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Physical activity and growth, maturation and performance: a longitudinal study

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ABSTRACT

BEUNEN, G. P., R. M. MALINA, R. RENSON, J. SIMONS, M. OSTYN, and J. LEFEVRE. Physical activity and growth, maturation and performance: a longitudinal study. *Med. Sci. Sports Exerc.*, Vol. 24, No. 5, pp. 576–585, 1992. The effects of increased physical activity upon physical growth, maturation and performance were investigated in samples of 32 active and 32 nonactive Belgian boys followed longitudinally from 13 to 18 yr of age. Active boys participated in sports activities for more than 5 $h \cdot wk^{-1} \cdot yr^{-1}$ during each of the first 3 yr of the study, in addition to compulsory physical education. Nonactive boys participated in less than 1.5 $h \cdot wk^{-1} \cdot yr^{-1}$ during the first 3 yr of the study, but did participate in required school physical education. Anthropometric dimensions included lengths, breadths, circumferences, and skinfolds. A physical fitness test battery was administered at each observation including nine health- and performance-related tests. Skeletal maturation was assessed; sociocultural determinants and sports participation were obtained through written questionnaires verified by a control interview. No significant effects of increased physical activity were observed on growth in somatic dimensions, including skinfolds, age at peak height velocity, skeletal maturation, and most of the physical fitness components. More active boys obtained better results from 14 yr onward only for pulse recuperation and for bent arm hang. These results can be generalized to the average population but do not necessarily apply for highly trained and selected elite athletes.

SPORTS PARTICIPATION, HEALTH- AND PERFORMANCE-RELATED FITNESS, SKELETAL MATURATION

Although knowledge about the influence of regular physical activity on somatic growth and maturation and on performance is expanding, many gaps exist in our understanding (1,10,11,25). For example, experimental training studies are usually of short duration, and the programs do not necessarily reflect the activity levels of youths who participate in a variety of sport activities. The short-term nature of many training programs makes it difficult to partition changes associated with training from those associated with normal growth and maturation. Furthermore, these studies do not ordinarily follow the boys after the training programs stop. The primary focus of most experimental studies is the physiological changes associated with training, generally endurance training. Changes in growth characteristics are typically secondary while biological maturation is not ordinarily considered (6,7). Co-twin training studies also primarily consider physiological variables and body composition (5), and until recently have not considered the effects of regular training on children and adolescents. Finally, subjects in many experimental training programs are young athletes, and athletes are a reasonably select group who often differ from the general population even at young ages (8,9,17). Inferences from such studies thus do not necessarily apply to the general population. The present study considers the effects of increased physical activity on the somatic growth, biological maturation, and physical performance of boys followed from 13 through 18 yr of age.

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MATERIALS AND METHODS

The subjects are from the Leuven Growth Study of Belgian Boys (18), a combined cross-sectional and longitudinal study of physical growth, maturation and performance of boys 12–19 yr of age. In this study, complete longitudinal data are available for 588 subjects observed annually (2). From these 588 subjects, 32 active and 32 nonactive boys were selected. More details about the design of the Leuven Growth Study and the analyses of the longitudinal data can be found in earlier reports (2,18). Anthropometric dimensions include body weight, stature, sitting height, skeletal breadths (biacromial, chest, bicristal, biepicondylar humerus, bicondylar femur), girths (arm, thigh, calf), and skinfolds (triceps, subscapular, suprailiac, calf). The motor test battery, which was constructed after age-specific validity and reliability studies (18), includes nine health- and performance-related fitness items: arm pull (static strength), vertical jump (explosive strength), leg lifts (trunk strength), bent arm hang (functional strength), running speed (50-m shuttle run), speed of limb movement (plate tapping), sit and reach (flexibility), pulse rate after a 1-min step test, and recovery pulse rate 1 and 2 min after the 1-min step test. Skeletal maturation was assessed with the Tanner-Whitehouse II method (27). Ages at peak velocity for height and weight (indices of somatic maturation) and peak velocities were estimated with nonsmoothed polynomials (2). Age at peak strength velocity and peak strength velocity were also estimated in a similar manner.

At each annual observation sociocultural characteristics of the boys' families were obtained by written questionnaire and verified in an interview. Information on sport participation of the boy and his parents was obtained in a similar manner. Sport activities of each boy was recorded on a standardized questionnaire in which sport activities during the year before the time of observation were recorded. Four aspects of sport participation were considered: type of activities (volleyball, swimming, gymnastics, and so on), diversity of activities (number of different sports practiced), amount of time spent in each sport (hours per week over a 1-yr period), and organizational context of sport involvement (sport club, school club, with friends, alone). The questionnaire was designed in such a way that it could be completed in an easy and correct manner. It was completed by the boys' parents and cross-checked during an interview with each boy. The information on frequency of participation for each sport was combined into a single score of hours of sport participation per week over 1 yr. Parents completed a questionnaire each year of the study (at the time of obtained informed consent for the child's participation in the study). For the purpose of the present analysis, *active* boys were those who participated in sports activities outside of compulsory physical education for *more than 5 $h \cdot wk^{-1}$ during each of the first 3 yr of the study. Non-active* boys were those who participated in *no more than 1.5 h per week during each of the first 3 yr of the study* outside of compulsory school physical education. Depending on the school system, the compulsory physical education varied between 1 and 3 $h \cdot wk^{-1}$. These categories were selected on the basis of several cross-sectional analyses of changes in the sports participation of Belgian boys with age (22). The first 3 yr of sport participation during the longitudinal study were considered of primary importance because they span the period during which most boys experience their growth spurt, i.e., about 12–15 yr of age (2). The active and nonactive groups each included 32 boys. The sociocultural characteristics (family size, birth order, degree of urbanization of residence, educational and professional level of father, and so on) of the families of boys in each activity group did not differ.

The influence of activity level on somatic growth, biological maturation, and physical performance was tested with a GLM analysis (SAS) with repeated measurements (24). Activity level and time of measurement were the main effects and activity by time of measurement was the interaction term. In this type of analysis, it is expected that the time of measurement effect is significant since it refers to increases or decreases of a characteristic with age. The physical activity effect and the interaction term should be significant in order to provide evidence for a significant impact of activity upon the characteristic considered. Besides the main effect of the activity level, it is expected that, due to the continuous higher activity level of the active boys, the growth, maturation, and performance of the active and nonactive boys will diverge more and more with increasing age, resulting in a significant interaction term. An alpha = 0.05 was chosen to reject the null hypothesis. In addition, growth curves of the active and nonactive boys were plotted relative to Belgian reference data (18).

RESULTS

There are no significant differences in chronological age between active and nonactive boys at the first observation (Table 1). Since subsequent observations were made at nearly exact annual intervals, all subsequent differences in mean chronological ages are not significant. Standard deviations also do not differ. The sociocultural characteristics: degree of urbanization of residence, educational and professional level of the father, family size, and birth order did not differ between the activity groups. Thus, it seemed unnecessary

TABLE 1. Chronological age and maturity characteristics of active and nonactive adolescent boys.

Characteristic	Active Boys (N = 32)	Nonactive Boys (N = 32)
Chronological age (yr) at 1st observation	12.86 ± 0.57	12.84 ± 0.64
Age (yr) at peak height velocity	14.17 ± 0.83	14.05 ± 0.81
Age (yr) at peak weight velocity	14.76 ± 1.10	14.71 ± 1.20
Age (yr) at peak strength velocity	15.37 ± 1.23	14.86 ± 1.43
Peak height velocity ($cm \cdot yr^{-1}$)	9.4 ± 1.5	8.9 ± 2.1
Peak weight velocity ($kg \cdot yr^{-1}$)	8.8 ± 2.1	8.9 ± 2.8
Peak strength velocity ($kg \cdot yr^{-1}$)	17.4 ± 4.9	17.9 ± 5.8

Values are means ± SD.

to take these factors into consideration in the further analyses.

Indicators of somatic (Table 1) and skeletal (Fig. 1) maturation do not differ between active and nonactive boys. Furthermore, peak velocities of growth in stature, weight and strength during the growth spurt do not differ between activity groups (Table 1).

Growth curves for stature and weight and for selected skeletal breadths and limb girths in active and nonactive boys are shown in Figures 2 and 3, respectively. The data are plotted relative to Belgian reference data, and it is clear that the growth status of active and nonactive boys follows closely the median values of the reference data. None of the measurements illustrated in the figures (and none of the other skeletal breadths and girths not shown) show a significant effect of activity or a significant interaction effect (Table 2). As expected, the time or age effect is significant.

Median skinfold thicknesses between 13 and 18 yr of age in active and nonactive boys are shown in Figure 4. The median growth curves for each skinfold tend to be quite similar in both groups and generally follow the medians of the reference values. Since skinfolds are skewed, statistical comparison of the activity groups was done on logarithmically transformed values in order to normalize the distributions at each age. Although there is a significant time effect, there are no significant differences between active and nonactive boys over the six observations and the interaction effect is also not significant (Table 2).

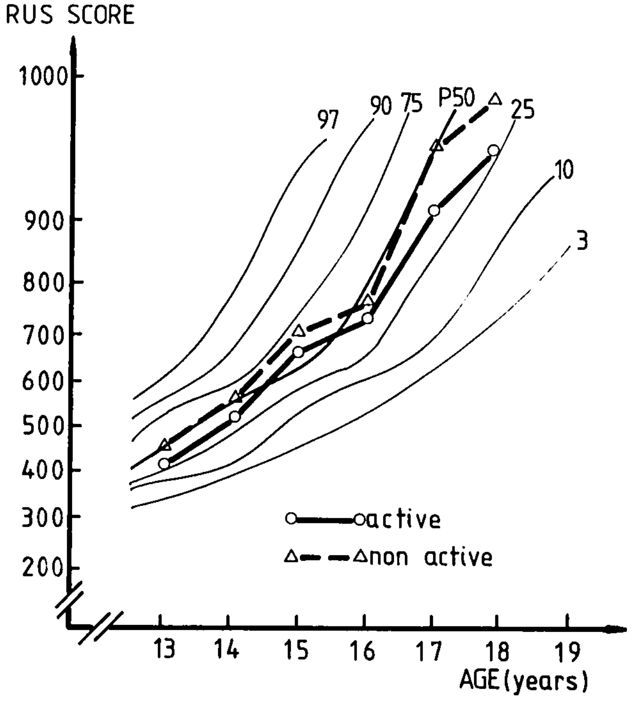

Figure 1—Skeletal maturation (Tanner-Whitehouse II RUS) of active and nonactive boys plotted relative to Belgian reference data (18).

Indicators of health-related fitness are shown in Figure 5. Active boys have lower pulse rates after a 1-min step test and a more rapid pulse recovery (pulse rates 1 and 2 min after the step test) than nonactive boys (Table 2). The differences are statistically significant at each age from 14 through 18 yr. A similar pattern is evident for the bent arm hang. Active boys perform better and age-specific differences are significant from 14 through 18 years. In contrast, leg lifts (trunk strength) and lower back flexibility (sit and reach) do not significantly differ between active and nonactive boys (Table 3). Only at 14 yr of age do active boys perform significantly better on leg lifts.

The four indicators of health-related fitness shown in Figure 5 improve with age (significant time effect), but the interaction of activity and time is not significant. Active boys tend to be, on average, above the reference medians for pulse recovery and the bent arm hang, and approach the median in leg lifts and the sit and reach.

Growth curves for strength and speed in the active and nonactive boys are shown in Figure 6. Both groups closely follow the reference medians in the arm pull (static strength) and vertical jump (explosive strength), but tend to exceed the reference medians in the two speed items after 15 yr of age (note that a lower time indicates better performance in the shuttle run). All performance tasks improve, on average, with age (significant time effect), but there are no significant differences between the performances of active and nonactive boys at all ages between 13 and 18 yr (Table 3).

DISCUSSION

Results of the present analysis indicate no significant influence of increased physical activity in the form of sport participation on the growth and maturation of Belgian boys during adolescence. The same is true for most fitness items with the exception of pulse rate after a step test, pulse recovery after the step test, and the bent arm hang. More active boys had significantly better results on these items from 14 through 18 yr. These results are generally consistent with observations from other longitudinal studies of active and nonactive boys.

Before comparing results of specific studies, a comparison of activity assessment and levels is warranted. In a comprehensive study of physical activity and body composition (19,20), three groups of Czechoslovak boys were followed from 11 through 17 yr. An active group (N=8) trained regularly 6 $h \cdot wk^{-1}$ in "intensive physical exercise," a moderately active group (N=18) had 4 $h \cdot wk^{-1}$ of "organized exercise" in sports schools, while a third group (N=13) had limited sport activity, less than 2.5 $h \cdot wk^{-1}$. It should be noted, however, that boys with "markedly accelerated or retarded somatic develop-

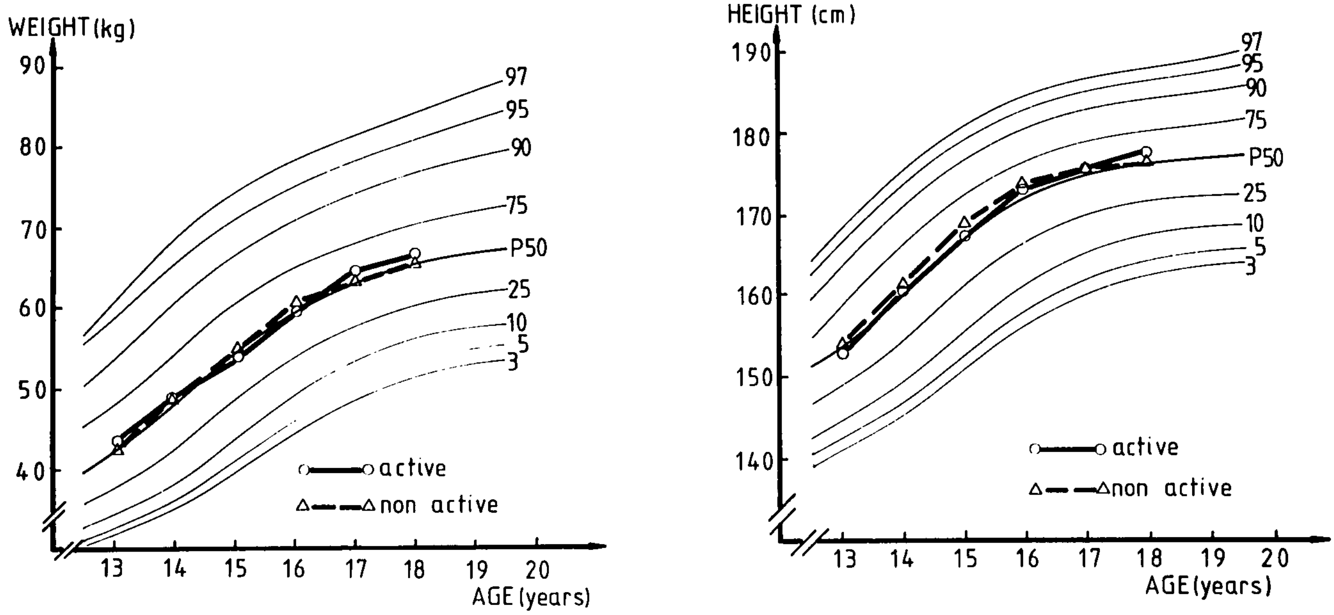

Figure 2—Stature and weight of active and nonactive boys plotted relative to Belgian reference data (18).

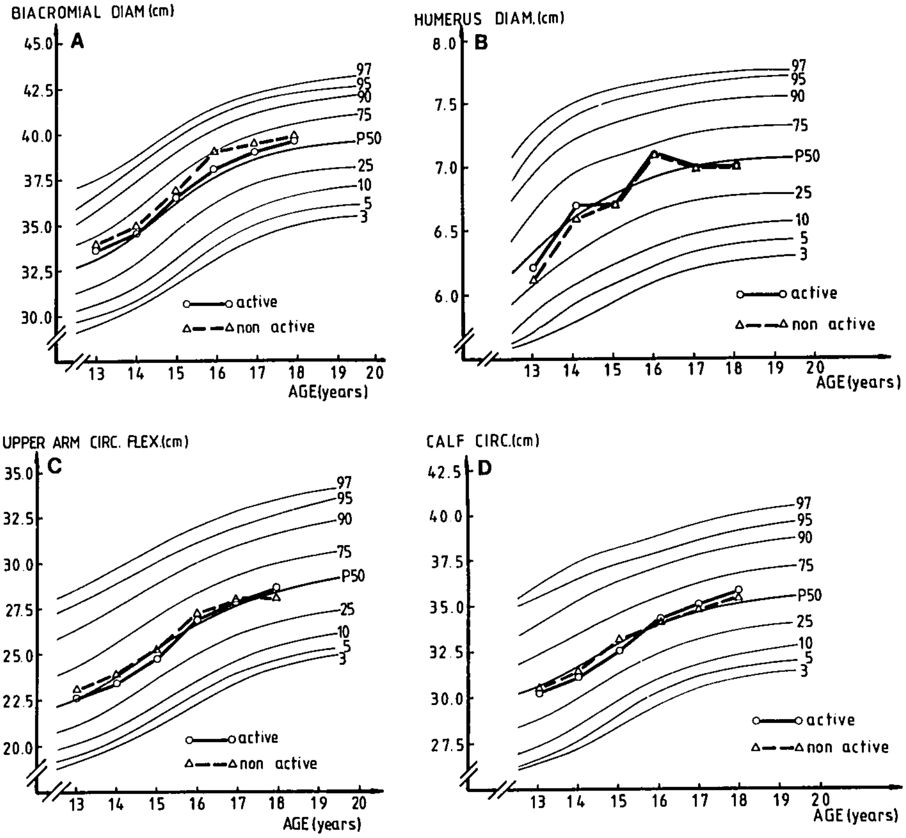

Figure 3—Skeletal breadths and limb circumferences of active and nonactive boys plotted relative to Belgian reference data (18).

ment were eliminated" (p. 235) in the sample selection process. Furthermore, the active group was taller at the start and completion of the study (19) and also attained peak height velocity at an earlier age (26) than boys in the other two groups. Hence, observations in this study may be confounded in part by maturity-associated variation in size and body composition (12). In another Czechoslovak study, four groups of boys were followed

TABLE 2. Effects * of physical activity on skeletal maturation and anthropometric characteristics.

Characteristics	Main Effect Activity Group		Interaction Effect Time * Activity	
	F-Value	Probability	*F*-Value	Probability
Skeletal maturity RUS-score	1.91	0.173	0.29	0.915
Height	0.03	0.862	1.13	0.356
Sitting height	0.02	0.880	1.44	0.224
Leg length	0.01	0.922	1.20	0.320
Weight	0.00	0.983	0.61	0.693
Chest diameter	0.16	0.691	0.43	0.828
Biacromial diameter	1.07	0.304	0.87	0.509
Biepicondylar humerus diameter	0.12	0.733	0.64	0.672
Bicondylar femur diameter	0.10	0.751	1.90	0.109
Upper arm circumference	0.18	0.673	0.29	0.918
Chest circumference	0.05	0.820	0.52	0.762
Thigh circumference	0.63	0.429	0.96	0.453
Calf circumference	0.00	0.945	1.69	0.152
Subscapular skinfold	0.65	0.424	1.80	0.127
Supra-iliac skinfold	0.22	0.644	0.70	0.629
Triceps skinfold	0.03	0.860	1.08	0.382
Calf skinfold	0.07	0.794	0.54	0.745
Sum of skinfolds	0.03	0.855	1.01	0.419

* The time-effect was not reported since, as expected, all characteristics increased significantly with age.

from 12 through 15 yr (8). The three active groups regularly practiced, respectively, cycling ($N = 6$), rowing ($N = 11$), and ice hockey ($N = 16$), while the fourth group served as a control ($N = 34$). In the sport groups, time spent in training increased each year. Over the 3 yr, the three active groups averaged 4–5 h of sport training per week during each year, while the control group averaged less than 1 $h \cdot wk^{-1} \cdot yr^{-1}$. The activity estimates in the two Czechoslovak studies are quite comparable to that used in the present analysis, i.e., active boys had more than 5 $h \cdot wk^{-1}$ of sport participation during the first 3 yr of the study. In the Sasketchewan Growth Study (13), boys were classified as active on the basis of several criteria, including activity questionnaires completed by the parents, teacher assessments of activity level, and a sport participation inventory. Three categories of physical activity level were provided consisting of 14 active, 11 inactive, and 50 average boys. In the Growth and Health of Teenagers, a longitudinal study of Dutch adolescents in Amsterdam (28), total daily time in physical activity was estimated by combined data from heart rate integrators, pedometers, and questionnaires, while sport participation was based on sport club membership and an activity score. Also three activity categories were considered of 53 inactive, 24 active, and 25 average active boys.

Allowing for methodological differences among studies, several comparisons with the study of Belgian boys are warranted. The short-term Czechoslovak study from 12 through 15 yr indicated no influence of regular training for sport on stature, skeletal breadths, and skeletal maturation, but a positive influence on estimated FFM, limb girths, isometric strength (8), and on the heart rate response to standardized work loads and maximum oxygen uptake (21). PWC $170 \cdot kg^{-1}$, however, was not influenced by activity. In the long-term study of body composition (19,20), the active boys developed significantly larger FFM and accumulated less relative fatness. As noted above, however, maturity-associated variation among the three groups may have influenced these trends.

In the Sasketchewan Growth Study, the timing of the adolescent growth spurts in stature, weight, and $\dot{V}O_{2max}$ did not differ between active and inactive boys (13,14). However, the inactive boys have an adolescent spurt in maximal aerobic power that is less than that observed in active boys and those with average levels of physical activity. Although active boys have a higher absolute maximal aerobic power than boys with average activity levels prior to the adolescent spurt, the two groups do not differ during the adolescent spurt. When expressed relative to body mass, active boys have a higher relative $\dot{V}O_{2max}$ than average and inactive boys before, during, and after the adolescent growth spurt.

In the study of Dutch teenagers (28), total activity time was not, but total sport participation was significantly correlated to anthropometric characteristics. However, the correlations were no longer significant when skeletal age was statistically controlled, which emphasizes the role of maturity-associated variation as a major factor influencing somatic growth during adolescence. In contrast to anthropometric dimensions, time spent in physical activities was significantly associated with several physical fitness items—better aerobic power, functional strength (flexed arm hang), and speed (shuttle run) in active boys from 13 through 16 yr. Again sport activity time showed higher correlations with the fitness items than total activity time.

Results of several longitudinal studies of active and nonactive boys, including the present study, thus indicate no specific influence of physical activity on indices of biological maturation (skeletal age, timing of growth spurts) and skeletal growth (lengths and breadths). The evidence for FFM, FM, and skinfold thicknesses is more variable. Regular physical activity is associated with better levels of cardiorespiratory efficiency and endurance and functional strength (bent arm hang).

Observations of these longitudinal studies are generally consistent with short-term experimental studies, studies of elite young athletes and cross-sectional studies comparing the growth and maturity of active and nonactive boys (1,4,10,12,23). The data for motor performance are somewhat more variable, but many cross-sectional studies indicate better levels of motor performance among active boys, especially in measures of speed, power, strength, and endurance (15,22). In cross-sectional studies, however, it is difficult to determine whether the observed differences reflect the influence of activity or prior selection. It is possible that more

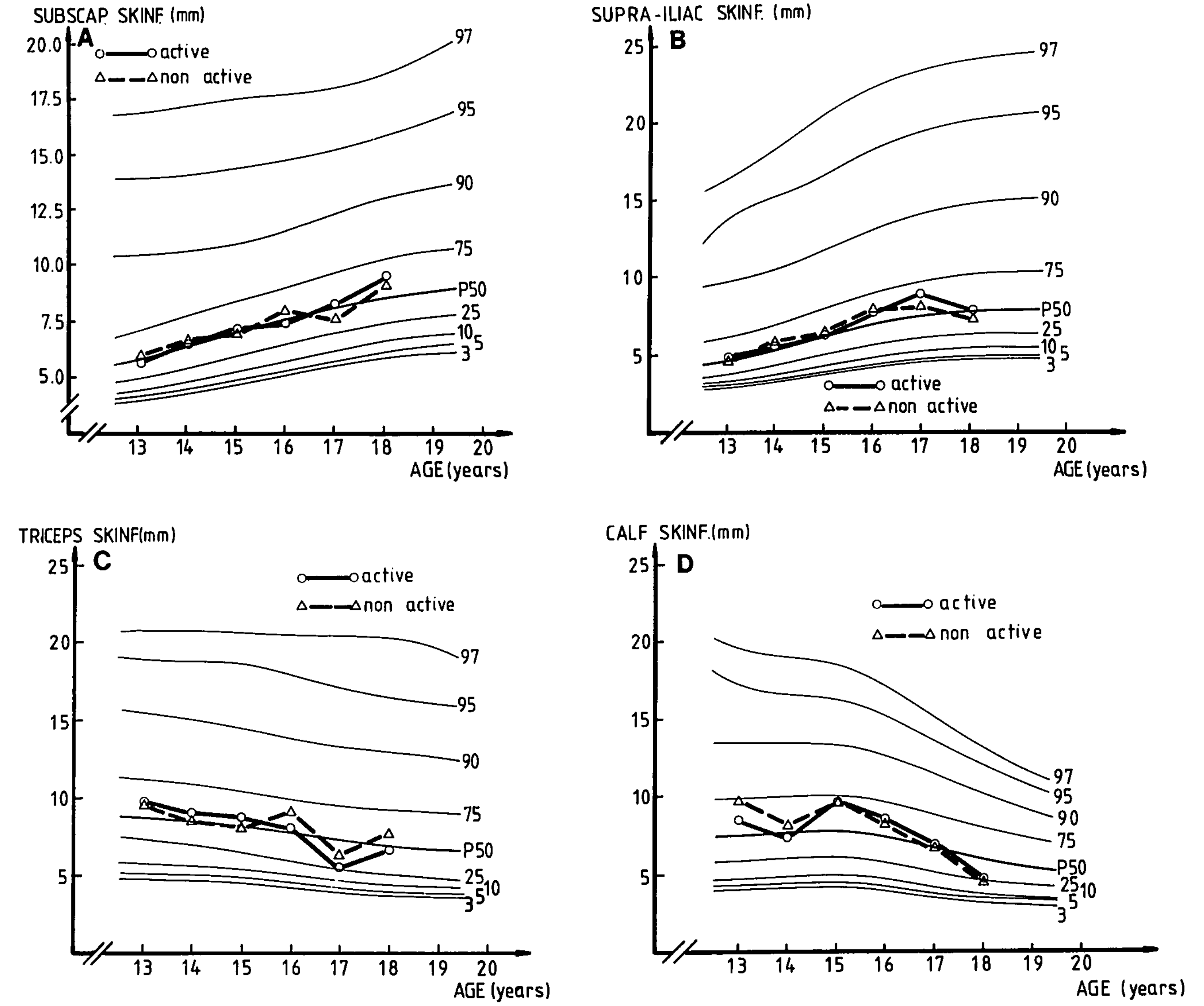

Figure 4—Skinfold thicknesses of active and nonactive boys plotted relative to Belgian reference data (18).

skilled individuals tend to be more physically active (29).

The strength of the present longitudinal study may be summarized as follows. It is longitudinal across a period of rapid change in growth, maturation, and performance. Several possibly confounding factors have been controlled, e.g., social background and biological maturation. There were no significant differences between active and nonactive boys in skeletal maturity at each "age level" in age at reaching peak height, peak weight, peak strength velocity, and in several social background determinants such as educational and professional level of the father and degree of urbanization of residence. In adequately nourished children and youth, social background has little influence on growth and maturation (12). Furthermore, although the active boys regularly participate in sport, they are not specialized in specific sport disciplines. This is also characteristic of the Dutch (28) and Saskatchewan (13) studies. Hence, the conclusions may be generalized to the majority of adolescents who are not athletes.

On the other hand, a weakness of the present study lies in assessment and quantification, and in control of the type of physical activity. The amount of habitual physical activity in sport participation for the active boys (5+ $h \cdot wk^{-1}$ over 3 yr), nevertheless, is quite consistent with that for other longitudinal studies of boys in specific sport schools (8,9,19,20). Information on the sport participation was obtained by written questionnaire and verified by an interview of an experienced interviewer. In order to obtain an overall participation score, detailed information, in hours per week, during each semester and during holidays, was recorded for each sport. Not only sports activities in a sportclub were

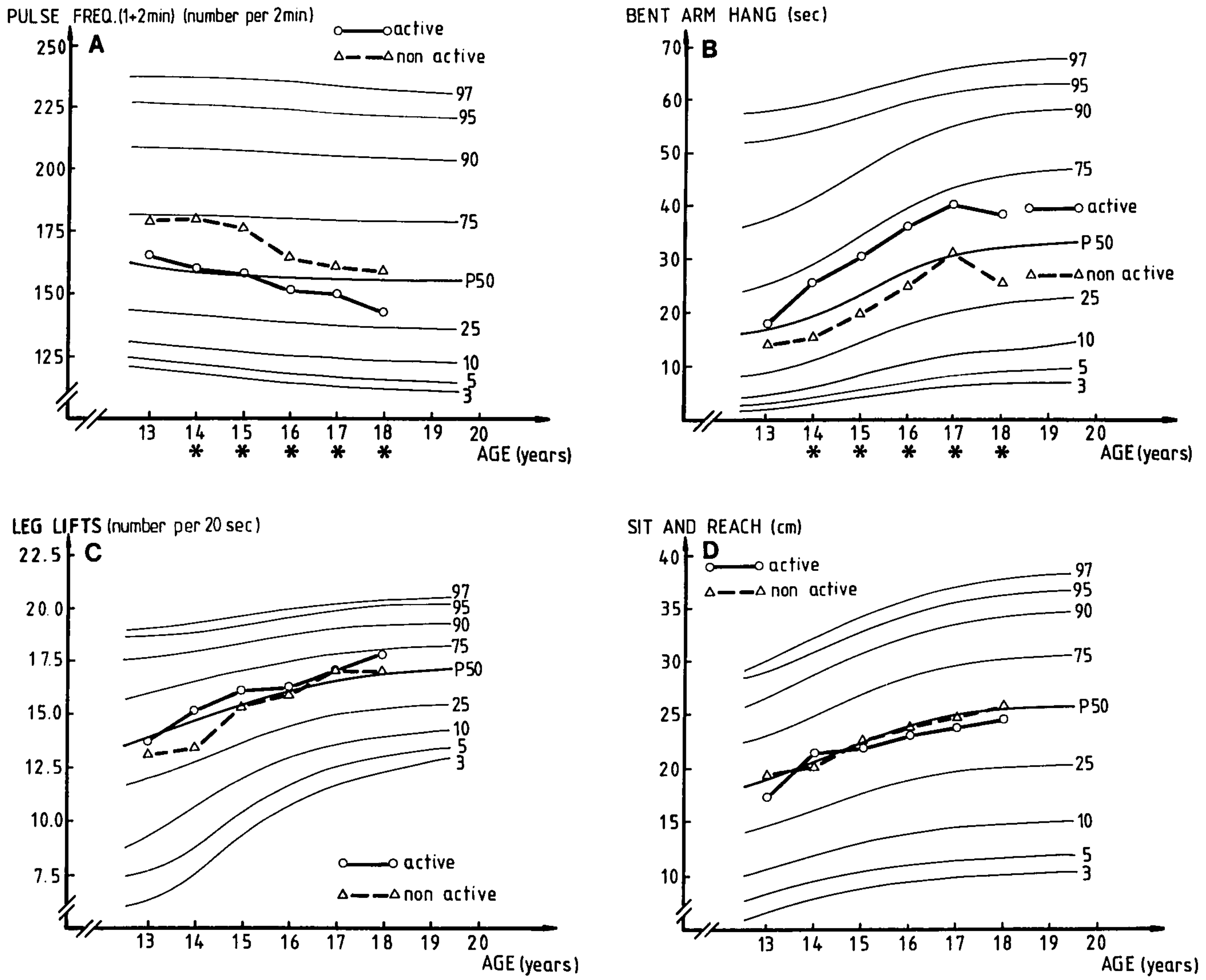

Figure 5—Health-related fitness of active and nonactive boys plotted relative to Belgian reference data (18). An * indicates a significant difference at $P = 0.05$.

TABLE 3. Effects * of physical activity on health- and performance-related fitness characteristics.

Characteristics	Main Effect Activity Group F-Value	Main Effect Activity Group Probability	Interaction Effect Time * Activity F-Value	Interaction Effect Time * Activity Probability
Pulse frequency rest	3.24	0.077	0.32	0.896
Pulse frequency recuperation	7.01	0.010	0.38	0.863
Bent arm hang	5.89	0.018	1.19	0.328
Leg lifts	1.49	0.227	1.44	0.225
Sit and reach	0.28	0.599	1.69	0.152
Arm pull	0.00	0.954	1.06	0.392
Vertical jump	0.00	0.957	0.73	0.606
Shuttle run	0.62	0.433	1.23	0.309
Plate tapping	0.05	0.817	1.17	0.334

* The time effect was not reported since, as expected, all characteristics increased significantly with age.

considered but also activities that were practiced with friends, in family, in youth organizations, or alone. This led to the construction of an objective and reliable sports participation score (18). With respect to the validity of the sports participation scores, it has been demonstrated that in 13- to 18-yr-old boys (N varies between 1198 and 2829 per age category) the amount of sports participation was significantly related to nearly all health- and performance-related fitness items (22). Moreover, it has been demonstrated that sporting boys are physically more active than their nonsporting peers. Physical activities outside the sports are not significantly different between sport participants and nonparticipants. This indicates that boys who do not participate in sports do not compensate by spending relatively more time in unorganized forms of physical activity (28). Finally, in the Dutch study (28) time spent in sports participation is more highly correlated with fitness items than total time in physical activities, which would lend validity to the sports activity questionnaire. Active boys in the present study participated primarily in soccer, volleyball, and basketball between 12 and 15 yr of age, and remained active in these sports after age

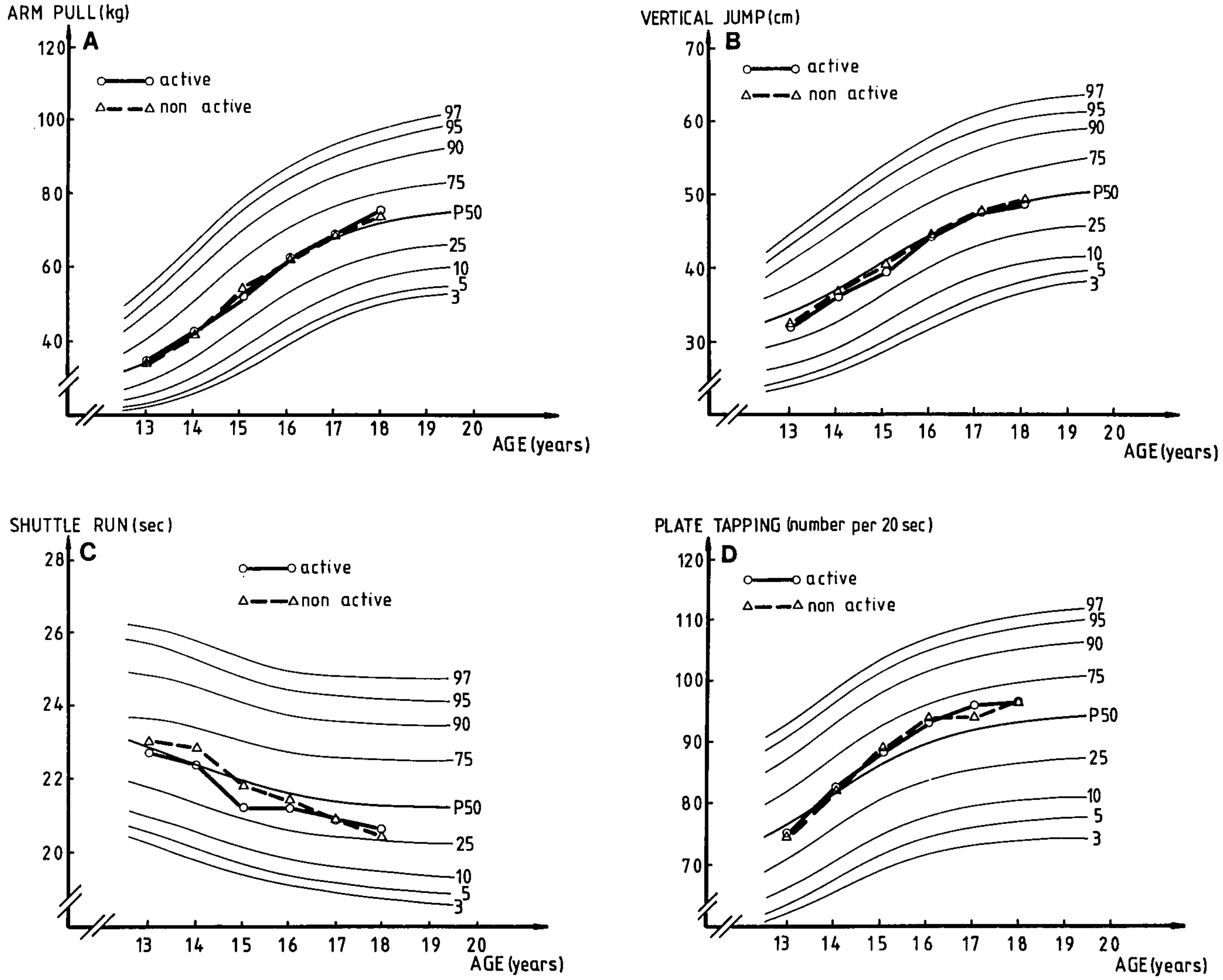

Figure 6—Motor performance of active and nonactive boys plotted relative to Belgian reference data (18).

15 yr. The nonactive boys were not engaged in any extracurricular sports outside of compulsory school physical education.

It can also be questioned whether the present longitudinal study on 32 active and 32 nonactive boys has enough power to detect biologically meaningful differences. In a cross-sectional analysis of the association between sport participation and physical growth, maturation, and performance (22), it was demonstrated that for fitness items an effect size of 0.5 σ can be expected. This implies that for the performance test, the means of the active and nonactive boys differ by 0.5 σ. Since the number of subjects in each age category was very large (N varies between 1198 and 2829), these differences accurately reflect the population differences. If such population differences between active and nonactive boys are present at each age level, for an alpha = 0.05, and 32 subjects in each group, a power of 0.70 is reached (3). However, starting from the same cross-sectional analysis (22), for anthropometric dimensions the population differences between active and nonactive boys are expected to be in the order of 0.1 σ or even smaller. In this case an uneconomical number of boys need to be followed in order to reach sufficient power. Alternatively, it would be somewhat precocious to conclude from this study alone that there are no differences in physical growth and maturation between active and nonactive adolescents unless a fairly high alpha-level is accepted.

It can be argued that the division of boys into active and nonactive groups is somewhat arbitrary, although it roughly corresponds to the 5% most active and inactive boys. To circumvent this argument, a more restrictive selection was made, resulting in smaller samples but with the expectation of a higher effect size. From the initial groups of 32 active and nonactive boys, the eight most active and the eight least active boys were selected. The most active boys participated in sports, on the average, almost 10 $h \cdot wk^{-1} \cdot yr^{-1}$ during each of the first 3 yr of the study, while the least active boys had no additional sport activity to school physical education. As in previous analyses, there were no significant differences between the most and least active boys in anthropometric dimensions, age at peak height velocity, skeletal maturation, and most fitness items. Significant differences favoring the active boys occurred in the pulse recovery after a step test and running speed. On the other hand, the active boys had lower sit and reach scores (less flexibility).

Since several longitudinal studies lead to the same finding, there is increasing evidence that in the general population of adolescent boys, growth and maturation are not influenced by level of physical activity either positively or negatively. There is a positive influence on components of fitness, especially related to aerobic power, muscular endurance, and running speed. However, given that the fitness level of the most active Belgian adolescent boys does not dramatically differ from that of nonactive boys or the general population of Belgian boys (Figs. 4–6), one may inquire whether the training stimulus provided in youth sport clubs can not be increased in order to induce greater positive effects on fitness components. For example, the estimated percentage of $\dot{V}O_{2max}$ during practice of basketball and badminton reaches only 57–60% of that sufficient for improving fitness (16). Perhaps more attention should be devoted to improvement of fitness in youth sports programs.

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