physical activity and sedentary behaviour over a period of seven days were accounted for in the written seven-day activity record.

During their visit at the lab, participants returned the accelerometer and the written seven-day activity record to the researchers and they were asked to complete the FPACQ for a second time. To prevent memory bias, the interval between the first and the second administration was set at two weeks and participants were not informed about this re-administration in advance.

Flemish Physical Activity Computerized Questionnaire (FPACQ)

The FPACQ was developed using Borland Delphi 6 (Borland, Cupertino, CA) and can be used in computers with operating system Windows98 (Microsoft, Redmond, WA) and higher. Data are automatically saved in an Access Database (Microsoft, Redmond, WA) and can be transferred to an Excel file (Microsoft, Redmond, WA) which can be imported into different (statistical) programs for further data analysis. At the moment an Internet version of the

FPACQ is being developed and will be maid available on the website of the Flemish Policy Research Centre SPAH: www.steunpuntsbg.be. In the mean time the software of the FPACQ can be obtained from the authors upon simple request.

At the start of the questionnaire, an introductory screen appears, informing participants about the anonymity of their answers and instructing them to answer as correctly and honestly as possible. Much attention is paid to user-friendliness, also enabling individuals with little or no computer experience to complete the questionnaire. The questions can be answered by clicking with the computer mouse on the chosen answer or answer category. Skip patterns are used to eliminate superfluous questions and all items on a screen have to be completed before participants can move on to the next screen. For paging back and forward, two command buttons (previous screen, next screen) are provided at the bottom of the screen. An initial empty bar that fills in every time a screen is completed shows how much of the questionnaire is already completed. At the end of the questionnaire, a final screen appears instructing the respondents to ask a staff member to save their questionnaire data.

The FPACQ was developed to collect detailed information on different dimensions of physical activity and sedentary behaviour during a usual week. To account for the different structure in the lifestyle of employed/unemployed and retired people, two different versions of the FPACQ were constructed. The self-administered long version of the International Physical Activity Questionnaire (IPAQ) with a reference period of a usual week was chosen as the basis for the development of the FPACQ. This long version of the IPAQ was designed to collect detailed information within the domains of occupational activity, transportation, household and garden activities, leisure-time physical activity and sedentary behaviour (Craig et al., 2003). Comparable activity domains were included in the FPACQ. In employed/unemployed people, the definitive phrasing of the questions within these domains further relied on the examination and comparison of the questions and response sets in the long version of the IPAQ (Craig et al., 2003), the Baecke Questionnaire of Habitual Physical Activity (Baecke, Burema, & Frijters, 1982), the Tecumseh Community Health Questionnaire (Reiff et al., 1967), the Seven-Day Physical Activity Recall (Sallis et al., 1985) and the Modifiable Activity Questionnaire (Kriska et al., 1990). In retired people, the questions and response sets in the Modified Baecke Questionnaire for older Adults (Voorrips, Ravelli, Dongelmans, Deurenberg, & Van Staveren, 1991), the Physical Activity Scale for the Elderly (Washburn, Smith, Jette, & Janney, 1993) and the Zutphen Questionnaire (Caspersen, Bloemberg, Saris, Merritt, & Kromhout, 1991) were additionally studied. The FPACQ for employed/unemployed people contains 57 to 90 newly developed closed-ended questions on demographic factors (11 items), occupation (1 to 20 items), transportation in leisure time (6 items), watching television or video and playing computer games (2 items), home and garden activities (3 items), eating (1 item), sleeping (1 item), moderate and vigorous physical activity in leisure time (2 items), sports participation (1 to 15 items) and determinants of physical activity (29 items). The FPACQ for retired people does not include the questions on occupation but all other questions are identical to those of employed/unemployed people (number of questions ranging from 56 to 70). Depending on the answers given and the computer experience of the respondents, the FPACQ takes 20 to 30 minutes to complete.

For the present study, 15 activity variables were calculated from the FPACQ: 12 for both employed/unemployed and retired people and an additional three concerning occupation only for the employed/unemployed group. *Tsport (h/week)* is the average time a week spent on a maximum of three different sports. This variable was assessed by asking the respondents to select a maximum of three of their most important sports out of a list of 196 sports and to report the frequency and duration. For each sport, the MET-value was determined using the Compendium of Ainsworth et al. (2000). To calculate the average energy expenditure a week related to sports participation, *EEsport (kcal/week)*, the average time a week spent on each reported sport was multiplied by its MET-value and the sum of these multiplications was subsequently multiplied by the reported body weight. *Isport (kcal/h)* indicates the average energy expenditure of sports participation and was calculated by dividing EEsport by Tsport. The variables *Teat (h/week)* and *Tsleep (h/week)* represent the time spent on eating and sleeping respectively during a usual week. *Ttv (h/week)* is the sum of the time spent on watching television or video and playing computer games during weekdays and weekend days. *Tatransl (h/week)* describes the time spent on active transportation (cycling and walking) during weekdays and weekend days in leisure time. *Tactl (h/week)* sums the time spent in active leisure time activities. This variable includes time spent on light, moderate and vigorous household and garden activities, time spent on sports participation and time spent on active transportation (cycling and walking) during weekdays and weekend days in leisure time. *EEactl (kcal/week)* is the total energy expenditure of active leisure time activities. For each active leisure time activity, the MET-value was determined (Ainsworth et al., 2000). The time spent on each leisure time activity was then multiplied by its MET-value and the sum of these multiplications was subsequently multiplied by the reported body weight. *Iactl (kcal/h)* indicates the average energy expenditure of the active leisure time activities and was calculated by dividing EEactl by Tactl. *Tocc (h/week)* is the time spent within the framework of the main and additional occupation. This variable not only includes the time spent working, but also the time spent on transportation by bike, on foot or motorized (e.g., by car, train,…) to and from the workplace. To be able to calculate *EEocc (kcal/week)*, the energy expenditure related to occupation, participants were also asked what percentage of their working time was spent on light, moderate and vigorous job activities. MET-values were determined for these activities and for transportation by bike, on foot and motorized (Ainsworth et al., 2000). The time spent on each activity within the framework of the occupation was then multiplied by its MET-value and the sum of these multiplications was subsequently multiplied by the reported body weight. *Iocc (kcal/h)* represents the average energy expenditure of the occupation and was calculated by dividing EEocc by Tocc. Finally, two general variables were calculated. *EEtotal (kcal/week)* is the overall energy expenditure during a usual week. This variable is calculated by summing EEactl, EEocc and the energy expenditure related to Teat, Tsleep and the calculated remaining quiet leisure time. *PAL (MET)* stands for physical activity level and is an indicator of the general activity level. To calculate *PAL*, *EEtotal* was divided by 168 (the number of hours in one week) and by the reported body weight. A more detailed description of the activity variables calculated from the FPACQ including the acronyms, the questions and response sets or other variables used for calculation, the calculations and the units is given in the Appendix. Of the 15 activity variables calculated from the FPACQ, Teat, Tsleep and Ttv can be considered as indicators of sedentary behaviour, whereas the other calculated activity variables can be considered as indicators of physical activity.

Combination of Tri-Axial Accelerometry and Written Seven-Day Activity Record

Besides the FPACQ, the RT3 Tri-axial Research Tracker (Stayhealthy Inc., Monrovia, CA) was also used to assess physical activity. The RT3 is a relatively new tri-axial accelerometer that has replaced the TriTrac-R3D. The RT3 has been shown to be reliable (Powell, Jones, & Rowlands, 2003; Powell & Rowlands, 2004) and has been successfully validated against oxygen consumption during four treadmill speeds (4, 6, 8 and 10 $km.h^{-1}$) and three nonregulated activities (hopscotch, kicking a ball to and fro, sitting quietly) in both boys and men (Rowlands, Thomas, Eston, & Topping, 2004). For the purpose of this study data collection mode three of the RT3 was used. This mode stores mean activity counts on individual axes (x, y, z) over one-minute epochs for approximately seven days. In addition, the vector magnitude ($VM = (x^2 + y^2 + z^2)^{0.5}$), activity calories and total calories for every one-minute epoch are calculated and stored (Powel & Rowlands, 2003; Powell et al., 2003; Rowlands et al., 2004).

In order to interpret the RT3 data in a more comprehensive way, participants concurrently kept a detailed written seven-day activity record containing all activities 24 hours a day for the seven days they wore the RT3. A code was added to each stored one-minute epoch of the seven-day RT3 output according to the specific activity reported at that time in the written seven-day activity record. The codes reflected the same activity domains as those described for the FPACQ (e.g., occupation, transportation in leisure time, watching television or video and playing computer games,…). When the entire output was coded, the same activity variables calculated from the FPACQ were also calculated from the RT3 output. For example, Tsport (h/week) was calculated by summing all stored one-minute epochs over seven days coded as sports participation, EEsport (kcal/week) was calculated by summing the stored total calories related to all one-minute epochs over seven days coded as sports participation, Isport (kcal/h) was calculated by dividing EEsport by Tsport. The calculation of the other activity variables from the RT3 was done in the same way. The combination of the RT3 output with the written seven-day activity record made it possible to compare the activity variables calculated from the FPACQ with objective measures of activity generated in the same dimensions.

Statistical Analysis

Because of the different degree of structure in their lifestyle, possibly influencing the reliability and validity of the FPACQ, data were analyzed separately for employed/ unemployed men and women and for retired men and women. Descriptive statistics (means and standard deviations) were calculated for all activity variables calculated from the RT3 and from the FPACQ. Shapiro-Wilk tests for normality showed, for both the reliability and the validity study, that not all activity variables calculated from the RT3 and from the FPACQ were normally distributed. To improve normality for positively skewed variables logarithmic transformations were used. Before taking logarithms, 1.0 was added to each value to account for the chance of having a zero value for some variables. Non-normality of negatively skewed variables was reduced by squaring each value.

In order to investigate two-week test-retest reliability of the FPACQ, single measure intraclass correlation coefficients (*ICC*s) and 95 percent confidence intervals (95% *CI*) were calculated, using a one-way analysis of variance (ANOVA) model (1, 1). The concurrent validity of the FPACQ with the criterion measure of the RT3 was studied by means of Pearson product-moment correlation coefficients (relative validity). In addition, paired *t*-tests were used to compare the magnitude of activity variables calculated from the RT3 and from the FPACQ (absolute validity). All analyses using the RT3 as criterion measure were performed after the exclusion of outliers, defined as a difference of ± 2 standard deviations, using the methods of Bland and Altman (1999). Minimal level of significance was set at $p < .05$. Data were analyzed using the SAS 9.1 statistical package (SAS Institute Inc, Cary, NC).

Results

Reliability

There are no universal criteria for what is an acceptably high *ICC* value. Fleiss (1986) suggests that *ICC* values less than .40 represent poor reliability, those between .40 and .75 fair to good reliability, those between .75 and .90 very good reliability and those greater than .90 excellent reliability. Descriptive statistics, *ICC*s and 95% confidence intervals for test-retest reliability in employed/unemployed men and women are shown in Table 1. For both employed/unemployed men and women *ICC*s for all activity variables were good to excellent ranging from .67 to .99 and they were significant at $p < .05$.

In Table 2, descriptive statistics, *ICC*s and 95% confidence intervals for test-retest reliability in retired men and women are presented. Except for Teat in men and women, *ICC*s for all physical activity variables in retired people were significant at $p < .05$ and values were good to excellent ranging from .64 to .96. Except for Tsleep in men and Isport in women, all *ICC*s in employed/unemployed people were comparable or higher than those for retired people.

Validity

Descriptive statistics, correlation coefficients and results of the *t*-test between physical activity variables calculated from the RT3 and from the first administration of the FPACQ in employed/unemployed men and women are presented in Table 3. Except for Tactl in men ($r = .35$) and Isport in women ($r = .27$), all Pearson correlation coefficients between the physical activity variables calculated from RT3 and FPACQ were significant and ranged from .37 to .88. Except for Ttv in men, Tactl in women and Tocc in both sexes, a significant difference was found between the activity variables calculated from the RT3 and from the FPACQ. Teat, Tsleep in men and women and Ttv in women were significantly lower when calculated from the FPACQ, whereas all other physical activity variables were significantly lower when calculated from the RT3.

Table 1. Descriptive statistics (non-transformed means and standard deviations (*SD*)), test-retest intraclass correlations (*ICC*) and 95% confidence intervals (*CI*) for the activity variables calculated from the FPACQ in employed/unemployed men and women

	Men				Women			
	Test	Retest	*ICC*	95% *CI*	Test	Retest	*ICC*	95% *CI*
	Mean (*SD*)	Mean (*SD*)			Mean (*SD*)	Mean (*SD*)		
Tsport (h/week)	3.83 (2.73)	3.67 (2.88)	.87	.75-.94	2.91 (2.67)	2.75 (2.35)	.91	.82-.95
EEsport (kcal/week)	2017.97 (1490.05)	1921.30 (1523.40)	.94	.88-.97	1055.95 (1018.67)	1044.13 (1028.87)	.91	.83-.95
Isport (kcal/h)	487.12 (242.03)	471.45 (234.15)	.97	.94-.98	327.22 (185.05)	298.47 (195.84)	.74	.55-.86
Teat (h/week)	5.32 (2.35)	4.98 (2.66)	.74	.53-.86	5.69 (2.87)	5.43 (2.49)	.67	.43-.82
Tsleep (h/week)	51.03 (7.27)	50.35 (6.11)	.84	.70-.92	53.00 (5.95)	53.00 (5.70)	.83	.70-.91
Ttv (h/week)	17.69 (10.46)	17.78 (10.17)	.93	.86-.97	14.78 (8.25)	16.46 (9.52)	.92	.84-.96
Tatransl (h/week)	1.73 (1.74)	2.06 (1.93)	.75	.55-.87	1.96 (1.93)	2.54 (2.51)	.71	.50-.84
Tactl (h/week)	13.32 (8.17)	13.04 (8.35)	.79	.62-.90	17.21 (10.06)	16.83 (9.45)	.85	.73-.92
EEactl (kcal/week)	4670.98 (3287.85)	4546.04 (3302.21)	.84	.70-.92	4058.57 (2416.45)	4051.38 (2416.41)	.86	.75-.93
Iactl (kcal/h)	353.44 (107.14)	354.55 (101.61)	.90	.81-.95	240.07 (59.57)	240.48 (62.34)	.94	.88-.97
Tocc (h/week)	41.62 (18.07)	41.57 (17.66)	.97	.94-.99	27.87 (18.66)	28.13 (18.51)	.99	.98-.99
EEocc (kcal/week)	7258.29 (3323.47)	7434.38 (3285.44)	.94	.88-.97	4033.04 (2578.58)	4223.07 (2686.78)	.97	.94-.98
Iocc (kcal/h)	152.17 (65.07)	156.04 (65.41)	.95	.91-.98	121.03 (68.27)	125.72 (71.61)	.98	.96-.99
EEtotal (kcal/week)	22893.06 (4325.70)	23115.41 (4369.41)	.95	.89-.97	18215.76 (2867.37)	18434.28 (3209.15)	.92	.85-.96
PAL (MET)	1.74 (0.17)	1.74 (0.18)	.92	.84-.96	1.66 (0.14)	1.67 (0.14)	.78	.61-.88

Table 2. Descriptive statistics (non-transformed means and standard deviations (*SD*)), test-retest intraclass correlations (*ICC*) and 95% confidence intervals (*CI*) for the activity variables calculated from the FPACQ in retired men and women

	Men				Women			
	Test	Retest	*ICC*	95% *CI*	Test	Retest	*ICC*	95% *CI*
	Mean (*SD*)	Mean (*SD*)			Mean (*SD*)	Mean (*SD*)		
Tsport (h/week)	2.21 (2.86)	2.72 (4.92)	.68	.37-.86	1.31 (1.82)	1.75 (2.20)	.92	.79-.97
EEsport (kcal/week)	861.16 (1211.42)	1167.83 (1999.93)	.68	.36-.86	366.80 (466.35)	472.33 (573.02)	.91	.78-.97
Isport (kcal/h)	255.08 (209.69)	307.22 (271.83)	.60	.23-.82	166.44 (158.19)	173.75 (145.60)	.94	.84-.98
Teat (h/week)	5.85 (2.44)	5.67 (1.97)	.24	-.20-.61	6.42 (2.99)	5.04 (1.84)	.14	-.35-.58
Tsleep (h/week)	52.85 (8.64)	53.90 (7.22)	.94	.86-.98	51.19 (8.37)	51.63 (9.52)	.90	.75-.97
Ttv (h/week)	20.30 (11.52)	19.10 (9.29)	.76	.49-.89	19.16 (9.73)	18.13 (9.46)	.89	.72-.96
Tatransl (h/week)	2.74 (2.54)	2.98 (2.36)	.81	.58-.92	1.34 (1.41)	2.05 (1.51)	.57	.14-.83
Tactl (h/week)	17.29 (10.97)	17.67 (13.17)	.83	.62-.93	17.49 (6.97)	16.33 (7.99)	.64	.24-.85
EEactl (kcal/week)	4864.41 (3275.20)	5247.56 (4175.20)	.83	.63-.93	3812.96 (1706.03)	3814.06 (2063.71)	.71	.35-.89
Iactl (kcal/h)	282.23 (42.85)	293.90 (36.74)	.71	.41-.87	218.00 (34.66)	231.68 (41.43)	.77	.48-.91
EEtotal (kcal/week)	21009.85 (2490.15)	21266.64 (2995.04)	.90	.76-.96	18018.17 (2934.23)	18149.10 (3296.88)	.96	.90-.99
PAL (MET)	1.52 (0.15)	1.54 (0.19)	.89	.76-.96	1.49 (0.08)	1.49 (0.10)	.77	.47-.91

Table 3. Descriptive statistics (non-transformed means and standard deviations (*SD*)), correlation coefficients (*r*) and results of the *t*-test between the activity variables calculated from the RT3 and from the first administration of the FPACQ (test) in employed/unemployed men and women

	Men				Women			
	RT3	FPACQ (test)	*r*	*t*-test	RT3	FPACQ (test)	*r*	*t*-test
	Mean (*SD*)	Mean (*SD*)			Mean (*SD*)	Mean (*SD*)		
Tsport (h/week)	2.64 (3.17)	3.49 (3.21)	.77***	2.69*	1.96 (1.89)	2.64 (2.34)	.63***	2.15*
EEsport (kcal/week)	1149.86 (1513.46)	1801.15 (1547.02)	.47**	2.26*	557.18 (688.76)	960.03 (828.01)	.67***	3.45**
Isport (kcal/h)	307.79 (242.15)	441.75 (259.54)	.54**	3.00**	223.16 (152.59)	329.51 (179.88)	.27	2.83**
Teat (h/week)	8.19 (2.52)	5.83 (2.71)	.53**	-5.44***	8.08 (1.93)	5.53 (2.55)	.56**	-6.49***
Tsleep (h/week)	57.76 (5.18)	50.70 (5.81)	.69***	-8.78***	59.73 (4.82)	51.90 (5.13)	.60***	-9.42***
Ttv (h/week)	19.54 (11.90)	17.52 (9.07)	.69***	-0.75	15.76 (8.14)	12.85 (7.39)	.83***	-3.32**
Tatransl (h/week)	0.34 (0.66)	1.72 (1.75)	.55**	7.15***	1.03 (1.67)	1.83 (1.67)	.49**	3.48**
Tactl (h/week)	8.15 (5.73)	12.83 (6.09)	.35	4.26*	16.09 (7.85)	14.47 (7.68)	.75***	-1.55
EEactl (kcal/week)	1944.57 (1747.01)	3991.00 (1811.29)	.37*	5.38***	2397.28 (1273.00)	3646.83 (1846.76)	.67***	4.54***
Iactl (kcal/h)	211.90 (85.03)	335.69 (86.02)	.51**	7.98***	140.20 (39.34)	245.43 (59.70)	.84***	21.16***
Tocc (h/week)	41.55 (17.39)	45.36 (15.19)	.78***	1.69	28.48 (17.42)	31.79 (19.46)	.88***	1.97
EEocc (kcal/week)	5316.62 (2480.35)	8258.68 (3269.80)	.85***	9.25***	2888.09 (1754.08)	4820.70 (2843.17)	.83***	6.29***
Iocc (kcal/h)	121.61 (42.25)	171.24 (56.10)	.84***	9.61***	95.60 (34.53)	141.54 (50.74)	.78***	7.58***
EEtotal (kcal/week)	18758.23 (3125.32)	23121.32 (4371.75)	.80***	9.02***	14842.17 (1626.13)	18495.35 (2581.88)	.65***	10.18***
PAL (MET)	1.44 (0.17)	1.77 (0.22)	.56**	9.87***	1.35 (0.15)	1.68 (0.14)	.44*	11.68***

*: $p < .05$, **: $p < .01$, ***: $p < .001$

In Table 4 descriptive statistics, correlation coefficients and results of the *t*-test between activity variables calculated from the RT3 and from the first administration of the FPACQ in retired men and women are shown. Significant Pearson correlation coefficients, ranging from .39 to .85, were found for Tsleep, Ttv, Tatransl, Iactl, EEtotal and PAL in both sexes, for Tsport and EEactl in men and EEsport in women. No significant differences between RT3 and FPACQ were found for EEsport and Isport in men and women, for Tactl in men and for Tsport and EEactl in women. Teat, Tsleep and Ttv in both sexes, Tsport in men and Tactl in women were significantly lower when calculated from the FPACQ, whereas all other physical activity variables were lower when calculated from the RT3. Except for EEtotal in women, all Pearson correlation coefficients were higher in employed/unemployed people compared to retired people.

Discussion

In the present study two-week test-retest reliability of the FPACQ is good to excellent in employed/unemployed men and women and generally lower but, except for time spent eating, still fair to excellent in retired people. These results are usually similar and sometimes even higher compared to other physical activity questionnaires found in the literature. Philippaerts and Lefevre (1998) reported very resembling one-month test-retest *ICC*s for most activity variables derived from an adapted version of the Tecumseh Community Health Questionnaire administered in 30- to 40-year-old Flemish men. Only reliability of time spent eating was substantially higher (*ICC* = .89) compared to our study. For a Dutch computerized version of the International Physical Activity Questionnaire, completed by 25- to 55-year-old Flemish adults, reliability of all physical activity variables was somewhat lower with *ICC*s ranging from .60 for energy expended on transportation to .83 for time spent on job-related physical activity (Vandelanotte et al., 2005). In a population of older adults (61-80 years of age), two-week test-retest reliability of a Spanish interview-administered version of the Yale Physical Activity Survey (YPAS) was also lower (*ICC*s ranging from .12 for standing to .66 for YPAS total time) than for retired people in our study (De Abajo, Larriba, & Marquez, 2001).

When comparing results of various questionnaires, it is important to keep in mind that test-retest reliability generally increases when the time interval between tests is reduced (Washburn, Heath, & Jackson, 2000). This can, at least partly, be explained by the fact that test-retest reliability of a questionnaire is not only affected by the measurement error associated with the physical activity assessment instrument itself but also by true changes in physical activity behaviour that may occur over time (Sallis & Saelens, 2000). For the present

Table 4. Descriptive statistics (non-transformed means and standard deviations (*SD*)), correlation coefficients (*r*) and results of the *t*-test between the activity variables calculated from the RT3 and from the first administration of the FPACQ (test) in retired men and women

	Men				Women			
	RT3	FPACQ (test)	*r*	*t*-test	RT3	FPACQ (test)	*r*	*t*-test
	Mean (*SD*)	Mean (*SD*)			Mean (*SD*)	Mean (*SD*)		
Tsport (h/week)	2.93 (2.74)	1.70 (2.71)	.66***	-2.88**	1.43 (1.39)	1.12 (1.40)	.38	-0.91
EEsport (kcal/week)	672.95 (645.29)	534.67 (800.79)	.37	-0.89	357.45 (353.98)	325.00 (398.92)	.51*	-0.37
Isport (kcal/h)	202.34 (141.74)	171.68 (187.01)	.25	-0.80	178.16 (164.64)	155.41 (157.23)	.23	-0.50
Teat (h/week)	10.00 (1.62)	6.09 (2.83)	.33	-7.20***	9.02 (1.33)	6.04 (2.75)	.15	-4.40***
Tsleep (h/week)	60.29 (5.63)	54.55 (7.57)	.57**	-4.85***	61.15 (8.86)	50.11 (8.50)	.51*	-5.78***
Ttv (h/week)	29.15 (14.53)	22.33 (11.43)	.78***	-3.98***	21.76 (10.84)	18.06 (9.50)	.80***	-2.41*
Tatransl (h/week)	1.58 (1.97)	3.01 (2.18)	.55**	4.83***	0.89 (1.39)	1.97 (1.86)	.52*	2.75*
Tactl (h/week)	14.08 (8.03)	16.42 (9.89)	.33	1.19	21.97 (7.86)	17.18 (6.58)	.28	-2.26*
EEactl (kcal/week)	2699.15 (1615.05)	4235.47 (2476.71)	.39*	3.43**	2907.35 (1497.66)	3699.40 (1497.66)	.44	1.83
Iactl (kcal/h)	189.37 (63.38)	281.58 (44.69)	.41*	8.05***	124.24 (26.06)	217.19 (35.44)	.64**	14.45***
EEtotal (kcal/week)	16694.00 (1363.93)	20818.17 (2323.99)	.55**	11.48***	13793.22 (2080.84)	17713.61 (2874.26)	.85***	10.79***
PAL (MET)	1.21 (0.09)	1.51 (0.14)	.39*	11.91***	1.17 (0.11)	1.50 (0.08)	.50*	13.93***

*: $p < .05$, **: $p < .01$, ***: $p < .001$

study a test-retest interval of two weeks was chosen. This interval was considered long enough to obtain a measure of reliability not contaminated by recall of answers from the first administration but yet short enough to minimize true changes in activity pattern. In addition, participants were asked to recall their usual activity pattern, since this should be less sensitive to the interval between tests compared to past-day or past-week recalls (Sallis & Saelens, 2000). However, Craig et al. (2003) noted that interpretation of a usual week is sometimes problematic as participants are not always able to identify what is usual and sometimes hesitate to recall the last seven days as a usual week. Another important methodological aspect of the reliability study also deserves attention. Because individuals participated both in the reliability and the validity study, they were asked to wear the accelerometer and to complete the written seven-day activity record in between the two measurements of the FPACQ. This may have increased their awareness about physical activity probably leading to an underestimation of the reproducibility of the FPACQ (Wendel-Vos, Schuit, Saris, & Kromhout, 2003). In addition, as pointed out by Schuler, Richardson, Ochoa and Wang (2001), it is possible that the first administration itself served as a form of "primer", i.e. participants may have paid closer attention to their activities after the first administration of the survey. Therefore the discrepancy between the first and second administration may reflect a more accurate recall on the second administration.

The lower test-retest reliability of retired people compared to employed/unemployed people is in accordance with results found by Norman, Bellocco, Bergström and Wolk (2000) in Swedish men. They reported lower Spearman correlations for the older age group (65-78 years; r = .54) compared to the younger age group (44-64 years; r = .72) between total physical activity values derived from a self-administered questionnaire assessed six months apart. This lower reliability in older or retired people could probably be explained by several conditions commonly observed in older adults that might affect performance on physical activity questionnaires (e.g., temporary distractions or lack of concentration, impaired cognitive ability, reduced information processing speed,…) (Rikli, 2000). A lower variability of the activity levels in retired individuals could also be an explanation. However, in the present study, this can not be generalised for all activity variables. Another possible reason is the fact that most of the physical activity engaged in by older or retired people is of light to moderate intensity and generally less structured compared to that of employed/unemployed people. These are exactly the types of activities shown to be the most difficult to recall (Washburn, 2000). Finally, lower reliability could also be attributed to less computer experience in older adults. However, in a comparative study of written versus computer administration of the Quality Of Life in Reflux And Dyspepsia (QOLRAD) questionnaire, prior computer experience alone did not influence score stability across methods of administration (*r* = .91 in people with and .94 in people without prior experience) (Kleinman, Leidy, Crawley, Bonomi, & Schoenfeld, 2001). Moreover, it seems reasonable to assume that in the future seniors will become as accustomed to using computers as are middle-aged and young adults now (Cutler, Hendricks, & Guyer, 2003).

Correlations calculated between RT3 and FPACQ generally support the relative validity of the FPACQ for employed/unemployed men and women. In retired people, except for EEtotal, relative validity of the FPACQ is somewhat lower compared to that found in employed/unemployed people but most variables still reach at least moderate correlations. Concerning absolute validity, with a few exceptions, the FPACQ generally overestimates physical activity and underestimates sedentary behaviour compared to tri-axial accelerometry in both employed/unemployed and retired people.

A review by Sallis and Saelens (2000) summarized validity results of several self- or interview administered physical activity questionnaires based on objective criterion measures. Results were expressed as a mean of correlations across studies weighted by sample size. Seven questionnaires were reviewed in young- to middle-aged adults and correlations with accelerometry ranged from .02 for the Baecke Questionnaire of Habitual Physical Activity (leisure physical activity versus Caltrac) to .53 for the Seven-Day Physical Activity Recall (total physical activity versus Tri-Trac). In older adults, four questionnaires were reviewed. Correlations ranged from .14 (vigorous physical activity versus Caltrac) to .31 (walking versus Caltrac) for the Yale Physical Activity Survey and a value of .22 was found for the Modified Baecke Questionnaire for Older Adults (versus Caltrac). In a study of Philippaerts et al. (2000) validity of the Baecke Questionnaire (BAQ) and an adapted version of the Tecumseh Community Health Questionnaire (TCQ) was investigated in 40-year-old Flemish men. Similar to our study, Tracmor-accelerometer output was divided into the same dimensions of daily activity as derived from the questionnaires according to a written activity log completed by each participant. The total activity indices calculated from both the BAQ and the TCQ showed a moderate correlation of .47 and .32 respectively with the total Tracmor counts. Correlations between measures of occupational activities from the TCQ and the Tracmor ranged from .26 to .50 and for the BAQ values of .42 and .33 were found. A correlation of .25 was reported between the active leisure time index from the TCQ and the mean Tracmor counts during active leisure time. Comparison of the different time variables from the TCQ and the written activity log from the Tracmor showed correlations ranging from

.16 for time spent eating to .58 for time spent working. As found in our study, paired *t*-tests revealed a significant underestimation of sedentary behaviour (eating and sleeping) in de TCQ compared to the written activity log from the Tracmor.

Although correlation coefficients between activity variables calculated from the FPACQ and from the RT3 are as high or higher as those found for other self-report physical activity questionnaires in adults, correlations are still predominantly moderate and several factors are reasonable to explain this. First, validity of a physical activity questionnaire is both subject to the quality of the self-report and to limitations imposed by the criterion measure used. In general, mainly due to social desirability bias, respondents tend to overreport physical activity and underreport sedentary behaviour such as watching television (Klesges et al., 1990). In contrast to overestimates of physical activity found with self-reports, accelerometry-measured physical activity tends to underestimate true physical activity due to missed activities (e.g., swimming, arm movements, cycling, locomotion on a gradient,…) (Hendelman, Miller, Baggett, Debold, & Freedson, 2000). Second, energy expenditure of the FPACQ was calculated from the Compendium of Activities (Ainsworth et al., 2000). However, it should be mentioned that these MET-values are merely averages not taking into account differences in intensity or movement efficiency. On the other hand, RT3-energy expenditure was estimated via the prediction equation provided by the manufacturer. This equation is proprietary and has not been validated in free-living conditions in the literature. Third, the FPACQ assessed usual week activity whereas the RT3 measured last week activity. Fourth, no information is available concerning the compliance of the participants with the completion of the written seven-day activity record and the maintenance of the usual activity pattern. Fifth, investigator's error associated with scoring the written seven-day activity records may also have contributed to the moderate associations found between the RT3 and the FPACQ. A possible solution to this problem could be the development of an accelerometer equipped with a palm top interface enabling participants to add detailed activity information directly into the activity record of the accelerometer (Healy, 2000).

Similar to results found for reliability, validity of the FPACQ is also lower in retired people compared to employed/unemployed people. Three reasons should be added to those already mentioned for reliability. First, motion sensors have been shown to be less accurate in older people characterized by slow walking, shuffling or gait abnormalities (Cyarto, Myers, & Tudor-Locke, 2004; Rikli, 2000). Next, the Compendium of Activities used to determine the MET-values of activities reported in the FPACQ has been developed based on normal activity patterns of young adults, but may be less accurate for use with older adults (Ainsworth et al., 2000). Finally, older adults may have difficulties following the rather tedious procedures of the validity study due to their inability to understand the directions or their lack of motivation (Rikli, 2000).

The present study has several advantages compared to other studies. In contrast to most physical activity questionnaires only focussing on leisure activities and sports participation, the FPACQ also assessed activities in other domains such as household and garden activities, occupation, transportation, watching TV or video and playing computer games,…. In addition, two different versions of the FPACQ were developed specifically adapted to the different structure in the lifestyle of employed/unemployed and retired people. Further, since systematic differences between instruments do not affect the correlation coefficients but may substantially affect agreement, in this study both relative and absolute validity was investigated. Finally, by combining the RT3 with a written seven-day activity record, the output could be divided in the same dimensions as derived from the FPACQ. This made it possible to investigate validity in a more comprehensive way compared to most studies only using broad sub-categories of light, moderate and high intensity activity based on predetermined accelerometer cut-points. A limitation of this study is the fact that participants were volunteers already participating in a large scale epidemiological study on physical activity, physical fitness and health. Their possibly greater knowledge of and familiarity with physical activity might have somewhat influenced the reliability and validity of the FPACQ.

From this study it can be concluded that the FPACQ is a reliable and reasonably valid questionnaire for the assessment of different dimensions of physical activity and sedentary behaviour.

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Appendix. Description of the activity variables calculated from the FPACQ

Acronym	Questions and response sets or other variables used for calculation	Calculation	Unit
Tsport	- How frequently do you perform your most important, second most important, third most important sport? ↳ *response: from 1 week/year to > 7 x/week* - How much time do you spend on your most important, second most important, third most important sport? ↳ *response: from < 7h in that 1 week to > 20 h/week*	1) Conversion of the reported duration of the most important, second most important, third most important sport into average h/week over one year 2) h/week most important sport + h/week second most important sport + h/week third most important sport	h/week
EEsport	- Average h/week over one year spent on most important, second most important, third most important sport (see questions described for Tsport) - What is your most important, second most important, third most important sport? ↳ *response: list of 196 sports* - What is your body weight? ↳ *response: from 20 kg to 150 kg*	[(average h/week most important sport x MET-value most important sport) + (average h/week second most important sport x MET-value second most important sport) + (average h/week third most important sport x MET-value third most important sport)] x reported body weight	kcal/week
Isport	- EEsport - Tsport	EEsport / Tsport	kcal/h
Teat	- How many minutes a day do you usually spend eating your daily meals? ↳ *response: from 0-10 min/day to > 120 min/day*	Conversion of the reported min/day spent eating to h/week spent eating by multiplication by 7 and subsequent division by 60	h/week
Tsleep	- How many hours a night do you usually spend sleeping? ↳ *response: from < 5 h/night to > 12 h/night*	Conversion of the reported h/night spent sleeping to h/week spent sleeping by multiplication by 7	h/week
Ttv	- How many hours do you usually spend watching TV/video or playing computer games on a weekday, a weekend day? ↳ *response: from 0 h/day to ≥ 6 h/day*	1) h/weekday TV x 5 = h/5 weekdays TV 2) h/weekend day TV x 2 = h/2 weekend days TV 3) h/5 weekdays TV + h/2 weekend days TV = h/week TV	h/week
Tatransl	- In leisure time, how many minutes do you usually spend on transportation by bike on a weekday, a weekend day? ↳ response: from 0 min/day to > *60 min/day* - In leisure time, how many minutes do you usually spend on transportation on foot on a weekday, a weekend day? ↳ *response: from 0 min/day to > 60 min/day*	1) min/weekday bike x 5 = min/5 weekdays bike 2) min/weekend day x 2 = min/2 weekend days bike 3) min/weekday foot x 5 = min/5 weekdays foot 4) min/weekend day foot x 2 = min/2 weekend days foot 5) min/5 weekdays bike + min/2 weekend days bike + min/5 weekdays foot + min/2 weekend days foot = Tatransl in min/week 6) Tatransl in min/week / 60 = Tatransl in h/week	h/week

Appendix. (Cont.)

Acronym	Questions and response sets or other variables used for calculation	Calculations	Units
Tactl	- How many hours a week do you usually spend doing home or garden activities of light intensity (e.g., cooking, ironing, watering flowers,…) ↳ *response: from 0 h/week to > 14 h/week* - How many hours a week do you usually spend doing home or garden activities of moderate intensity (e.g., vacuuming, mowing lawn,…) ↳ *response: from 0 h/week to > 14 h/week* - How many hours a week do you usually spend doing home and garden activities of vigorous intensity (e.g., scrubbing, digging,…) ↳ *response: from 0 h/week to > 14 h/week* - Tsport - Tatransl	h/week light home and garden activities + h/week moderate home and garden activities + h/week vigorous home and garden activities + Tsport + Tatransl	h/week
EEactl	- h/week spent doing home and garden activities of light, moderate and vigorous intensity (see questions described for Tactl) - EEsport - Tatransl - Reported body weight (see question described for EEsport)	[(h/week light home and garden activities x 2.5 METs) + (h/week moderate home and garden activities x 3.5 METs) + (h/week vigorous home and garden activities x 4.5 METs) + EEsport + (Tatransl x 4 METs)] x reported body weight	kcal/week
Iactl	- Tactl - EEactl	EEactl / Tactl	kcal/h
Tocc†	- How many hours a week do you usually spend doing your main occupation, additional occupation? ↳ *response: from 0-5 h/week to > 60 h/week* - How many minutes a day do you usually spend on transportation to and from your main occupation, additional occupation by bike ? ↳ *response: from 0 min/day to > 60 min/day* - How many minutes a day do you usually spend on transportation to and from your main occupation, additional occupation on foot? ↳ *response: from 0 min/day to > 30 min/day* - How many minutes a day do you usually spend on transportation to and from your main occupation, additional occupation by car, train, tramcar, bus or motorcycle? ↳ *response: from 0 min/day to > 120 min/day*	1) Conversion of the transportation to and from the main occupation, additional occupation to h/week by multiplication by 5 and subsequent division by 60 2) h/week main occupation + h/week additional occupation + h/week transportation to and from main occupation by bike, foot, car, train, tramcar, bus, motorcycle + h/week transportation to and from additional occupation by bike, foot, car, train, tramcar, bus, motorcycle	h/week

Appendix. (Cont.)

Acronyms	Questions and response sets or other variables used for calculation	Calculations	Units
EEocc[†]	- During a usual week at your main occupation, additional occupation, what percentage of the time do you spend doing light activities (e.g., sitting, standing without lifting or carrying weights, walking short distances,…)? ↳ response: from 0% to 100% - During a usual week at your main occupation, additional occupation, what percentage of the time do you spend doing moderate activities (e.g., lifting or carrying light weights, walking continuously,…)? ↳ response: from 0% to 100% - During a usual week at your main occupation, additional occupation, what percentage of the time do you spend doing vigorous activities (e.g., lifting or carrying moderate to heavy weights, construction worker,…) ↳ response: from 0% to 100% (The sum of light, moderate and vigorous activities has to equal 100%) - h/week spent on the main and additional occupation derived from the questions described for Tocc - h/week spent on transportation to and from main and additional occupation by bike, on foot, by car, train, tramcar, bus, motorcycle (see questions described for Tocc) - Reported body weight (see question described for EEsport)	[(h/week main occupation x % light activities x 2 METs) + (h/week main occupation x % moderate activities x 3 METs) + (h/week main occupation x % vigorous activities x 4 METs) + (h/week transportation to and from main occupation by bike x 4 METs) + (h/week transportation to and from main occupation on foot x 4 METs) + (h/week transportation to and from main occupation by car, train, tramcar, bus, motorcycle x 1.5 METs) + (h/week additional occupation x % light activities x 2 METs) + (h/week additonal occupation x % moderate activities x 3 METs) + (h/week additional occupation x % vigorous activities x 4 METs) + (h/week transportation to and from additional occupation by bike x 4 METs) + (h/week transportation to and from additonal occupation on foot x 4 METs) + (h/week transportation to and from addional occupation by car, train, tramcar, bus motorcycle x 1.5 METs)] x reported body weight	kcal/week
Iocc[†]	- EEocc - Tocc	EEocc / Tocc	kcal/h
EEtotal[†]	- Teat - Tsleep - Tocc - Tactl - EEocc - EEactl - reported body weight (see question described for EEsport)	1) 7 days x 24 h = 168 hours in 1 week 2) h/week remaining quiet leisure time = 168 - Tactl - Tocc - Teat - Tsleep 3) EEtotal = EEactl + EEocc + (Teat x 1.8 METs x reported body weight) + (Tsleep x 0.9 METs x reported body weight) + (h/week remaining quiet leisure time x 1.5 METs x reported body weight)	kcal/week
PAL	- EEtotal - reported body weight (question described for EEsport)	1) 7 days x 24h = 168 hours in 1 week 2) PAL = EEtotal / (168 x reported body weight)	MET

All MET-values used for the calculation of the activity variables on energy expenditure were determined using the Compendium of Ainsworth et al. (2000)

[†] Tocc, EEocc and Iocc only available for employed/unemployed people

PART 2. Longitudinal epidemiological studies

Chapter 1. Secular trends in anthropometric characteristics, physical fitness, physical activity, and biological maturation in Flemish adolescents between 1969 and 2005

American Journal of Human Biology, accepted for publication

Chapter 2. Tracking of physical fitness and physical activity from youth to adulthood in females

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CHAPTER 1

Secular trends in anthropometric characteristics, physical fitness, physical activity, and biological maturation in Flemish adolescents between 1969 and 2005

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Abstract

In this study, secular trends in anthropometric characteristics, physical fitness, physical activity and biological maturity over the past 25 to 35 years in Flemish adolescents were investigated. Representative cross-sectional samples of 12-18-year-old secondary school children (11899 assessments in boys in 1969-1974, 4899 girls in 1979-1980, 1429 boys and 1772 girls in 2005) and parent-offspring pairs tested at approximately the same age during adolescence (55 father-son pairs, mean age fathers = 15.47 years, mean age sons = 15.38 years; 62 mother-daughter pairs, mean age mothers = 16.63 years, mean age daughters = 15.01 years) were used. The cross-sectional data were analysed in six yearly age-categories using Wilcoxon rank sum tests. For the parent-offspring data paired t-tests, simple linear regressions to adjust for parent-offspring differences in chronological age and multiple linear regressions to adjust for parent-offspring differences in chronological and skeletal age were conducted. The cross-sectional study generally revealed an increase in weight, stature, BMI, skinfolds and trunk-extremity index and a decrease in the performance on several physical fitness tests. In the parent-offspring study, only sons were maturationally advanced compared to fathers. Even after adjustment for parent-offspring differences in chronological age and in chronological and skeletal age, results for stature, trunk-extremity index and physical fitness were generally similar to the cross-sectional study. No secular trend was observed for sports participation. The fact that the positive secular trends in weight, BMI and skinfolds of the cross-sectional study were not entirely confirmed in the parent-offspring study is probably due to higher similarity in genetic and familial background, higher socio-economic status and more health-consciousness of the latter.

Key words

secular trend, anthropometric characteristics, physical fitness, physical activity, skeletal maturation

Introduction

Numerous health benefits of physical fitness and physical activity in adults have been extensively documented (Kesaniemi et al., 2001). So far, the links between physical fitness and physical activity on the one hand and health on the other hand are yet to be further confirmed in children and adolescents. However, growing evidence identifies at least modest positive effects. Moreover, it is often assumed that physical fitness and physical activity during childhood and adolescence have a positive influence on adult health and that they track from childhood over adolescence into adulthood (Biddle et al., 2004; Boreham and Riddoch, 2001, Strong et al., 2005). Consequently, to be able to develop appropriate health strategies it is important to regularly monitor secular trends in physical fitness and physical activity of children and adolescents.

Secular trend research has historically focused on weight, height and sexual maturity, particularly age at menarche. In developed countries, children and adolescents today are heavier and taller than several decades ago. This reflects in part the secular trend towards earlier maturation. However, evidence is accumulating that the secular trends in stature and maturation are slowing or have ceased in a number of populations (Malina, 1978, 2004; Malina et al., 2004; Roche, 1979). In contrast, weight and fatness generally continue to increase resulting in positive secular trends in overweight and obesity (Craig et al., 1994; Duvigneaud et al., 2006; Freedman et al., 1997; Hulens et al., 2001; Kautianen et al., 2002; Malina, 1978, 2004; Malina et al., 2004; Moreno et al., 2000; Porkka et al., 1997; Thompson et al., 2002; Tremblay and Willms, 2000). Secular change data for physical fitness and physical activity are relatively scarce and the time span across which comparisons can be made is generally not as extensive. The literature has shown variable results regarding temporal changes in physical fitness of children and adolescents (Craig et al., 1994; Dawson et al., 2001; Duvigneaud et al., 2006; Malina, 1978, 2004; Malina et al., 2004; Nishijima et al., 2003; Westerstahl et al., 2003a). Moreover, physical fitness is, in part, related to biological maturity and body size (Beunen et al., 1981, 1997; Jones et al., 2000; Malina, 1975; Malina, 1978, 2004; Malina et al., 2004; Roche, 1979). Hence, when investigating the secular trend in physical performance, the possible relationship with secular changes in maturation and size should be taken into account. Concerning physical activity, a positive secular trend is generally reported in children and adolescents for physical activity, particularly sports participation, during leisure-time, whereas for non-leisure-time physical activity a negative secular trend is usually found (Dollman et al., 2005; Eisenmann et al., 2004; Westerstahl et al., 2003b).

Observations of secular changes are most commonly derived from cross-sectional independent population samples. However, the constantly changing demographic composition may hamper valid cross-sectional analyses. Family studies offer another interesting approach. Although they are generally less representative and more small-scaled compared to population-wide cross-sectional studies, they have the advantage of a greater control over time-specific genetic and environmental variation. To our knowledge, only a limited amount of studies have been published in which weight, height or physical ability has been assessed in like-sexed pairs of parents and offspring at approximately the same age during adulthood and no such studies are available during adolescence (Bock and Sykes, 1989; Cratty, 1960; Damon, 1968).

The purpose of this study is to investigate secular trends in anthropometric characteristics, physical fitness, physical activity and biological maturation in Flemish adolescents between 1969 and 2005, using both a cross-sectional and a parent-offspring approach.

Materials and methods

Subjects

Cross-sectional

Data for the first time point in the cross-sectional analysis in males are derived from the Leuven Growth Study of Belgian Boys (LGSBB), 1969-1974. The LGSBB was a mixed cross-sectional and longitudinal study designed to provide information concerning growth, maturity and physical fitness of a large representative sample of Belgian secondary school boys. A total of 21175 assessments were made, the majority of the boys were tested only once but 588 were followed throughout the six years. A more detailed description is given elsewhere (Beunen et al., 1988, Ostyn et al., 1980). For the present study only Flemish-speaking boys between 12 and 18 years were considered (11899 assessments).

Data for the first time point in the cross-sectional analysis in females are derived from the Leuven Growth Study of Flemish Girls (LGSFG), 1979-1980. The purpose of the LGSFG was to study growth, maturity and physical fitness of a representative sample of Flemish primary and secondary school girls (n = 9954). A more detailed description is given elsewhere (Simons et al., 1990). For the present study only girls between 12 and 18 years were considered (n = 4899).

Data for the second time point in the cross-sectional analysis in males and females are from the Eurofit-Barometer 2005, an interuniversity research project to investigate the physical fitness of Flemish youth between 12 and 18 years (Duvigneaud et al., 2006). A multistage proportional cluster sampling procedure was used. In the first stage, a proportionate stratified sample with schools as the primary sampling units was selected. The different strata were operationalized according to the Belgian school system, the geographic distribution of the schools within and over the five Flemish provinces and the gender of the subjects. This resulted in the selection of 21 secondary schools. In the second stage, entire classes were randomly chosen from each grade of the secondary school. A total of 1429 males and 1772 females were tested.

Parent-offspring

The fathers of the present study participated in the LGSBB. In 1986 the LGSBB was extended in what is called the Leuven Longitudinal Study on Lifestyle, Fitness and Health (LLSLFH). Of the 588 boys followed over six years during adolescence, 441 were Flemish speaking and were considered for further follow-up. The males were re-examined in 1986 (30 years, n = 174), 1991 (35 years, n = 176), and 1996 (40 years, n = 166). In 2002-2004, within the scope of the Flemish Policy Research Centre Sport, Physical Activity and Health (SPAH), the longitudinally followed males were tested again (47 years, n = 154) but this time spouses (n = 106) and offspring (111 sons, 78 daughters) older than 10 years were also included. This project within the LLSLFH was called the Flemish Longitudinal Offspring Study (FLOS). For the present analyses only father-son pairs with a chronological age between 12 and 18 years, without missing data on skeletal age and with an adolescent chronological age difference between father and son of less than one year were used (n = 55; mean adolescent chronological age fathers = 15.47 years; mean adolescent chronological age sons = 15.38 years).

The mothers of this study participated in the LGSFG. Within the scope of the Flemish Policy Research Centre SPAH, a subsample of the oldest girls (14-18 years in 1979-1980) was contacted, now 37-43 years. Hundred and thirty eight of them agreed to participate in the FLOS with their spouses (n = 120) and offspring (153 sons, 132 daughters) older than 10 years. Since mothers were only measured once during adolescence, the number of mother-daughter pairs with an adolescent chronological age difference of less than one year was insufficient. Therefore, for the present analyses, all mother-daughter pairs with an adolescent chronological age of the mother between 14 and 18 years, a chronological age of the daughter between 13 and 19 years and without missing data on skeletal age were included (n = 62, mean adolescent chronological age mothers = 16.63 years, mean adolescent chronological age daughters = 15.01 years).

All stages of the study were approved by the medical and ethical committee of the Katholieke Universiteit Leuven. Prior to participation, the purpose and procedures of the study were explained to the adolescents and written informed consent was obtained from the parents.

Anthropometry

Anthropometric dimensions were taken by trained staff with subjects barefoot and in underwear following standardized procedures (Claessens al., 1990). Body weight was measured to the nearest 0.1 kg using a digital scale (Seca 841, Hamburg, Germany) and standing height was measured to the nearest millimeter using a Harpenden portable stadiometer (Holtain, Crymych, UK). Skinfolds were measured to the nearest millimeter using a Harpenden calliper (Holtain, Crymych, UK).

Measures for males from both the cross-sectional and parent-offspring study included weight, height, skinfold triceps, subscapula and suprailiac. In fathers and sons skinfold calf popliteus was additionally measured. Body mass index (BMI) (weight (kg) / height (m)^2) was calculated for males from both the cross-sectional and parent-offspring study. Sum of three skinfolds (triceps + suprailiac + subscapula) and trunk-extremity index based on three skinfolds ((subscapula + suprailiac) / triceps) were calculated for males from the cross-sectional study and sum of four skinfolds (triceps + suprailiac + subscapula + calf popliteus) and trunk-extremity index based on four skinfolds ((subscapula + suprailiac) / (triceps + calf popliteus)) were calculated for fathers and sons.

In females from both the cross-sectional and parent-offspring study weight, height, skinfold biceps, triceps, subscapula, suprailiac and medial calf were measured. BMI, sum of five skinfolds (biceps + triceps + suprailiac + subscapula + medial calf) and trunk-extremity index based on four skinfolds ((subscapula + suprailiac) / (triceps + medial calf)) were calculated.

In-field reliability of the anthropometric dimensions in 1969-1974 and 1979-1980 is reported elsewhere (Lefevre et al., 1990; Van ‘T Hof et al., 1980). In 2002-2004 and 2005, no additional in-field reliability was carried out. However, high quality of measuring techniques was aimed at by careful selection of test instructors, thorough training by experienced anthropometrists and regular supervision.

Physical Fitness

Physical fitness items included both health- and performance-related fitness. In males and females from both the cross-sectional and parent-offspring study upper-body muscular endurance (bent arm hang), flexibility (sit and reach) and running speed (10 x 5 m shuttle run) were assessed. In the parent-offspring study speed of limb movement (plate tapping), explosive strength or power (vertical jump), static strength (arm pull) and lower-body muscular endurance (leg lifts) were also added. Balance (flamingo balance) was only tested in females from both the cross-sectional and parent-offspring study. Tests were taken as described by Claessens et al. (1990).

Methods and procedures were kept as similar as possible during both phases of the study. Test-retest reliability of the physical fitness tests in 1969-1974 and 1979-1980 is reported elsewhere (Lefevre et al., 1990; Van 'T Hof et al., 1980). Again, no additional in-field reliability was carried out in 2002-2004 and 2005.

Physical Activity

Data on sports participation were only collected in parents and offspring. A standardized questionnaire with retrospective approach was used: sports activities during the period of one year before the date of investigation were recalled. Participants were asked to report their sports participation in different contexts (i.e. in a club, in a youth organization, at school, with friends, with family, alone) (Renson and Vanreusel, 1990). The detailed information on the frequency of sports participation was combined into a global average score of sport practice per week over one year. Reliability and validity of the questionnaire was determined in a previous study (Philippaerts et al., 1998).

Skeletal age

During adolescence an X-ray of the left hand and wrist of the fathers, mothers, sons and daughters was taken. Skeletal age was assessed according to the method of Tanner and Whitehouse (TW2) (Tanner et al., 1975). In 1969-1974 and 2002-2004, the assessments were made by the same observer. In 1979-1980, assessments were made by two different well-trained observers. Intra- and inter-observer agreement for the assessments of skeletal age in 1969-1974 and 1979-1980 is reported elsewhere (Beunen, 1970; Beunen and Cameron, 1980; Lefevre et al., 1990). In 2002-2004, intra-observer agreement in the assignment of stages to the individual bones ranged from 87% (metacarpal 1 and 2, distal phalanx 1) over 93% (middle phalanx 5, distal phalanx 5, trapezoid) to 100%. Differences in assigning stages were limited to one stage and no systematic over- or under-ratings were observed.

Menarche

In mothers and daughters during adolescence the occurrence of menarche and the exact age at menarche were determined according to the retrospective method using the same questionnaire (Claessens et al., 1990). Because 14 daughters did not yet reach menarche and six did not remember the exact date, only data on 42 mother-daughter pairs could be included in the present analyses.

Statistical analysis

Cross-sectional

Subjects were divided into six yearly age-categories (12 years = 12.00 to 12.99 years, 13 years = 13.00 to 13.99 years,…). Because Shapiro-Wilk tests for normality revealed that several variables were not normally distributed, Wilcoxon Rank Sum Tests were used to investigate the difference in anthropometric and physical fitness variables between 1969-1974 and 2005 in males and between 1979-1980 and 2005 in females.

Parent-offspring

The parent-offspring differences in adolescent chronological and skeletal age and the secular trend in age at menarche were investigated using paired t-tests.

To study the secular trend in skeletal maturation, the significance of the intercept of the simple linear regression with the parent-offspring difference in adolescent chronological age as the independent variable and the parent-offspring difference in adolescent skeletal age as the dependent variable was calculated. For this analysis, only skeletally immature father-son and mother-daughter pairs (< 18 years in boys, n = 55; < 16 years in girls, n = 26) were included.

The secular trend in anthropometric characteristics, physical fitness and physical activity was analysed in three different ways. First, the secular trend was investigated unadjusted for the parent-offspring difference in adolescent chronological or skeletal age using paired t-tests. Second, the secular trend adjusted for the parent-offspring difference in adolescent chronological age was investigated by calculating the significance of the intercept of the simple linear regression with the parent-offspring difference in adolescent chronological age as the independent variable and the parent-offspring difference in adolescent anthropometric characteristics, physical fitness or physical activity as the dependent variable. To illustrate this, in Figure 1 a visual representation is given of the calculation of the secular trend in body weight. Third, the secular trend was investigated adjusted for both the parent-offspring difference in adolescent chronological and skeletal age by calculating the significance of the intercept of the multiple linear regression with the parent-offspring difference in adolescent chronological and skeletal age as the independent variables and the parent-offspring difference in adolescent anthropometric, physical fitness or physical activity characteristics as the dependent variable. This can only be visually represented in three dimensions by adding a third axis, reflecting the parent-offspring difference in adolescent skeletal age, perpendicular to the two axes already drawn in Figure 1.

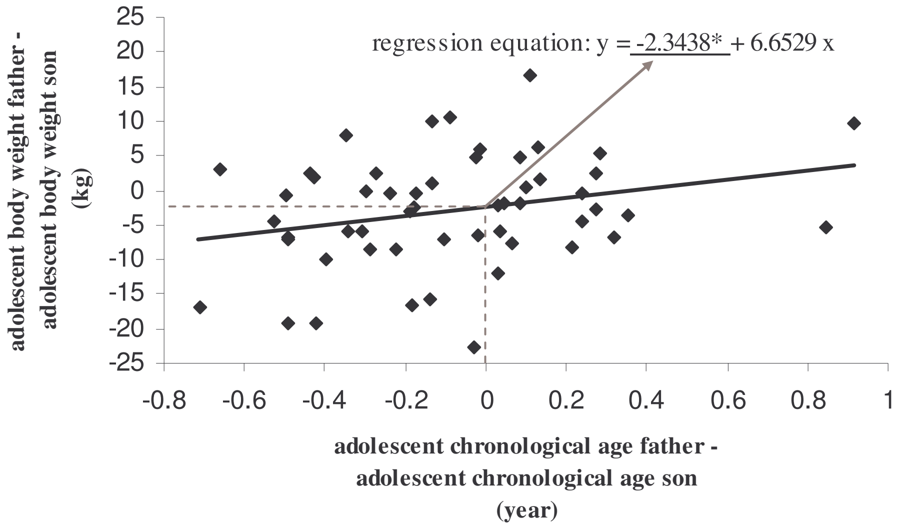

Fig. 1. Visual representation of the calculation of the secular trend in body weight adjusted for the observed difference in adolescent chronological age between fathers (1969-1974) and sons (2002-2004) both tested during adolescence.

All analyses were conducted for males and females separately using the SAS 9.1 statistical package (SAS Institute Inc, Cary, NC). Minimal level of significance was set at $p < 0.05$.

Results

Cross-sectional

Secular trends in anthropometric characteristics and physical fitness for Flemish adolescent males (12-17 years) between 1969-1974 and 2005 are shown in Table 1. In all age categories boys measured in 2005 are significantly heavier and taller compared to 1969-1974 and, except for 13-year-olds, they also have a significantly higher BMI. Except for 13- to 15-year-olds, more recently measured boys have a significantly higher triceps skinfold and except for 15- and 17-year olds also a significantly higher subscapular skinfold and sum of three skinfolds. In 2005 skinfold suprailiac and trunk-extremity index of 17- and 16- to 17-year-old boys respectively is significantly lower compared to 1969-1974, whereas for all other age categories significantly higher values are found. Concerning physical fitness, boys tested in 2005 perform significantly better on the 10 x 5 m shuttle run but they perform significantly worse on sit and reach compared to 1969-1974. A significantly worse performance is also found for bent arm hang in 12- to 14-year-olds.

In Table 2 an overview is given of secular trends in anthropometric and physical fitness variables for Flemish adolescent females (12-17 years) between 1979-1980 and 2005. Girls measured in 2005 are significantly heavier and, except for 16-year-olds, significantly taller than in 1979-1980. Except for 14-year-olds, they also have a significantly higher BMI. In all age categories, more recently measured girls have a significantly higher subscapular skinfold and trunk-extremity index but the other skinfolds and sum of five skinfolds are only significantly higher for the three oldest age categories. Concerning physical fitness, girls tested in 2005 perform significantly worse on bent arm hang, flamingo balance and 10 x 5 m shuttle run. For sit and reach this is only the case for 14-year-olds.

Parent-offspring

Sons were measured at a significantly higher adolescent chronological (15.47 years versus 15.38 years) and skeletal (15.69 years versus 15.23 years) age than fathers, whereas daughters were measured at a significantly lower adolescent chronological (15.01 years versus 16.63 years) and skeletal (14.38 years versus 15.41 years) age than mothers. After adjustment for the father-son difference in adolescent chronological age, sons are 0.40 year ($p < 0.01$) advanced in skeletal maturation compared to fathers. No significant secular trends in age at menarche and skeletal maturation can be observed between mothers and daughters.

Secular trends in anthropometric characteristics, physical fitness and physical activity for Flemish fathers (1969-1974) and sons (2002-2004) both tested during adolescence are presented in Table 3. Both unadjusted and adjusted for the father-son difference in adolescent chronological age, sons are significantly heavier and taller, have a significantly higher suprailiac skinfold and trunk-extremity index, and a significantly lower skinfold calf popliteus compared to fathers. They also perform significantly worse on sit and reach, plate tapping and arm pull. After additional adjustment for the father-son difference in adolescent skeletal age, sons remain significantly taller and their skinfold calf popliteus and performance on sit and reach, plate tapping and arm pull remain significantly lower compared to fathers. On the other hand, sons no longer have a significantly higher weight, skinfold suprailiac and trunk-extremity index and their BMI becomes significantly lower compared to fathers.

Secular trends in anthropometric characteristics, physical fitness and physical activity for Flemish mothers (1979-1980) and daughters (2002-2004) both tested during adolescence are

TABLE 1. Cross-sectional secular trends in anthropometric and physical fitness variables for Flemish adolescent males (12-17 years) between 1969-1974 and 2005

	12 years		13 years		14 years		15 years		16 years		17 years	
	1969-‘74	2005	1969-‘74	2005	1969-‘74	2005	1969-‘74	2005	1969-‘74	2005	1969-‘74	2005
	n = 1582-1629	n = 160-162	n = 2176-2130	n = 267-268	n = 2172-2142	n = 274-275	n = 2041-2059	n = 294-295	n = 1747-1766	n = 222-229	n = 1420-1453	n = 189-200
	mean (± SD)	mean (± SD)	mean (± SD)	mean (± SD)	mean (± SD)	mean (± SD)	mean (± SD)	mean (± SD)	mean (± SD)	mean (± SD)	mean (± SD)	mean (± SD)
Weight (kg)	40.87	46.78***	45.47	49.38***	51.37	57.02***	56.97	61.10***	61.28	66.74***	64.45	68.46***
	(± 7.69)	(± 10.67)	(± 8.52)	(± 11.07)	(± 9.19)	(± 11.23)	(± 8.89)	(± 10.37)	(± 8.50)	(± 10.87)	(± 8.35)	(± 10.21)
Height (cm)	150.62	156.07***	156.39	160.84***	163.15	168.64***	169.41	173.60***	173.34	176.63***	175.32	178.52***
	(± 7.25)	(± 7.66)	(± 8.17)	(± 9.00)	(± 8.58)	(± 7.95)	(± 7.69)	(± 7.80)	(± 6.80)	(± 6.74)	(± 6.18)	(± 6.79)
BMI (kg/m²)	17.90	19.08***	18.47	18.91	19.18	19.97***	19.77	20.21*	20.35	21.37***	20.93	21.44*
	(± 2.36)	(± 3.48)	(± 2.32)	(± 3.16)	(± 2.29)	(± 3.24)	(± 2.19)	(± 2.84)	(± 2.19)	(± 3.18)	(± 2.22)	(± 2.67)
Skinfold triceps (mm)	9.90	12.20***	9.58	10.77	9.67	10.56	9.14	9.21	7.81	9.89***	7.53	9.37***
	(± 4.48)	(± 6.21)	(± 4.03)	(± 5.80)	(± 4.47)	(± 6.15)	(± 4.15)	(± 4.88)	(± 3.86)	(± 5.66)	(± 3.76)	(± 4.84)
Skinfold subscapula (mm)	6.59	10.23***	6.79	9.02***	7.65	9.36***	7.97	8.80	8.38	10.15***	9.02	9.76
	(± 3.90)	(± 7.28)	(± 3.41)	(± 6.06)	(± 4.08)	(± 6.58)	(± 3.42)	(± 5.34)	(± 3.42)	(± 6.00)	(± 3.25)	(± 4.24)
Skinfold suprailiac (mm)	5.26	10.14***	5.73	9.07***	6.91	9.34***	7.83	8.06*	8.76	9.14***	8.64	8.57***
	(± 3.37)	(± 7.81)	(± 3.57)	(± 7.44)	(± 4.84)	(± 7.63)	(± 4.73)	(± 6.17)	(± 4.80)	(± 7.49)	(± 4.54)	(± 5.74)
Sum 3 skinfolds (mm)[1]	21.72	32.57***	22.09	28.86***	24.12	29.26**	24.90	26.08	24.82	29.12*	25.17	27.70
	(± 11.04)	(± 20.39)	(± 10.16)	(± 18.64)	(± 12.25)	(± 19.74)	(± 11.39)	(± 15.84)	(± 10.84)	(± 18.54)	(± 10.41)	(± 14.02)
Trunk-extremity index[2]	1.22	1.60***	1.33	1.62***	1.54	1.74***	1.79	1.83*	2.34	1.97***	2.52	2.01***
	(± 0.31)	(± 0.46)	(± 0.38)	(± 0.40)	(± 0.46)	(± 0.41)	(± 0.47)	(± 0.42)	(± 0.73)	(± 0.43)	(± 0.75)	(± 0.43)
Bent arm hang (sec)	19.49	13.06***	19.95	16.64***	23.12	20.35**	27.61	26.11	32.38	31.15	33.10	32.64
	(± 14.03)	(± 11.84)	(± 13.69)	(± 13.49)	(± 14.83)	(± 15.15)	(± 15.72)	(± 16.22)	(± 16.89)	(± 17.09)	(± 16.72)	(± 16.37)
Sit and reach (cm)	18.34	15.76***	19.93	16.53***	21.59	17.53***	23.37	18.70***	24.50	20.63***	25.26	22.02***
	(± 5.96)	(± 6.63)	(± 6.14)	(± 7.43)	(± 6.52)	(± 7.54)	(± 6.88)	(± 8.2)	(± 7.10)	(± 9.00)	(± 7.18)	(± 8.38)
10 x 5m shuttle run (sec)	23.01	22.77*	22.69	21.95***	21.94	21.65**	21.58	21.10***	21.41	21.12**	21.16	20.82*
	(± 1.65)	(± 1.81)	(± 1.58)	(± 1.64)	(± 1.55)	(± 1.52)	(± 1.45)	(± 1.50)	(± 1.45)	(± 1.59)	(± 1.55)	(± 1.33)

*: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$
[1] triceps + subscapula + suprailiac
[2] (subscapula + suprailiac) / triceps

TABLE 2. Cross-sectional secular trends in anthropometric and physical fitness variables for Flemish adolescent females (12-17 years) between 1979-1980 and 2005

	12 years		13 years		14 years		15 years		16 years		17 years	
	1979-'80	2005	1979-'80	2005	1979-'80	2005	1979-'80	2005	1979-'80	2005	1979-'80	2005
	n = 657-747	n = 195-197	n = 730-873	n = 341-343	n = 757-854	n = 289-296	n = 587-700	n = 346-351	n = 675-796	n = 304-315	n = 613-721	n = 254-266
	mean (± SD)	mean (± SD)	mean (± SD)	mean (± SD)	mean (± SD)	mean (± SD)	mean (± SD)	mean (± SD)	mean (± SD)	mean (± SD)	mean (± SD)	mean (± SD)
Weight (kg)	43.43	47.39***	48.48	52.95***	52.42	54.87***	54.23	57.81***	55.88	59.27***	57.02	60.74***
	(± 8.54)	(± 9.42)	(± 9.22)	(± 10.90)	(± 8.39)	(± 10.10)	(± 8.68)	(± 9.54)	(± 7.93)	(± 10.30)	(± 7.82)	(± 10.19)
Height (cm)	153.06	156.47***	158.00	160.92***	161.37	163.18***	162.53	164.32***	163.75	164.31	164.22	165.33**
	(± 7.16)	(± 6.70)	(± 6.56)	(± 6.82)	(± 6.40)	(± 7.21)	(± 6.26)	(± 5.88)	(± 6.18)	(± 6.32)	(± 5.85)	(± 6.75)
BMI (kg/m^2)	18.43	19.27***	19.34	20.37***	20.10	20.57	20.51	21.39***	20.83	21.95***	21.13	22.21***
	(± 2.78)	(± 3.16)	(± 3.04)	(± 3.60)	(± 2.78)	(± 3.35)	(± 2.88)	(± 3.31)	(± 2.66)	(± 3.60)	(± 2.65)	(± 3.41)
Skinfold biceps (mm)	7.28	7.25	7.36	7.90	7.53	8.11	7.76	8.58**	7.77	8.99**	7.71	9.42***
	(± 3.22)	(± 3.54)	(± 3.04)	(± 4.51)	(± 2.75)	(± 4.31)	(± 3.09)	(± 3.91)	(± 3.01)	(± 4.77)	(± 2.79)	(± 5.39)
Skinfold triceps (mm)	13.33	13.48	13.98	15.00	15.01	15.35	15.62	17.15***	16.02	17.97***	16.14	18.32***
	(± 4.96)	(± 5.65)	(± 4.96)	(± 6.54)	(± 5.21)	(± 6.05)	(± 5.26)	(± 5.59)	(± 5.06)	(± 6.86)	(± 4.78)	(± 6.94)
Skinfold subscapula (mm)	9.87	11.36***	10.26	12.45***	11.12	13.03***	11.58	14.33***	11.87	15.24***	12.31	15.71***
	(± 5.43)	(± 6.36)	(± 5.17)	(± 6.95)	(± 4.83)	(± 6.61)	(± 5.23)	(± 6.36)	(± 4.85)	(± 7.66)	(± 4.84)	(± 7.54)
Skinfold suprailiac (mm)	10.80	11.52	11.73	12.41	12.39	13.06	12.38	14.56***	12.55	15.31***	12.71	15.49***
	(± 6.45)	(± 6.92)	(± 6.25)	(± 7.74)	(± 5.71)	(± 7.23)	(± 5.92)	(± 7.00)	(± 5.98)	(± 7.74)	(± 6.00)	(± 7.94)
Skinfold medial calf (mm)	14.86	15.51	16.29	17.24	16.81	17.39	17.27	18.66**	17.45	19.19**	17.53	19.62***
	(± 6.54)	(± 6.27)	(± 7.23)	(± 7.75)	(± 6.69)	(± 7.00)	(± 6.72)	(± 6.97)	(± 6.53)	(± 7.87)	(± 6.25)	(± 7.71)
Sum 5 skinfolds (mm)[1]	56.13	59.12	59.64	65.01	62.86	66.81	64.47	73.27***	65.66	76.70***	66.29	78.56***
	(± 24.60)	(± 26.84)	(± 24.21)	(± 31.36)	(± 22.56)	(± 28.49)	(±22.77)	(± 26.35)	(± 21.91)	(± 32.00)	(± 21.13)	(± 32.39)
Trunk-extremity index[2]	0.72	0.77**	0.73	0.76*	0.75	0.78**	0.74	0.81***	0.74	0.82***	0.75	0.82***
	(± 0.18)	(± 0.19)	(± 0.17)	(± 0.18)	(± 0.18)	(± 0.19)	(± 0.18)	(± 0.22)	(± 0.20)	(± 0.20)	(± 0.20)	(± 0.22)
Bent arm hang (sec)	10.31	6.78***	10.52	9.38*	11.37	9.83*	11.65	9.24***	13.90	9.28***	14.65	8.82***
	(± 10.30)	(± 6.26)	(± 9.30)	(± 9.26)	(± 10.85)	(± 9.67)	(± 10.56)	(± 9.77)	(± 12.38)	(± 9.69)	(± 11.77)	(± 9.28)
Sit and reach (cm)	22.16	21.84	23.84	23.62	25.48	24.38*	25.76	26.18	26.71	25.44	26.79	25.87
	(± 6.32)	(± 7.51)	(± 6.45)	(± 8.00)	(± 6.63)	(± 7.41)	(± 7.13)	(± 7.81)	(± 6.91)	(± 8.39)	(± 7.01)	(± 8.32)
Flamingo balance (n/min)	14.44	16.17**	14.27	15.70**	13.94	15.20*	12.83	14.70***	12.41	15.14***	11.93	14.82***
	(± 6.29)	(± 6.03)	(± 5.92)	(± 6.41)	(± 6.34)	(± 6.85)	(± 5.80)	(± 6.44)	(± 5.70)	(± 6.85)	(± 5.78)	(± 6.52)
10x5m shuttle run (sec)	22.31	23.37***	21.94	22.93***	21.85	22.86***	21.74	22.90***	21.66	23.27***	21.51	23.02***
	(± 1.49)	(± 1.80)	(± 1.30)	(± 1.86)	(± 1.40)	(± 1.61)	(± 1.41)	(± 1.56)	(± 1.35)	(± 2.00)	(± 1.34)	(± 1.87)

*: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$

[1] biceps + triceps + subscapula + suprailiac + medial calf

[2] (subscapula + suprailiac) / (triceps + medial calf)

TABLE 3. Parent-offspring secular trends in anthropometric characteristics, physical fitness and physical activity between Flemish fathers (1969-1974) and sons (2002-2004) both tested during adolescence

	Father (1969-1974) n = 50-55		Son (2002-2004) n = 50-55		Unadjusted difference[1]		Adjusted difference[2]		Adjusted difference[3]	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Weight (kg)	55.56	10.48	58.46	11.86	-2.91*	8.10	-2.34*	7.87	-1.04	7.24
Height (cm)	165.79	10.98	171.27	10.77	-5.48***	7.46	-5.49***	7.53	-4.33***	7.02
BMI (kg/m^2)	20.04	2.10	19.70	2.45	0.34	2.20	0.54	2.07	0.74*	2.03
Skinfold triceps (mm)	9.55	5.41	9.67	3.37	-0.12	5.91	0.30	5.74	-0.02	5.74
Skinfold subscapula (mm)	7.76	2.62	7.98	2.26	-0.22	2.63	-0.07	2.59	-0.00	2.61
Skinfold suprailiac (mm)	6.78	3.02	8.81	4.37	-2.03**	4.99	-1.64**	4.79	-1.46	4.81
Skinfold calf popliteus (mm)	8.56	5.56	6.43	2.58	2.12**	5.09	2.39**	5.04	2.23**	5.07
Sum 4 skinfolds (mm)[4]	32.01	12.89	32.76	11.04	-0.75	14.90	0.49	14.20	0.66	14.34
Trunk-extremity index[5]	0.95	0.42	1.06	0.23	-0.12*	0.37	-0.13*	0.37	-0.11	0.37
Bent arm hang (sec)	29.13	15.98	26.39	13.89	2.75	17.73	2.14	17.17	1.21	17.78
Sit and reach (cm)	25.16	6.09	18.64	8.54	6.53***	7.68	6.16***	7.64	5.95***	7.70
10x5m shuttle run (sec)	21.56	1.59	21.54	1.54	0.02	1.93	0.05	1.95	0.08	1.97
Plate tapping (n/ 20 sec)	87.78	11.32	76.73	13.03	5.53***	6.46	5.72***	6.49	5.45***	6.52
Vertical jump (cm)	42.16	8.44	42.56	8.28	-0.40	8.43	-0.13	8.45	-0.18	8.53
Arm pull (kg)	58.25	18.50	50.33	18.49	7.91***	16.27	8.28***	16.37	9.99***	15.96
Leg lifts (n/20 sec)	16.58	2.60	16.33	2.86	0.25	3.38	0.30	3.41	0.06	3.39
Sport participation (h/week)	6.44	4.19	6.46	4.28	-0.02	5.71	-0.05	5.76	-0.08	5.82

*: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$
[1] adolescent value father – adolescent value son
[2] adolescent value father – adolescent value son, adjusted for the father-son difference in adolescent chronological age
[3] adolescent value father – adolescent value son, adjusted for the father-son difference in both adolescent chronological and skeletal age
[4] triceps + subscapula + suprailiac + calf popliteus
[5] (subscapula + suprailiac) / (triceps + medial calf)

shown in Table 4. Unadjusted for the mother-daughter difference in chronological and skeletal age, daughters have a significantly lower weight and BMI and a significantly higher suprailiac skinfold and trunk-extremity index compared to mothers. They also perform significantly worse on bent arm hang, sit and reach, 10 x 5 m shuttle run, plate tapping, vertical jump and arm pull. After adjustment for the mother-daughter difference in adolescent chronological and in both adolescent chronological and skeletal age, suprailiac skinfold and trunk-extremity index remain significantly higher and performance on sit and reach, 10 x 5 m shuttle run and arm pull of the daughters remain significantly lower compared to mothers. On the other hand, the differences in weight, BMI, bent arm hang, plate tapping and vertical jump are no longer significant and daughters become significantly taller and perform significantly worse on leg lifts compared to mothers.

For most variables in males and females from both the cross-sectional and parent-offspring study, standard deviations are larger in 2002-2004 and 2005 compared to 1969-1974 and 1979-1980.

Discussion

The purpose of this study was to investigate secular trends in anthropometric characteristics, physical fitness, physical activity and biological maturation in Flemish adolescents between 1969 and 2005, using both a cross-sectional and a parent-offspring approach.

The cross-sectional analysis revealed that presently measured adolescents are generally taller, heavier and have a higher BMI compared to 25 to 35 years ago. They are also generally fatter, have a more android fat patterning and perform worse on most physical fitness tests. In addition, the increased standard deviation for most variables reflects larger differences between subjects measured in 2005 than in 1969-1974 and 1979-1980.

Differences in methodology might hamper comparison of secular trends across studies. However, the secular trends in anthropometric characteristics found in the present study are generally in agreement with those found in other studies conducted in industrialized countries (Craig et al., 1994; Duvigneaud et al., 2006; Freedman et al., 1997; Hulens et al., 2001; Kautianen et al., 2002; Moreno et al., 2000; Porkka et al., 1997; Tremblay and Willms, 2000). Mean weight, height and BMI of 12- to 18-year-old Finns increased from 1977 to 1999. Depending on gender and age, the average change per 10 years ranged from 1.0 kg to 2.4 kg for weight, from 0.3 cm to 1.4 cm for height, and from 0.3 kg/m^2 to 0.5 kg/m^2 for BMI (Kautianen et al., 2002). Between 1985 and 1995, mean BMI of 13- and 14-year-old Spanish

TABLE 4. Parent-offspring secular trends in anthropometric characteristics, physical fitness and physical activity between Flemish mothers (1979-1980) and daughters (2002-2004) both tested during adolescence

	Mother (1979-1980) n = 59-62		Daughter (2002-2004) n = 59-62		Unadjusted difference[1]		Adjusted difference[2]		Adjusted difference[3]	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Weight (kg)	56.24	6.45	53.29	9.07	2.95*	9.48	-0.68	8.78	-0.73	8.68
Height (cm)	163.86	5.83	163.92	6.16	-0.06	7.57	-3.53***	6.72	-3.52**	6.77
BMI (kg/m^2)	20.94	2.13	19.80	3.13	1.14**	3.15	0.59	3.12	0.57	3.06
Skinfold biceps (mm)	7.28	2.64	7.70	4.25	-0.42	4.05	-0.12	4.07	-0.12	4.09
Skinfold triceps (mm)	15.40	5.10	15.42	5.81	-0.02	6.33	-0.74	6.34	-0.75	6.39
Skinfold subscapula (mm)	11.29	4.27	12.27	7.12	-0.98	6.57	-1.04	6.62	-1.05	6.67
Skinfold suprailiac (mm)	10.96	5.39	13.23	6.51	-2.27*	7.44	-3.45*	7.39	-3.47*	7.33
Skinfold medial calf (mm)	16.82	6.42	15.88	6.57	0.94	6.86	1.11	6.92	1.09	6.96
Sum 5 skinfolds (mm)[4]	61.32	20.34	62.35	24.58	-1.03	24.22	-3.06	24.33	-3.13	24.28
Trunk-extremity index[5]	0.71	0.20	0.80	0.17	-0.09**	0.23	-0.12**	0.23	-0.12**	0.23
Bent arm hang (sec)	14.24	9.64	10.12	10.29	4.12*	13.17	3.29	13.25	3.33	13.31
Sit and reach (cm)	27.48	6.13	22.69	7.95	4.79***	9.68	4.10*	9.73	4.07*	9.77
10x5m shuttle run (sec)	21.04	1.24	22.64	3.30	-1.60***	1.94	-1.52***	1.96	-1.56***	1.88
Flamingo balance (n/min)	11.64	5.62	13.02	6.57	-1.38	7.33	0.20	7.20	0.17	7.19
Plate tapping (n/20 sec)	85.18	9.68	79.17	13.42	3.01**	8.38	-0.11	7.77	-0.10	7.80
Vertical jump (cm)	34.79	5.99	31.92	5.61	2.87**	8.01	1.52	7.95	1.52	8.02
Arm pull (kg)	42.58	8.11	32.09	9.21	10.50***	12.04	8.68***	11.98	8.64***	12.03
Leg lifts (n/20 sec)	16.14	3.04	14.92	3.21	1.22	4.82	2.36**	4.71	2.36**	4.75
Sport participation (h/week)	4.38	2.46	5.31	3.30	-0.93	4.07	-0.19	4.03	-0.18	4.04

*: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$

[1] adolescent value mother – adolescent value daughter

[2] adolescent value mother – adolescent value daughter, adjusted for the mother-daughter difference in adolescent chronological age

[3] adolescent value mother – adolescent value daughter, adjusted for the mother-daughter difference in both adolescent chronological and skeletal age

[4] biceps + triceps + subscapula + suprailiac + medial calf

[5] (subscapula + suprailiac) / (triceps + medial calf)

boys increased by 0.84 kg/m^2 and 0.90 kg/m^2 respectively. In 13- and 14-year-old Spanish girls, increases of 0.43 kg/m^2 and 0.42 kg/m^2 respectively were found (Moreno et al., 2000). BMI of 7- to 13-year-old Canadians increased at a rate of nearly 0.1 kg/m^2 per year between 1981 and 1996 (Tremblay and Willms, 2000). On the other hand, in 12- to 18-year old Flemings no difference was found between mean weight, height and BMI assessed in 1990 and 2005 (Duvigneaud et al., 2006). Examination of the entire BMI distribution revealed that the increase in BMI was primarily caused by a growing number of subjects in the top percentiles, resulting in an increased prevalence of overweight and obesity. (Hulens et al., 2001, Kautianen et al., 2002; Moreno et al., 2000; Tremblay and Willms, 2000). Although adipose tissue is the component of overweight most closely related to health (Prentice and Jeb, 2001), the majority of studies have focused on BMI, reflecting bone and muscle mass as well as adipose tissue. Only a limited amount of studies also investigated secular trends in skinfolds and results are generally comparable to those of the present study (Craig et al., 1994; Duvigneaud et al., 2006; Freedman et al., 1997; Porkka et al., 1997). In the Bogalusa Heart Study (Louisiana), between 1973 and 1994, the mean of triceps and subscapular skinfolds increased by 2.2 mm in 5- to 14-year-olds and by 2.8 mm in 15- to 17-year-olds (Freedman et al., 1997). Between 1980 and 1992, no clear trends in biceps skinfold could be found in 15- and 18-year-old Finns, but subscapular and triceps skinfolds tended to become slightly thicker, especially during 1986-1992 and in the group aged 18 years (Porkka et al., 1997). In 10- to 19-year-old Canadians, the sum of five skinfolds increased significantly between 1981 and 1988 (Craig et al., 1994). This was also the case for the sum of five skinfolds in Flemish 12- to 18-year old males, but not in females, between 1990 and 2005 (Duvigneaud et al., 2006).

Studies investigating secular trends in different components of physical fitness are scarce, have generally shorter time spans, and results are generally more variable. In 2000, 10- to 14-year-old New-Zealand boys were 0.23 seconds and girls 0.43 seconds slower in the shuttle run compared 1991. On the other hand, both sexes were able to complete eight more curl-ups and boys improved their sit and reach scores by 3.6 cm (Dawson et al., 2001). Between 1981 and 1988, trunk flexibility and muscular strength of 10- to 19-year-old Canadians remained at the same level, whereas a decrease in muscular endurance was reported (Craig et al., 1994). The overall physical fitness test score and the overall motor ability test score of Japanese youth aged 12 to 17 years increased from 1964 to 1980, remained stable from 1980 to 1985 and decreased from 1985 to 1997 (Nishijima et al., 2003). In Flemish 12- to 18-year old boys and girls tested in 1990 and 2005, a decrease was observed in the performance on sit and reach, vertical jump, handgrip, sit-ups and 10 x 5 m shuttle run, an increase was reported in the performance on plate tapping and no change was found for flamingo balance. Performance on bent arm hang decreased in males and remained the same in females, whereas performance on the endurance shuttle run increased in females and did not change in males (Duvigneaud et al., 2006).

Similar to the cross-sectional analysis, the parent-offspring analysis also revealed positive secular trends for height and trunk-extremity index and negative secular trends for the performance on several physical fitness tests. In contrast, no clear positive secular trend for weight, BMI, most skinfolds and sports participation is observed.

The limited amount of studies on secular trends in height, weight and physical ability in related subjects were only conducted in adults and consequently do not allow comparison with the present results (Bock and Sykes, 1989; Cratty, 1960; Damon, 1968).

Four potential explanations for the absence of clear positive secular trends in weight, BMI, and most skinfolds in the parent-offspring analysis compared to the cross-sectional analysis can be given. First, parents and offspring are more alike than unrelated subjects because they share half of their genes. Second, although familial environment is not directly shared between the parents measured during adolescence and their offspring measured at present, familial environmental factors probably change less over time compared to macro-environmental factors in the general population. Third, because level of education and employment of the parents is higher compared to the general population and especially the fathers also have a higher socio-professional status, they might be able to provide their offspring with more opportunities to adopt a healthier lifestyle (Lowry et al., 1996). Fourth, since the parents belong to a longitudinal study and they voluntary agreed to take part in the present follow-up with their families, they and their offspring are probably also more health-conscious than the general population.

That sports participation remained unchanged between parents and offspring seems incongruent with the observed decrease in performance on several fitness tests. However, sports participation is only one dimension of physical activity. Other studies have suggested that although sports participation remained stable or even increased, changes in contemporary lifestyle including safety and increased availability of sedentary technologies may nevertheless decrease the overall physical activity level (Dollman et al., 2005; Eisenmann et al., 2004; Westerstahl et al., 2003b).

Changes in anthropometric and physical fitness characteristics between children and adolescents of different generations might, in part, reflect maturity-associated variation

(Beunen et al., 1981, 1997; Jones et al., 2000; Malina, 2004; Malina et al., 2004; Roche, 1979; Thompson et al., 2002). In the present study this was the case in the father-son analysis for weight, skinfold suprailiac and trunk-extremity index where the positive secular trend disappeared and for BMI where a negative secular trend appeared after additional adjustment for the father-son difference in adolescent skeletal age. Apart from biological maturity, secular trends in body dimensions might also contribute to the explanation of secular trends in strength and motor performance. (Beunen et al., 1983; Malina et al., 1975; Westerstahl et al., 2003a). Therefore the secular trend in physical fitness was also investigated after adjustment for body weight and height in both the cross-sectional and parent-offspring study (data not shown). However, apart from a few exceptions in girls (cross-sectional study: flamingo balance / weight 12-14 years, 10 x 5 m shuttle run / weight 14-17 years; 10 x 5 m shuttle run / height 14 years; parent-offspring study: 10 x 5 m shuttle run / weight), the secular trends observed in several fitness items remained significant after expression per unit weight or stature. These results indicate that the trend observed in physical fitness is largely independent of the observed positive secular trends in weight or stature.

Factors underlying secular trends in anthropometric characteristics, physical fitness, physical activity and biological maturation are complex including both behavioural/environmental and genetic changes (Malina, 1978, 2004; Malina et al., 2004, Roche, 1979). Pure genetic changes generally occur over a large time span and are caused by variations in the DNA sequence or by major changes in the ethnicity of populations. In the present study, the rapid changes over approximately one generation suggest that behavioural/environmental causes are largely responsible. However, these changes in behavioural/environmental factors might also induce different effects on the gene-environment interaction.

The current study has several advantages compared to others studies. Both a cross-sectional and parent-offspring approach was used to investigate the secular trends in anthropometric and physical fitness characteristics in males and females over a large time frame of 25 to 35 years. Moreover, both BMI and skinfolds were used as indicators of body composition. In addition, in the parent-offspring study data on physical activity and biological maturity were also available. The latter allowed adjustment of secular trends in anthropometric characteristics, physical fitness and physical activity for a possible secular trend in biological maturation. Some limitations of this study should also be addressed. First, in both the cross-sectional and parent-offspring study, no data were available on aerobic fitness. Second, in the cross-sectional study, no data on physical activity and biological maturity were available. Third, because of the lack of data for other components of physical activity during the first phases of the parent-offspring study, only sports participation could be taken into account. Fourth, no clear comparisons of gender differences in secular trends could be maid because the time frame in the male studies was 5 to 10 years longer than in the female studies. This could possibly also explain the larger or more significant secular trends observed in males. Finally, the higher socio-economic status and possibly higher health-consciousness of the parent-offspring compared to the general population might somewhat hamper the generalizability of these results.

In conclusion, the cross-sectional study generally revealed an increase in weight, stature, BMI, skinfolds and trunk-extremity index and a decrease in the performance on several physical fitness tests. In the parent-offspring study, only sons were maturationally advanced compared to fathers. Even after adjustment for parent-offspring differences in chronological age and in chronological and skeletal age, results for stature, trunk-extremity index and physical fitness were generally similar to the cross-sectional study. No secular trend was observed for sports participation. The fact that the positive secular trends in weight, BMI and skinfolds of the cross-sectional study were not entirely confirmed in the parent-offspring study is probably due to higher similarity in genetic and familial background, higher socio-economic status and more health-consciousness of the latter.

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CHAPTER 2

Tracking of physical fitness and physical activity from youth to adulthood in females

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Abstract

Purpose: To evaluate stability of physical fitness and physical activity from adolescence into middle adulthood in Flemish females. **Methods:** Within the scope of the Leuven Longitudinal Study on Lifestyle, Fitness and Health, 138 females (mean age = 16.6 ± 1.1 years) from the Leuven Growth Study of Flemish Girls were seen in adulthood (mean age = 40.5 ± 1.1 years). Several body dimensions and motor fitness tests were taken. Physical activity was assessed by means of a sports participation inventory. Interage correlations were calculated between adolescent and adult values. Cross-tabulation was used to identify the percentage of subjects remaining in the same BMI and physical activity group or shifting from one group to another from adolescence to adulthood. Odds ratios for less activity and overweight in adulthood according to adolescent activity or weight status were calculated. **Results:** Except for flamingo balance, plate tapping, leg lifts and arm-pull, all anthropometric and physical fitness characteristics were stable from adolescence to adulthood (r ranging from 0.49 to 0.96). Sports participation was not a stable characteristic (r = 0.13). From adolescence to adulthood, 84.5% and 63.6% respectively remained in the normal weight and overweight group, whereas 62.5% and 54.4% respectively remained in the less active and active group. The odds of being overweight in adulthood was 9.53 (95% CI: 3.1-29.8) times greater in overweight compared to normal weight adolescent girls. **Conclusion:** In Flemish females anthropometric and fitness characteristics demonstrate higher levels of stability from adolescence to middle adulthood than physical activity. Weight status during adolescence is indicative of adult weight status and a pattern of less activity rather than activity tends to be continued from youth to adulthood.

Key words

stability, adolescence, middle adulthood, health-related fitness, performance-related fitness, sports participation

Introduction

Substantial evidence supports the hypothesis that physical inactivity and lack of physical fitness increase the risk of morbidity and mortality from a number of chronic diseases. In adults a physically active and fit way of life protects against or retards the development of coronary heart disease, stroke, hypertension, obesity, non-insulin-dependent diabetes mellitus and some cancers. It also appears to reduce depression and anxiety, improve mood and is important for the health of muscles, bones and joints (7).

It is often assumed that physical activity and physical fitness during childhood and adolescence is beneficial for health during adulthood. A conceptual model illustrating possible relationships between physical activity and physical fitness during youth and health during adulthood has been proposed by Blair et al. (4). In this model physical activity and fitness in youth affect adult health in three pathways: a) directly, b) through its effect on youth health (which in turn affects adult health), or c) through its effect on adult physical activity and fitness (which in turn affects adult health).

The number of studies to support these different pathways is relatively small. Only longitudinal research in which physical activity, physical fitness and health are measured repeatedly in the same individual over an extended period of time can provide a definite answer. However, longitudinal studies are relatively scarce. They not only require a large financial effort and much patience, but are also faced with a number of specific problems such as long term commitment of staff and subjects, obsolescence of techniques and confounding effects that inevitably occur in repeated measurements (27).

Although there are indicators of beneficial associations in some areas, relatively little evidence unambiguously relates adolescent physical activity or physical fitness to adolescent or adult health or a more favourable adolescent or adult disease risk profile. It seems more reasonable to assume that adolescent physical activity or physical fitness may have an indirect influence on adult health status by increasing the likelihood of becoming an active adult, which in turn is beneficial for adult health (14).

In epidemiology, the analysis dealing with this phenomenon is called tracking. Tracking refers to 1) the stability of relative rank or position within a group over time or 2) the predictability of a measurement early in life for the value of the same variables later in life (15-17).

The available data are generally consistent in showing moderate tracking of physical activity during childhood and adolescence and more variable but lower levels of tracking across longer intervals within adolescence, from adolescence into young adulthood and across various ages in adulthood. Longitudinal data for measures of performance- and health-related physical fitness through childhood and adolescence, and into adulthood are limited but generally show higher interage correlations and thus somewhat better tracking than for indicators of physical activity (15-17).

Most studies concerning tracking of physical activity and physical fitness from childhood and adolescence into adulthood largely focus on young adulthood, the 20s and early 30s. Tracking of physical activity and physical fitness from adolescence to older ages in adulthood is less studied and generally suggests weak associations. Moreover, data are more available for males than for females (15-17).

The purpose of the present study is to investigate the tracking of physical fitness and physical activity from adolescence (14-18 years of age) into middle adulthood (37-43 years of age) in Flemish females.

Materials and methods

Subjects

This study is a follow-up of a subsample from the Leuven Growth Study of Flemish Girls, a cross-sectional multidisciplinary survey designed to provide information on the growth status and physical fitness of Flemish school girls. In 1979-1980, a large representative sample of elementary and high school girls from 88 schools was tested. Observations for each girl included a physical fitness test battery, anthropometric dimensions, somatotype, skeletal maturity, age at menarche, sports practice, and sociocultural characteristics of the family. A detailed description of the design of the study, the sampling and measurement procedures and reference data is given elsewhere (22).

Within the scope of the Leuven Longitudinal Study on Lifestyle, Fitness and Health, conducted by the Policy Research Centre Sport, Physical Activity and Health, a subsample of the oldest girls (14-18 years in 1979-1980) was contacted in 2003-2004, now 37-43 years of age. A sample of 138 women agreed to participate in the follow-up study (response rate: 32.9%).

The study was approved by the medical and ethical committee of the Katholieke Universiteit Leuven. Prior to participation, the purpose and procedures of the study were explained and subjects gave their written informed consent. During adolescence parental consent was given in addition.

To assess the representativeness of the study sample, adolescent age, anthropometric, physical fitness and physical activity values of women participating in the follow-up were compared to those of non-participants during adolescence. Since the majority of the variables was not normally distributed, the non-parametric Wilcoxon rank-sum test was used. Results are shown in Table 1. Participants were significantly older ($p < 0.01$) in adolescence than non-participants. This could be due to the fact that, since the tracking study was part of a larger study also investigating familial resemblance in physical fitness and physical activity, only women with at least two children older than 10 years of age were included in the study to have sufficient familial correlations and because children ≤ 10 years of age are generally unable to correctly perform the different tests. Participants had a significantly lower skinfold suprailiac ($p < 0.05$) and trunk-extremity skinfold index ($p < 0.01$) and needed significantly less time for the shuttle run ($p < 0.01$) compared to non-participants. Although statistically significant, the mean differences in age (3 months), skinfold suprailiac (1.1 mm), trunk-extremity index (0.5) and shuttle run (0.36 sec), are very small and can be considered irrelevant. For the other variables, no significant differences were found between the groups. Hence, for the variables assessed in this study, the adolescent values of the subsample of 138 women participating in the follow-up study, were reasonably representative for the total sample of 14 to 18 year old girls tested in 1979-1980.

TABLE 1. Comparison of adolescent age, anthropometric, physical fitness and physical activity values between participants (follow-up) and non-participants (non follow-up) in adulthood.

	Follow-up (n = 118-138)		Non Follow-up (n = 2247-2803)		
Variables	Mean	SD	Mean	SD	p-value
Age (years)	16.6	1.1	16.3	1.1	0.007
Height (cm)	164.1	5.7	163.3	6.3	0.179
Weight (kg)	55.6	6.6	55.4	8.3	0.131
BMI (kg/m^2)	20.7	2.3	20.7	2.7	0.812
Skinfold biceps (mm)	7.4	2.8	7.7	2.9	0.164
Skinfold triceps (mm)	15.6	5.0	15.8	5.0	0.808
Skinfold subscapular (mm)	11.4	4.5	11.8	4.9	0.488
Skinfold suprailiac (mm)	11.4	5.2	12.5	5.9	0.017
Skinfold medial calf (mm)	17.6	6.1	17.3	6.4	0.281
Sum 4 skinfolds (mm)	45.9	15.3	47.8	16.6	0.251
Trunk-Extremity Index	0.7	0.2	0.8	0.2	0.002
Sit-and-reach (cm)	26.1	6.9	26.4	7.0	0.748
Flamingo balance (n)	12.0	5.2	12.6	5.9	0.339
Plate tapping (n)	41.5	4.9	41.0	4.7	0.256
Arm-pull (kg)	42.4	8.3	42.2	8.7	0.818
Leg lifts (n)	15.8	3.2	16.0	3.6	0.349
Vertical jump (cm)	34.3	6.7	33.6	5.9	0.364
Bent-arm-hang (sec)	14.1	10.9	13.1	11.6	0.090
Shuttle run 50 m (sec)	21.3	1.3	21.7	1.4	0.003
Sports participation (h/week)	4.3	3.0	4.2	3.3	0.496

Anthropometry

All anthropometric dimensions were taken by trained staff; subjects were barefoot and in underwear (8). Standing height was measured to the nearest millimeter using a Holtain stadiometer and body weight was measured to the nearest 0.1 kg using an electronic scale (Seca 841). BMI was calculated as body mass (kg) devided by squared height (m^2). Skinfold thicknesses of biceps, triceps, subscapula, suprailiac and medial calf were measured to the nearest millimeter using a Harpenden calliper.

The sum of four skinfolds (biceps + triceps + suprailiac + supscapula) and the trunk-extremity skinfold index ((scapula + suprailiac) / (triceps + medial calf)) were calculated.

In-field reliability of the anthropometric dimensions in adolescence was evaluated by re-examining about 3% of the subjects. The coefficients of variation, as an expression of the magnitude of the measurement error in function of the mean were small. For body weight and height the coefficients were < 1%. For skinfolds the coefficients varied between 5% and 10% (13). In adulthood the study design did not allow re-examining a subset of participants to check in-field reliability. However, high quality of measuring techniques during adulthood was aimed at by careful selection of test instructors (M.Sc. in Physical Education or Physiotherapy), thorough training by experienced kinanthropometrists (staff members of the Leuven Growth Study of Flemish Girls in 1979-1980) and regular supervision throughout the entire testing period.

Physical Fitness

Physical fitness items included both health- and performance-related fitness components. Performance-related fitness items were balance (flamingo balance), static strength (arm-pull), explosive strength or power (vertical jump), running speed (50 meter shuttle run) and speed of limb movement (plate tapping). Health-related fitness items were flexibility (sit-and-reach), upper-body muscular endurance (bent-arm-hang) and lower-body muscular endurance (leg lifts). All tests were taken as described by Claessens et al. (8). Methods and procedures were kept as similar as possible during both phases of the study. Test-retest reliability of the fitness tests in adolescence ranged from r = 0.61 to r = 0.94 (13). The same explanation given for the absence of a reliability check on the anthropometric dimensions also applies to the physical fitness tests.

Physical Activity

Data on sports participation were collected by a standardized questionnaire during adolescence via a retrospective approach: sports activities during the period of one year before the date of investigation were recalled. Participants were asked to report compulsory physical activity at school as well as sports participation during leisure time. The questionnaire was completed by the girls' parents and cross-checked during an interview with each girl (20). The detailed information on the frequency of sports participation was combined into a global average score of sport practice per week over one year. Reliability and validity of the questionnaire was determined in a previous study (18).

Sports participation of the women was assessed in a different way. In adulthood, subjects were asked to select their three most important sports out of a list of 196 different sports in a computerized questionnaire. For each of these three sports, they were were asked to report frequency (from one week per year to more than seven times per week) and duration (from less than one hour per week to more than 20 hours per week). The reported frequency and time of sports participation, were combined into a global average score per week.

Statistical analysis

Descriptive statistics (means and standard deviations) were calculated for all anthropometric, physical fitness and physical activity characteristics during adolescence and adulthood. Because the majority of the variables were not normally distributed, non-parametric statistics were applied. Wilcoxon signed rank tests were used to evaluate differences between adolescence and adulthood.

Tracking of anthropometric characteristics, physical fitness and physical activity was assessed with Spearman's rank order correlations between measurements in adolescence and adulthood.

Tracking of BMI and sports participation was further explored using relative distribution. Subjects were divided into different BMI and physical activity groups (see below) and by means of cross-tabulation, the percentage of subjects remaining in the same group or shifting from one group to another from adolescence to adulthood was calculated. Subjects were divided into a normal weight and an overweight group on the basis of the BMI. When applying the age and sex specific cut-off points for overweight in children and adolescents as described by Cole at al. (9), only 7.4% of the entire sample of 14 to 18 year old girls and only 5.8% of the subsample of 138 girls was categorized as overweight in comparison to about 12% (percentile 88) in the study of Cole et al. (9). For this reason it was decided that these cut-points could not be used in the follow-up study. Instead, for the entire sample of 14 to 18 year old girls divided into half year ages, the BMI at percentile 80 was calculated and these cut-off values were used to place the 138 girls into the normal weight or overweight group as adolescents. For adults, the widely accepted cut-off point of 25 kg/m^2 for overweight was used. Depending on their reported hours of sports participation, subjects were divided into less active and active groups. In 1979-1980, the compulsory school physical education program in Belgium varied between one and three periods of 50 minutes per week depending on the school type. Adolescents reporting less than three hours of sports per week were considered less active, meaning that they did not do any or only sporadically participated in sports during leisure time in addition to the compulsory physical education program at school. Girls reporting three or more hours of sports participation per week were considered as active during leisure time. In adulthood, women reporting less than 1.5 hours of sports per week in leisure time were considered less active and those participating in 1.5 hours or more per week were labelled active.

Odds ratios for less activity and overweight in adulthood according to adolescent activity or weight status were calculated.

For all statistical analyses the SAS 9.1 package was used (2).

Results

Descriptive statistics, differences and interage correlations between adolescence and adulthood for anthropometric, physical fitness and physical activity variables are shown in Table 2. All anthropometric variables and indices increased on average significantly from adolescence to adulthood. Except for flamingo balance, mean performances on all motor tests decreased significantly. Sports participation also decreased. Sports participation ($r = 0.13$, NS) and arm-pull strength ($r = 0.20$, $p < 0.05$) both showed a low correlation between adolescence and adulthood, whereas correlations for height ($r = 0.96$) and sit-and-reach ($r = 0.76$) were high and significant ($p < 0.001$). For all other variables, correlations were significant ($p < 0.001$) and moderate ranging from 0.34 to 0.56. It is remarkable that correlations for weight, BMI, all skinfolds and the trunk-extremity skinfold index were virtually identical.

The percentage of subjects remaining in the same BMI group or shifting from one BMI group to another from adolescence to adulthood is shown in Figure 1. In adolescence, 84.1% of the girls had a normal weight and 15.9% were overweight. Of the normal weight girls in adolescence, 84.5% remained normal weight in adulthood and only 15.5% became overweight. In contrast, 63.6% of overweight adolescent girls remained overweight and 36.4% became normal weight.

Active and less active adolescents are compared with regard to level of sports participation in adulthood in Figure 2. During adolescence, 58.5% of the girls was active and 41.5% was less active. Of the active adolescent girls, 54.4% remained active and 45.6% became less active in adulthood. Of the less active adolescent girls, 62.5% remained less active and only 37.5% became active in adulthood.

TABLE 2. Descriptive statistics (means and standard deviations), change and interage correlations (r) between adolescence and adulthood for anthropometric, physical fitness and physical activity variables.

	Adolescence (14.5-18.5 years)		Adulthood (37.7-43.6 years)			
Variables	Mean	SD	Mean	SD	Change†	r
Height (cm)	164.1	5.7	165.9	5.8	1.8***	0.96***
Weight (kg)	55.6	6.6	65.2	10.4	9.6***	0.56***
BMI (kg/m^2)	20.7	2.3	23.7	3.9	3.1***	0.53***
Skinfold biceps (mm)	7.4	2.8	11.3	6.8	3.9***	0.50***
Skinfold triceps (mm)	15.6	5.0	22.2	7.8	6.6***	0.55***
Skinfold subscapular (mm)	11.4	4.5	19.3	9.0	7.8***	0.50***
Skinfold suprailiac (mm)	11.4	5.2	19.6	10.1	8.2***	0.50***
Skinfold medial calf (mm)	17.6	6.1	20.3	8.2	2.7***	0.56***
Sum 4 skinfolds (mm)	45.9	15.3	72.5	30.0	26.5***	0.53***
Trunk-extremity index	0.7	0.2	0.9	0.3	0.2***	0.53***
Sit-and-reach (cm)	26.1	6.9	22.3	9.6	-3.8***	0.76***
Flamingo balance (n)	12.0	5.2	12.2	6.5	0.2	0.39***
Plate tapping (n)	41.5	4.9	42.7	6.9	1.3*	0.34***
Arm-pull (kg)	42.4	8.3	36.8	8.3	-5.5***	0.20*
Leg lifts (n)	15.8	3.2	14.5	3.7	-1.4***	0.34***
Vertical jump (cm)	34.3	6.7	28.6	5.8	-5.6***	0.59***
Bent-arm-hang (sec)	14.1	10.9	4.3	6.5	-9.6***	0.56***
Shuttle run 50 m (sec)	21.3	1.3	23.8	2.0	2.5***	0.49***
Sports participation (h/week)	4.3	3.0	1.8	2.1	-2.5***	0.13

*: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$

† Change = adulthood – adolescence

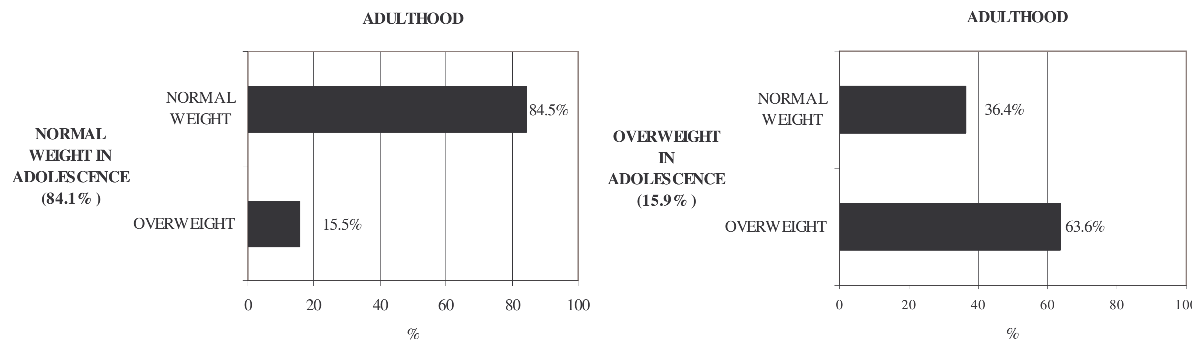

FIGURE 1. Shift in normal weight and overweight category from adolescence to adulthood in Flemish females.
Overweight is defined as a BMI ≥ percentile 80 in adolescence and ≥ 25 kg/m^2 in adulthood.

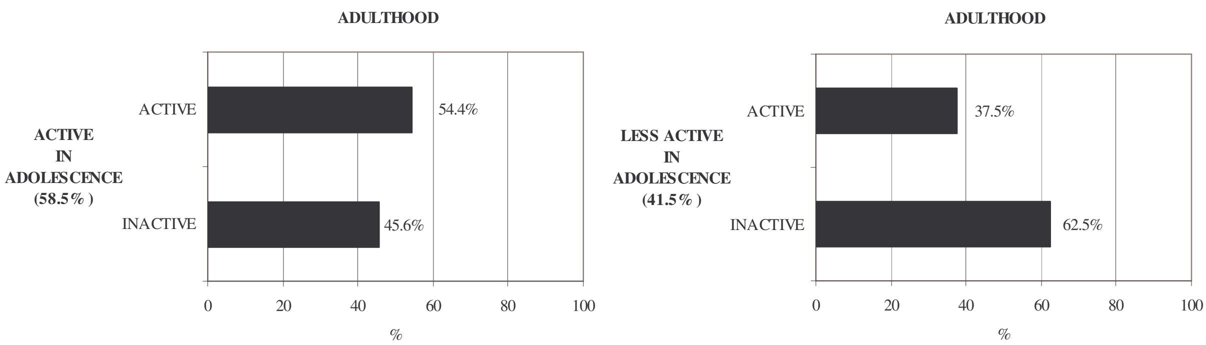

FIGURE 2. Shift in active and less active categories from adolescence to adulthood in Flemish females.
Less active is defined as sports participation < 3 hours/week in adolescence and < 1.5 hours/week in adulthood.

Odds ratios and 95% CI for less activity or overweight in adulthood according to adolescent activity or weight status are presented in Table 3. The odds of being overweight in adulthood are 9.53 times greater in overweight compared to normal weight adolescents. The odds ratios for overweight in adulthood according to adolescent activity status and for less activity in adulthood according to adolescent activity or weight status vary between 1.34 and 2.18, but are not significant. The confidence interval for the odds ratio of the overweight-overweight pairing is much wider than that of the other pairings. This could be attributed to the higher odds ratio itself and to the fact that only 22 (= 15.9%) girls were overweight in adolescence compared to 116 (= 84.1%) girls in the normal weight group (see Figure 1).

TABLE 3. Odds ratio's (OR) and 95% confidence intervals (CI) for less activity or overweight in adulthood according to adolescent activity or weight status.

	Adulthood			
	Less active†		Overweight‡	
Adolescence	OR	95% CI	OR	95% CI
Less active†	2.0	0.9 – 4.3	1.3	0.6 – 3.2
Overweight‡	2.9	0.8 – 6.8	9.5*	3.1 – 29.8

*: $p < 0.05$
†: sports participation < 3 hours/week in adolescence; sports participation < 1.5 hours/week in adulthood
‡: BMI ≥ percentile 80 in adolescence; BMI ≥ 25 kg/m^2 in adulthood

Discussion

The purpose of this study was to investigate tracking of physical fitness and physical activity from adolescence into middle adulthood in Flemish females. First, for all variables interage correlations were calculated. Following the criterion of Bloom (5), all anthropometric and physical fitness characteristics, except for flamingo balance, plate tapping, leg lifts and arm-pull are stable from adolescence to adulthood in Flemish females. On the other hand, sports participation is not a stable characteristic. Over a period of 23 years, anthropometric and physical fitness variables demonstrate higher levels of stability than physical activity.

It is difficult to compare tracking coefficients across studies because of differences in methodology, age at first observation and time span between repeated measures. It must also be noted that tracking refers to the relative position within a group over time. When tracking of a variable is high, it does not necessarily mean that absolute values of that variable remain at the same level.

Tracking coefficients found in the present study are comparable to other studies. In Flemish males tracking was high for flexibility (r = 0.68-0.82) and low to moderate (r = 0.22-0.69) for other fitness parameters between adolescence (13-15-18 years) and adulthood (30-35 years) (3). The correlation between 18 and 30 years of age for the BMI was 0.69 (11) and about 0.50 for skinfold thicknesses (12). In contrast correlations for sports participation from adolescence (12-18 years) to 35 years of age were low, 0.14 to 0.20 (29). In females of the Cardiovascular Risk in Young Finns Study, correlations for a physical activity index between ages 15 and 36 years and between ages 18 and 39 years were 0.14 and 0.26, respectively (23).

Three potential explanations for the higher stability of physical fitness compared to physical activity are reasonable. First, physical activity is a behaviour associated with more modifiable and volatile factors (e.g., social support, occupation,…) (24), whereas physical fitness is likely to be associated with more stable factors (e.g., genotype, morphology,…) (6). Second, the praising of physical activity may change with age – as do opportunities – especially with children in the household (15, 17). A third factor concerns the possibly greater measurement error associated with assessment of physical activity by questionnaire compared to the more objective physical fitness tests (28).

To further investigate tracking of BMI and physical activity, the percentage of subjects remaining in the same BMI or physical activity group or shifting from one group to another from adolescence to adulthood was identified. In Flemish females it is clear that weight status in adolescence is indicative of weight status in middle adulthood; 84.5% and 63.6% respectively remained in the normal weight and overweight group.

The present study confirms what has been observed in previous studies. For 6 to 18 year old females of the Fels Longitudinal Study at the 75th percentile on the CDC BMI-for-age growth charts, a probability of 40% to 59% of being overweight at 35 years of age was reported. At the 85th percentile, the probability increased to 60%-79.9% for 10 to 18 year old girls, and at the 95th percentile girls older than 10 years of age had a probability of $\geq$ 80% of becoming overweight adults (10). In Danish females, 71% remained in the upper quintile for the BMI from adolescence to young adulthood (1).

In the present study less activity appears to track better than activity; 62.5% of less active adolescents remained less active, whereas only a small majority of 54.4% remained active.

Results of the stability of physical activity are somewhat more variable among studies of European samples. Similar results were obtained in Flemish males (29). Of inactive 17-year-old boys, 78% remained inactive at 30 years, whereas boys who were very active in sports during adolescence only had a slightly higher chance of belonging to the moderately active (38%) or active group (34%) as adults. On the other hand, among Finnish men who had taken physical exercise at least once a week during leisure time at 14 years of age, the majority

(71%) continued to do so at 24 years of age, while 55% participating in no exercise or less than once a week in their youth, remained in the same group in adulthood (19). In the Amsterdam Growth and Health Longitudinal Study, 42% of adolescent girls (13-17 year) in the highest risk group (under percentile 25) for physical activity remained in the same risk group at 27 years of age (26).

These variable results can be attributed, in part, to the different cut points used to categorize subjects into risk groups. In the present study, except for adolescent BMI, the groups were objectively defined according to absolute values while in most other studies groups were arbitrarily defined based on the distribution of values. Because results of a tracking analysis greatly depend on the arbitrary choice for division of subgroups, defining risk groups according to the distribution of values is suitable only in situations where no objective risk values are available (25).

Finally, odds ratios were calculated for less activity or overweight in adulthood according to adolescent activity or weight status. Overweight adolescent girls showed a 9.5 fold higher risk of becoming overweight adults.

This is consistent with the literature. In Flemish males, overweight 13 to 17 year old boys had a 5 to 7 times higher risk of becoming an overweight at 40 years (11). In the Fels Longitudinal Study, the odds of overweight at 35 years for girls 15 to 18 years at percentile 75 for the BMI varied between 2.9 and 7.3 times those for girls with BMI values at percentile 50 (10).

The current study has several important strengths compared to other studies. It is a longitudinal study of females in which both tracking of physical fitness and physical activity from adolescence to middle adulthood was investigated. The literature on females is relatively scarce and most studies focus on young adulthood. The longitudinal approach also circumvents recall biases, a major issue in many retrospective studies.

This study also has several limitations, especially concerning the definition and assessment of physical activity. While physical activity is a complex behaviour consisting of several dimensions (e.g., occupation, transportation, leisure time,…), only sports participation was taken into account because of lack of available data for other components of physical activity during the first phase of the study. Furthermore, the physical activity questionnaire used during adolescence differed from that in adulthood. However, this was also the case in the Cardiovascular Risk in Young Finns Study where it did not seem to influence the results (23). Finally, the use of questionnaires may represent a weakness compared with more objective measures of physical activity such as heart rate monitoring or motion sensors (21).

In summary, results of this study show lower stability of physical activity compared to physical fitness from adolescence to adulthood. Weight status during adolescence is reasonably indicative of adult weight status and a pattern of less activity rather than activity tends to be continued from youth into adulthood. This leads to the recommendation that during adolescence, effective strategies should be implemented to encourage physical activity and to prevent overweight. In addition, during life constant efforts should be made to keep people active and efforts need to be made to reactivate those who have shifted from an active to a more sedentary lifestyle.

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PART 3. Genetic epidemiological studies

Chapter 1. Aggregation of anthropometric characteristics, physical fitness and physical activity in Flemish nuclear families
Twin Research and Human Genetics, in revision

Chapter 2. Parent-offspring resemblance in physical fitness and physical activity: date-of-exam-matched versus adolescent age-matched analysis
American Journal of Epidemiology, submitted

CHAPTER 1

Aggregation of anthropometric characteristics, physical fitness and physical activity in Flemish nuclear families

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Twin Research and Human Genetics, in revision

Abstract

The aims of this study were 1) to investigate familial aggregation in anthropometric characteristics, physical fitness and physical activity in Flemish nuclear families and 2) to determine the proportion of the variability in these dimensions attributable to genetic (Vg), common environmental (Vc) and unique environmental (Ve) factors. Familial correlations were calculated and a variance components model-fitting approach was used in a combined family and twin design. The observed familial aggregation was completely explained by genetic factors for BMI (58%), sum of five skinfolds (53%), trunk-extremity skinfold index (47%), flexibility (61%) and muscular endurance (48%) and by shared environmental factors for balance (21%) and sports participation (20%), while both genetic and shared environmental factors were important for waist circumference (Vg = 12%; Vc = 31%) and explosive strength (Vg = 13%; Vc = 24%). However, for all variables at least about half of the variance was explained by unique environmental factors (ranging from 42% for BMI to 80% for sports participation).

Key words

anthropometry, environment, family, genes, physical activity, physical fitness, twin

Introduction

There is ample evidence supporting the beneficial effects of physical fitness and regular physical activity on health. Especially in adults, a physically fit and active lifestyle leads to a reduced risk of morbidity and mortality from a number of chronic diseases (Blair et al., 2001; Bouchard et al., 1994; Kesaniemi et al., 2001). So far, the role of physical fitness and physical activity on child and adolescent health is less clear but growing research identifies at least modest positive effects. In addition, physical fitness and physical activity during childhood and adolescence might positively affect adult health (Biddle et al., 2004; Blair et al., 1989, Boreham & Riddoch, 2001; Strong et al., 2005).

To be able to develop effective health interventions, it is important to understand the causes underlying the phenotypic variation in physical fitness and physical activity in the population. In the basic genetic model, the total variation (Vtot) in complex, multifactorial traits can be partitioned into genetic (Vg), common environmental (Vc) and unique environmental (Ve) factors (Vtot = Vg + Vc + Ve). Heritability (h^2) refers to the proportion of the total variation attributable to genetic factors (Vg / Vtot). Various study designs, including nuclear families, extended pedigrees, twin and adoption studies, each with their own strengths and limitations, can be used. Ideally, as many different relatives with as many different degrees of relatedness as possible should be combined (Bouchard et al., 1997).

During the past decades, a number of studies have assessed the relative contribution of genetic and environmental factors to anthropometric characteristics and different aspects of physical fitness (Allison et al., 1996; Beunen & Thomis, 2000; Beunen et al., 2003; Bouchard et al., 1988, 1997; Katzmarzyk et al., 2000; Maes et al., 1996, 1997; Okuda et al., 2005; Peeters et al., 2003; Pérusse et al., 1987, 1988b, 2000). Until now, fewer studies have investigated this for physical activity (Beunen & Thomis, 1999; Bouchard et al., 1997; Koopmans et al., 1994; Maia et al., 2002; Pérusse et al., 1988a, 1989; Stubbe et al., 2005). From the majority of these studies, it is clear that genetic factors play a significant role. Most studies also find little or no common environmental effects. Higher heritability estimates are usually reported for skeletal dimensions compared to body composition, physical fitness and physical activity. However, there are considerable inconsistencies in the estimates ranging from none or weak to moderate and even high. Twin studies typically yield higher heritability estimates than family and adoption studies and traditional family studies cannot disentangle the effects of genes and common environment. This large variability of heritability estimates across studies is not unexpected given the variety of study designs, observed populations, sample sizes, different assessment methods of the same phenotype and statistical procedures.

Nevertheless, the accurate estimation of the heritability within a population is important for at least two reasons. First, it is useful to quantify the influence of non-genetic factors and the potential impact of genotype-environment interactions on the phenotype. Second, the power of studies searching for genes contributing to anthropometric characteristics, physical fitness or physical activity is largely affected by the heritability estimate (Allison et al., 1996).

The aims of the present study are 1) to investigate the familial aggregation of anthropometric characteristics, physical fitness and physical activity in Flemish nuclear families and 2) to determine the proportion of the variability in these traits that can be explained by genetic, common and unique environmental factors. A combined family and twin design will be used to address these aims.

Materials and methods

Subjects

The subjects used for the present study are part of the Flemish Longitudinal Offspring Study (FLOS) and the Leuven Longitudinal Twins Study (LLTS).

Flemish Longitudinal Offspring Study

The FLOS is a project within the most recent phase of the Leuven Longitudinal Study on Lifestyle, Fitness and Health (LLSLFH) conducted within the framework of the Flemish Policy Research Centre Sport, Physical Activity and Health (SPAH). The LLSLFH originated from two earlier studies: the Leuven Growth Study of Belgian Boys and the Leuven Growth Study of Flemish Girls and comprises observations on anthropometric characteristics, physical fitness and physical activity in males from 12 to 18 years (1969-1974), at 30 years (1986), 35 years (1991), 40 years (1996) and 47 years (2002-2004) and in females between 6 and 18 years (1979-1980) and at 40 years (2002-2004). A more detailed description of those studies is given elsewhere (Beunen et al., 1988; Matton et al., in press; Ostyn et al., 1980; Simons et al., 1990). In the FLOS, conducted in 2002-2004, the spouses and offspring older than 10 years (mean age = 14.51 years, age range: 10.01-23.44 years) of the longitudinally followed males and females were also tested. This resulted in a total of 292 nuclear families including 55 families without children, 80 families with one child, 123 families with two children, 29 families with three children and five families with four children. Data on a maximum of 273 fathers, 242 mothers, 189 daughters, 258 sons, one monozygotic male twin, one monozygotic female twin, two dizygotic male twins, one dizygotic female twin and one trizygotic triplet (1 male, 2 females) were collected.

Leuven Longitudinal Twins Study

The LLTS was conducted between 1985 and 1999 to investigate the genetic and environmental contribution to the variation in and covariation between physical characteristics and to explore the genetic determination of growth and development of these characteristics (Maes et al., 1996, Peeters et al., 2003). Hundred and five non-obese twins participated in the study at age 10 together with their parents. Anthropometric characteristics, physical fitness and physical activity were assessed in both parents and twins. Subsequently, a follow-up of the twins was conducted with semi-annual measures of anthropometric characteristics and annual assessments of physical fitness and physical activity from 10 to 16 years and again at 18 years. For the analyses in the present study, data on anthropometric characteristics, physical fitness and physical activity of the parents and of the twins at the fifth annual visit (mean age = 14.53 years, age range: 13.66-15.46 years) were used. This resulted in data on a maximum of 91 fathers, 101 mothers, 20 monozygotic male twins, 21 monozygotic female twins, 21 dizygotic male twins, 20 dizygotic female twins and 20 dizygotic opposite-sex twins.

The FLOS and the LLTS were approved by the medical and ethical committee of the Katholieke Universiteit Leuven. Prior to participation, the purpose and procedures of the studies were explained and parents and offspring gave their written informed consent. For offspring less than 18 years parental consent was given in addition.

Zygosity

The determination of the zygosity of the twins of the LLTS was described elsewhere (Loos et al.,1998; Maes et al., 1996; Peeters et al., 2003; Vlietinck et al., 1986).
In the FLOS, information on the zygosity of the twins and the triplet was obtained from the parents.

Anthropometry

Anthropometric dimensions were taken by trained staff with subjects barefoot and in underwear following standardized procedures (Claessens al., 1990). Standing height was measured to the nearest millimetre using a Harpenden portable stadiometer (Holtain, Crymych, UK) and body weight was measured to the nearest 0.1 kg using a digital scale (Seca 841, Hamburg, Germany). Waist circumference was measured to the nearest millimetre at the narrowest level between the lowest ribs and iliac crests in standing position using a metal tape (Rosscraft, Surrey, BC, Canada). Skinfold thicknesses of biceps, triceps, subscapula, suprailiac and medial calf were measured to the nearest millimetre using a Harpenden calliper (Holtain, Crymych, UK). BMI (body mass (kg) / height $(m)^2$), the sum of five skinfolds (biceps + triceps + subscapula + suprailiac + medial calf) and the trunk-extremity skinfold index ((scapula + suprailiac) / (triceps + medial calf)) were calculated.

Physical fitness

Performance-related fitness items were balance (flamingo balance) and explosive strength or power (standing broad jump). Health-related fitness items were flexibility (sit and reach) and upper-body muscular endurance (bent arm hang). All tests were taken according to the procedures described by Claessens et al. (1990).

Physical activity

Parents and offspring of the FLOS completed the Flemish Computerized Physical Activity Questionnaire (FPACQ). To assess the average time a week spent on leisure time sports participation they were asked to select a maximum of three of their most important sports out of a list of 196 sports and to report the frequency and duration (Philippaerts et al., 2006, Matton et al., in press).

In the parents and twins of the LLTS data on sports participation during leisure time were collected using a standardized questionnaire via a retrospective approach: all sports activities during the period of one year before the date of investigation were recalled. The detailed information on the frequency of sports participation was combined into a global average score of time per week spent on sports practice over one year (Renson & Vanreusel, 1990).

Statistical analysis

Descriptive statistics (means ± standard deviations) for age, anthropometric characteristics, physical fitness and physical activity were calculated in parents, siblings and each twin type for males and females separately. Shapiro-Wilk tests for normality revealed that not all variables were normally distributed. To improve normality logarithmic or square root transformations were applied. To adjust for the effects of age, in the four sex-by-generation groups multiple stepwise regressions were carried out for each variable up to a cubic polynomial in age, retaining only those terms significant at the 5% level. The obtained residuals or raw scores (if no term was significant) were standardized to a mean of zero and unit variance within each sex-by-generation group prior to further analysis. Descriptive statistics and data preparation was carried out with the SAS 9.1 statistical package (SAS Institute Inc, Cary, NC).

To investigate familial aggregation in anthropometric characteristics, physical fitness and physical activity, Pearson product moment correlations between parents and offspring and between siblings were calculated in PEDSTATS (Wigginton & Abecasis, 2005) and spousal correlations were calculated with the SAS 9.1 statistical package (SAS Institute Inc, Cary, NC).

The relative contribution of genetic (Vg), common environmental (Vc), and unique environmental (Ve) factors to the total variance in anthropometric characteristics, physical fitness and physical activity was investigated by decomposing the total variance in variance components in QTDT (Abecasis et al., 2000). In a first step, two full models assuming unique environmental and genetic factors (Ve + Vg) or unique environmental and common environmental factors (Ve + Vc) were compared to a null model assuming only unique environmental factors (Ve). Subtracting the -2*log likelihood value of the full model from that of the null model, resulted in a Chi^2 goodness-of-fit statistic with one degree of freedom. This Chi^2 test was then used to determine the best fitting model. Minimal level of significance was set at $p < 0.05$. In a second step, depending on which model was identified as the best fitting in the first step, a full model assuming unique environmental, genetic and common environmental factors (Ve + Vg + Vc) was compared to a model assuming unique environmental and genetic factors (Ve + Vg) or one assuming unique and common environmental factors (Ve + Vc). The best fitting model was again determined as described in the first step. Explained variance of unique environmental, genetic and common environmental factors was calculated based on the best fitting model.

Results

Table 1 provides descriptive statistics for age, anthropometric characteristics, physical fitness and physical activity for the different members of Flemish nuclear families.

In Table 2 the correlations between family members for anthropometric characteristics, physical fitness and physical activity in Flemish nuclear families are presented. All correlations between monozygotic twins are lower than 1.0 and most correlations between dizygotic twins, siblings and parent-offspring do not reach 0.5. With a few exceptions, the correlations between dizygotic twins and between siblings are lower than those between monozygotic twins and they generally vary around half of the monozygotic correlations. Most correlations between siblings are quite comparable to those between dizygotic twins. Parent-offspring correlations are generally similar or lower than dizygotic or sibling correlations. Opposite-sex dizygotic, sibling or parent-offspring correlations are generally similar or lower than same-sex correlations. Spousal correlations are low but significant for BMI, waist circumference, balance and explosive strength and moderate and significant for sports participation.

The model-fitting results and Chi^2-ratio tests for physical fitness and physical activity in Flemish nuclear families are summarized in Table 3. The -2*log likelihood of the best fitting models is indicated in bold. In the first step, the full models Ve + Vg (Model 2) and Ve + Vc (Model 3) were tested against the null model Ve (Model 1). The Ve + Vg-model fits the data best for anthropometric characteristics, sit and reach, standing broad jump and bent arm hang. For balance and sports participation the Ve + Vc-model gives the best fit. In the second step, the full model Ve + Vg + Vc (Model 4) was tested against the Ve + Vg model for anthropometric characteristics, flexibility, muscular endurance and explosive strength and against the Ve + Vc model for balance and sports participation. Only for waist circumference and explosive strength the fit of the full model Ve + Vg + Vc is significantly better compared to the null model Ve + Vg.

Table 1. Descriptive statistics (non-transformed means and standard deviations (SD)) for age, anthropometric characteristics, physical fitness and physical activity for the different members of Flemish nuclear families

Variables	Fathers n = 349-364 mean (± SD)	Mothers n = 315-343 mean (± SD)	Sons n = 225-258 mean (± SD)	Daughters n = 185-189 mean (± SD)	Monozygotic twin sons n = 34-42 Mean (± SD)	Monozygotic twin daughters n = 32-44 Mean (± SD)	Dizygotic twin sons n = 57-67 Mean (± SD)	Dizygotic twin daughters n = 58-64 Mean (± SD)
Age (yrs)	43.76 (± 4.05)	41.27 (± 3.67)	14.70 (± 2.58)	14.38 (± 2.58)	14.55 (± 0.44)	14.80 (± 0.66)	14.35 (± 0.68)	14.24 (± 0.90)
Height (cm)	176.98 (± 6.12)	164.77 (± 5.71)	167.22 (± 14.13)	161.01 (± 9.45)	166.23 (± 9.40)	163.05 (±7.49)	164.37 (± 10.34)	160.11 (± 6.78)
Weight (kg)	80.23 (± 10.43)	65.06 (± 9.88)	54.41 (± 15.20)	50.86 (± 10.56)	51.54 (± 8.04)	49.61 (± 5.80)	50.23 (± 8.69)	50.06 (± 8.78)
BMI (kg/m^2)	25.60 (± 2.97)	23.98 (± 3.60)	19.04 (± 2.89)	19.46 (± 2.95)	18.54 (± 1.51)	18.67 (± 1.96)	18.46 (±1.68)	19.43 (± 2.59)
Waist circumference (cm)	89.17 (± 8.49)	76.32 (± 8.05)	67.81 (± 7.26)	65.32 (± 6.55)	66.60 (± 3.73)	63.39 (± 3.47)	66.36 (± 4.96)	64.35 (± 5.00)
Sum 5 skinfolds (mm)[†]	65.43 (± 25.52)	92.32 (± 34.27)	42.40 (± 19.56)	62.91 (± 24.15)	35.99 (± 13.35)	52.05 (± 14.95)	37.52 (± 14.48)	59.44 (± 24.86)
Trunk-extremity index[‡]	1.69 (± 0.57)	0.93 (± 0.31)	0.86 (± 0.25)	0.79 (± 0.20)	0.77 (± 0.18)	0.75 (± 0.16)	0.78 (± 0.20)	0.74 (± 0.15)
Flamingo balance (n/min)	12.72 (± 6.20)	13.08 (± 6.53)	13.43 (± 6.14)	11.95 (± 5.93)	12.36 (± 4.05)	10.36 (± 5.31)	12.02 (±5.46)	10.82 (± 4.73)
Sit and reach (cm)	20.09 (± 9.42)	24.09 (± 8.77)	15.76 (± 8.25)	21.73 (± 7.81)	17.33 (± 7.68)	26.86 (± 7.68)	17.88 (± 7.92)	23.92 (± 8.52)
Standing broad jump (cm)	183.46 (± 24.72)	138.33 (± 23.91)	178.66 (± 30.70)	154.49 (± 22.13)	190.93 (± 23.14)	178.95 (± 24.40)	187.52 (± 22.91)	169.43 (± 22.23)
Bent arm hang (sec)	19.14 (± 13.99)	5.85 (± 7.61)	20.68 (± 14.88)	9.18 (± 9.41)	27.40 (±23.36)	11.48 (± 8.81)	21.30 (± 16.59)	11.86 (± 10.24)
Sports participation (h/week)[§]	2.79 (± 3.27)	1.75 (± 2.12)	6.89 (± 5.80)	4.55 (± 3.89)	3.34 (± 2.11)	1.06 (± 1.50)	3.38 (± 3.83)	2.61 (± 2.63)

[†] biceps + triceps + subscapula + suprailiac + medial calf
[‡] (subscapula + suprailiac) / (triceps + medial calf)
[§] In the Flemish Longitudinal Offspring Study: FPACQ (Matton et al., in press; Philippaerts et al., 2006); in the Leuven Longitudinal Twin Study: standardized questionnaire with retrospective approach (Renson et al., 1990)

Table 2. Correlations between family members for anthropometric characteristics, physical fitness and physical activity in Flemish nuclear families

Variables	FM§	FSo§	MD§	FD§	MSo§	BB§ siblings	SiSi§ siblings	BSi§ siblings	MZ§ male twins	MZ§ female twins	DZ§ male twins	DZ§ female twins	DZ§ opposite sex twins
	n = 273-309	n = 297-317	n = 253-275	n = 244-261	n = 291-321	n = 66-71	n = 39-41	n = 109-112	n = 20-21	n = 15-22	n = 19-23	n = 20-22	n = 20-22
BMI	0.11*	0.38***	0.39***	0.16**	0.21***	0.42***	0.60***	0.36***	0.75***	0.92***	0.36	0.39	0.34
Waist circumference	0.13*	0.23***	0.32***	0.14*	0.22***	0.25*	0.56***	0.33***	0.74***	0.78***	0.46*	0.36	0.28
Sum 5 skinfolds†	0.01	0.26***	0.31***	0.10	0.25***	0.20	0.47**	0.36***	0.52*	0.91***	0.49*	0.36	0.17
Trunk-extremity index‡	0.09	0.20***	0.20***	0.14*	0.26***	0.26*	0.35*	0.27**	0.82***	0.80***	0.42*	0.36	0.46*
Flamingo balance	0.14*	0.25***	0.24***	0.25***	0.25***	0.35**	0.10	0.19*	0.45*	0.17	0.42	0.16	0.13
Sit and reach	0.05	0.30***	0.25***	0.30***	0.28***	0.35**	0.44**	0.36***	0.67***	0.82***	0.32	0.50*	0.70***
Standing broad jump	0.15*	0.18**	0.16**	0.20**	0.22***	0.41***	0.22	0.31**	0.71***	0.39	0.60**	0.53*	0.26
Bent arm hang	0.07	0.18**	0.34***	0.14*	0.20***	0.36**	0.01	0.14	0.89***	0.70***	0.65***	0.28	0.35
Sports participation	0.31***	0.17**	0.04	0.12	0.13*	0.05	0.36*	0.26**	0.83***	0.99***	0.67**	0.14	0.35

*: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$

† biceps + triceps + subscapula + suprailiac + medial calf

‡ (subscapula + suprailiac) / (triceps + medial calf)

§ F = father, M = mother, So = son, D = daughter, B = brother, Si = sister, MZ = monozygotic, DZ = dizygotic

Table 3. Model-fitting results and Chi^2-ratio tests for anthropometric characteristics, physical fitness and physical activity in Flemish nuclear families

		Model fit (-log likelihood)††				Chi^2-ratio tests (Δ Chi^2)‡‡				
Variables	df§	Model 1 Ve	Model 2 Ve + Vg	Model 3 Ve + Vc	Model 4 Ve + Vg + Vc	Model 2 vs. Model 1		Model 3 vs. Model 1	Model 4 vs. Model 2	Model 4 vs. Model 3
BMI	1340	1902.02	**1834.79**	1841.76	1832.97	134.45***	>	120.52***	3.64	/
Waist circumference	1338	1899.30	1852.74	1854.83	**1850.47**	93.13***	>	88.95***	4.53*	/
Som 5 skinfolds†	1336	1896.41	**1845.78**	1859.92	1845.78	101.26***	>	72.97***	0.00	/
Trunk-extremity index‡	1336	1896.46	**1854.90**	1861.87	1854.60	83.13***	>	69.18***	0.58	/
Flamingo balance	1312	1862.34	1828.17	**1827.37**	1825.81	68.34***	<	69.94***	/	3.12
Sit and reach	1315	1866.95	**1795.08**	1812.88	1795.06	143.75***	>	108.15***	0.05	/
Standing broad jump	1306	1853.93	1816.89	1817.23	**1814.40**	74.10***	>	73.41***	4.97*	/
Bent arm hang	1287	1826.61	**1785.61**	1796.33	1785.61	82.02***	>	60.58***	0.00	/
Sports participation	1289	1829.61	1810.48	**1800.93**	1800.93	38.26***	<	57.37***	/	0.00

*: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$

† biceps + triceps + subscapula + suprailiac + medial calf

‡ (subscapula + suprailiac) / (triceps + medial calf)

§ degrees of freedom of model 1 (Ve)

†† Ve: variance explained by unique environmental factors; Vg: variance explained by genetic factors; Vc: variance explained by common environmental factors

‡‡ Δ Chi^2 = (-2*log likelihood null model) – (-2*log likelihood full model); Model 2 vs. Model 1: evidence of Vg additional to Ve; Model 3 vs. Model 1: evidence of Vc additional to Ve; Model 4 vs. Model 2: evidence of Vc additional to Ve + Vg; Model 4 vs. Model 3: evidence of Vg additional to Ve + Vc; The -log likelihood of the best fitting models is indicated in bold

Table 4 gives the proportions of the variance components of the best fitting model for physical fitness and physical activity in Flemish nuclear families. Unique environmental factors (Ve) explain about 40% of the variance in BMI and flexibility, about 50% to 60% in waist circumference, sum of five skinfolds, trunk-extremity index, explosive strength and muscular endurance and about 80% in balance and sports participation. For BMI, sum of five skinfolds, trunk-extremity index, flexibility and muscular endurance, the remainder of the variance (47% to 58%) is only explained by genetic factors (Vg). For balance and sports participation, only common environmental factors account for the remaining 20% of the variance. Both genetic and common environmental factors each explain a low to moderate proportion (12% to 31%) of the remaining variance for waist circumference and explosive strength.

Table 4. Proportions of the variance components of the best fitting model for anthropometric characteristics, physical fitness and physical activity in Flemish nuclear families

Variables	Variance components[§]		
	Ve	Vg	Vc
BMI	0.42	0.58	/
Waist circumference	0.57	0.12	0.31
Sum 5 skinfolds[†]	0.47	0.53	/
Trunk-extremity index[‡]	0.53	0.47	/
Flamingo balance	0.79	/	0.21
Sit and reach	0.39	0.61	/
Standing broad jump	0.63	0.13	0.24
Bent arm hang	0.52	0.48	/
Sports participation	0.80	/	0.20

[†] biceps + triceps + subscapula + suprailiac + medial calf
[‡] (subscapula + suprailiac) / (triceps + medial calf)
[§] Ve: variance explained by unique environmental factors; Vg: variance explained by genetic factors; Vc: variance explained by common environmental factors

Discussion

The purpose of the present study was to investigate the familial aggregation of physical fitness and physical activity in Flemish nuclear families and to determine the relative contribution of genetic, common and unique environmental factors to the explanation of the observed variability in these traits.

First familial correlations were calculated. These correlations generally confirmed the existence of a familial aggregation in anthropometric characteristics, physical fitness and physical activity also observed in other studies (Beunen & Thomis, 1999, 2000; Bouchard et al., 1997; Koopmans et al., 1994; Maes et al., 1997). Familial aggregation results from genetic and/or common environmental factors, while unique environmental factors contribute to dissimilarity between family members. Taking into account several assumptions, correlations between family members provide indications about the proportion of the observed variation in a phenotype attributable to genetic, common and unique environmental factors. For most variables, the lower correlations than expected for a purely genetic trait (1.0 for monozygotic twins, 0.5 for dizygotic twins, siblings and parent-offspring) suggest an influence of unique environmental factors. The higher monozygotic compared to dizygotic and sibling correlations for the anthropometric characteristics, muscular endurance and sports participation point to a possible role for genetic factors. However, in several variables the dizygotic or sibling correlations are higher than one half of the monozygotic correlations, indicating that common environmental factors might also be important. The higher sibling compared to parent-offspring correlations (e.g., for flexibility) and the higher same-sex compared to opposite-sex correlations (e.g., for BMI) suggest generational or age effects of genes and/or environment and sex-specific effects of genes and/or environment respectively. If the significant spousal correlations for BMI, waist circumference, balance, explosive strength and sports participation are caused by shared spousal environmental factors during the years of cohabitation (shared household) and/or similarities in the interests and backgrounds of spouses (assortative mating by social homogamy) they indicate the importance of common environmental factors. However, if selection of spouses is based on visible characteristics (assortative mating by phenotypic assortment), this is likely to induce a genetic relationship between spouses and an increased genetic relatedness between offspring.

To estimate the relative contribution of genetic, common and unique environmental factors more exactly, model-fitting techniques decomposing the total variance based on the kinship information were used. For BMI, sum of five skinfolds, trunk-extremity index, flexibility and muscular endurance a model including both unique environmental and genetic factors gave the best fit with each factor explaining about half of the variance. A combination of unique and common environmental factors was most adequate for balance and sports participation, while a combination of all three factors fitted the data best for waist circumference and explosive strength. However, for these variables most of the variance was explained by unique environmental factors.

Many studies and several reviews have been published on the genetic and environmental influences on anthropometric characteristics and physical fitness and to a lesser extent also on physical activity (Allison et al., 1996; Beunen & Thomis, 1999, 2000; Beunen et al., 2003; Bouchard et al., 1988, 1997; Katzmarzyk et al., 2000; Koopmans et al., 1994; Maes et al., 1996, 1997; Maia et al., 2002; Okuda et al., 2005; Peeters et al., 2003; Pérusse et al., 1987, 1988a, 1988b, 1989, 2000; Stubbe et al., 2005). However, to our knowledge, only three studies have reported on all three of these dimensions. Within the 1981 Canada Fitness Survey (CFS) data for anthropometric characteristics and physical fitness were available for 13804, 7- to 69-year-old, relatives. The TAU path model was used to partition the phenotypic variation into transmissible and non-transmissible factors, where transmissible factors include both genetic and common environmental factors. The total transmissibility for anthropometric characteristics was 28% for waist-hip ratio, 36% for BMI and 37% for sum of five skinfolds and trunk-extremity index. For physical fitness, transmissibility estimates were 37% and 44% for muscular endurance assessed by sit ups and push ups respectively and 48% for flexibility assessed by a trunk flexion test (Pérusse et al., 1988b). The degree of familial resemblance in leisure energy expenditure, total time spent on activity and activity level was assessed by calculating different familial correlations between 16477 relatives aged 10 years and older. Comparison of the correlations indicated a weak contribution of inherited factors and suggested that familial resemblance might have resulted primarily from environmental factors common to members of the same generation (Pérusse et al., 1988a). Transmissibility estimates calculated from the present study are higher than those observed in the CFS. Similar to the CFS, the familial correlations for sports participation are generally higher between spouses and between siblings compared to parents and offspring. The first phase of the Québec Family Study (QFS) was conducted between 1978 and 1981 to investigate the role of genetic factors on body composition and fitness in French-Canadian families including parents with a mean age of about 43 years and biological and adopted children with a mean age of about 14.5 years. A BETA path model allowing for the separation of the transmissible effects into genetic and common environmental factors was used. Data on 1698 members from 409 families were available for body composition. For physical fitness and physical activity data on respectively 1630 and 1610 members from 375 families were used. For BMI and sum of six skinfolds, about 65% of the variance was explained by unique environmental factors, about 30% by common environmental factors and only about 5% by genetic factors. The magnitude of the common environmental component was similar for the extremity-trunk ratio (about 30%) but the unique environmental component was lower (about 45%) and the genetic component was higher (about 25%) (Bouchard et al., 1988). For muscular endurance obtained by 60 seconds sit ups, the contribution of genetic, common and unique environmental factors was 21%, 33% and 45% respectively (Pérusse et al., 1987). Although genetic factors accounted for 29% of the variation in habitual physical activity and common environmental factors accounted for 12% of the variation in exercise participation, unique environmental factors remained the major determinants (71% and 88% respectively) (Pérusse et al., 1989). The magnitude of the genetic component for body composition and physical fitness is higher in the present study compared to the QFS, whereas common environmental factors are generally less important and the variance explained by unique environmental factors is similar or lower. Results for sports participation are in agreement with those found for exercise participation in the QFS. Maes et al. (1996) used structural equation modelling on data of the same twins of the LLTS included in the present analysis but at 10 years of age. The best fitting model for the sum of five skinfolds, explosive strength, balance and muscular endurance included both additive genetic (Vg ranging from 47% to 86%) and unique environmental factors (Ve ranging from 14% to 53%). For flexibility, the addition of common environmental factors, explaining 32% of the total variance in males and 42% in females, resulted in a significantly better fit. Including the fitness characteristics of the parents of these twins allowed the testing of a variety of models including cultural transmission versus genetic transmission, non-parental shared environment, assortative mating, dominance, and reduced genetic transmission in which different genes are modelled to play a role in children and adults. For explosive strength and muscular endurance, a model with additive genetic, dominance genetic and unique environmental factors or a model with additive genetic and unique environmental factors and reduced genetic transmission best represented these familial data. For balance and the sum of five skinfolds, heritability estimates were very similar to the twins alone analysis, with a significant but small proportion of genetic variance attributable to assortative mating. For flexibility, the common environmental component in males was no longer significant (Maes et al. 1996). In 15-year-old twins, additive genetic factors explained about 83% of the total variance in male sports participation, while unique environmental factors explained the remaining 17%. A combination of common environmental (54%) and additive genetic (44%) factors accounted for the major part of the observed variance in female sports participation and only 2% was explained by unique environmental factors (Beunen & Thomis, 1999). For most variables in the present analyses, the genetic component is lower, the common environmental component is similar or higher and the unique environmental component is higher compared to the analyses of the LLTS alone. This suggests the possibility of generational and/or sex differences and the role of assortative mating. In the future, these issues will be further investigated using extended twin and family models.

Discrepancies between some of the results obtained in the present study and those in the above described and other studies have to be viewed in the light of the broad range of used designs, methodologies, sample sizes and populations. Variations in the level of genetic and environmental factors across the lifespan might also explain some of the apparent inconsistencies. In the present study, as in several other studies, age corrections were made in each sex-by-generation group using stepwise multiple regressions. This allows for the adjustment of age effects on the mean but not on the variance of the traits. Therefore, in all studies except for the LLTS, it is assumed that the effect of genes and environment remains stable across different ages. However, evidence refuting this assumption has already been reported for somatotype components, physical fitness and sports participation (Beunen et al., 2003; Maes et al., 1996; Peeters et al., 2003; Stubbe et al., 2005).

Three remarks pertaining to the current study deserve attention. First, since the unique environmental component also includes measurement error, it is very important to use reliable and valid instruments. The reliability and validity of most tests and measurements used in the present study has been reported elsewhere and is generally high (Lefevre et al., 1990; Matton et al., in press; Philippaerts & Lefevre, 1998; Philippaerts et al., 2006; Van 'T Hof et al., 1980). Second, the absent or low genetic component and the low or moderate common environmental component for waist circumference, balance, explosive strength and sports participation have to be interpreted with caution. For these variables significant spousal correlations were observed. The correlations within the 273-309 parental pairs contribute to the estimation of the common environmental component in the QTDT program (a kinship correlation of 0 is expected between spouses). This is correct in the case that spousal resemblance is only caused by shared household and/or social homogamy. However, when phenotypic assortment is involved, this might result in an underestimation of the genetic component and an overestimation of the common environmental component. It is difficult to disentangle the different causal mechanisms behind significant spousal correlations. Maes et al. (1996) reported that 2 to 10% of the genetic variance in several physical fitness tests in the LLTS was due to phenotypic assortment. Silventionen et al. (2003) used a factor/delta path model on data derived from self-reported questionnaires on height and weight, administered to the adult Finnish Twin Cohort in 1990, to study the effect of social homogamy and phenotypic assortment on assortative mating. For height, the effects of social homogamy and phenotypic assortment were about the same. For BMI, the effect of social homogamy was stronger than the effect of phenotypic assortment. When assortative mating was taken into account, environmental factors shared by both twins and their spouses had no effect on phenotypic variation in body height or weight. From the lack of consistently increasing trends in the spousal correlations for several cardiovascular risk factors with marriage duration in the Busselton Population Health Survey over the period 1966-1981, Knuiman et al. (1996) concluded that phenotypic assortment might be a more likely explanation for spousal resemblance than the shared household. Third, genetic and environmental factors should not be understood as being mutually exclusive. They are intrinsically linked and interact with each other in a complex manner. Several feeding and training experiments have revealed significant genotype-environment interactions for body weight, body fat and physical fitness (Bouchard et al., 1997). However, genotype-environment interactions and genotype-environment correlation effects were omitted in the present model-fitting approach.

The advantage of the present study compared to other studies is that the familial aggregation in anthropometric characteristics, as well as physical fitness and physical activity, is investigated using both familial correlations and a straightforward model-fitting approach in a combined family and twin design. Unfortunately, some limitations also need to be recognized. First, variance components testing in QTDT only allowed to model additive genetic (A) (or dominance D), common environmental (C) and unique environmental (E) components, without detailed modelling of assortative mating, cultural transmission versus non-parental shared environmental factors, or reduced transmission as was performed in the Maes et al. (1996) study. Second, the LLTS sample was smaller compared to the FLOS sample and data collection was about 8 to 14 years earlier. Third, since the subjects used for this investigation belong to two longitudinal studies they might be somewhat more health-conscious compared to the general population. This might result in more favourable physical fitness and physical activity characteristics possibly hampering the generalizability of the results. Fourth, although physical activity consists of several dimensions, only data on sports participation were available. Moreover, the sports participation questionnaire used in the FLOS differed from that in the LLTS. Finally, no data were available on aerobic fitness measured with the same protocol.

In summary, familial aggregation in Flemish nuclear families is explained by genetic factors for BMI, sum of five skinfolds, trunk-extremity index, flexibility and muscular endurance and by common environmental factors for balance and sports participation, while both factors are important for waist circumference and explosive strength. However, for all variables at least about half of the variance is explained by unique environmental factors. This emphasizes the importance of environmental modifications (e.g., physical fitness, physical activity or nutritional intervention programs), viewed against the background of genetic susceptibility, as potential strategies to improve anthropometric, physical fitness and physical activity characteristics of the Flemish population.

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CHAPTER 2

Parent-offspring resemblance in physical fitness and physical activity: date-of-exam-matched versus adolescent age-matched analysis

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Abstract

Although time-point-matched parent-offspring correlations might be disturbed by generation-specific genetic and/or environmental factors, familial resemblance is usually investigated using intra-pair correlations between family members measured at the same time-point. The Leuven Longitudinal Study on Lifestyle, Fitness and Health (1969-2004) provides unique data on anthropometric characteristics, physical fitness and physical activity of Flemish parents at adolescent and adult age and their adolescent offspring. The purpose of this study was to test if sex-specific correlations between parents and offspring measured at the same adolescent chronological age are higher than those measured at the same data-of-exam (adult parents-adolescent offspring). Eighty father-son pairs and 65 mother-daughter pairs were included. For height (r = 0.76 versus 0.36), weight (r = 0.71 versus 0.37), trunk-extremity skinfold index (r = 0.51 versus 0.32) and vertical jump (r = 0.58 versus 0.14), adolescent chronological age-matched father-son correlations were significantly higher than data-of-exam-matched father-son correlations. For these variables, parent-offspring similarity and associated heritability or transmissibility might be underestimated in classical parent-offspring (time-point-matched) designs. For body mass index, sum of four skinfolds, bent arm hang, sit and reach and sports participation in males and for all anthropometric, physical fitness and physical activity variables in females, no significant differences were found between adolescent chronological age-matched and date-of-exam-matched parent-offspring correlations.

Key words

adolescent, adult, anthropometry, child, correlation study, parents, physical fitness, sports

Introduction

Since it is widely accepted and extensively documented that physical fitness and regular physical activity are related to health it is important to have a clear insight into their determinants to be able to develop effective health promotion strategies (1-7).

Physical fitness and physical activity are influenced by many factors (5, 8, 9). Familial aggregation could be a major determinant of the level of physical fitness and physical activity. Familial aggregation is often investigated by calculating correlations between family members measured at the same time-point (10-17). Generation-specific genetic and/or environmental factors might explain the often observed lower correlations between parents and offspring compared to siblings. Evidence for changing effects of genes and/or environment across different ages has already been reported for somatotype components, physical fitness and sports participation and needs longitudinal study designs to be unravelled (18-21). To prevent the disturbance of parent-offspring correlations by generation-specific factors, parents and offspring should be tested at the same age during adolescence or adulthood. From a comparison of year-of-exam and age-matched estimates of heritability in the Framingham Heart Study, it was also concluded that the optimal design to identify genetic effects in traits with large age-related effects might be to measure parents and offspring at similar ages and not to rely on age adjustment or longitudinal measures to account for these differences (22). To our knowledge, only two studies have been published in which correlations for BMI or physical ability have been calculated between parents and offspring at similar adult ages (23, 24). No studies are available during adolescence.

The Leuven Longitudinal Study on Lifestyle, Fitness and Health (LLSLFH) provides a unique source of data on anthropometric characteristics, physical fitness and physical activity of parents at adolescent and adult age and of their adolescent offspring (25). Therefore, the purpose of the present study is to compare sex-specific correlations for anthropometric characteristics, physical fitness and physical activity between parents and offspring measured at approximately the same adolescent chronological age (age-matched) with those measured at the same date-of-exam (date-of-exam-matched: adult parents-adolescent offspring). In addition, tracking and the variability in secular trends will be investigated as possible explanations for the observed parent-offspring correlations. Secular trends refer to changes over time, usually between successive generations (26). Tracking refers to stability of relative rank or position within a group over time (27). It is hypothesized that chronological age-matched parent-offspring correlations will be higher than date-of-exam-matched parent-offspring correlations in case of changing genetic and/or environmental factors over the life span. This will probably be more clearly reflected in traits with a small variability in within-family secular trends and low tracking.

Materials and methods

Subjects

Data of the fathers at adolescent age are from the Leuven Growth Study of Belgian Boys (LGSBB), 1969-1974. The LGSBB was a mixed cross-sectional and longitudinal study designed to provide information concerning growth, maturity, physical fitness and physical activity of a large representative sample of Belgian secondary school boys. A total of 21175 assessments were made, the majority of the boys were tested only once but 588 boys were followed longitudinally between 12 and 18 years. A more detailed description of the LGSBB is given elsewhere (28, 29).

Data of the mothers at adolescent age are from the Leuven Growth Study of Flemish Girls (LGSFG), 1979-1980. The purpose of the LGSFG was to investigate growth, maturity, physical fitness and physical activity of a representative sample of Flemish primary and secondary school girls (6-18 years, n = 9954). A more detailed description of the LGSFG is given elsewhere (30).

Data of the fathers and mothers at adult age and their adolescent sons and daughters are from the Flemish Longitudinal Offspring Study (FLOS). The FLOS is a project within the Leuven Longitudinal Study on Lifestyle, Fitness and Health (LLSLFH) conducted within the framework of the Flemish Policy Research Centre Sport, Physical Activity and Health. The LLSLFH is a follow-up of the LGSBB and the LGSFG. Of the 588 boys followed over six years during adolescence in the LGSBB, 411 were Flemish speaking and were considered for further enrolment in the LLSLFH. With the intention of five-yearly follow-ups, these males were re-examined in 1986, 1991 and 1996. In the FLOS, conducted between 2002 and 2004, the longitudinally followed males were tested again (n = 154). A subsample of the oldest girls (14-18 years) measured in the LGSFG, with at least two offspring older than 10 years was also contacted. One hundred and thirty eight women agreed to participate and were re-examined for the first time. Spouses and offspring older than 10 years of the longitudinally followed men and women were also included in the FLOS. A more detailed description of the LLSLFH is given elsewhere (25). A visual representation of the samples from the LLSLFH used for the present study is given in Figure 1.

For the present analyses, only father-son pairs with an adolescent chronological age between 12 and 18 years and an adolescent chronological age difference of less than one year were used (n = 80; adolescent age fathers = 15.52 (1.78) years; adult age fathers = 46.92 (0.59) years; adolescent age sons = 15.58 (1.88) years). Since mothers were only measured once during adolescence, the number of mother-daughter pairs with an adolescent chronological age difference of less than one year was insufficient (n = 19). Therefore, all mother-daughter pairs with an adolescent chronological age of the mother between 14 and 18 years and a chronological age of the daughter between 13 and 19 years were included (n = 65; adolescent age mothers = 16.69 (1.04) years; adult age mothers = 40.60 (1.12) years; adolescent age daughters = 15.03 (1.50) years).

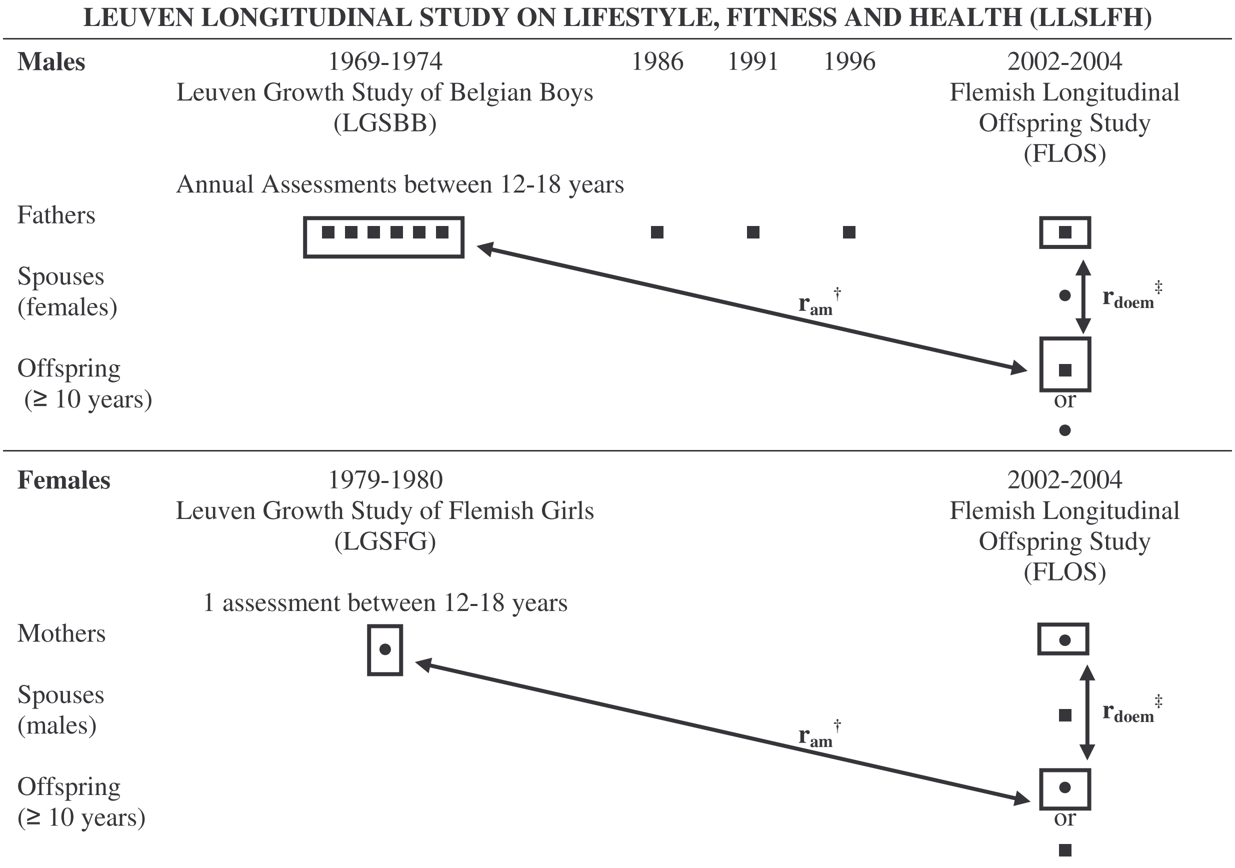

Figure 1. Visual representation of the samples from the Leuven Longitudinal Study on Lifestyle, Fitness and Health (LLSLFH) used for the calculation of the adolescent age-matched and date-of-exam-matched parent-offspring correlations.
† r_{am} = age-matched parent-offspring correlation
‡ r_{doem} = date-of-exam-matched parent-offspring correlation
■: male
●: female

All stages of the study were approved by the medical and ethical committee of the Katholieke Universiteit Leuven. Prior to participation, the purposes and procedures of the study were explained and written informed consent was given.

Anthropometry

Anthropometric dimensions were taken by trained staff following standardized procedures (31). Body weight was measured to the nearest 0.1 kg using a digital scale (Seca 841, Hamburg, Germany), standing height was measured to the nearest millimetre using a Harpenden portable stadiometer (Holtain, Crymych, UK) and skinfolds were measured to the nearest millimetre using a Harpenden calliper (Holtain, Crymych, UK). Measures for males included weight, height, skinfold triceps, subscapula, suprailiac and calf popliteus. Body mass index (BMI), sum of four skinfolds and trunk-extremity skinfold index ((subscapula + suprailiac) / (triceps + calf popliteus)) were calculated. In females, height, weight, skinfold biceps, triceps, subscapula, suprailiac and medial calf were measured. BMI, sum of five skinfolds and trunk-extremity skinfold index ((subscapula + suprailiac) / (triceps + medial calf)) were calculated.

In-field reliability of the anthropometric dimensions of parents at adolescent age is reported elsewhere (32, 33). For parents at adult age and offspring at adolescent age no additional in-field reliability was carried out. However, high quality of measuring techniques was aimed at by careful selection of test instructors, thorough training by experienced anthropometrists and regular supervision.

Physical fitness

In males and females, upper-body muscular endurance (bent arm hang), flexibility (sit and reach) and explosive strength or power (vertical jump) were assessed. In females, running speed (10 x 5 m shuttle run), balance (flamingo balance), speed of limb movement (plate tapping), static strength (arm pull) and lower-body muscular endurance (leg lifts) were also administered. Tests were taken as described by Claessens et al. (31).

Test-retest reliability of the physical fitness tests in parents at adolescent age is reported elsewhere (32, 33). Again, no additional in-field reliability was carried out for parents at adult age and offspring at adolescent age.

Physical activity

In parents and offspring at adolescent age, data on sports participation were collected using a standardized questionnaire via a retrospective approach: all sports activities during the period of one year before the date of investigation were recalled. The detailed information on the frequency of sports participation was combined into a global average score of time per week spent on sports practice over one year (34). Reliability and validity of the questionnaire was determined in a previous study (35).

Parents at adult age completed the Flemish Computerized Physical Activity Questionnaire (FPACQ). The FPACQ is a reliable and valid questionnaire to assess different dimensions of physical activity and sedentary behaviour in students, employed/unemployed and retired people (36, 37). To assess the average time a week spent on sports participation during leisure time parents were asked to select a maximum of three of their most important sports out of a list of 196 sports and to report the frequency and duration.

Statistical analysis

Descriptive statistics (means and standard deviations) were calculated for anthropometric characteristics, physical fitness and physical activity in parents at adolescent and adult age and in adolescent offspring.

Because Shapiro-Wilk tests for normality revealed that several variables were not normally distributed, non-parametric statistics were used. The secular trend between parents at adolescent age and adolescent offspring was investigated using Wilcoxon signed rank tests. Tracking was assessed with Spearman's rank order correlations calculated between parents at adolescent and adult age. Parent-offspring resemblance was investigated by calculating Spearman's rank order correlations between parents at adolescent age and adolescent offspring and between parents at adult age and adolescent offspring. A visual representation of the samples from the LLSLFH used for the calculation of these adolescent age-matched and the date-of-exam-matched parent-offspring correlations is given in Figure 1. To test if adolescent age-matched parent-offspring correlations were significantly higher than date-of-exam-matched parent-offspring correlations, a one-tailed t-test was used. The t-value was calculated with the formula for the difference between two dependent correlations from the same sample (38).

All analyses were conducted for males and females separately using the SAS 9.1 statistical package (SAS Institute Inc, Cary, NC). Minimal level of significance was set at $p < 0.05$.

Results

Descriptive statistics for anthropometric characteristics, physical fitness and physical activity in Flemish fathers at adolescent and adult age and their sons at adolescent age, secular trends and tracking are presented in Table 1. Adolescent sons are significantly taller, heavier, have a significantly higher trunk-extremity index and perform significantly worse on sit and reach compared to their fathers at adolescent age. No secular trends are observed for the remaining anthropometric and physical fitness characteristics nor for sports participation. For all variables the standard deviation for the father-son pair difference at adolescent age is large and exceeds the mean difference. All anthropometric and physical fitness characteristics of the fathers show a moderate and significant interage correlation between adolescence and adulthood (r = 0.29 to 0.61). Only for sports participation a low and non significant correlation is observed.

TABLE 1. Descriptive statistics (means and standard deviations) for anthropometric characteristics, physical fitness and physical activity in Flemish fathers at adolescent and adult age and their sons at adolescent age, secular trends and tracking

	Father adolescence (n = 76-78)		Father adulthood (n = 76-78)		Son adolescence (n = 76-78)		Secular trends[§]		Tracking[#]
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	r
Height (cm)	166.86	11.66	177.79	5.23	172.91	11.05	6.05***	7.47	0.40***
Weight (kg)	56.25	11.72	81.76	11.29	59.33	12.37	3.08**	9.35	0.39***
BMI (kg/m^2)	19.97	2.29	25.85	3.26	19.63	2.63	-0.34	2.56	0.51***
Sum 4 skinfolds (mm)[†]	31.73	12.87	60.90	22.60	32.73	12.68	1.00	17.28	0.49***
Trunk-extremity index[‡]	1.02	0.49	1.91	0.60	1.09	0.24	0.07*	0.42	0.35**
Bent arm hang (sec)	27.93	15.51	16.91	12.79	26.91	15.68	-1.02	19.96	0.33**
Sit and reach (cm)	24.40	6.62	19.94	9.33	17.87	8.49	-6.53***	8.25	0.61***
Vertical jump (cm)	43.14	9.13	43.35	6.85	43.00	8.72	-0.14	8.30	0.29*
Sports participation (h/week)	6.90	4.08	2.94	2.95	6.56	4.26	-0.34	5.80	0.08

*: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$

[†] triceps + subscapula + suprailiac + calf popliteus

[‡] (subscapula + suprailiac) / (triceps + calf popliteus)

[§] adolescent value son – adolescent value father

[#] correlation between adolescent value father and adult value father

Descriptive statistics for anthropometric characteristics, physical fitness and physical activity in Flemish mothers at adolescent and adult age and their daughters at adolescent age, secular trends and tracking are shown in Table 2. Adolescent daughters have a significantly lower weight and BMI and a significantly higher trunk-extremity index compared to their mothers at adolescent age. Except for flamingo balance, they perform significantly worse on all assessed physical fitness tests but a positive secular trend is found for sports participation. For all variables the standard deviation for the mother-daughter pair difference at adolescent age is large and exceeds the mean difference. Height (r = 0.97), trunk-extremity index (r = 0.67), sit and reach (r = 0.69) and vertical jump (r = 0.65) of the mothers show a high and significant tracking between adolescence and adulthood. For the remaining anthropometric and, except for arm pull, physical fitness characteristics the correlations are moderate and significant (r = 0.27 to 0.59). Only for arm pull (r = -0.06) and sports participation (r = 0.06) low and non-significant correlations are found.

Table 3 provides the father-son correlations for anthropometric characteristics, physical fitness and physical activity in adolescent age-matched and date-of-exam-matched Flemish father-son pairs. Except for sum four skinfolds, bent arm hang and sports participation, correlations between fathers and sons at similar adolescent ages are significant and range from 0.41 for sit and reach to 0.76 for height. Except for bent arm hang, vertical jump and sports participation father-son correlations at the same date-of-exam are significant and range from 0.30 for sum four skinfolds to 0.39 for BMI. Significantly higher correlations between adolescent age-matched father-son pairs compared to date-of-exam-matched father-son pairs are indicated in bold. Only for height, weight, trunk-extremity index and vertical jump age-matched father-son correlations are significantly higher than date-of-exam-matched father-son correlations. No significant differences between both correlations are found for the other variables.

Table 4 gives the mother-daughter correlations for anthropometric characteristics, physical fitness and physical activity in adolescent age-matched and date-of-exam-matched Flemish mother-daughter pairs. Only for BMI (r = 0.25) and trunk-extremity index (r = 0.27), significantly positive correlations are observed between mothers and daughters at similar adolescent ages, whereas for leg lifts (r = -0.36) the correlation is significantly negative. Correlations between mothers and daughters measured at the same date-of-exam are only significant for weight (r = 0.33), BMI (r = 0.43), sum five skinfolds (r = 0.36) and trunk-extremity index (r = 0.27). No significant differences were found between the adolescent age-matched and date-of-exam-matched mother-daughter correlations.

TABLE 2. Descriptive statistics (means and standard deviations) for anthropometric characteristics, physical fitness and physical activity in Flemish mothers at adolescent and adult age and their daughters at adolescent age, secular trends and tracking

	Mother adolescence (n = 51-65)		Mother adulthood (n = 51-65)		Daughter adolescence (n = 51-65)		Secular trends§		Tracking#
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	r
Height (cm)	163.90	5.69	165.53	5.60	164.02	5.83	0.13	7.38	0.97***
Weight (kg)	56.52	5.94	65.39	9.60	53.82	8.79	-2.70*	9.45	0.56***
BMI (kg/m^2)	21.04	2.00	23.89	3.53	19.99	3.13	-1.05**	3.14	0.51***
Sum 5 skinfolds (mm)†	61.87	19.76	90.17	31.39	63.70	24.74	1.83	24.91	0.51***
Trunk-extremity index‡	0.72	0.19	0.95	0.28	0.82	0.18	0.10**	0.24	0.67***
Bent arm hang (sec)	13.72	9.58	5.09	8.01	10.42	10.62	-3.29*	13.10	0.59***
Sit and reach (cm)	27.69	6.29	24.03	8.85	23.10	8.15	-4.59***	9.83	0.69***
Vertical jump (cm)	34.59	5.93	29.52	5.17	31.57	5.54	-3.02**	7.95	0.65***
10 x 5 m shuttle run (sec)	21.07	1.24	23.85	1.79	22.67	1.50	1.60***	1.90	0.37**
Flamingo balance (n/min)	11.60	5.68	11.27	5.64	13.27	6.54	1.67	7.49	0.33**
Plate tapping (n/20 sec)	84.66	9.96	85.81	14.75	79.35	13.38	-5.31**	16.88	0.27*
Arm pull (kg)	42.48	8.11	36.84	9.90	32.83	8.49	-10.66***	12.03	-0.06
Leg lifts (n/20 sec)	16.49	3.24	15.04	3.48	14.96	3.32	-1.53*	5.28	0.38**
Sports participation (h/week)	4.41	2.53	1.82	2.07	5.41	3.27	0.99*	4.15	0.06

*: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$
† biceps + triceps + subscapula + suprailiac + medial calf
‡ (subscapula + suprailiac) / (triceps + medial calf)
§ adolescent value daughter – adolescent value mother
# correlation between adolescent value mother and adult value mother

TABLE 3. Father-son correlations for anthropometric characteristics, physical fitness and physical activity in adolescent age-matched and date-of-exam-matched Flemish father-son pairs

	r_{am}§ father adolescence-son adolescence (n = 76-78)	r_{doem}# father adulthood-son adolescence (n = 76-78)
Height	**0.76*** **	**0.36** **
Weight	**0.71*** **	**0.37*** **
BMI	0.51***	0.39***
Sum 4 skinfolds†	0.20	0.30**
Trunk-extremity index‡	**0.51*** **	**0.32** **
Bent arm hang	0.22	0.08
Sit and reach	0.41***	0.34**
Vertical jump	**0.58*** **	**0.14**
Sports participation	-0.00	-0.00

*: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$
† biceps + triceps + subscapula + suprailiac + medial calf
‡ (subscapula + suprailiac) / (triceps + medial calf)
§ r_{am} = age-matched correlation
# r_{doem} = date-of-exam-matched correlation
Significantly higher father adolescence-son adolescence compared to father adulthood-son adolescence correlations are indicated in bold

TABLE 4. Mother-daughter correlations for anthropometric characteristics, physical fitness and physical activity in adolescent age-matched and date-of-exam-matched Flemish mother-daughter pairs

	r_{am}§ mother adolescence-daughter adolescence (n=51-65)	r_{doem}# mother adulthood-daughter adolescence (n = 51-65)
Height	0.13	0.09
Weight	0.17	0.33**
BMI	0.25*	0.43***
Sum 5 skinfolds†	0.23	0.36**
Trunk-extremity index‡	0.27*	0.27*
Bent arm hang	0.25	0.25
Sit and reach	0.11	0.19
Vertical jump	0.05	0.14
10 x 5 m shuttle run	0.12	0.22
Flamingo balance	0.22	0.23
Plate tapping	0.03	0.22
Arm pull	-0.14	0.25
Leg lifts	-0.36**	-0.14
Sports participation	-0.02	-0.09

*: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$
† biceps + triceps + subscapula + suprailiac + medial calf
‡ (subscapula + suprailiac) / (triceps + medial calf)
§ r_{am} = age-matched correlation
# r_{doem} = date-of-exam-matched correlation
No significant differences were found between the mother adolescence-daughter adolescence compared to mother adulthood-daughter adolescence correlations

Discussion

The purpose of this study was to compare sex-specific parent-offspring correlations for anthropometric characteristics, physical fitness and physical activity measured at the same adolescent chronological age with those measured at the same date-of-exam (adult parents-adolescent offspring).

The magnitude of the date-of-exam-matched parent-offspring correlations generally falls within the range of time-point-matched parent-offspring correlations reported in the literature (10-17). Since, to our knowledge, no other studies have calculated correlations between parents and offspring at the same adolescent age, no comparison could be made for the age-matched correlations. Only for height, weight, trunk-extremity index and vertical jump in males, the hypothesis of higher age-matched compared to date-of-exam-matched parent-offspring correlations could be confirmed. In the Trois-Rivières Study, correlations for BMI between adult fathers (39.5 (0.4) years) and mothers (36.6 (0.4) years) and their sons and daughters at 10, 11, 12 and 35 years were also very similar (24). In 10-year-old Belgian twins and their parents, Maes et al. (13) found a reduced genetic transmission for vertical jump, arm pull and bent arm hang but not for shuttle run, plate tapping flamingo balance, sit and reach, leg lifts and sum of skinfolds. However, Peeters et al. (39) showed that the observed stability of vertical jump during adolescence in these twins was mainly caused by stable genetic factors.

Four potential explanations for the fact that the stated hypothesis could not be confirmed for most variables can be formulated. A first factor concerns the variability in the observed secular trends. At population level, average secular trend effects are reported without attention to standard deviations as consecutive cross-sectional datasets are used (26, 40). However, the relatively large standard deviations found for the parent-offspring pair differences at adolescent age in the present study reflect variability in secular trends between parent-offspring pairs. This variability lowers the age-matched parent-offspring correlations and consequently increases the similarity between the age-matched and date-of-exam-matched correlations. Both behavioural/environmental and genetic changes might underlie secular trends in anthropometric characteristics, physical fitness and physical activity (26). Since the present study only spans one generation, behavioural/environmental factors are likely responsible. The variability in secular trends between parent-offspring pairs is probably caused by gene-environment interactions, i.e. the way a subject reacts to environmental changes depends on his/her genotype (11). A second explanatory phenomenon is tracking. If tracking would be perfect ($r = 1$), the age-matched and date-of-exam-matched parent-offspring Spearman’s rank order correlations would be the same because all parents would keep their relative position within the group of parents from adolescence to adulthood. Consistent with the literature (27, 41), in the present study correlations between the adolescent and adult values of the parents for anthropometric characteristics and, except for arm pull in females, physical fitness are moderate to high causing a moderate to high similarity between the age-matched and date-of-exam-matched correlations. Third, although anthropometric and physical fitness characteristics in adolescents might, in part, reflect maturity associated variation (42-44), in the present study parents and offspring were matched on chronological age. However, 47 of the 80 father-son pairs could also be matched on less than one year difference in skeletal age, assessed with the Tanner-Whitehouse II method (45), and this did not substantially change the results in favour of the stated hypothesis (data not shown). The higher correlations observed for height and weight in chronological age-matched compared to date-of-exam-matched pairs remained significantly higher for skeletal age-matched pairs and the skeletal age-matched correlation for BMI also became significantly higher than the date-of-exam-matched correlation. On the other hand, the skeletal age-matched correlation for vertical jump was no longer significantly higher than the date-of-exam-matched correlation and for the sum of four skinfolds the date-of-exam-matched correlation became significantly higher than the skeletal age-matched correlation. Since mothers were only tested once during adolescence, this could not be investigated in mother-daughter pairs. Fourth, apart from biological maturity, body dimensions might also contribute to the explanation of strength and motor performance (46, 47). Therefore, the difference between age-matched and date-of-exam-matched parent-offspring correlations was also investigated after adjustment of the physical fitness tests for height, weight, BMI and sum of skinfolds but results did not lead to an acceptance of the stated hypothesis (data not shown). In males, after division by weight, BMI or sum of four skinfolds, the age-matched correlation for vertical jump was no longer significantly higher than the date-of-exam-matched correlation and sit and reach expressed by unit weight resulted in a significantly higher date-of-exam-matched compared to age-matched correlation. In females, arm pull divided by unit weight revealed higher date-of-exam-matched compared to age-matched correlations and leg lifts expressed by unit weight showed a higher but negative age-matched compared to date-of-exam-matched correlation.

The higher age-matched compared to date-of-exam-matched father-son correlations for height, weight, trunk-extremity index and vertical jump do not appear in mothers and daughters. This could be attributed to the fact that mother-daughter pairs were not matched at an adolescent chronological age difference of less than one year. The adolescent chronological age difference was 1.66 (1.64) years ($p < 0.001$) between mothers and daughters whereas it was only 0.05 (0.37) year (NS) between fathers and sons. In addition, the adolescent chronological age of the mothers was 16.69 (1.04) years with an associated skeletal age of 15.43 (0.84) years (females with a skeletal age of 16 years are skeletally mature). This indicates that the mothers at adolescent age were closer to maturity compared to the fathers with an adolescent chronological age of 15.52 (1.78) years and an associated skeletal age of 15.07 (2.06) years (males with a skeletal age of 18 years are skeletally mature).

It should be noted that the hypothesis for the present study was stated primarily from a biological point of view. Alternatively, especially for variables largely influenced by shared familial- or macro-environmental factors (e.g., sports participation; nutrition: body composition) also the opposite hypothesis might be plausible. For most variables in females, although not significant, the date-of-exam-matched mother-daughter correlations tended to be higher than the age-matched mother-daughter correlations. However, except for height, weight, trunk-extremity index and vertical jump in males, no clear evidence was found supporting one of both hypotheses in the present study.

To our knowledge, this is the first study to compare sex-specific correlations for anthropometric characteristics, physical fitness and physical activity between parents and offspring measured at the same adolescent age and those measured at the same date-of-exam. However, some limitations of this study should also be addressed. First, since it concerns a longitudinal study in which only sex-specific parent-offspring pairs were selected with approximately the same adolescent chronological age, the sample size was limited. This might hamper the detection of significant differences between age-matched and date-of-exam-matched parent-offspring correlations. In addition, the longitudinal design might also reduce the generalizability of the results. Third, the number of mother-daughter pairs with less than one year difference in adolescent chronological age was limited and therefore larger age-differences were included in the study. Fourth, whereas physical activity is a complex behaviour consisting of several dimensions, only sports participation was taken into account because of lack of available data for other components of physical activity for the parents at adolescent age. Moreover, the sports participation questionnaire used for parents and offspring at adolescent age differed from that used for the adult parents. Finally, no data were available on aerobic fitness measured with the same protocol.

In conclusion, results from the present study indicate that in males adolescent chronological age-matched father-son correlations are significantly higher than date-of-exam-matched father-son correlations for height, weight, trunk-extremity index and vertical jump. For these variables, parent-offspring similarity and associated heritability or transmissibility might be underestimated in classical parent-offspring (data-of-exam-matched) designs. For BMI, sum four skinfolds, bent arm hang, sit and reach and sports participation in males and for all assessed anthropometric, physical fitness and physical activity variables in females, no significant differences were found between adolescent chronological age-matched or date-of-exam-matched parent-offspring correlations. However, additional studies, preferably with larger sample sizes are necessary to confirm or contradict these findings.

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SECTION 3

SUMMARY AND GENERAL DISCUSSION

The importance of regular physical activity and of physical fitness for health has been widely accepted and extensively documented (Biddle, 2004; Blair et al., 2001; Bouchard et al., 1990, 1994; Kesaniemi et al., 2001; Strong, 2005). However, before developing and implementing health strategies to improve physical activity and physical fitness it is important to 1) be able to accurately assess physical activity and physical fitness, 2) be well informed about the status and (generation- or age-related) change of the levels of physical activity and physical fitness and 3) have clear insight into the causes underlying the phenotypic variation in physical activity and physical fitness. The purpose of this thesis was to document each of these aspects in the Flemish population using data from the Leuven Longitudinal Study on Lifestyle, Fitness and Health (LLSLFH) 1969-2004. In accordance with this, the research articles in Section 2 of this thesis were divided into 3 parts: 1) a methodological part (Part 1), 2) a longitudinal epidemiological part (Part 2), and 3) a genetic epidemiological part (Part 3). Each part consisted of two chapters each addressing one specific research question related to the topic of that part.

In the third section of this thesis a summary of the main findings of the six research questions is provided followed by a general discussion including implications, limitations and opportunities for future research.

1. Summary

Because each of the six research questions of this thesis and the respective results have already been extensively documented, compared with other studies and discussed in Section 2, only a summary of the main findings, a brief discussion and a conclusion is provided here. For more detailed information, the reader is referred to the specific chapters in Section 2.

Section 2, Part 1: Methodological issues

Research question 1 (Section 2, Part 1, Chapter 1): What are the methodological issues associated with longitudinal research? Findings from the Leuven Longitudinal Study on Lifestyle, Fitness and Health (1969-2004).

Three difficulties associated with longitudinal research were documented by means of findings from the LLSLFH, more specifically, the “imperfect” design, the evolution of data collection methods and the representativeness of the ongoing study sample.

The Leuven Growth Study of Belgian Boys (LGSBB) (1969-1974) and the Leuven Growth Study of Flemish Girls (LGSFG) (1979-1980) were primarily initiated to collect information on status, change and progress of anthropometric characteristics, physical fitness, physical activity and biological maturation. The extension of the LGSBB into the LLSLFH with five-yearly follow-ups since 1986 and the expansion of the LLSLFH with spouses and offspring in the Flemish Longitudinal Offspring Study (FLOS) in 2002-2004 resulted in a unique dataset of anthropometric characteristics, physical fitness and physical activity assessed in parents at adolescent and adult age and their adolescent offspring. This allowed answering more complex research questions related to secular trend, tracking, familial aggregation and parent-offspring resemblance (see research questions 3 through 6).

The evolution of data collection methods associated with the adaptation of the research design throughout the LLSLFH largely reflected the changing ideas about physical fitness (from performance- to health-related fitness), body composition (from skinfolds over bio-electrical impedance to dual-energy X-ray absorptiometry) and physical activity (from sports participation to a broad range of activities of daily life), the continuing search for new and better measurement techniques (e.g., laboratory tests, computerized questionnaires, accelerometers) and the need for adaptations with age (from childhood and adolescence to adulthood).

Ongoing study participants could generally be considered representative with regard to body composition and, except for adolescence in males, physical activity. For physical fitness results were somewhat less straightforward. Follow-up participants performed better or worse than non-follow-ups or participants of Theme 1 of the Policy Research Centre SPAH for some physical fitness tests, while for others no significant differences were found. Especially men and women with a higher socio-economic status (level of education or level of employment) seem to continue participating in the LLSLFH. This might somewhat hamper the generalizability of results.

→ *In conclusion, the LLSLFH provides unique research opportunities but is also faced with several limitations. However, when aware of these possible "pitfalls" several measures (e.g., thorough planning, appropriate sampling procedures, reimbursement of travel expenses, personal results, newsletters, telephone interviews with dropouts) should be taken to prevent or limit them as much as possible and to interpret the results in the right perspective.*

Research question 2 (Section 2, Part 1, Chapter 2): Is the Flemish Physical Activity Computerized Questionnaire (FPACQ) a reliable and valid instrument to assess different dimensions of physical activity and sedentary behaviour in Flemish adults?

The FPACQ, a computerized questionnaire developed to assess different dimensions of physical activity (e.g., occupation, transportation, sports participation) and sedentary behaviour (e.g., watching TV) during a usual week, was used in the most recent phase of the LLSLFH. Reliability was investigated with a test-retest interval of two weeks. Validity was studied with the RT3 Tri-axial Research Tracker (RT3), in combination with a written seven-day activity record, as objective criterion measure.

Two-week test-retest reliability of the FPACQ was good to excellent in employed/unemployed men and women (ICCs ranging from 0.67 to 0.99) and somewhat lower, but except for time spent eating (ICC = 0.24 in males and 0.14 in females), still fair to excellent in retired people (ICCs ranging from 0.57 to 0.96). The two-week test-retest interval was considered long enough to obtain a measure of reliability not contaminated by recall of answers from the first administration but yet short enough to minimize true changes in activity pattern. In addition, recall of the usual activity pattern should be less sensitive to the interval between tests compared to past-day or past-week recalls. It should be noted that, because individuals participated both in the reliability and validity study, they were asked to wear the RT3 and to complete the written seven-day activity record in between the two measurements of the FPACQ. This may have increased their awareness about physical activity probably leading to an underestimation of the reproducibility of the FPACQ (Wendel-Vos et al., 2003). Moreover, the first administration of the FPACQ itself might have served as a form of “primer”, i.e. participant might have paid closer attention to their activities after the first administration of the questionnaire. Therefore, the discrepancy between the first and second administration might reflect a more accurate recall on the second administration (Schuler et al., 2001). Several factors often observed in older or retired people are likely to explain the lower reliability in this group: 1) mental conditions (e.g., temporary distractions or lack of concentration, impaired cognitive ability, reduced information processing speed) affecting performance on questionnaires (Rikli, 2000), 2) lower variability of activities, 3) more light to moderate and less structured activities which are more difficult to recall (Washburn, 2000), and 4) less computer experience (Cutler et al., 2003).

Correlations between the RT3 and the FPACQ generally supported the relative validity of the FPACQ for employed/unemployed people (r ranging from 0.27 to 0.88). In retired people, again somewhat lower values were found but most variables still reached at least moderate correlations (r ranging from 0.15 to 0.85). Concerning absolute validity, the FPACQ generally overestimated physical activity and underestimated sedentary behaviour compared to the RT3. Several factors are reasonable to explain the predominantly moderate correlations between the FPACQ and the RT3. First, mainly due to social desirability bias, respondents tend to overreport physical activity and underreport sedentary behaviour whereas waist-mounted accelerometers tend to underestimate true physical activity due to missed activities (e.g., swimming, arm movements, cycling, locomotion on a gradient) (Hendelman et al., 2000; Klesges et al., 1990). Second, energy expenditure of the FPACQ was calculated using the MET-values of the Compendium of Activities (Ainsworth et al., 2000) not taking into account differences in intensity or movement efficiency whereas RT3-energy expenditure was estimated via the prediction equation provided by the manufacturer. Third, the FPACQ assesses usual week activity whereas the RT3 only measures the specifically monitored last week activity. Fourth, no information is available concerning the compliance of the participants with the completion of the written seven-day activity record and the maintenance of the usual activity pattern. Fifth, the use of the written seven-day activity record might be associated with reporting or coding errors. To explain the lower validity of the FPACQ in retired people compared to employed/unemployed people, three reasons should be added to those already mentioned for reliability. First, motion sensors have been shown to be less accurate in older people characterized by slow walking, shuffling or gait abnormalities (Cyarto et al., 2004). Next, the Compendium of Activities (Ainsworth et al., 2000) used to determine the MET-values of the activities reported in the FPACQ has been developed based on normal activity patterns of young adults, but may be less accurate for use with older adults. Finally, older adults may have difficulties following the rather tedious procedures of the validity study due to their inability to understand the directions or their lack of motivation (Rikli, 2000).

→ *In conclusion, particularly in employed/unemployed people and slightly less in retired people, the FPACQ is a reliable and reasonably valid questionnaire for the assessment of different dimensions of physical activity and sedentary behaviour.*

Section 2, Part 2: Longitudinal epidemiological studies

Research question 3 (Section 2, Part 2, Chapter 1): Is there a secular trend in anthropometric characteristics, physical fitness, physical activity and biological maturation in Flemish adolescents?

Secular trends refer to changes over time, usually between successive generations, and are most commonly derived from cross-sectional independent population samples (Malina, 1978, 2004; Malina et al., 2004; Roche, 1979). In the present study cross-sectional data of boys participating in the LGSBB (1969-1974) and of girls participating in the LGSFG (1979-1980) were compared with those of boys and girls from the Eurofit-Barometer 2005 (Duvigneaud et al., 2006). However, unique intra-familial secular trends could also be studied by combining data of the fathers and mothers participating in the LGSBB or LGSFG with data of their sons or daughters measured at approximately the same adolescent age in the FLOS (2002-2004).

The cross-sectional analysis generally revealed that recently measured adolescents were taller, heavier and had a higher BMI compared to those measured 25 to 35 years ago. They were also generally fatter, had a more android fat patterning and performed worse on most physical fitness tests.

Similar to the cross-sectional analysis, the parent-offspring analysis generally revealed positive secular trends for height and trunk-extremity index and negative secular trends for the performance on several fitness tests. The fact that the positive secular trends in weight, BMI and skinfolds of the cross-sectional study were not entirely confirmed in the parent-offspring study was probably due to higher similarity in genetic and familial background, higher socio-economic status and more health-consciousness of the latter (Lowry et al., 1996). That sports participation also remained unchanged between parents and offspring seemed incongruent with the observed decrease in performance on several fitness tests. However, it should be noted that sports participation is only one dimension of physical activity and other studies have suggested that changes in contemporary lifestyle including safety and increased availability of sedentary technologies might nevertheless decrease the overall physical activity level (Dollman et al., 2005; Eisenmann et al., 2004; Westerstahl et al., 2003b;).

Changes in anthropometric and physical fitness characteristics between children and adolescents of different generations might, in part, reflect maturity-associated variation (Beunen et al., 1981, 1994, 1997; Jones et al., 2000; Malina, 1978, 2004; Malina et al., 2004; Roche, 1979). This was the case in father-son pairs for weight, skinfold suprailiac and trunk-extremity index where the positive secular trend disappeared and for BMI where a negative secular trend appeared after adjustment for the observed positive secular trend in adolescent skeletal age between fathers and sons. Between mothers and daughters, no secular trend was observed in skeletal maturation or age at menarche.

Apart from biological maturity, secular trends in body dimensions might also contribute to the explanation of secular trends in strength and motor performance (Beunen et al., 1983; Malina, 1975, 1978; Westerstahl et al., 2003a). However, the expression of the physical fitness tests per unit weight or stature in both the cross-sectional and parent-offspring analyses generally revealed that the observed negative secular trend in physical fitness was largely independent of the observed positive secular trends in weight or stature.

→ *In conclusion, several anthropometric characteristics in both sexes and skeletal age in males demonstrate a positive secular trend from 1969 to 2005 in Flemish adolescents, while a negative secular trend is observed for most physical fitness tests. No secular trend is apparent for sports participation.*

Research question 4 (Section 2, Part 2, Chapter 2): Do anthropometric characteristics, physical fitness and physical activity track from adolescence to adulthood in Flemish females?

Tracking refers to the stability of relative rank or position within a group over time and requires longitudinal follow-ups to be investigated. Limited data are available on tracking of physical fitness and physical activity from childhood and adolescence into adulthood and even fewer in females (Malina 2001a, 2001b, 2001c). The LLSLFH uniquely contributes to the study of tracking of physical fitness and physical activity in females from adolescence to middle adulthood.

Most anthropometric and physical fitness characteristics were relatively stable from adolescence to adulthood (r ranging from 0.20 to 0.96). Sports participation was not a stable characteristic (r = 0.13). Three potential explanations for the higher stability of physical fitness compared to physical activity are reasonable. First, physical activity is a behaviour associated with more modifiable and volatile factors (e.g., social support, occupation), whereas physical fitness is likely to be associated with more stable factors (e.g., genotype, morphology) (Bouchard et al., 1997; Trost et al., 2002). Second, the praising of physical activity may change with age – as do opportunities – especially with children in the household (Malina, 2001a, 2001c). A third factor concerns the greater measurement error associated with assessment of physical activity by questionnaire compared to the more objective physical fitness tests (Vanhees et al., 2005).

From adolescence to adulthood, 84.5% and 63.6% respectively remained in the normal weight (BMI < percentile 80) and overweight (BMI ≥ percentile 80) group, whereas 54.4% and 62.5% respectively remained in the active (sports participation ≥ 3 hours/week in adolescence and ≥ 1.5 hours/week in adulthood) and less active group (sports participation < 3 hours/week in adolescence and < 1.5 hours/week in adulthood).

The odds of being overweight in adulthood were 9.53 times greater in overweight compared to normal weight adolescent girls. The odds ratios for overweight in adulthood according to adolescent activity status were not significant. This was also the case for the odds ratios for less activity in adulthood according to adolescent activity or weight status.

→ *In conclusion, in Flemish females anthropometric and physical fitness characteristics demonstrate higher levels of stability from adolescence to middle adulthood than physical activity. Weight status during adolescence is reasonably indicative of adult weight status and a pattern of less activity rather than activity tends to be continued from youth into adulthood.*

Section 2, Part 3: Genetic epidemiological studies

Research question 5 (Section 2, Part 3, Chapter 1): 1) Do anthropometric characteristics, physical fitness and physical activity aggregate within Flemish nuclear families and 2) what proportion of the variability in these traits can be explained by genetic (Vg), common environmental (Vc) and unique environmental (Ve) factors?

Inclusion of spouses and offspring in the FLOS provided the opportunity to investigate familial aggregation in anthropometric, physical fitness and physical activity characteristics and to quantify the proportion of the variability observed in these traits attributable to genetic, common and unique environmental factors.

Correlations between different family members generally confirmed the existence of a familial aggregation in anthropometric characteristics, physical fitness and physical activity also observed in other studies (Beunen and Thomis, 1999, 2000; Bouchard et al., 1997; Koopmans et al., 1994; Maes et al., 1997).

To estimate the relative contribution of genetic, common and unique environmental factors, model fitting-techniques decomposing the total variance based on the kinship information were used. For BMI, sum of five skinfolds, trunk-extremity index, flexibility and muscular endurance a model including both unique environmental (Ve ranging from 39% to 53%) and genetic factors (Vg ranging from 47% to 61%) gave the best fit. A combination of unique and common environmental factors was most adequate for balance (Ve = 79%, Vc = 21%) and sports participation (Ve = 80%, Vc = 20%), while a combination of all three factors fitted the data best for waist circumference (Ve = 57%, Vc = 31%, Vg = 12%) and explosive strength. (Ve = 63%, Vc = 13%, Vg = 24%). Three remarks should be kept in mind when interpreting these results. First, unique environmental factors also include measurement error. Consequently the higher explained variance by unique environmental factors for sports participation compared to anthropometric and physical fitness variables might, at least partly, be attributed to a greater measurement error associated with assessment of physical activity by questionnaire compared to the more objective anthropometric measures and physical fitness tests (Vanhees et al., 2005). Second for balance, sports participation, waist circumference and explosive strength significant spousal correlations were observed (r ranging from 0.11 to 0.31). These correlations contribute to the estimation of the common environmental component in the QTDT program (according to a kinship of 0 between spouses a spousal correlation of 0 is expected) (Abecasis et al., 2000). This is correct in the case that spousal resemblance is only caused by shared spousal environmental factors during the years of cohabitation (shared household) and/or similarities in the interests and backgrounds of spouses (assortative mating by social homogamy). However, when selection of spouses is based on visible characteristics (assortative mating by phenotypic assortment) this might result in an underestimation of the genetic component and an overestimation of the common environmental component (Knuiman et al., 1996; Maes et al., 1996; Silventionen et al., 2003). Third, genetic and environmental factors should not be viewed as being mutually exclusive. They are intrinsically linked and interact with each other in a complex manner (Bouchard et al., 1997).

→ *In conclusion, familial aggregation in Flemish nuclear families is explained by genetic factors for BMI, sum of five skinfolds, trunk-extremity skinfold index, flexibility and muscular endurance and by common environmental factors for balance and sports participation, while both factors are important for waist circumference and explosive strength. However, for all variables at least about half of the variance is explained by unique environmental factors.*

Research question 6 (Section 2, Part 3, Chapter 2): Is the parent-offspring resemblance in anthropometric characteristics, physical fitness and physical activity higher in adolescent chronological age-matched compared to date-of-exam-matched Flemish parent-offspring pairs?

Although time-point-matched parent-offspring correlations might be disturbed by generation-specific genetic and/or environmental factors, familial resemblance is usually investigated using intra-pair correlations between family members measured at the same time-point (Beunen and Thomis, 1999; Beunen et al., 2003; Bouchard et al., 1988, 1997; Maes et al., 1996, 1997; Peeters et al., 2003; Pérusse et al., 1987, 1988a, 1988b, 1989; Stubbe et al., 2005). The unique combination of longitudinal and familial assessments in the LLSLFH provided data on parents at adolescent and adult age and their adolescent offspring. This created the opportunity to compare correlations between parents and offspring measured at approximately the same adolescent chronological age (age-macthed) with those measured at the same date-of-exam (date-of-exam-matched: adult parents-adolescent offspring). It was hypothesized that age-matched parent-offspring correlations would be higher than time-point-matched parent-offspring correlations.

For height, (r = 0.76 versus 0.36), weight (r = 0.71 versus 0.37), trunk-extremity skinfold index (r = 0.51 versus 0.32) and vertical jump (r = 0.58 versus 0.14) in males, adolescent chronological age-matched father-son correlations were significantly higher than date-of-exam-matched father-son correlations. For these variables, parent-offspring similarity and associated heritability or transmissibility might be underestimated in classical parent-offspring (time-point-matched) designs. For BMI, sum four skinfolds, bent arm hang, sit and reach and sports participation in males and all assessed anthropometric, physical fitness and physical activity variables in females, no significant differences were found between adolescent chronological age-matched or date-of-exam-matched parent-offspring correlations. This failure to support the stated hypothesis for most variables might have four explanations. First, the large variability in the observed within-family secular trends lowers the age-matched parent-offspring correlations and consequently increases the similarity between the age-matched and date-of-exam-matched correlations. Second, the moderate to high tracking observed for most variables causes a moderate to high similarity between the age-matched and date-of-exam-matched correlations. Third, anthropometric and physical fitness characteristics in adolescents might, in part, reflect maturity associated variation (Beunen et al., 1981, 1994, 1997; Jones et al., 2000). However, matching a subsample of the father-son pairs on skeletal age assessed according to the method of Tanner and Whitehouse (TW2) (Tanner et al., 1975) instead of chronological age did not substantially alter the results in favour of the stated hypothesis. Since mothers were only tested once during adolescence this could not be investigated in mother-daughter pairs. Fourth, apart from biological maturity, body dimensions might also contribute to the explanation of strength and motor performance (Malina, 1975; Beunen et al., 1983). Therefore, the difference between age-matched and date-of-exam-matched parent-offspring correlations was also investigated after adjustment of the physical fitness tests for height, weight, BMI or sum of skinfolds but this also did not lead to an acceptance of the stated hypothesis. The absence of higher chronological age-matched compared to date-of-exam-matched correlations for height, weight, trunk-extremity skinfold index and vertical jump in mother-daughter pairs compared to father-son pairs could be attributed to the fact that the adolescent chronological age difference between mothers and daughters was higher than between fathers and sons. Moreover, at adolescent age the mothers were closer to skeletal maturity compared to the fathers.

It should be noted that the hypothesis for this study was primarily stated from a biological point of view. However, especially for variables largely influenced by shared familial- or macro-environmental factors (e.g., sports participation; nutrition: body composition) the opposite hypothesis might be more plausible. In the present study no clear evidence was found supporting one of both hypotheses.

→ *Only for height, weight, trunk-extremity skinfold index and vertical jump in males, the stated hypothesis of higher chronological adolescent age-matched compared to date-of-exam-matched parent-offspring correlations could be confirmed.*

2. General discussion

The research questions of this thesis were derived from the unique and valuable dataset of the LLSLFH from 1969 to 2004. Therefore, the methodological part of this thesis started with an extended overview of the evolution of the design, the data collection methods and the representativeness of this study over the years.

During that extended period of time, advancing knowledge about physical fitness, body composition and physical activity, newly developed techniques and the need for adaptations with age resulted in the change and improvement of the applied assessment methods. Concerning physical activity, the FPACQ, a newly developed computerized questionnaire to assess different dimensions of physical activity and sedentary behaviour during a usual week, was introduced in the most recent phase of the study (2002-2004). Before new instruments can be widely applied, their reliability and validity has to be investigated. The reliability and validity of the FPACQ for 12- to 18-year-old boys and girls was already shown in a previous study (Philippaerts et al., 2006). In the present thesis, particularly in employed/unemployed and slightly less in retired adults, the FPACQ has also been demonstrated to be a reliable and reasonably valid questionnaire. However, three limitations should be kept in mind when interpreting these results. First, participants of the reliability and validity study of the FPACQ were all volunteers already participating in Theme 1 of the Policy Research Centre SPAH. Their possibly greater knowledge of and familiarity with physical activity might somewhat hamper the generalizability of the results. A comparison of the participants of Theme 1 with people refusing to participate but willing to complete a mailed questionnaire on several key variables of the study revealed no difference between both groups for weight, BMI and time spent watching TV/video or playing computer games. However, participants had a significantly higher socio-economic status (level of education, level of employment) and spent significantly more time in sports. On the other hand, non-participants willing to complete the mailed questionnaire spent significantly more time in moderate and vigorous physical activities, possibly related to their occupation. Moreover, non-participants who completed the mailed questionnaire probably also differ from those refusing to complete it (non-participants without information on the key variables of the study). Therefore, it might be generalized that in all studies where participants are actually measured or tested the question should be raised if it is possible to obtain a sample representative for the general population. In theory it is perfectly possible to draw a representative sample but, because people cannot be obliged to participate, it is difficult to turn this into practice. This generally results in study samples representative for the population that can and wants to be measured and tested but less representative for the entire population.

Second, the combination of the RT3 Triaxial Research Tracker with the written seven-day activity record, as the objective criterion measure to investigate the concurrent validity of the FPACQ made it possible to divide the RT3-output into the same dimensions as calculated from the FPACQ, allowing a more comprehensive investigation of concurrent validity compared to most other studies where only broad sub-categories of light, moderate and high intensity activities based on predetermined accelerometer cut-points are used. However, the coding of each one-minute epoch of the seven-day RT3 output according to the specific activity reported at that time in the written seven-day activity record was very time-consuming and could be associated with reporting or coding errors. A possible solution might be the development of an accelerometer equipped with a palm top interface enabling participants to add detailed activity information directly into the activity record of the accelerometer (Healy, 2000). The development of an accelerometer with different sensors on different parts of the body able to determine what activities are being performed based on the stored activity counts of the x-, y-, and z-axis of each sensor might also be worthwhile but is probably more difficult to accomplish.

Third, despite the important advantages computerized questionnaires have compared to written surveys (Turner et al., 1998; Crawley et al., 2000; Schmitz et al., 2000; Vereecken, 2001; Wijndaele et al., in press), some difficulties may occur in people without computer experience. After a brief explanation of the use of the computer mouse, most of them are able to complete the FPACQ on their own but a limited number of mainly older people still do not succeed without assistance of a staff member. Due to social desirability bias, the presence of this staff member might result in more overreporting of physical activity and underreporting of sedentary behaviour (Klesges et al., 1990). Although it seems reasonable to assume that in the future seniors will be as accustomed to using computers as are middle-aged and young adults now (Cutler et al., 2003), it might be useful to adapt the FPACQ for people who are not able to operate a computer mouse. The conversion of the computerized version of the questionnaire into a paper-and-pencil format might be a possibility. However, this nullifies all advantages associated with computerized questionnaires. Another, possibly better, solution maintaining all advantages of computerized questionnaires might be the development of a touch-screen version of the FPACQ.

To further expand the use of the FPACQ as a physical activity-assessment tool, an online webpage application is being developed at present. This instrument will have multi-center/multi-computer abilities without need of individual installation of the program application and will allow simultaneous completion of the questionnaire by large numbers of people from different locations.

Apart from the evolution of data collection methods, the research design and associated research questions also evolved throughout the LLSLFH. Whereas the LGSBB (1969-1974) and the LGSFG (1979-1980) were primarily initiated to collect information on status, change and progress of anthropometric characteristics, physical fitness and physical activity, the extension of the LGSBB into the LLSLFH with five-yearly follow-ups since 1986 and the expansion of the LLSLFH with spouses and offspring in the FLOS in 2002-2004 allowed answering new and more complex research questions related to secular trend, tracking, familial aggregation and parent-offspring resemblance. A schematic overview of the specific samples of the LLSLFH used for each of these research questions was given in Figure 3 of the introduction and outline of this thesis. To our knowledge, until now no other studies have such a valuable dataset, including anthropometric characteristics, physical fitness and physical activity assessed in parents at adolescent and adult age and their adolescent offspring, at their disposal.

In the general introduction and outline of this thesis, the “Toronto consensus model” on relationships between physical activity, health-related fitness and health proposed by Bouchard and Shepard (1994) and the conceptual model on how childhood exercise habits may affect health throughout life proposed by Blair et al. (1989) was also described. The combination of both models permits the construction of an *extended model* induced by the longitudinal data structure of the LLSLFH. A visual representation of this *extended model* and the integration of the research questions of the longitudinal epidemiological (secular trend and tracking) and genetic epidemiological (familial aggregation and parent-offspring resemblance) part of this thesis in this model is shown in Figure 1.

In parents at adolescent and adult age and in their adolescent offspring, physical activity, physical fitness and health influence each other in a reciprocal manner (double headed grey arrows). In addition, adolescent physical activity, physical fitness and health may directly (single headed grey or blue arrows) or indirectly (through the double headed grey arrows) influence adult physical activity, physical fitness and health. Moreover, genetic and environmental factors (bold black arrows) also affect physical activity, physical fitness and health and their interrelationships during adolescence and adulthood, from adolescence to adulthood and from parents to offspring (bold grey lines).

The main focus of the present thesis was on the physical activity and physical fitness components of the model. The longitudinal epidemiological part included the study of secular trend and tracking of these traits. In addition to the traditional cross-sectional analysis of secular trends, the combination of parents at adolescent age with their adolescent offspring also allowed the investigation of unique intra-familial secular trends (red arrows). The adolescent and adult values of the parents were used to study tracking (blue arrows). The familial analyses in the genetic epidemiological part were conducted to provide a better understanding of the causes underlying the observed phenotypic variation in physical activity and physical fitness. For the study on familial aggregation data of parents at adult age and their adolescent offspring were combined (yellow lines). Parent-offspring resemblance was investigated between parent-offspring pairs measured at the same time-point (adult parent-adolescent offspring) and parent-offspring pairs measured at the same adolescent age (green lines).

The calculation of familial or parent-offspring correlations to investigate this familial or parent-offspring resemblance and the use of the straightforward variance components testing in QTDT (Abecasis et al., 2000) to determine the relative contribution of genetic, common and unique environmental factors were useful statistical techniques for a first exploration of

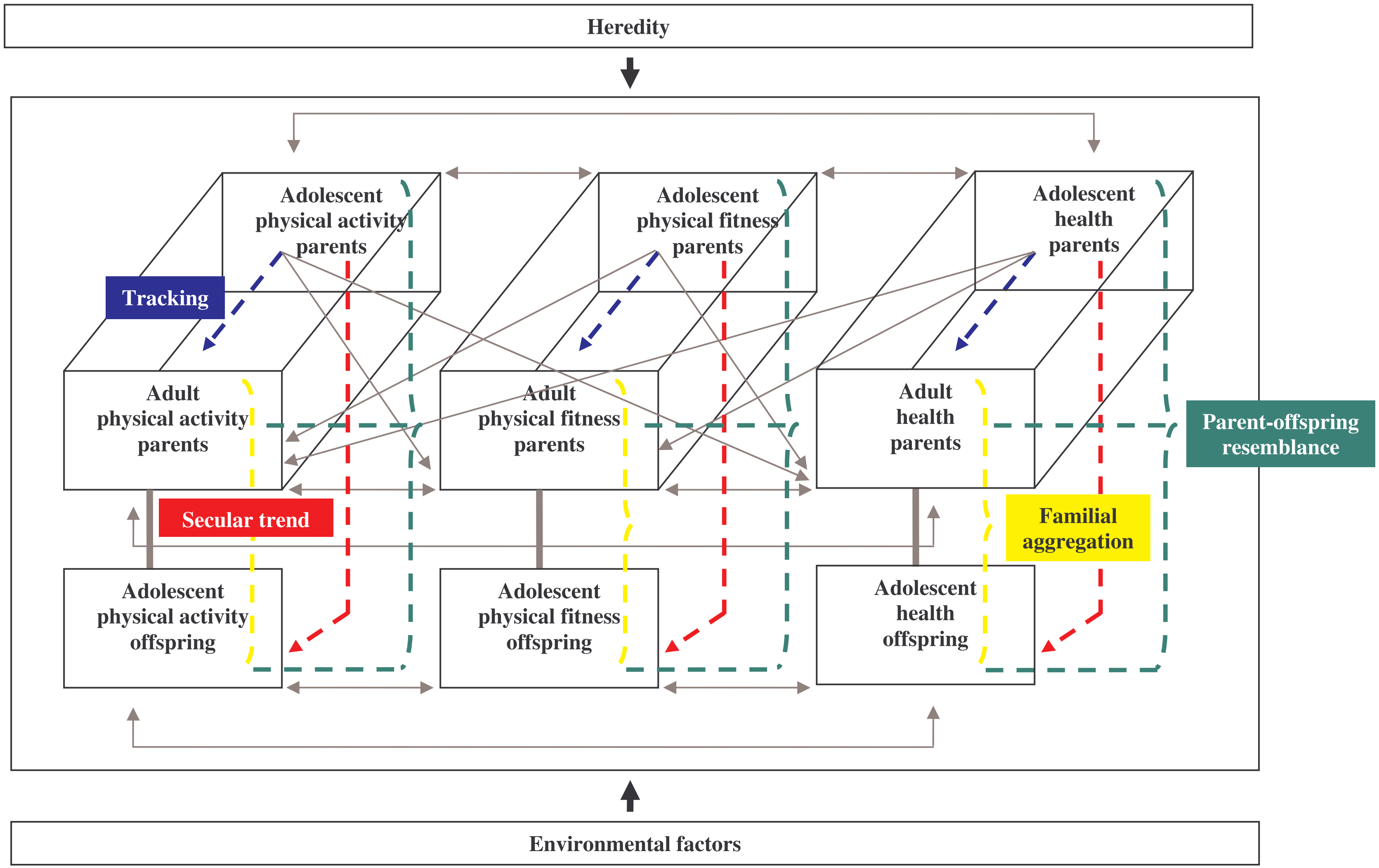

Figure 1. Integration of the research questions of the longitudinal epidemiological and genetic epidemiological part of this thesis in an *extended model* resulting from the combination of the “Toronto consensus model” on relationships between physical activity, health-related fitness and health (Bouchard and Shepard, 1994) and the conceptual model on how childhood exercise habits may affect health throughout life (Blair et al., 1989) (see text for further explanation).

the data. However, in the future data of parents and offspring at adolescent age and parents at adult age should be combined into more extended twin and family path models also allowing detailed modelling of assortative mating, cultural transmission, non-parental shared environmental factors and reduced genetic transmission.

Moreover, estimating the heritability of a trait is only a first step in learning about the relative influences of environment and heredity on the variation. Once the contribution of genetic and environmental factors to a multifactorial phenotype has been established, the next step is to identify the genes underlying the genetic effects and the specific factors underlying the environmental effects. The presence of major gene effects in quantitative traits, i.e. a single gene with a detectable effect on the level of a quantitative trait, can be detected with the unmeasured genotype or top-down approach (e.g., commingling analysis, segregation analysis) and with the measured genotype or bottom-up approach (e.g., association analysis, linkage analysis) (Bouchard et al., 1997). The Human Obesity Gene Map (Rankinen et al., 2006b) and the Human Gene Map for Performance and Health-related Fitness Phenotypes (Rankinen et al., 2006a) are annually published since 1996 and 2000 respectively to review all markers, genes and mutations with evidence of association or linkage with obesity, performance or health-related fitness phenotypes. Besides specific genes, several environmental determinants of physical fitness and physical activity have also already been identified in children, adolescents and adults (Sallis et al., 2000; Trost et al., 2002). The identification of specific genes or environmental factors affecting physical activity and physical fitness was beyond the scope of this thesis.

The findings from the longitudinal epidemiological and genetic epidemiological part of this thesis have important implications with regard to the necessity and efficacy of developing and implementing health strategies (e.g., prevention/sensitivity campaigns) to improve physical activity and physical fitness. In the study on secular trend it was shown that the present generation of adolescent boys and girls has a less favourable anthropometric profile and is less fit than the previous generation. This might have a negative influence on their adolescent health status. Moreover, in the study on tracking it was demonstrated that, in contrast to physical activity, most anthropometric and physical fitness characteristics are relatively stable from adolescence to adulthood in Flemish females. Comparable tracking results have also been published for Flemish males (Lefevre et al., 2000; Vanreusel et al., 1997). This indicates that lack of physical fitness during adolescence might also influence adult health. Consequently, during adolescence, health strategies to encourage physical activity and improve physical fitness are necessary and during adulthood constant efforts should be made to keep people active and to reactivate those who have shifted from an active to a more sedentary lifestyle.

However, is it possible to substantially modify physical fitness and physical activity by environmental adaptations or are these traits primarily influenced by genetic factors? In the study on secular trend the rapid change in anthropometric and physical fitness characteristics over approximately one generation suggests that environmental causes are largely responsible. Moreover, in the study on familial aggregation it was shown that although genetic factors explain a significant part of the observed variability in anthropometric characteristics and most physical fitness items, at least about half of the variance in these traits is explained by environmental factors. The total variance in physical activity is even completely explained by environmental factors, although other studies also report a genetic basis for exercise behaviour (Beunen and Thomis, 1999; Bouchard et al., 1997; Maia et al., 2002; Pérusse et al., 1989). Furthermore, several feeding and training experiments have revealed significant genotype-environment interactions (i.e. the way a subject reacts on environmental factors depends on his/her genotype) for body weight, body fat and physical fitness. This indicates that genetic and environmental factors should not be viewed as mutually exclusive but as intrinsically linked and interacting with each other (Bouchard et al., 1997). Recent findings from epigenetics also emphasize the importance of environmental factors. Epigenetics is a relatively new branch within the field of genetics. While "genetics" is primarily involved with the identification of the influence of genetically inherited factors on the phenotype, "epigenetics" refers to the study of chemical modifications of genes (DNA methylation, histone acetylation and methylation marks on histones) that are heritable from one cell generation to the next and that affect gene expression but do not alter the DNA sequence. There is increasing evidence that these chemical modifications might be caused by environmental factors like nutrition, smoking and possibly also physical activity. Moreover, although epigenetic modifications were generally considered to be erased upon fertilization, recent studies have demonstrated that they might be maintained through the production of germ cells and therefore might be transmitted from one generation to the next (Bradbury, 2003; Morgan et al., 1999; Petronis, 2006). The identification of environmental factors, viewed against the background of genetic susceptibility, as major causes of the observed phenotypic variance in anthropometric, physical activity and physical fitness characteristics emphasizes the potential efficacy of health intervention programs to improve physical activity and physical fitness, not only in the present generations but in more generations to come. In Theme 3 of the Policy Research Centre SPAH several possible intervention programs, in different age groups (children, adolescents, adults, seniors) and settings (schools, sociocultural associations, transportation), to promote physical activity are investigated (De Geus, in press; Geldhof, 2006; Haerens, in press; Spittaels, in press; Steens, 2006; Verstraete, 2006). Although not all studies resulted in large and significant intervention results, it would be even more interesting to identify and quantify the underlying determinants and characteristics of high versus low responders to these programs.

Although the longitudinal study design of the LLSLFH provides unique research opportunities it is also faced with several limitations that need to be taken into account when interpreting the results of the longitudinal epidemiological and genetic epidemiological part of this thesis. A first limitation concerns the representativeness of the study sample and the generalizability of the results. Despite the use of appropriate sampling procedures at the start of the longitudinal study and the application of special measures (e.g., reimbursement of travel expenses, personal results, newsletters) to enhance retention and avoid selective dropout during the course of the study, it remains difficult to retain a representative study sample. As in cross-sectional studies, this is, at least partly, due to the fact that participation inevitably relies on voluntariness. Moreover, in longitudinal studies where participants are tested several times, test effects might also confound the results, especially for motor tests. On the first measurement occasion participants have no experience or expectations related to the tests. However, on following occasions attitudes may have changed for several reasons (e.g., loss of motivation due to an unpleasant prior experience, more experience resulting in a better performance, competition with others or with past results) (Van ‘T Hof et al., 1980). For most anthropometric, physical fitness and physical activity characteristics, the difference between ongoing study participants of the LLSLFH and non-follow-ups or participants of Theme 1 of the Policy Research Centre SPAH was not significant or relevant. However, it should be noted that, as mentioned earlier, participants of Theme 1 of the Policy Research Centre SPAH itself are also not completely representative for the Flemish population. Moreover, ongoing study participants of the LLSLFH have an above average socio-economic status. This might indeed somewhat hamper the generalizability of the results. However, the attainability of a longitudinal study representative for and generalizable to the total population could be questioned. If a representative sample is required, the selection of a new cohort might be a better solution and already involves quite a challenge. This does by no means reduce the value of longitudinal studies since they provide the opportunity to answer different questions compared to cross-sectional studies. In addition, for many analyses the representativeness of the study sample is of less importance. A second limitation associated with the longitudinal study design involves the availability of variables that could be used to investigate secular trend, tracking, familial aggregation and parent-offspring resemblance. Although aerobic fitness, metabolic fitness, nutrition and activities of daily life (e.g., occupation, home and garden activities, transportation) are very interesting variables related to health and assessed in the most recent phase of the LLSLFH, they could not be included in the analyses because they were not measured in the LGSBB, LGSFG or the Leuven Longitudinal Twins Study (LLTS). Most of the above-mentioned opportunities for future research seem accomplishable in the near future. Moreover, another interesting challenge, however beyond the scope of this thesis, is the translation of the reported scientific results into appropriate policy advice. Finally, as risk factors for morbidity and mortality increase with advancing age, efforts should be made to continue the five-yearly follow-ups of the LLSLFH and enrich its unique and valuable dataset even more.

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