PHYSICAL GROWTH, MATURATION AND PERFORMANCE: BACK TO THE FUTURE

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In order to advance our knowledge in auxology, as it relates to performance and physical activity, we need to look back on what is presently already documented and which scientific procedures have been used to accumulate this knowledge. Undoubtedly my account will be biased by my knowledge and interests in this area and it is certainly not be regarded as an historical meta-analysis of the field.
My walk through the gardens of our field from an auxological perspective will cover the following topics :
— the design of growth studies and questions that can be answered
— growth patterns and impact of physical activity
— stages of motor development: towards a theory of motor development
— pediatric biomechanics a field of study
— norms for physical fitness and activity

The design of growth studies
Over the last century our predecessors have used four research designs to answer auxiological questions i.e. (1) cross sectional designs to provide reference data on the present states of growth and maturation of representative samples, (2) longitudinal designs to investigate growth patterns, growth velocity, and tracking, (3) time-lag designs to document secular changes over time, and (4) most recently multiple or mixed longitudinal studies. These mixed longitudinal studies were first proposed by Schaie (1965) a developmental psychologist, as the most efficient design to study developmental changes. The design permits, under certain assumptions, to differentiate between growth, cohort and time of measurement effects. Although I believe that the design is indeed appropriate to answer a number of questions, it is not adequate for a number of questions that are still of major interest for future research. Our knowledge is indeed very limited with regard to the adolescent changes in a variety of performance characteristics in boys and especially in girls (Malina & Bouchard 1991, Beunen & Malina 1996). We barely know if there is a growth spurt in a number of fundamental fitness abilities or physiological functions. Furthermore there is a complete lack of knowledge about adolescent changes in a variety of motor skills, and longitudinal studies, covering long enough periods, of elite athletes are also lacking (Malina 1994). Finally there is also a large gap in our knowledge about the mechanisms (metabolic), biochemic, physiologic, molecular, biomechanic, endocrinologic) that underly patterns in somatic growth, maturation and performance characteristics.

Growth patterns and impact of physical activity
Frank Shuttleworth (1937) was the first to recognize that in order to identify correctly changes in the growth or maturation process, individual growth data have to be synchronized on biological milestones. This has been successfully applied to somatic dimensions in a number of European and North American longitudinal studies (Tanner 1981, Malina & Bouchard 1991), and to a limited number of performance characteristics (Beunen & Malina 1988). This also has led to the development of a number of mathematical functions to adequately describe the growth process. We now have an accurate description of the growth velocity in postnatal stature and the characterization of the adolescent growth spurt has been carefully documented (Tanner, Whitehouse & Takaishi 1966). Recently it has been demonstrated that over short periods of time, growth in length is characterized by a salutatory growth pattern (Laugh et al. 1992), or by repeated small continuous growth accelerations or little growth spurts (Hermanussen et al. 1988). Regardless of the fact that this process of short term growth is salutatory or continuous with small sports, the question remains unanswered if this occurs in different body parts, tissues and/or performance characteristics, and why these changes in velocity occur. Furthermore, there is a need for short term experimental growth studies to document the impact of physical activity on the short term growth process.

Stages of motor development
In the first decades of last century Gesell (1928) and his collaborates contributed greatly to our knowledge with the detailed description of stages in motor development early in life in a variety of fundamental motor behaviors.
Furthermore the stages of motor development in a number of gross motor behaviors of the pre-school child have been accurately described (Gallahue & Ozmun 2002, Keogh & Sugden 1985). Unfortunately, these descriptions are qualitative and no underlying mechanisms are identified. A notable exception is the work of Thelen (1991) and her collaborators. They made a significant effort to apply the theory of dynamic systems to explain infant behavior in motor tasks such as learning to walk. This theory is probably a good starting point to go beyond the purely descriptive stage of motor development. Here the input of recent advances in the neurosciences, motor control and techniques such as magnetic resonance imaging of brain functions need to be integrated (Knutzen & Martin 2002).

Pediatric biomechanics
In a recent review it was clearly demonstrated that our knowledge about biomechanical parameters of movement behavior, skills and performance characteristics of children and adolescents is fragmented (Knutzen & Martin 2002).
Tremendous efforts and advances have been made in the biomechanical analysis of a variety of sport skills, and biomechanics have also contributed significantly to the development of better ortheses, protheses, surgical interventions and safe and efficient training and rehabilitation programs. Even in the field of gerontology biomechanists have joined the geriatric teams. The largely forgotten species are the children and adolescents. As already indicated in the previous section, we have to go beyond the descriptive stage in motor development and pediatric biomechanics can help to further our understanding and to develop theories about motor development throughout the whole growth process.

Norms for physical fitness and physical activity
Since Sargent proposed the vertical jump as a test of a man (1921), the concept of physical fitness, its components and the tests used to quantify these components has evolved considerably (Bouchard & Shephard 1994). In the eighties there has been a shift towards health- and performance-related fitness.

And along the same lines, attempts have been made to define criterion-referenced norms. Unfortunately, the criteria that have been used mostly lack validity. Only for aerobic power some evidence exists about the health associations and the cut-off scores that could be used in adults (Updyke 1992). For all other so called health-related fitness items virtually no such evidence is readily available. There is thus a need to reconsider fitness tests, and probably to reconsider the split in health- and performance-related fitness items. Furthermore, there is a need to provide evidence for the associations with health, risk factors, and construct valid cut-off scores (Updyke 1992).
Along the same lines we learned a lot about the beneficial effects of physical activity on health and disease. In children and adolescents this is limited to a number of risk factors and the effects are often limited or at best moderate (Riddoch 1998).
Again, here we need to study what is the optimal physical activity (mode, frequency, intensity, time) that children and adolescents need for their physical, mental and psycho-social health, well-being, optimal, harmonious development, and later health outcomes.

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INCIDENCE AND PLAYER RISK FACTORS FOR INJURY IN YOUTH FOOTBALL (AMERICAN)

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Introduction

Risk of injury is a given in sport at all levels from youth to professional. The injury-related literature in youth sports focuses largely on descriptions of risk factors related both to the host (young athlete, internal), and to the sport environment (external), and to a lesser extent on the prevalence and incidence of injuries. The contribution of risk factors individually or in combination to injuries in youth sports is neither known with certainty nor specified in available studies. Some are seemingly obvious, e.g., poor playing conditions and equipment; others need more systematic specification. Estimates of injury rates in studies of youth sports are limited commonly by the lack of suitable exposure data for practices and competitions, in addition to variable definitions of injury.
Information on injuries associated with regular participation in sport is regularly collected at the high school and collegiate levels in the United States. However, it is at the local level where numbers of participants in youth sports are greatest. About five times as many children and youth under the age of 14 participate in organized youth sports as participate in interscholastic sports (Carnegie Corporation, 1997); yet, relatively little is known of the prevalence and incidence of injuries at the youth sport level. The presently available data are variable and often limited to accident reports; records from hospitals, emergency rooms and sport injury clinics; interviews; and retrospective questionnaires (Malina, 2001). These studies provide estimates of age-, sex- and sport-associated variation in the occurrence and type of injuries. The specific contexts of injuries are generally not considered.
The purposes of the study were threefold: (1) to estimate the incidence of injuries in youth football (American), (2) to assess the perception of the risk of injury in football by the participants, and (3) to assess the relationship between player-related risk factors (body size, biological maturity status, perception of risk of injury) and the occurrence of injury in youth football.

Injuries in American Football among Youth

In an early study, the type and frequency of injuries occurring during a 12 week season in about 2000 participants in tackle football 9-15 years were described (Roser and Clawson, 1970). Coaches reported injuries; the criterion was "…missing practice or a game." Only 48 injuries were reported (2.3% of the players); they were more likely to occur in games rather than in practice. In a more recent study of about 5000 players 8-15 years (Goldberg et al., 1988) a similar protocol was used, i.e., coaches reported injuries, but reported injuries were those that "…required restricted participation for more than 1 week." During the season (August to November), 257 injuries were reported (about 5%). Injuries occurred more often in heavier players, in participants who had more playing time, and in quarterbacks and running backs. Age and height were not considered in the analysis. Data for injuries in high school football are more extensive, and estimated rates are higher than for youth football (Thompson et al., 1987). However, studies vary in definitions of injury and methods of reporting. A 5 year epidemiologic study involving about 9000 high school football players in North Carolina considered an injury when it restricted "usual activity for one day beyond the day of the injury," or when it required professional treatment (Blyth and Mueller, 1974). With these criteria, the estimated injury rate was lower than corresponding data based on insurance claims. Rates increased with age, weight and height, but interrelationships among these variables were not considered. The distribution of injuries was approximately equal between games and practices.
In one of the more complete analyses of injuries in several high

school sports, reportable injuries were more systematically defined relative cessation of and return participation on the day of injury or the following day, and fractures, dental injuries, and mild brain injury (Powell and Barber-Foss, 1999). The overall case rate for high school football was 8.1/1000 athlete exposures (AE), but rates were higher for games versus practice, 26.4/1000 and 5.3/1000 AE, respectively.
Variation in maturity status, size and physique are often indicated as risk factors for injury in American football. Skeletal age did not differ between injured and non-injured junior high school players 13-16 years of age (Rochelle et al., 1961), and a composite index of sexual maturity differed only slightly between injured and non-injured high school players 13-17 years of age (Violette, 1976). Body build and "looseness" of joints were poor predictors of injury in high school football players (Godshall, 1975), but an elevated BMI was associated with greater risk for lower extremity injuries among high school linemen (Gomez et al., 1998).
Systematic data on the incidence of injuries in American football for youth at the community level, i.e., below the interscholastic level, are limited. Although the available data suggest lower rates than for high school football, suitable exposure statistics are not reported and variable definitions of an injury are used. Host- or player-related risk factors are not systematically considered.

Methods
Subjects were 678 boys, 9-14 years of age, who were members of 33 youth football teams in two central Michigan communities in the 2000 and 2001 seasons (Mid-Michigan PONY League). Teams were formed by players' grade in school. Each community had combined 4^{th}-5^{th}, and 6^{th} and 7^{th} grade teams; one community had 8^{th} grade teams.
Height and weight were measured at the start of the season; the BMI (wt/ht^2) was calculated. The RISK OF INJURY IN SPORTS SCALE (RISSc) was completed. The scale included 24 items reflecting six risk factors: uncontrollable, controllable, overuse, upper body, surface-related, and re-injury (Kontos et al., no date). Parents reported their heights, which were adjusted for overestimation (Epstein et al., 1995). Age, height and weight of the player and midparent height were used to predict the adult height for the boy (Khamis and Roche, 1994). The player's current height was expressed as a percentage of predicted adult height to provide an estimate of biological maturity status (Roche et al., 1983; Malina et al., 2003).
Three graduate assistants, who were certified athletic trainers, measured the players and administered the risk scale. The trainers were on site to record the number of participants at all practices and games, i.e., coach-directed sessions which were opportunities for injury (exposures) and injuries as they occurred. A reportable injury was defined after Powell and Barber-Foss (1999, p. 278): "Any injury that causes cessation of participation in the current game or practice and prevents the player's return to that session, … that causes cessation of a player's customary participation on the day following the day of onset." All fractures, dental injuries, and any mild brain injury were also classified as reportable injuries. The trainers also provided on field care for injuries. Information about the type, location (body part) and severity of injuries, position or activity of the injured player, and context were recorded.
Case rates based on athlete exposures (AE), total number of injuries per 1000 AE, were calculated by grade and for the total sample. Case rates were calculated for practices and games, and both combined. Hierarchical log linear modeling was used to identify variables that were potentially related to injury status. Logistic regression was used to evaluate the relationship between player-related risk factors (body size, estimated maturity status, perception of risk) and the risk of injury.

Results
Mean heights of the sample move from the U.S. reference median at 9 years towards the 75^{th} percentile at 14 years. Mean weights move from the 75^{th} percentile of the reference at 9 years to just below the 90^{th} percentile at 14 years. As a result, the BMI, on average, is slightly below the 85^{th} percentile of the reference from 10 to 14 years of age. Many of the players would be classified as overweight and/or obese.
Over the two seasons and across grades, there were 24,854 exposures, 20,496 in practices (82.5%) and 4,358 (17.5%) in games. The injury rate was 10.4/1000 AE, but the rate was twice as high in games (18.6/1000AE) as in practices (8.7/1000 AE). Case rates per AE during practices increased with grade level, whereas corresponding case rates during games were about twice as great in the 7^{th} and 8^{th} grades compared to the lower grades (Table 1). Case rates for games among 7^{th} and 8^{th} grade players (26.1 and 27.4/1000 AE) were virtually identical to estimates for high school players (26.4/1000 AE) using the same definition of a reportable injury (Powell and Barber-Foss, 1999). Case rates for pratices, ever, were higher in 7^{th} and 8^{th} grade players (10.7 and 13.6) than in high school players (5.1).

Table 1. Estimated injury rates (case rates per 1000 AE) within grade.

Grade	Practices	Games	Total
4^{th}-5^{th}	5.2	13.3	6.6
6^{th}	9.1	12.9	9.9
7^{th}	10.7	26.1	13.4
8^{th}	13.6	27.4	16.2
Total	8.7	18.6	10.4

About two-thirds of the injuries was classified as minor in severity, so that case rates per AE for injuries of moderate (18%) and major (13%) severity were very low (Table 2).

Table 2. Estimated injury rates (case rates per 1000 AE) by severity within grade.

Grade	Mild	Moderate	Major
4^{th}-5^{th}	4.4	1.4	0.8
6^{th}	7.4	1.6	0.8
7^{th}	9.2	2.2	1.9
8^{th}	10.4	3.2	2.6
Total	7.2	1.9	1.3

The youth football players exhibited moderate levels of perceived risk. Scores on five of the six risk factors were significantly higher among 4^{th}-5^{th} grade players, but did not differ between 6^{th} and 7^{th}-8^{th} grade players. This suggests that the perception of risk of injury decreases with age and perhaps experience. The sixth, concern for re-injury, was significantly higher among 7^{th}-8^{th} grade players, followed by 6^{th} and then

4th-5th grade players, suggesting that concern for re-injury increases with age and experience in football.
Results of logistic regressions within grade indicated no consistent pattern of associations between age, indicators of body size and maturity status and risk of injury. When scores on the RISSc were included in the logistic regressions with age, body size and maturity status within grade, there were no consistent associations with risk of injury. However, when the total sample was treated as a single group, high concern for re-injury and grade emerged as predictive of injury. This suggests that older, presumably more experienced players who scored high on the perception of risk related to re-injury were more at risk for injury. And, players in 7th and 8th grades combined are more likely to be injured than those in the 4th through 6th grades combined. This probably reflects the fact that games in the two older grades more closely follow high school rules (e.g., inclusion of special teams), whereas rules for kick-offs and punts are modified for the lower grades (e.g., no run backs).

Conclusions
Injuries occurred twice as often in games as in practices. Case rates (per 1000 AE) for games and practices were lower among 4th-5th and 6th grade players than among 7th and 8th grade players. Body size and estimated biological maturity status were not significant risk factors for injury in youth football. Among perception of risk factors, concern for re-injury increased with grade and was significantly related to risk of injury.
Athletes classified as advanced, average or late in biological maturity status on the basis of percentage of predicted adult height showed the same pattern of variation in body size compared to studies which used more traditional and invasive estimates of maturity status (skeletal age and secondary sex characteristics). This emphasizes the potential utility of percentage of predicted adult height as a non-invasive indicator of biological maturity status for use in studies of injuries in youth sports.
American football is a sport in which large body size is an advantage, and many boys are selected for a position by their body size. By about 12-15 years, boys assigned to line positions (interior linemen and linebackers) are generally taller and especially heavier than boys who are receivers, running backs and quarterbacks, and it is not uncommon for position specialization to start at these ages.

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THE RELATIONSHIP BETWEEN PHYSICAL FITNESS AND CLUSTERED RISK, AND TRACKING OF CLUSTERED RISK FROM ADOLESCENCE TO YOUNG ADULTHOOD

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Introduction
Hard endpoints of atherosclerotic CVD is not prevalent in young people, but as atherosclerosis develops gradually over the years, it may be effective to prevent high levels in CVD risk factors already in children. The rationale behind this thinking is that risk factors track, i.e. subjects keep rank order within a risk factor. Most CVD risk factors show moderate tracking (1,2). A tracking coefficient is a measure of variability between two time points. Variation in a risk factor value is caused by assessment error, short time fluctuations, and more permanent changes in mean risk factor levels. Only the latter is interesting in the prediction of atherosclerotic development. Many of the risk factors show great variability caused by assessment problems and day-to-day variation, i.e. blood pressure and cholesterol show great short-term fluctuations and physical activity is usually self reported with great assessment problems. A more correct tracking coefficient can be obtained by minimising some of the short-term variation, which can be removed by repeated measurements, i.e. two to three blood samples over a week both at baseline and at the follow-up. However, this is rarely done in epidemiological studies. Also, assessment error can often be diminished, but it may be expensive in large longitudinal studies. Therefore, it may be more convenient to

analyse the stability of clustered risk. Many of the risk factors are related to a common causal factor, the metabolic syndrome. In an insulin insensitive person, the risk factors related to the metabolic syndrome will be elevated simultaneously, and this may to some extend overrule the error variation. We have earlier shown that physical fitness is weakly related to each single CVD risk factor in cross sectional studies (3), but probably due to a strong effect of training on insulin sensitivity, a strong relationship is found between fitness and clustered risk (4). The main aim of the present study was to calculate tracking of clustered risk in an eight years longitudinal study from adolescence to young adulthood.

Methods
Two examinations were conducted 8 years apart. First time, 133 males and 172 females were 16-19 years of age. Eight years later 98 males and 137 females participated. They were each time ranked into quartiles by sex in four CVD risk factors all related to the metabolic syndrome. Risk factors were the ratio between total cholesterol and HDL, triglyceride, systolic BP and body fat. The upper quartile was defined as being at risk, and if a subject had two or more risk factors, he/she was defined as a case (15-20 % of the subjects). Odds ratio (OR) for being a case at the first examination was calculated between quartiles of fitness, and the same analysis was performed at the second examination. The stability of combined risk factors was calculated as the OR between cases and non-cases at the first examination to be a case at the second examination.

Results
Tracking coefficients in single risk factors were between 0.2 and 0.8. At the first examination, OR for having 2 or more risk factors between quartiles of fitness were 3.1, 3.8 and 4.9 for quartiles two to four, respectively. At the second examination, OR were 0.7, 3.5 and 4.9, respectively. The probability for "a case" at the first examination to be "a case" at the second was 6.0.

Conclusions
The relationship between an exposure like physical fitness and CVD risk factors is much stronger when clustering of risk factors are analysed compared to the relationship to single risk factors. Also, the stability over time in multiple risk factors analysed together is strong with an OR of 6 for having 2 or more risk factors 8 years after in those who were at risk at the first examination. This relationship should be seen in the light of moderate or weak tracking of single risk factors, and is a strong evidence for a benefit of early intervention in children where risk factors cluster.

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SOCIAL PSYCHOLOGY OF PHYSICAL ACTIVITY AND SEDENTARY BEHAVIOUR IN YOUNG PEOPLE

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There is growing concern over the effects of sedentary lifestyles on the health of young people. Recent rapid increases in juvenile obesity have received a great deal of attention in the scientific and popular press and have been attributed partly to television viewing, computer games and other sedentary behaviours. These are thought to compete with physical activity. Project STIL (*Sedentary Teenagers and Inactive Lifestyles*) at Loughborough University is investigating 'what young people do' and focuses on active and inactive pursuits chosen in their leisure time. We address the following issues in young people: a) what is the current social and psychological climate of physical activity and inactivity for young people in western society? b) Do key sedentary media-based behaviours displace physical activity? c) Are key media-based sedentary behaviours obesogenic? d) What are the secular trends for children and youth for TV viewing? Our results for young people suggest that: a) TV viewing and video-game playing are largely uncorrelated with physical activity, suggesting that there is time for both; b) meta-analytic findings show that body fatness is not related in any clinically meaningful way with screen media use; c) although more children and youth have greater access to TVs than in previous generations, the amount of TV watched per head has not changed for 40 years. Inactivity is more complex than we sometimes think. Indeed, measures of 'couch potatoism' expressed as media use, may be inappropriate as markers of inactivity. There is growing concern over the effects of sedentary lifestyles on the health of young people in western society. Recent rapid increases in obesity for this age group, as well as for adults, have received a great deal of attention in the scientific and popular press. Such trends have partly been attributed to television viewing, computer games and other sedentary behaviours thought to be occupying large amounts of time for young people. These are thought to compete with physical activity, thus creating an 'inactive lifestyle'. Indeed, there is somewhat of a 'moral panic' concerning the 'couch kids' culture in modern western society, fuelled by adults – themselves largely sedentary and overweight of course! – extolling the evils of couch potato-ism!
At Loughborough University we have established Project STIL - (*Sedentary Teenagers and Inactive Lifestyles*) to investigate 'what young people do'. The project[1] focuses on active and inactive pursuits chosen by young people in their leisure time. Through this research, we hope to better understand the multifaceted correlates and determinants of such lifestyle choices and in particular the nature, extent and correlates of sedentary behaviours.
In this short paper, I will outline some key findings from our review of the literature. Although we have data from prior research (Marshall, Biddle, Murdey, Gorely, & Cameron, 2003;

Marshall, Biddle, Sallis, McKenzie, & Conway, 2002), currently we are collecting large-scale prevalence and smaller-scale longitudinal data, and these are not yet analysed. As part of the initial phase of the project, we have undertaken systematic reviews of the literature. I will draw on these to answer the following questions:
Do key sedentary media-based behaviours displace physical activity?
Are key media-based sedentary behaviours obesogenic?
What are the secular trends for children and youth for TV viewing?

1.Do key sedentary media-based behaviours displace physical activity?
It is commonly thought that media-based sedentary behaviours, such as TV viewing, video game playing and leisure-time computer use, compete for time that would otherwise be spent in physical activity. In other words, one would assume a negative correlation.
We conducted a meta-analysis of 24 studies and 41 independent samples (k) (Biddle, Marshall, Gorely, Cameron, & Murdey, 2003). Effect sizes were calculated for physical activity and TV viewing (k = 39) and physical activity and video/computer game use (k = 10). A total of 143,235 young people were studied. The sample-weighted effect size (Pearson *r*) between TV viewing and physical activity was -0.096 (95% CI = -0.080 to -0.112). The sample-weighted fully corrected effect size[2] was -0.129. This small correlation was statistically significant and may provide evidence for a displacement hypothesis – that is, TV viewing displaces physical activity. However, the effect is too small to be of much clinical or practical significance.
The sample-weighted effect size between video/computer game use and physical activity was -0.104 (95% CI = -0.080 to -0.128). The sample-weighted fully corrected effect size was 0.141. This suggests that the relationship is best described as 'small.' However, this should be interpreted with caution because the mean effect size is based on only 10 primary effects and second-order sampling error may be present.
In summary, it appears that the displacement hypothesis has limited support and that key media-based sedentary behaviours in young people are not strongly associated with the amount of physical activity they undertake. This was supported by our own primary data (Marshall et al., 2003; Marshall et al., 2002). Thus we conclude that there appears to be time for both these behaviours.

2. Are key media-based sedentary behaviours obesogenic?
In another meta-analysis (Biddle et al., 2003), we located 30 studies with data available on 52 independent samples investigating associations between body fatness and TV viewing and video/computer use. A total of 44,707 young people were studied.
The sample-weighted effect size (Pearson *r*) between TV viewing and body fatness was 0.066 (95% CI = 0.056 to 0.078). The sample-weighted fully corrected effect size was 0.084. Thus, the TV viewing habits of young people explain less the 1% of the variance in their body fatness. While this relationship is statistically significant (p<.05), it is likely to be clinically irrelevant. This conclusion is in contrast to many statements in the literature.
The sample-weighted effect size between video/computer game use and body fatness was 0.070 (95% CI = -0.048 to 0.188). The sample-weighted fully corrected effect size was 0.128. The 95% CI for the sample-weighted effect size suggests that the relationship in the population is probably zero. However, this should be interpreted with caution because the mean effect size is based on only 6 effect sizes.

3. What are the secular trends for children and youth for TV viewing?
We have located 81 useable studies reporting some level of incidence, prevalence or developmental data for the sedentary behaviours of television viewing, video game playing or computer use in youth. From these, data were available on 463 independent samples.
Based on 45 independent samples published since 1997, the incidence of TV viewing amongst young people is estimated to be just under 2.5 hours per day. The mean incidence reported for video game playing is just over 30 $minutes.day^{-1}$ and for computer use is about 45 $minutes.day^{-1}$.
In accordance with the guidelines from the American Academy of Pediatrics (1986), the boundaries for prevalence estimates for TV viewing were set at less than 2 hours per day for 'low users' and more than 4 hours per day for 'high users'. Just over one quarter of young people (27.67%, SD = 9.11, range 9 – 56%, K = 169) are high users of TV, but around two-thirds (66.21%, SD = 13.93, range 35.30 – 94, K=13) appear to be low users. A significant difference between prevalence estimates for males and females was observed, with a higher proportion of males compared to females (30% vs. 25.27%) being high users of TV (p>.05).
We have been able to estimate secular changes in TV incidence levels since the introduction of TV. Surprisingly, while the content of media has changed, the absolute volume appears remarkably stable at around 35-40 $hr.wk^{-1}$ for 11-17 yr olds. This might suggest a maximum time that young people can devote to it. However, these estimates are for the amount of time young people watch TV and may only account for those having TVs available. With the increasing use number of TV sets in houses, including being located in the bedrooms of teenagers, these estimates may be biased downwards. However, it has yet to be established that, if it was the case that more children are watching TV than in previous generations, whether TV viewing is replacing previously active pursuits.

Conclusion
Inactivity is more complex than we sometimes think. Indeed, measures of 'couch potato-ism', expressed as media use, may be inappropriate as markers of inactivity in youth. There are likely to be complex social psychological processes at work that preclude, at this time, simple conclusions regarding whether key sedentary behaviours such as TV viewing a) displace physically active pursuits or b) create negative health outcomes such as overweight and obesity. One might predict that in the absence of simple associations between these constructs, there might be clusters, or groups, of young people showing 'negative' health profiles, such as high TV viewing, low physical activity, and high body fat. It might be argued that it is these types of young people that we need to focus on rather than on assuming general associations between variables for all children and youth.

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[2] Corrected for sampling and measurement error.

APPLYING THE TRANSTHEORETICAL MODEL FOR CHANGE IN PHYSICAL ACTIVITY IN YOUNG PEOPLE

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Research on behavioural determinants of physical activity in youth originating from a public health perspective is relatively new. In the past, such physical activity research focused primarily on adults, based on the assumption that adults were the population especially at risk of ill health from physical inactivity. Children and adolescents were considered to be exercising enough. However, recently more attention has been given to the importance of studying physical activity in children and adolescents, including determinants. The main reasons for this recent focus are the increase in childhood obesity, the findings that not all children are active enough, and the steep decline in physical activity found in adolescence.

A good understanding of the determinants of physical activity in youth is essential in developing appropriate activity promotion interventions resulting in long-term increases in physical activity levels in this population. It should be noted, however, that because of the cross-sectional nature of most studies, the term 'determinant' mostly indicates only a reliable association or correlation, and the methods used in most studies do not allow any inference of causality.

The Theories of Reasoned Action and Planned Behaviour were found to be relevant frameworks for studying determinants of physical activity in youth. Perceived behavioural control and attitudes towards physical activity have been found to be correlates of physical activity in youth. However, most studies have shown associations between these constructs and intentions to be physically active rather than physical activity itself. Further, the Social Cognitive Theory, and especially its most studied concept of self-efficacy, was found to be a strong correlate of physical activity in children and adolescents. General, as well as more specific measures of perceived competence in relation to physical activity are also relevant. Empirical support has been found for the relationship between self-efficacy and physical activity in youth.

The Transtheoretical Model, initially constructed by Prochaska and DiClemente (1983) to explain changes made by people who stop smoking, has also been proposed as useful for understanding the adoption and maintenance of exercise behaviour. In the Transtheoretical Model it is argued that people progress through the stages of change during the process of changing their behaviour. The stages have been labelled precontemplation, contemplation, preparation, action, and maintenance. In the precontemplation stage, individuals do not intend to change their behaviour. In the contemplation stage, people seriously intend to change in the next 6 months. In the preparation stage, individuals intend to take action in the near future (within a few weeks) or are already changing their behaviour at an inconsistent level. Action is the stage in which behaviour changes have occurred recently (within the past 6 months). In the maintenance stage, people have made changes more than 6 months previously or until the risk no longer exists of relapse to the old behaviour. The result of the progression through the stages is the stable adoption of new healthy behaviour. The Transtheoretical Model is more a model giving guidelines for intervention than it is a model for studying behavioural determinants per se. A major contribution of the Transtheoretical Model, however, is its matching of determinants of health behaviour with the readiness of the individual to change, or in other words, its taking into account of stage differences.

In recent years many theorists and researchers have shown the mismatch between the action-oriented physical activity programmes offered and the condition of the very sedentary population (mostly in precontemplation). Consequently, the Transtheoretical Model has become influential in adult physical activity. Many researchers have found evidence supporting the use of the Transtheoretical Model for the understanding of adoption and maintenance of exercise in adults. Two central determinants useful in the application of the Transtheoretical Model to physical activity are self-efficacy and the decision-balance between perceived benefits and barriers (pros and cons). Marshall and Biddle (2001) showed in a recent meta-analysis of 71 studies that there are sufficient data to confirm that stage membership is associated with different levels of physical activity, self-efficacy, pros and cons, and processes of change.

Until now the utility of the Transtheoretical Model applied to youth physical activity has not been studied extensively. Some problems may be expected such as the higher levels of physical activity in youth resulting in less people in the precontemplation and contemplation stages. In addition, the processes of change may be different for adults and young people.

Moreover, it is not clear whether the decision-making model is relevant for children. This concept might stress cognitive considerations and rational choices too much, not taking environmental factors sufficiently into account. Children are also engaged in some compulsory physical activity in physical education, making it difficult to fit in to the concepts of the Transtheoretical Model. However, because of the promising results using the Transtheoretical Model in adult populations, the investigation of its application to physical activity in children and adolescents, and how the model might be adapted for youth, should be encouraged.

Nigg & Courneya (1998) examined the applicability of the entire Trantheoretical Model for adolescent exercise behaviour. A sample of 819 students was recruited through grades 9 to 12 (mean age was 15.0 years). They found that the distribution of the sample across the stages was 2.1% in precontemplation, 4.2% in contemplation, 28.% in preparation, 15.7% in action and 49.3% in maintenance. They found preliminary evidence for the applicability of the Transtheoretical Model to adolescents, with significant differences of the construct across stages. However, low rates of adolescents in the precontemplation and contemplation stages were found. As they only had a 61% response rate, it is possible that nonexercisers did not want to fill out a questionnaire about exercise. The premier goal of Nigg & Courneya (1998) was not to supply accurate estimates of the population prevalence in each stage. However, they suggest that in the future more representative sampling should be employed.
Hausenblas et al. (2002), Walton et al. (1999), and Cardinal et al. (1998) focused on the applicability of the Transtheoretical Model in younger children, resp. Middle school children, fifth- and sixth-graders and first- through fifth-graders. Distribution across stages was very different with over 87% in action and maintenance in the youngest age group (Cardinal et al., 1998), 60% in the fifth- and sixth-graders (Walton et al., 1999) and about 88% in the young adolescents (Hausenblas et al. 2002). However, most samples were relatively small and none of them were representative for the population. All authors argue for studies in large, more representative samples before the validity and generalizability of the Thanstheoretical model in young people can be accepted.
At the Ghent University, a study was executed to examine the validation and usefulness of the Transtheoretical Model, and more specific of the Stages of Change in a sample of adolescents (De Bourdeaudhuij et al., submitted). A random sample of secondary schools was drawn in Flanders, the Dutch speaking part of Belgium.
A large sample of adolescents (n=6117) participated in the study, all following secondary education. Their mean age was 14.8 (±1.9) and 61.1% were females. All students completed a computerised questionnaire including physical activity and psycho-social determinants. The questionnaire was validated in a previous study with CSA accelerometers (Philippaerts et al., 2003). The instrument showed good test-retest reliability and adequate validity.
Distribution of the sample across the stages was: precontemplation, n=684 (11.5%); contemplation, n=948 (16.0%); preparation, n=818 (13.8%); action, n=492 (8.3%); and maintenance, n=2989 (50.4%). Results showed sex ($p<0.001$) and age ($p<0.001$) differences across stages, with girls and older adolescents being more prevalent in earlier stages. Multivariate analysis of variance and univariate follow-up tests, controlled for sex and age, showed that stages of change were distinguished by hours of sport participation per week in leisure time, by hours of sport participation at school outside physical education, and by hours of transportation per week. Analyses of variance further showed that psychosocial variables consistently varied as function of stage classification: those in earlier stages reported less positive attitudes, less social support, less self-efficacy, less benefits and more barriers related to physical activity (all mean scores gradually increased with higher stages, for all $p<0.001$).
The results of this study provide support for the usefulness of the stages of change algorithm related to physical activity in adolescents. Intervention strategies focussing at the promotion of physical activity in adolescents can be based on stages of change and use the relevant constructs in each stage.

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EFFECTS OF BODY FAT ON CARDIOVASCULAR FITNESS IN YOUTH

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Degree of body fat content has often been associated with one's level of cardiovascular fitness. In particular, excessive adiposity is expected to profoundly depress aerobic capacity. High body fat content lowers weight-relative maximal aerobic power (VO_2max per kg) and diminishes functional fitness, such as the ability to perform in distance running events. In the first situation, VO_2max per kg is lessened largely because body fat inflates the denominator (i.e., body mass), while in the latter, excess fat acts as an additional load which must be transported during weight-bearing physical activities. In addition, both of these factors may be further decreased by the sedentary lifestyle often adopted by overweight persons.
Certain cardiovascular anatomic features are typically observed in obese children and adults. These individuals have a greater left ventricular size and mass as well as expanded plasma volume, and these characteristics translate into a greater resting cardiac output and stroke volume compared to nonobese individuals. Such findings have been attributed to adaptations to the high metabolic demands of the obese state. Persons with moderate obesity usually tolerate this high output state well, but those with long-standing morbid obesity eventually display

systolic and diastolic dysfunction and congestive heart failure. This is compounded by both pulmonary and systemic hypertension that are common in these individuals.

The effects of obesity on cardiac functional reserve itself are not clear. Some information, both in adults and children, indicates that absolute maximal oxygen uptake is higher in overweight persons, indicating that depressed aerobic fitness is not a reflection of any decline in cardiac capacity. In fact, these data would suggest that if cardiovascular fitness is defined as the maximal ability of the heart to generate cardiac output, the obese subject actually possesses *greater* cardiac functional reserve than the nonobese. There is evidence to suggest, too, that this increase in cardiac output is a reflection of increase in lean body mass, typical of the obese individual, rather than his or her greater body fat content.

This information is of practical importance to those designing therapeutic exercise programs for obese youth. If true cardiovascular fitness of the obese person is not reduced, such programs can focus on low-level, acceptable activities that raise caloric expenditure rather than using more intense interventions that would be needed to augment cardiac function.

We recently compared cardiac responses to a progressive cycle exercise test in 13 moderately obese adolescent girls (mean age 13.6$\pm$1.5 years) to those of non-obese teenagers. Body mass index of the obese subjects ranged from 30 to 43 kg/m^2. Peak oxygen uptake, both absolute and relative to height$^{3.0}$, was significantly greater in the obese compared to the control subjects. This difference was explained by a higher peak cardiac output and stroke volume in the obese when values were expressed in absolute terms or in respect to height$^{3.0}$. No significant differences were observed when cardiac variables were adjusted for body surface area. The pattern of rise in stroke volume and peak aortic velocity, markers of myocardial performance, were identical in the two groups. Resting echocardiograms showed that mean left ventricular end-diastolic dimension was significantly greater in the obese, but shortening fraction values were similar to those of the nonobese.

These data confirm previous information in adults that low aerobic fitness in moderately obese adolescents (as indicated by depressed peak VO_2 per kg body mass and limited endurance performance), does not reflect decreased cardiac functional capacity. In fact, the obese individual responds to greater body fat and lean mass content by an increase in cardiac functional capacity, characterized anatomically by a larger left ventricular size. The mechanism for this response is unknown.

At the other end of the body composition spectrum are those youth with anorexia nervosa, who are characterized by an often-times dramatic decrease in body fat and lean mass. Adolescents with anorexia typically demonstrate bradycardia, low blood pressure, small heart size, and diminished resting cardiac output. Endurance fitness is usually depressed, with a low VO_2max, heart rate, and blood pressure responses to a standard exercise test. These features have been considered secondary to a decrease in sympathetic tone.

Certain other cardiac characteristics have been observed in some patients with anorexia that are of greater concern. Prolonged QT interval, dysrhythmias, and ischemic-like ST changes on the electrocardiogram have been described. Since sudden death can be a complication of anorexia, the cardiac features of these patients have received particular attention. Little information is available, however, regarding their cardiac responses to exercise. There is reason, however, to suspect that cardiac reserve might be limited: normal myocardial performance is contingent upon adequate sympathetic nervous stimulation, circulating catecholamines, and energy substrate, as well as normal mass and functional integrity of myocardial tissue.

Using the same protocol as in the study of the obese subjects described above, we evaluated cardiac responses to a progressive cycle exercise bout in eight girls (mean age 16.3$\pm$2.7 years) who satisfied standard diagnostic criteria for anorexia nervosa of moderate severity. Resting and maximal heart rates were reduced in the patients compared to healthy controls, and VO_2max was subsequently lower. Maximal stroke index was greater in the patients than the controls. Pattern of stroke volume response, peak aortic velocity, and mean acceleration of flow were similar in the two groups when adjusted for heart rate.

This study confirmed findings of diminished heart rate and aerobic fitness previously described in patients with anorexia nervosa. However, there was no evidence of abnormal myocardial performance during maximal exercise testing. The cardiac responses to exercise which were unique to the anorexia patients appeared to be related entirely to a dampened response of heart rate to exercise. This chronotropic response could be related to lower sympathetic tone, but, if so, this autonomic alteration did not influence other circulatory responses to exercise.

The combined data regarding the responses of young individuals with body fat content ranging from moderate obesity to moderately severe anorexia nervosa suggest that body fat itself does not negatively influence cardiac functional capacity. Future studies in youth with more serious levels of obesity and anorexia will be important in determining if cardiovascular fitness is adversely impacted when these conditions become more extreme.

ASTHMA AND EXERCISE

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In the last years, asthma has become the most prevalent chronic disease among children and adolescents, affecting up to 10% of them.

Exercise has long been known as a common and potent trigger of asthma attacks.

Exercise induced asthma (EIA) affects 70 – 80% of all asthmatics and its prevalence among school children is about 19 to 23%.

In 40 % of children with demonstrable EIA no clinical diagnosis has been made, showing how unprepared we all still are – doctors, nurses, teachers and parents. The fact that breathlessness, wheezing or cough, the clinical picture of EIA appear almost 10 minutes after stopping the effort and not during exercise, may explain the magnitude of under diagnosed EIA.

Anyway, it is well controlled in 50 to 65% of the patients, and many competition athletes have this form of disease.

It's defined as a transient reduction of lung function that occurs after vigorous exercise, with a fall of FEV1 and the previous levels are reached after 20 to 60 minutes of rest.

The rationally of EIA is not fully understood, and there is still some arguing going on, but it seems that loss of heat and water by the respiratory tract play the most important role.

The recognition of EIA is very, very important because full par-

ticipation in sporting activities is a goal in the management of childhood asthma. With medication before exercise (usually a short acting Beta 2 – agonist), a warming period and a progressive increase in it's duration, the asthmatic patient will probably be able to practice any kind of sports.
It must be considered a crucial part of treatment, not only improving lung function with time, but also self-esteem and making real the possibility of being "part of the group".
Also specified exercises, directed to the respiratory rehabilitation, and teaching the children how to breath during an asthma attack are part of the treatment, as important as the prescription of the medication.
So there is a dual relationship between asthma and exercise, being exercise a way of improving lung function but also still the most common trigger of asthma attacks.

THE JUVENILE OBESITY EPIDEMIC: IS PHYSICAL ACTIVITY RELEVANT?

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The last two decades have seen a major surge in the prevalence of childhood and adolescence ("juvenile") obesity. With the spread of this condition in numerous countries, the World Health Organization has termed it a Global Epidemic. Concurrently, there has been an increase in the incidence and prevalence of insulin resistance and even in overt type 2 ("adult onset") diabetes mellitus in obese adolescents and children. One also sees a surge in, among others, dyslipidemia and polycystic ovarian syndrome.
While such a rise in the prevalence of juvenile obesity reflects a progressively increasing positive energy balance, the causes for this are not entirely clear. In some societies, particularly those that used to suffer from undernutrition, this surge reflects an increase in energy intake, secondary to improved accessibility to nourishing food. Children who undergo improved energy-protein nourishment show, at least initially, an increase in body mass, with little or no increase in body stature. As a result, their Body Mass Index increases and some are categorized as "overweight" or "obese". There are few epidemiologic data to tell whether children and youth in technologically developed countries have undergone a secular increase their energy consumption in the last two decades. One study, based on a US nationwide sample, suggests that several age groups had a *reduction* in the percentage of fat in their diet.
Another plausible reason is an increase in sedentary pursuits and a decrease in active pursuits among children and youth. While more epidemiologic evidence is needed to substantiate this theory, young people in many countries spend much of their leisure time on sedentary "activities" such as the Internet, computer games, video and TV. There is compelling evidence for a strong association between the risk of being obese and the amount of time spent on watching TV, among US adolescents. Likewise, the likelihood for remission from obesity over time is inversely related to the amount of TV watching.
As a group, obese children and adolescents are less active than their non-obese peers. This may be explained by physical and, in particular, psychosocial barriers. The literature is less clear as to whether juvenile obesity is accompanied by reduced daily energy expenditure. Some of this inconsistency reflects the way energy expenditure is calculated.
While enhanced physical activity has little or no effect on adiposity of non-obese children and youth, it is an important element in the treatment and, possibly, in the prevention of juvenile obesity. Some of the benefits affect body composition. Others include increased insulin sensitivity, reduction in arterial blood pressure, improved plasma lipid profile and in self-esteem, as well as increased physical fitness.

THE AEROBIC FITNESS AND PHYSICAL ACTIVITY PARADOX: ARE WE FIT BECAUSE WE ARE ACTIVE, OR ARE WE ACTIVE BECAUSE WE ARE FIT?

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Introduction
Multiple randomized controlled trials have demonstrated that in males and in females, in children and adults the physical fitness can be improved by effective physical activity programs. All these training studies however, are relatively short in duration (from 6 weeks to 12 months) and most of the time in populations of healthy volunteers. These results can therefore be confounded by self-selection. Moreover the short-term effects of these training programs are not indicative for lifetime changes of physical activity patterns on physical fitness. Lifetime intervention studies, even if these are performed over several years, are not feasible and also not ethical in human populations.
Positive relationships between physical activity and physical fitness in children as well as in adults are often demonstrated by significant correlations in cross sectional studies. However in these studies the correlations do not indicate the direction of the relationship: a high correlation between activity and fitness can be explained in both ways: the population under study is more physically fit because they are more active or the other way around: the population is more active because they are more fit. One way to come out of this dilemma is to do a prospective observatory study in a population and to compare fitness and in subpopulations of subjects who showed during the observation period respectively relatively low and high physical activity patterns.

Methods
In the Amsterdam Growth and Health Longitudinal Study (AGAHLS) ca 300 boys and 300 girls at age 13 years, were followed over a period of almost 25 years till age 36 years (Kemper, ed., 1985; Kemper, ed., 1995) with a maximum.

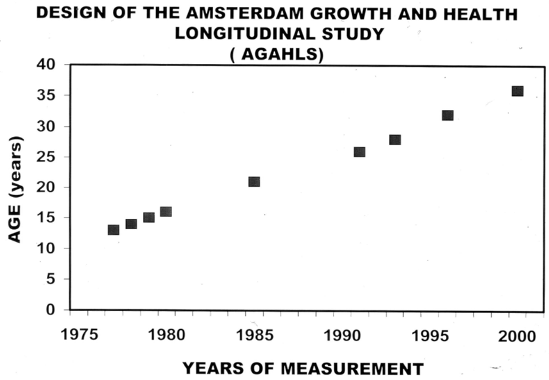

Figure 1: General design of the AGAHLS, with time of measurement (horizontal axis) and mean calendar age (vertical axis) of the study cohort.

Physical activity and aerobic fitness were measured repeatedly at least three times and maximally nine times. Physical activity was measured by a cross-check interview (Montoye et al, 1996) estimating weighted metabolic energy expenditure (MET score) during the three previous months, and aerobic fitness (Kemper et al, 1976) by a maximal treadmill test (running at 8km/hour with increasing slope) while measuring directly and continuously the maximal oxygen uptake from expired air (VO_2max).

To get an indication of a possible long-term effect of these patterns of activity on aerobic fitness a different longitudinal analyses were carried out, correcting for possible confounders such as other lifestyle (dietary intake, alcohol and smoking behaviour) and biological variables (biological age, percentage body fat, serum cholesterol and blood pressure).

The statistical analysis used was generalized estimating equations (GEE) (Zeger et al, 1986), in which the longitudinal relationship was analysed including all available physical activity and aerobic fitness data with adjustment for both time dependent (biologic and lifestyle variables) and time independent covariates (gender).

Because the aerobic fitness at the start of the study could have biased the effect on physical activity, in one GEE analysis was also adjusted for differences in initial aerobic fitness at age 13 years. In a second GEE analysis an autoregressive model was used, in which the longitudinal relation of present physical activity on the VO_2max value of the next measurement was calculated.

Results

From the results it can be concluded that over the 25 years period of follow-up the development of aerobic fitness between 13 and 36 years of age is independently and positively related to daily physical activity in both sexes (p<.01). This relationship was significant in the crude model as well as in the models adjusted for lifestyle and adjusted for biological parameters.

	VO_2-max	
	ß	p-value
analysis		
crude	0.09	<0.01
adjusted1	0.08	<0.01
adjusted2	0.07	<0.01

Figure 2: Standardized regression coefficients and p-values obtained by GEE regarding the longitudinal relationship between physical activity and maximal aerobic power

However, the functional implications of the highly statistical significant relationships seem to be small: a 10% difference in MET-score was positively related to a 0.3% difference in VO_2max.

In contrast, the results of the autoregressive model in which was controlled for present VO2max, reveal no significant relations between physical activity and aerobic fitness over the period of follow-up in both sexes over the 13-36 years age period: a difference in physical activity of 10% appeared to be positively related to a non-significant difference in VO_2max of only 0.04% (95%CI: -0.06 to 0.13).

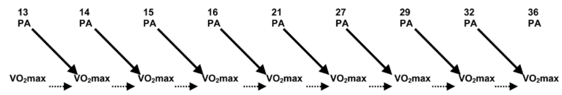

Figure 3: Representation of the autoregression model of present physical activity (PA) on future aerobic power (VO2max) with correction for present VO2max. Numbers represent the mean calendar age of the population at the nine points of measurements.

Conclusion

The longitudinal data from AGAHLS do not fully support the hypothesis that physical activity effects aerobic fitness.

This may indicate that that genetic factors are more important for aerobic fitness than environmental factors such as daily physical activity (Joyner, 2001).

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MUSCLE-BONE MUTUALISM, MECHANICAL LOADING AND THE MECHANOSTAT THEORY: A PEDIATRIC PERSPECTIVE

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Introduction
The mechanostat theory is an evolving paradigm that describes the putative interplay between mechanical loading and skeletal adaptation in animals and humans (3). The paradigm incorporates a biological model of feedback control consisting of mechanical strain sensors, bone cell transduction mechanisms and mechanical loading or strain thresholds. The function of this feedback mechanism, by mobilizing bone modeling, remodeling and growth, is to normalize activity-related increases in bone strains, to within their homeostatic range. In this model, mechanical loading effects on bone, although predominant, may also be modulated by genetic, nutritional, and hormonal influences. Mechanical loading in this context refers to bone strains engendered either directly or indirectly from muscle contractile forces during physical activity or exercise. The purpose of this review is to examine the role of muscle forces, independent of other loading characteristics of physical activity, in inducing skeletal adaptations in children and adolescents. The review focuses on certain operational features of the mechanostat model, that are perhaps more peculiar or relevant to the young growing, than to the fully developed adult skeleton. The implications of the peculiar pediatric features of this model will be discussed in relation to research study design considerations that are required to advance our understanding of the muscle-bone interaction (mutualism) within the context of this model.

The Mechanostat — A Brief Review
The mechanostat theory stipulates that the magnitude of the skeletal adaptive response will vary according to the "change" in mechanical strain history in relation to three intrinsic bone strain (ε) thresholds: the minimum effective strains for remodeling (MESr), modeling (MESm) and microdamage (MESp). Strain is synonymous with a change in bone length from its unloaded state e.g. 1000 uε = 0.1 % change in bone length. In children, mostly because of the influence of increasing body mass, even normal daily activities will induce mechanical strains in bone that approach or exceed the MESm. Strains within the MESr-MESm range (adapted window or comfort zone), may therefore increase modeling (and perhaps even growth) in children, depending on modulating factors like growth rate, nutrition and hormone status. The skeleton adapts to the increased strain levels with net increases in bone mineral accrual and concomitant changes in bone structure (geometry, size and shape). The high level of modeling activity during childhood favors loading related changes in bone structural properties. Compared to adults, normal healthy children operate further to the right within the adapted window (comfort zone), or somewhere within the mild overload window, depending on background modulating factors like activity level and growth rate. Muscle force engendered in physical activity, exercise and sport is considered a major modulator of bone strain and resulting osteotropic adaptive responses to loading in children.

Muscle-Bone Mutualism
Intuitively, given their shared functional role in movement, one might anticipate close coordination in the growth and development of both skeletal muscle and bone: the muscle-bone unit (4). Skeletal development in the very early stages of pre-natal growth, however, appears driven by intrinsic regional growth and genetic factors, initially presumably independent of direct mechanical strain associated with muscle activity. Once the muscle-bone unit is anatomically established, muscle forces begin to induce strain in bones even in-utero, as evidenced by underdeveloped and even fractured bones in certain neuromuscular or bone mineral disorders. The magnitude of muscle induced mechanical strain is potentiated in the transition from pre-natal to post-natal life, due to the influences of gravity and physical activity-associated muscle force requirements acting against an increasing body mass. Besides the obligatory coordinated increases in muscle lengths with increasing bone lengths, post-natal development of the morphological features of the muscle-bone unit is not as tightly coordinated as might be expected (5). The proportion of muscle mass increases, whereas that of bone decreases with growth, along with regional variation and sexual dimorphism in the distribution of the proportions of muscle and bone.
Due to poor mechanical advantage (force arm < resistance arm in most muscle-bone units), however, especially in weight bearing bones, muscle forces acting on the skeleton in humans are generally quite large, usually exceeding by far the peak ground reaction impact forces associated with extreme loading conditions such as tumbling in gymnastics (3). Theoretically then, activity associated contractile forces of muscles acting on bones may be considered an important determinant of bone strain and skeletal adaptation within the context of the mechanostat theory in growing children. Besides the expected close coordination of bone and muscle length changes, development of other morphological characteristics, for example, muscle and bone cross-sectional areas, may be less closely correlated. These characteristics may be more dependent on external factors such as ground reaction forces, activity histories, magnitude, rate and type of loading strains, and their interaction with intrinsic systemic and tissue specific endocrine factors. Muscle force and bone strength (under certain loading conditions) are related to their respective cross-sectional areas, which are in turn related to body size. Hence, some association might be expected between gross morphological and functional measures of muscle size with structural factors influencing bone strength in children during growth.

Muscle Force, Bone Strain and the Mechanostat
Theoretically, the mechanostat sensor is unaware of, and incapable of differentiating the source of the load, responding only to local or regional changes in detectable strain levels. The

osteotrophic effector response, however, is sensitive to the parameters of the loading stimulus which influence strain, including the magnitude, rate, frequency and latency of the applied loads. In humans, bone strain derives from three predominant sources: *ground* (during weight bearing activity) and *joint reaction forces*, that vary proportionately as a function of the mass of the body or body part moved and its acceleration in gravity and *muscle forces* acting on bone. Muscle forces also vary in proportion to the mass being moved (inertia and any externally applied loads), but are also dependent on the mechanical advantage of the muscle-bone unit (7). Muscle forces engender bone strain both locally at tendon insertion points, as well as along the lengths of bone, causing mostly bending moments. The absolute and relative contributions of these sources of strain to bone will vary by activity type, intensity, and training history, age, sex and maturity-related influences on body size (mass mostly). Experimentally, it is difficult to isolate the exclusive contribution of muscle forces to bone development, since muscle mass comprises a variable but substantial proportion of body mass during growth, thus also contributing to strain engendering ground and joint reaction forces. Furthermore, absolute growth of both muscle and bone co-vary with changing body mass during childhood, precluding easy differentiation of the unique influence of muscle size and force. Lastly, there are several muscle-bone unit phenomena such as regional myoelectric and circulatory influences that may, because of their shared anatomical and functional relationships, influence skeletal development independent of the influence of muscle contractile forces. While it is difficult to differentiate and quantify the independent contributions of these putative modulators of strain, variation in muscle forces acting on bone apparently explain upwards of 50% of the post-natal variability in development of bone strength and mass in humans (4).

Strain Engendering Bone Loading Conditions

Normal activity in humans results in skeletal loading under conditions of mostly bending and compression, with a lesser degree of torsion. Because of the curvature of most weight-bearing bones and the biarticular nature of many of the muscle arrangements, physical activity apparently imposes mostly bending loads on the skeleton, accounting for more than 80% of the total bone strain load. The nature of the predominant loading condition during activity is important, because it predicts whole as well as regional bone strain distribution patterns and ultimately the amount and type of expected osteotrophic adaptive response. The loading condition in turn determines the location and functional effectiveness of regional skeletal adaptive responses. For example, bending loads impose high tension and compression strains respectively, on the convex and concave portions of long hollow bones, predicting larger adaptations on these surfaces than on the inner surfaces of the bone where strains along the neutral axis are lowest. Further, the osteotrophic adaptive response to activity induced strain is multi-varied, including possible alterations in the bone's material or structural properties, which separately or in combination attempt to bring the regional strain distribution level back to within its normal range. These adaptations ultimately increase bone strength under the imposed loading condition. Mechanically, the strength of bone is dependent on its material and structural (geometric and biomechanical) properties, their relative importance varying under differing loading conditions (2,6). Under *bending loads*, bone strength is largely dependent on its material (including its mineral content), geometric (size and material distribution) and biomechanical properties (cross-sectional moment of inertia-CSMI). Under *axial compression*, bone strength is largely dependent upon its material properties and its cross-sectional area for dispersion of load bearing. *Torsional bone strength* by comparison is dependent largely upon its polar moment of inertia (PMI), material composition and radius. The influence of muscle forces on the various properties of bone, therefore, will depend on the magnitude and type of loading condition-specific strains imposed both globally and regionally by the activity. The specificity of these interactions suggests that no single in vivo osteotrophic measure will adequately or accurately reflect the skeletons' adaptive response to loading under the myriad conditions that characterize human movement. Furthermore, knowledge of the nature of the predominant loading condition sub-served by the muscle-bone unit, and the specific mechanical correlates influencing bone strength under these conditions will facilitate selection of the most physiologically relevant bone outcomes. It follows, therefore, that non-invasive studies investigating the importance of muscle force as a modulator of skeletal adaptation to exercise in children must include an array of measures including both the material and structural properties of bone to ensure accurate interpretation (8).

Muscle Force and Bone Measures

Investigations of musculo-skeletal development in children have typically assessed muscle force as muscle group specific isometric, isotonic or isokinetic strength or torque measured by dynamometry. With the advent of non-invasive imaging techniques (e.g. dual energy x-ray absorptiometry-DXA, peripheral quantitative computer tomography-pQCT or magnetic resonance imaging-MRI), lean tissue mass (LTM) and muscle size (CSA and volume) determined using these approaches have sometimes served as perhaps more reliable surrogates of muscle strength. The use of these surrogates recognizes the close physiological relationship between muscle size and its force producing capacity.

Until recently, the majority of studies investigating the muscle-bone unit in children have related muscle force or size measures to bone mineral content (BMC) or areal bone mineral density (aBMD), both measures of the material properties of bone, and to bone area (BA), a measure of bone geometry, determined by DXA. With DXA, BMC, aBMD and BA are all body size dependent, making it difficult to differentiate the independent influence of muscle strength and size, which themselves are size dependent. Furthermore, aBMD does not represent the volumetric density of the various bone compartments (bone organ, cortical or medullary compartments) and BA reflects the distribution of bone only in the anterior-posterior plane, not reflecting its true circumferential distribution. Recent advances with DXA technology (Hip Strength Analysis software) have permitted estimates of regional geometry (CSA) and biomechanical properties (cross-sectional moment of inertia-CSMI and section modulus) of bone based on assumptions of a cylindrical model of bone shape. In addition, MRI and pQCT permit determination of bone compartmental volumetric BMD (g/cm^3), geometry (e.g. circumferential CSA of the entire bone region or its cortical shell and medullary cavity), bone biomechanical properties (e.g. CSMI or PMI), integrated measures of bone material and biomechanical properties (e.g. bone strength index-BSI) as well as region or site specific measures of muscle CSA or volume. The emergence of these newer and more accurate, reliable and safer non-invasive muscle and bone assessment technologies will clarify and enhance our understanding of the interaction between muscle forces and skeletal adaptation both in healthy children and in children with chronic disease or disability.

Muscle Force — is it a major determinant of skeletal adaptation in children?

The muscle-bone unit has not been extensively investigated in pediatric populations. The influence of muscle force and size has been examined using a variety of analytical procedures including simple correlation, multiple regression and principle components analysis for both population and cross-sectional comparative studies of groups differing in sport or exercise training background. The relationship appears to be highly complex, varying by anatomical site, age, sex, maturity, sport specialization and bone outcome measure. For bone mineral outcomes (BMC and aBMD), associations in children are generally weak to moderately strong in population studies and vary between significant and non-significant within specific age and sport groups. In these studies, strength sometimes accounts for a significant but nevertheless relatively small proportion of the variability in BMC or aBMD across collapsed groups, even when there are no significant inter-group differences for strength measures or differences in bone mass among strength quartiles. Further, although still controversial, there is some suggestion of a maturity related sexual dimorphism favoring females in the development of the muscle-bone relationship around puberty, with higher total body BMC per LTM (just to be consistent) in post-pubertal girls compared to prepubertal males and females and post-pubertal males. This latter maturity related relationship between LTM, a proxy for muscle size and force, and BMC may, however, be artifactual, simply reflecting sampling bias. Low to moderate site-specific correlations have also been reported between forearm muscle force and volumetric measures of total radial BMD, but not volumetric trabecular or cortical bone BMD determined by pQCT. Of the limited number of prospective studies involving high intensity resistance or strength training, the association between strength gains and changes in BMC or aBMD are weak at best, and on a proportional basis, strength gains usually far exceed gains in bone mass.

Even less is known about the relationship between muscle forces and bone structural properties in children and adolescents. Again, most of the work in this area has focused on comparisons among athletes representing different sports and loading conditions. Generally, muscle strength of the legs (quadriceps and hamstrings) has been reported to account for significant proportions of the explained variation in some, but not all bone areas determined by DXA, despite non-significant differences in leg strength among adolescent sport groups. In these comparative studies, leg strength was more strongly correlated with and accounted for the largest proportion of the explained variation in total body BA, than more region specific BA at the trochanter, proximal femur and tibia, with generally weaker relationships among females. Grip strength has also been reported to be weakly to moderately correlated with several measures of DXA determined distal and ultradistal radial bone diameters, cortical thickness and biomechanical indices of bone strength in peri-pubertal girls. Based on pQCT assessment, slightly more favorable, moderate to strong site-specific correlations have also been reported between forearm strength (grip), geometric measures of total and cortical bone areas and a biomechanical measure of bone strength index in mostly prepubertal boys and girls. In elite adolescent female athletes neither absolute, nor lean mass normalized leg strength (knee extension and flexion strength or their ratio) were significantly correlated with, or differentiated among MRI determined mid-femur measures of bone geometry and biomechanical indices of bending strength among swimmers, cyclists, runners and triathletes.

Summary

Clearly, the theorized strong positive association between muscle size and strength and skeletal adaptation has not been consistently demonstrated in the pediatric bone and exercise research to date. In the context of the mechanostat theory, the influence of activity-associated muscle forces on bone must be considered against the background of normal developmental variation in the muscle size, strength and bone relationships. Given the age, sex and maturity dependent variations in these developmental relationships, it may be wishful thinking to expect a simple monotonic relationship to describe the muscle-bone interaction, especially given the multi-faceted nature of the skeletal adaptive response to exercise in children. Our inability to confirm a strong muscle–bone relationship stems in part from not appreciating the sophisticated interaction between the nature of the loading conditions induced by muscle forces, the mechanical properties of bone responsive to the condition-specific strain patterns, and consequently the best outcome measure to assess the adaptive response.

Furthermore, for young athletes involved in specialized training, the skeletal adaptive response may also be influenced by activity type (the relative strength requirements of different sports), by the timing of the measurements of strength and muscle mass compared to the measurements of bone (e.g. recognizing the lag time between bone and muscle strength adaptations) and by the nature of the predominant non-muscular ground and joint reaction forces inherent in the training activity. Establishment of the dominance of muscle force in this relationship also requires proof of a strong association between increased muscle size and strength and bone mass or size, independent of body size influences: this has not been satisfied in most of the pediatric studies to date. Establishment of cause and effect requires proof of a temporal dissociation between changes in muscle size or strength and changes in bone in response to either increased or decreased loading (1). Clearly, these are areas requiring further investigation and clarification.

Practical Applications

Unraveling the unique contribution of muscle forces to skeletal adaptation is not merely a theoretical and intellectual exercise. Understanding the operational characteristics of the muscle-bone relationship may improve exercise prescription for optimization of bone strength in normal healthy children and adolescents. Further, adapted exercise approaches focusing on muscle strengthening activities may prove more effective for rehabilitation of weakened or fractured bones that characterize many chronic pediatric diseases and their pharmaceutical treatment strategies. Additionally, appreciation of the normal muscle force-bone relationship may enhance clinical differentiation of "physiologic" osteopenia in pediatric disease (defined as low bone mass proportionate to inactivity-associated reductions in muscle size and force) from osteoporosis, a deficit in bone mineralization that reflects abnormal bone metabolism. Improved diagnostic accuracy may result in improved and more effective treatment strategies and enhanced recovery of bone health status.

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SCHOOL AGE PHYSICAL ACTIVITY AS A PREDICTOR OF PHYSICAL ACTIVITY IN ADULTHOOD 21 YEARS LATER

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Enhancing life-long physical activity has long been an important goal of physical education curricula and sport policy in many countries. However, rather little is known how physical activity in childhood predicts active lifestyle in adulthood. Even less is known how the type and nature of youth physical activity and sport participation are connected with physical activity in adulthood. The aim of this paper is to investigate how well type of physical activity and long term participation in physical activity and sport participation at school age predict physical activity in adulthood.
In 1980 2309 9-, 12-, 15- and 18-year-old boys and girls were randomly sampled to be the subjects of this study (Young Finns Study). The measurements were replicated in 1983, 1986, 1989, 1992, and 2001. In 2001 the subjects were respectively 30-, 33-, 36-, and 39-year-old (Åkerblom et al. 1985, 1999). Physical activity and participation in sports in 1980 were measured by means of a short self-report questionnaire. Questions concerned the frequency and intensity of leisure-time physical activity, participation in both organized sports and recreational sports. By summing up after re-coding these variables the index of physical activity was calculated. (Telama et al., 1985; 1997).
Rank order correlation for the 21 years tracking of physical activity index was significant but low in all cohorts, in males higher (0.29 - 0.39) than among females (0.16 - 0.27). Multiple step wise regression analysis showed a little higher predictability, R varying from 0.31 to 0.44 among males and from 0.17 to 0.32 in females. According to r and beta coefficients the best predictors among individual variables were participation in sport club training sessions, participation in sport competitions, vigorous physical activity and the grade of physical education. The effect of stability of physical activity at school age on adult physical activity was studied categorising the subjects to those who had stayed in most active third of physical activity index from 1980 to 83, and to those who had stayed in most inactive third during same interval. Odds ratios showing the probability to belong to the most active third as compared to most inactive group 2001 were 4.3 (1.8 - 9.7) and 2.9 (1.3 - 6.4) among 9 -12-years-old boys and girls, and 7.1 (2.6 - 19.0) and 5.6 (2.2 - 14.1) in 15 - 18-years-old boys and girls. When persistent activity/inactivity from 1980 to 86 were compared the probability was higher, OR varying from 5.9 to 10.8. In addition it was found that activity tracks better than inactivity. Physical activity at school age (9 - 18 years) predicts physical activity at adult age 21 years later. The linear correlation although significant is low, higher among males than females. Long-term persistence of physical activity and persistent participation in competitive sport at young age increases the probability to be physically active in adulthood. The results emphasise the importance of promoting physical activity at school age.

AGE AND GENDER DIFFERENCES IN PATTERNS AND TYPES OF PHYSICAL ACTIVITY IN YOUTH

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Introduction
Extensive evidence has documented the health benefits of regular physical activity (PA). Several studies have shown that many of the known risk factors for chronic diseases are also present in youth (Teixeira et al. 2001) and it has been suggested that inactivity during youth is linked to several health-related risks in adulthood (Twisk et al. 1997) On the other hand, lifetime physical activity and the establishment of healthy patterns of lifestyle, in childhood tend to generate active adults (Malina, 1996). General guidelines are widely used to describe health-related PA benefits in youth addressing the important role played by the moderate-to-vigorous physical activity (MVPA) (Cavill et al. 2001). Moreover, during the last years a debate concerning the health benefits and the characteristics of the activity such as MVPA versus light activities, and intermittent versus continuous activity - address the need to assess not only a general measure of activity but also the characteristics and dimensions of the activities (e.g. intensity and duration) (Sallis and Saelens, 2000). Because, usually policies and programs strategies are based on prevalence estimates for meeting these guidelines, it is crucial that prevalence estimates be accurate (Sarkin et al, 2000). As researchers begin to explore the PA dose-response relationship with health parameters, it is increasingly important to provide a more precise estimate of

both the quantity and the quality of PA. Therefore, would be useful to provide a more complex and accurate understanding of how children differ in their activity patterns (Janz et al. 1995). The mechanisms beyond those facts are confusing, because participation in physical activity appears to be influenced by a large number of factors, including environmental, social and psychological variables. Age and sex are the two most studied biological covariates of participation in physical activity in youth. In fact age-related changes depend on physical activity type and characteristics (Telama, et al. 1994), and research findings support the idea that physical environments are closely associated with physical activity (Owen et al., 2000). However, the question whether patterns of PA, during specific periods of time, are or are not representative of the entire day's PA patterns is still unanswered (Trost et al. 2000). One way to approach this issue may be to focus the assessment of PA on key times or places that allow youth to be active. This is a timely topic and an answer can guide the development of measurement protocols in field-based studies that are needed to investigate high priority issues related to youth PA. Furthermore, the influence of participation in structured or unstructured programs has not been well quantified during adolescence. In fact, few studies have examined the differences among groups with different PA participation levels (from sedentary to high level of physical activity). Thus structured vs. unstructured activities choices is a research interesting area because such contributions are extremely important to develop effective physical activity interventions in youth.

Purpose
According to the age and sex:
1 — Identify patterns of MVPA in youth
2 — Identify places of MVPA participation during school period
3 — Determine whether there are specific periods of the day that could be representative of MVPA participation
4 — Determine the associations with choice of structured and unstructured physical activity programs outside school

Results
Data from our research showed that PA was consistently higher in boys than in girls.. The findings also support the idea that from a public health perspective children appear to meet the minimum PA recommendations for health. Regarding the engagement in MVPA it was not possible to found any clear pattern of PA. Girls, showed higher percent of time engaged in MVPA during the morning and early afternoon periods (sum of two periods 51.0%), while boys' percent of time engaged in MVPA is higher at late afternoon and evening periods (sum of two periods 53.8%). A principal components analysis showed four distinct components that accounted for 67% of the variance, indicating that within each time component, students' participation in MVPA remained consistent yet distinct from other times during the day. The results showed an important period of MVPA participation, corresponding to the school hours (component 1) and another important key period, corresponding to lunchtime and outside-school activities (component 2). Morning time before school period (component 4) and period before bedtime (component 3) appear as distinct periods of daily time. Our data pointed out that, in adolescents, participation that there is an increase in structured physical activity participation as the physical activity level increases. The differences were greater among girls ($\chi^2 = 20.663$, $p=0.001$) than among boys ($\chi^2 = 7.762$, $p=0.05$). Our findings also showed that there are changes in the nature of physical activity choices across adolescence. The tendency reported for the frequency rate of adolescents not participating in structured activities seems to confirm those ideas. We reported a significant decrease in the tendency for non-oriented sports participation with increasing age. However, no differences in the tendency of the formal sports participation were found.

Conclusion
From a public health point of view, our data suggested that lunchtime and after-school periods (afternoon) might be an appropriate target for PA intervention programs. It was interesting to observe that lunchtime has been associated with outside school activities, which suggest lunchtime as an important period of engagement in MVPA, likely spontaneously.
Girls tend to be more active during school periods, while boys are more active after school.
Only 33% of adolescents participated in structured physical activities out side school.
As age group increases, sports activities become a relatively more important component of total weekly activity both in male and female subjects.
The policy implications are that we cannot expect formal programs to provide sufficient activity of most young people. Therefore it can also be suggested the recommendations to link schools and students to community PA programs and to develop effective systems allowing this relationship.

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THE RESPONSE TO EXERCISE: FROM GREGOR MENDEL TO ODED BAR-OR

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This paper summarizes the content of a lecture presented at the 22nd Pediatric Work Physiology Meeting to honor Professor Oded Bar-Or on the occasion of his retirement from the faculty at McMaster University, Ontario, Canada. Gregor Mendel (1822-1884) published a landmark paper in 1866 based on crosses between plants. He defined a set of rules that eventually became known as the three Mendel Laws of Genetics. These principles did not influence the science and practice of medicine for a long time. However, they were proven later to be fundamental laws of biology and genetics with wide ranging implications for contemporary modern biology and human genetics. More recently, in the last 20 years or so, we have discovered that these laws of genetics also have implications for the response to exercise and for fitness-related phenotypes. This is where the contributions of Professor Oded Bar-Or become highly relevant. Oded was one of a handful of physicians and exercise scientists who focused on children and adolescents, beginning in the 1960s. His training in medicine, pediatrics and physiology allowed him to ask questions and pursue research problems that had not been much addressed before him in pediatric exercise physiology. Some of these research questions, particularly those pertaining to exercise physiology and thermal physiology, are quite relevant to the paradigms of contemporary molecular biology and genetics. It is a pleasure for me to dedicate this lecture to Professor Bar-Or.

Importance of exercise in children

Regular exercise is known to have beneficial effects on health. Based on a large number of studies, the evidence is quite strong that regular exercise is associated with a more favorable risk profile for common chronic diseases, reduced morbidity, and lower death rates. A vivid illustration of this phenomenon is provided by a report of the Centers for Disease Control and Prevention (CDC) in the USA, estimating that about 300,000 premature deaths per year can be attributed to a sedentary lifestyle and poor nutritional habits. Moreover, regular exercise in the form of exercise training increases physical performance. For instance, endurance training sustained for months and years can dramatically improve endurance performance in children and adults. Health-related fitness and performance-related fitness traits have in common the fact that they are complex multifactorial phenotypes whose heterogeneity in any population of children and adolescents depends upon lifestyle, environmental and social conditions, as well as genetic differences. Physical inactivity and obesity are known to be quite prevalent not only in adults but also in children and adolescents of industrialized countries. When both coexist in a child, pernicious effects are predicted. Excess storage of fat in the form of triglycerides is known to lead to fat deposition in non-adipose tissues and organs, a phenomenon known as ectopic fat deposition. Fat infiltration in skeletal muscle, pancreas, and heart has deleterious consequences on metabolism that have been defined as being "lipotoxic" (1). A sedentary life style is likely to increase the severity of the lipotoxic effects of ectopic fat deposition in children and adolescents. Indeed, exercise is one of the most efficient modalities known to increase lipid oxidation and thereby reduce the burden of positive energy balance and excess lipids available for storage.

Even though there is as of yet no direct proof that ectopic fat deposition has deleterious effects in children and adolescents, it is likely to be the case. The growing prevalence of type 2 diabetes mellitus in obese adolescents is compatible with the hypothesis that excessive fat infiltration in non-adipose tissue reduces insulin action in skeletal muscle and curtail the ability of the pancreas to meet the demands for insulin in these youths. Whether there is a genetic predisposition for ectopic fat deposition is unknown at this time.

Here we are reviewing some of the evidence for a role of human genetic variation on health and performance traits that are influenced by regular exercise with an emphasis on children and adolescents. Three main questions are considered: Are genetic differences contributing to variation among sedentary people? Are genetic differences involved in accounting for the heterogeneity in the response to regular exercise? What do we know about specific genes, DNA sequence variants and candidate chromosomal regions?

Genes and health-related fitness in sedentary youths

What is the evidence that genetic variation plays a role in blood pressure, blood lipids and lipoproteins, glucose and insulin metabolism, adipose tissue and skeletal muscle morphological and metabolic properties, brain and peripheral regulation of food intake and metabolic rates, stroke volume and cardiac output, VO_2 max, and many other health and performance related traits among sedentary people? A large number of family and twin studies have considered the issue of the presence or the absence of familial and genetic effects. By and large, these studies have concluded that a significant familial aggregation is observed for any of the health and performance traits of interest here. When a genetic hypothesis for the intergeneration transmission could be tested, it typically yielded significant genetic heritabilities ranging from about 20% (e.g. resting blood pressure, fasting insulin) to about 50 to 60% (HDL-cholesterol, lean body mass, % Type I fibers in muscle) for phenotypes adjusted for age, sex and often other concomitants (2). Interestingly, there is some evidence to the effect that the level of physical activity is also partly inherited. For instance, twin studies have revealed significant genetic component to the level of habitual physical activity or sedentarism. Familial studies have indicated significant familial aggregation for participation in physical activity or for sedentary behavior. Recently, we were able to complete a genome-wide scan for physical activity and inactivity phenotypes using the Quebec Family Study cohort (3). Three highly suggestive linkages were uncovered with physical inactivity as a phenotype, on chromosomes 2, 7 and 20. The most convincing result was for a QTL on chromosome 2. A positional cloning effort is currently underway with the goal of identifying the gene and mutation responsible for this sedentary behavior QTL. In another series of studies, we have been able to show that a genetic marker in exon 6 of the dopamine receptor 2 (DRD2) was associated with physical activity level in the women of Quebec Family Study and HERITAGE Family Study cohorts (4).

Individual differences in response to regular exercise

One important question pertains to the heterogeneity in the responsiveness to regular exercise. We now have solid evidence that there are considerable individual differences in the capacity to adapt to an exercise-training program. For instance, after exposure to a laboratory-based standardized program lasting 20 weeks, in which compliance was not an issue for more than 700 participants ranging in age from 17 to 65 years, we observed that a good number of subjects did not register an increase in VO_2 max, stroke volume, HDL-cholesterol, and other health and performance-related traits while others registered very significant gains (5). Age, sex, baseline level and ethnic background accounted for 10% or less of the variation in response for cardiorespiratory endurance. The main determinant of the individual differences in trainability was the familial background. Indeed, familial aggregation accounted for about 50% of the variance in the training response, thus strongly suggesting that genetic factors played a key role in the ability to benefit from a physically active lifestyle or the capacity to attain very high levels of endurance performance. All health-related fitness phenotypes investigated thus far in the HERITAGE Family Study exhibit the same pattern: individual differences in response to regular exercise but significant familial aggregation of the response pattern.

About the genes involved
The third question has to do with the identification of the genes and mutations responsible for these apparent genetic effects. The task is extraordinary complex. The genetic dissection of multifactorial traits requires a variety of strategies based on in vitro technologies, animal models and human studies. Breeding experiments selecting for endurance performance in rats have generated high and low lines in which cardiac properties were strong determinants of performance. Gene expression studies with cardiac and skeletal muscles are yielding candidate genes that will be subjected to detailed sequence analysis. Crossbreeding experiments with inbred strains can also be used to identify chromosomal regions (known as quantitative trait loci or QTLs) harboring genes contributing to the phenotype of interest. Candidate genes and genome-wide scans together with expression studies in skeletal muscle or adipose tissue are the most common strategies currently used with human subjects. Comparisons of allelic differences between cases (e.g. people exercising regularly or elite athletes) and controls (e.g. sedentary individuals or subjects known to be low responders) can also provide useful information. Genomic scans performed with hundreds of DNA markers on the HERITAGE Family Study cohort have generated several QTLs for the response to regular exercise of VO_2 max, stroke volume, exercise blood pressure, body composition, insulin sensitivity, and other phenotypes. Positional cloning of some of these QTLs and candidate gene explorations has produced evidence for a role of DNA sequence variation in muscle creatine kinase, nitric oxide synthase 3, titin and other genes. The human gene map for the phenotypes of interest is updated every year by our laboratory in Medicine & Science in Sports & Exercise (6).
We may be able one day to identify at the DNA level those who are likely to benefit more from a physically active lifestyle in terms of health outcomes or to be highly trainable in terms of cardiorespiratory endurance and other types of physical attributes. If shown to be true, such advances would have practical applications for education, youth sports, pediatrics and preventive medicine.

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