The European Youth Heart Study (EYHS) is a multicenter, international study addressing the prevalence and etiology of cardiovascular disease (CVD) risk factors, including physical activity, in children aged 9 and 15 yr. Very limited physical activity data exist that have been collected from representative samples of children and even fewer data collected where physical activity has been measured using objective methods.

The purpose of this study was to assess physical activity levels and patterns from children participating in the European Youth Heart Study (EYHS). Very limited physical activity data exist that have been collected from representative samples of children and even fewer data collected where physical activity has been measured using objective methods.

Methods: Subjects were 2185 children aged 9 and 15 yr from Denmark, Portugal, Estonia, and Norway. Physical activity data were obtained using MTI (formerly CSA) accelerometers. The primary outcome variable was established as the child’s activity level (accelerometer counts per minute). Children wore the accelerometer for 3 or 4 d, which included at least 1 weekend day.

Results: Boys were more active than girls at age 9 (784 ± 282 vs 649 ± 204 counts·min⁻¹) and 15 yr (615 ± 228 vs 491 ± 163 counts·min⁻¹). With respect to time engaged in moderate-intensity activity, gender differences were apparent at age 9 (192 ± 66 vs 160 ± 54 min·d⁻¹) and age 15 (99 ± 45 vs 73 ± 32 min·d⁻¹). At age 9, the great majority of boys and girls achieved current health-related physical activity recommendations (97.4% and 97.6%, respectively). At age 15, fewer children achieved the guidelines and gender differences were apparent (boys 81.9% vs girls 62.0%).

Conclusions: Accelerometers are a feasible and accurate instrument for use in large epidemiological studies of children’s activity. Boys tend to be more active than girls, and there is a marked reduction in activity over the adolescent years. The great majority of younger children achieve current physical activity recommendations, whereas fewer older children do so—especially older girls.

Key Words: ACCELEROMETERS, HEALTH, EPIDEMIOLOGY
and the balance of light, moderate, and vigorous activities in which children participate. These data are important, as it can inform public health policy in two ways. First, more accurate quantification of levels of activity adds strength to observed relationships with health risk factors (e.g., obesity), enabling more valid recommendations for children’s activity to be formulated. Second, information on children’s patterns of activity, together with the factors that influence them, can inform the design and delivery of public health interventions to promote physical activity in children. The purpose of this study was to assess objectively measured physical activity levels and patterns from children participating in the EYHS.

**METHODS**

**Subjects and Settings**

**Settings.** Physical activity data were collected from defined areas in four European countries—Denmark (city of Odense), Portugal (island of Madeira), Estonia (city and county of Tartu), and Norway (city of Oslo). Odense is the third largest city of Denmark and is situated on the island of Fyn. Oslo is the capital city of Norway. Tartu is the second city of Estonia—an “emerging” eastern European country and former member of the Soviet Union. Madeira is a small island in the North Atlantic Ocean, 964 km west from Lisbon. We therefore have data from children who live in differing climatic, physical, and cultural environments representing northern, eastern, and southern Europe.

**Populations and samples.** Each research team complied with the ethical procedures of that country. Written, informed consent was obtained from the child’s parent or legal guardian after they were given, in writing, a full explanation of the aims of the study, its possible hazards, discomfort, and inconvenience. In addition, children had all the procedures verbally explained to them, together with any possible discomfort they might encounter, using language that they find easy to understand.

Children selected for participation in the EYHS were boys and girls aged 9 and 15 yr old. These age groups were selected to broadly represent children either side of puberty. At each study location, a defined population of children was identified, and from this population, a two-stage cluster sample of children was randomly selected. The primary sampling units were schools, and secondary units were the school registers. A minimum of 20 schools was randomly selected from local authority lists within appropriate age, gender, and socioeconomic strata using probability proportional to school size (15).

Sample sizes were estimated separately for a) assessment of the prevalence of coronary heart disease (CHD) risk factors (including physical activity), b) assessment of pre-specified subgroup differences in CHD risk factors, and c) the need to achieve minimum cell-sizes for multivariable analyses. Sample size estimations were based in each case on the comparison of two independent groups of equal size, using a two-tailed test ($1 - \beta = 0.80$; two-tailed $\alpha = 0.05$).

It was established that at each study location 200 children within each of the four age/gender groups (total $N = 800$ per country) would give an acceptable level of power for the projected analyses. The primary outcome variable was established as the child’s activity level (average accelerometer counts per minute). With respect to this primary outcome variable, 200 children gave us the ability to detect subgroup differences of 50 counts min$^{-1}$ ($1 - \beta = 0.80$; two-tailed $\alpha = 0.05$), using a two-tailed test. Because cluster (school) sampling has been used, a design effect of 1.25 was incorporated, giving a final target sample size of 250 children per age and gender group in each of the four countries.

**Physical Activity Measurement**

**Instrumentation.** Physical activity was assessed using the MTI accelerometer, model 7164 (Manufacturing Technology Incorporated, formerly known as the Computer Science Applications activity monitor, Shalimar, FL). This is a lightweight, electronic motion sensor comprising a single-plane (vertical) accelerometer. The accelerometers are small ($4.5 \times 3.5 \times 1.0$ cm) and light (about 43 g), and are worn on the hip secured by an elastic waist belt. Movement in a vertical plane is detected as a combined function of the frequency and intensity of the movement, while an electronic filter rejects motion outside the range of normal human movement. Movement counts are averaged over defined epochs (usually 1 min), and these data are stored in memory and subsequently downloaded to a computer. The accelerometer has been well validated in both children and adolescents against a range of outcomes (4,7,8,26).

**Physical activity measurement protocol.** Measurements were taken over a full school year to minimize the effects of seasonal variations in activity patterns (21). Children wore the accelerometer for four consecutive days, which included both weekend days. Four days of measurement was selected as the optimal balance between obtaining a sufficiently long measurement period to ensure a representative measure of the child’s habitual activity and the logistical limitations of a large field-based study. Trost et al. (24) reported that the number of days recording needed to provide reliable activity data in children varies with age. For younger children, 4 d of measurement gives a correlation of $r = 0.80$ with a full week’s activity monitoring. From these data, we established that 4 d of measurement would be sufficient in our sample of children. A 1-min recording epoch was selected. Children wore the accelerometer during all waking hours but removed it during swimming and bathing.

**Data reduction and transformation.** Data-reduction software written specifically for the EYHS performed the following tasks.

1. Automatic deletion of missing data—defined as sequences of 10 or more consecutive zero counts.
2. Exclusion of children failing to provide a minimum of three separate days of 10-h valid recording after removal of missing data. The choice of 3 d ensures that at least 1
TABLE 1. Main physical activity data (mean ± SD).

<table>
<thead>
<tr>
<th></th>
<th>9-yr-Olds</th>
<th>15-yr-Olds</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Boys</strong></td>
<td><strong>Girls</strong></td>
<td><strong>Boys</strong></td>
</tr>
<tr>
<td>Overall physical activity level (counts·min⁻¹)</td>
<td>784 ± 282</td>
<td>649 ± 204*</td>
</tr>
<tr>
<td>Average daily moderate and vigorous activity (min·d⁻¹)</td>
<td>192 ± 66</td>
<td>160 ± 64*</td>
</tr>
<tr>
<td>Children estimated to achieve activity recommendation (%)</td>
<td>97.4</td>
<td>97.6</td>
</tr>
</tbody>
</table>

* Significant gender difference within age group (P < 0.05).
† Significant age difference within gender (P < 0.05).

weekend day is included. The majority of children (70%) achieved the full 4 d recording, with the remaining 30% achieving 3 d. To confirm whether differing lengths of recording time introduced any systematic error, two analyses were performed. First, the primary activity variable (counts·min⁻¹) was compared across quartiles of valid recording time. One-way ANOVA suggested a significant difference across quartiles (P < 0.05). However, Tukey post hoc tests indicated that the differences were not systematic, with the only significant difference being observed between quartiles 1 and 3. Second, children with 3 and 4 d recording were compared in terms of the primary outcome variable. Children with 4 d recording had significantly higher activity levels compared with children with 3 d recording (665 ± 254 vs 631 ± 242 counts·min⁻¹, P < 0.05). In the main analysis, the number of days recording was therefore used as a covariate.

3. Calculation of primary and secondary physical activity variables. The primary physical activity variable (counts·min⁻¹) was selected as it is the only accelerometer variable that has been rigorously validated during children’s free-living conditions. In a validity study using 9 yr-old children, accelerometer counts per minute correlated strongly (r = 0.58) with free-living physical activity level measured by doubly labeled water (7). Secondary variables were established as the number of minutes the child engaged in activity of different intensities. Ten intensity categories were established in multiples of 500 counts·min⁻¹ from 0 to >4500. For children, age specific cut-points for accelerometer counts representing activity of varying intensities can be estimated using a previously published regression equation (25). Using this equation, cut-points of 906 counts·min⁻¹ for 9-yr-old children and 1706 counts·min⁻¹ for 15-yr-olds represent an energy expenditure of 3 METs (arbitrary threshold for moderate-intensity activity). We therefore selected our nearest intensity cut-points —1000 and 1500 counts·min⁻¹—as cut-points for 9- and 15-yr-old children, respectively. Finally, the proportion of children achieving current health-related physical activity recommendations established by the United Kingdom Expert Consensus Group (3) was estimated. These recommendations suggest a minimum daily accumulation of at least 60 min of moderate-intensity activity.

Data Analysis

All analyses were performed using the Statistical Package for the Social Sciences (SPSS) version 11 (SPSS Inc. Chicago, IL). Age, gender, and country differences were tested by three-way (age × gender × country) analysis of variance. Tukey post hoc comparisons were used to identify specific between-country differences. Differences between proportions of children achieving activity recommendations were analyzed using chi-square analysis.

RESULTS

A total of 4168 children were invited to participate in the study. Of these, 1262 either did not consent to the study or were not available for measurement, giving an overall study response rate of 70% (2906 children). Of these children, 2185 provided valid measurements that met all inclusion criteria. Of the omitted children, 459 were excluded for failing to achieve at least 3 d of measurement, 143 for failing to achieve at least 10 h of valid recording on each measurement day, and 119 because of instrument malfunction.

Mean ages were boys 9.7 ± 0.4 and 15.5 ± 0.5 yr; girls 9.6 ± 0.4 and 15.4 ± 0.6 yr. Boys achieved an average of 3048 ± 786 min valid recording and girls achieved 2998 ± 781 min. Table 1 contains the main physical activity data for age and gender groups.

Although we omitted from the analyses all children who failed to achieve at least 3 valid days recording, we sought to ascertain how this might affect our results. We therefore repeated our primary analysis reintroducing the children who achieved 1–2 d recording—that is, we included all children who did not suffer a broken instrument. Inclusion of these children (N = 602) had very little effect on our results. In each age/gender group inclusion of these children lowered the mean activity level (counts·min⁻¹) by 1–3% (9-yr-old boys 772 vs 784; 9-yr-old girls 635 vs 649; 15-yr-old boys 597 vs 615; and 15-yr-old girls 485 vs 491).

Figure 1 shows the age and gender distribution of total physical activity across the four countries. Three-way ANOVA (age × gender × country) indicated significant age, gender, and country differences in activity level within this sample of children (F1,1,3 = 41.487, P < 0.05). One significant interactive effect was observed: age * country. Because significant differences in activity level were detected between children with 3 and 4 d recording, the above analysis was repeated using number of days recording as a covariate. Age, gender, and country differences remained significant and one further interactive effect was observed: age * gender * country. Post hoc comparisons indicated some small but statistically significant differences between countries (P < 0.05), but the main impression is one of consistency in activity levels between countries.
Figure 2 shows the age and gender distribution of time engaged in physical activity of at least moderate intensity across the four countries. Three-way ANOVA (age \times gender \times country) indicated significant age, gender, and country differences in activity level within this sample of children ($F_{1,3} = 91.380, P < 0.001$). No significant interactive effects were observed. Using number of days recording as a covariate, age, gender, and country differences remained significant, and no interactive effects were observed. Post hoc comparisons indicated small but statistically significant differences in activity levels ($P < 0.05$), but again the main impression is one of consistency.

From Figures 1 and 2, it is clear that there is a particularly marked decline in time engaged in moderate activity over the adolescent years. From Table 1, it can be seen that the great majority of 9-yr-old children meet current physical activity recommendations.
activity recommendations. However, the proportions of 15 yr olds meeting the recommendation are markedly lower, especially in girls.

DISCUSSION

This study is the first to report objectively measured physical activity data in a representative sample of European children. The study has three main findings. First, the study has confirmed significant gender differences in physical activity. Boys are more active than girls at both 9 yr (21% more active) and 15 yr (26% more active). Gender differences in time spent in activity of at least moderate intensity are even more marked (20% and 36% difference respectively). Second, using total activity, 9-yr-olds are considerably more active than 15-yr-olds (27% more active in boys, 32% in girls). This is even more marked with time spent in moderate activity (94% more active in boys, 129% more active in girls). Third, virtually all 9-yr-old children achieve current activity recommendations, whereas fewer 15-yr-olds achieve them, a trend particularly noticeable in girls. These differences demonstrated consistency across all four countries.

The findings of this study need to be interpreted in the light of a number of residual limitations. First, accelerometers may be “reactive”—in other words, they might modify the child’s habitual activity. Second, during swimming, contact sports, showering, and bathing, the accelerometers must be removed. These “nonmonitored” activities may result in underestimation of physical activity level in some children. During cycling—an activity involving minimal vertical displacement of the body—the accelerometers also underestimate activity level. Third, in order to obtain 4 d of recordings, activity counts were averaged using a 1-min epoch in order ensure that the accelerometer’s memory capacity was not exceeded. This level of averaging dilutes the child’s vigorous activity because such activity is rarely sustained for as long as 1 min. Previous studies have shown that vigorous activity may be substantially underestimated (16). Fourth, malfunctioning accelerometers can register spurious data. Finally, whenever a child forgets to wear the monitor, registered counts will be zero, whereas the child is likely to be moving to some extent. Unless accounted for, activity levels will be underestimates leading to misclassification errors in more forgetful children. It is necessary to estimate the potential influence of such limitations on the validity of the data. In this respect, the following should be considered:

1. Visual inspection of data from individual days of activity measurement suggests no systematic differences in the early days of measurement that might be ascribed to reactive changes in behavior.
2. Trost et al. (25) reported that the addition of children’s self-reported minutes of “nonmonitored” activities to registered accelerometer data resulted in no significant changes to calculated activity levels.
3. The underestimation of vigorous activity is unlikely to be important in this study, as we focus on overall activity level, of which vigorous activity constitutes only a very small proportion.
4. Our software highlighted “suspicious” recordings that were then checked manually. Where recordings were obviously from broken accelerometers, they were omitted from the analysis.
5. Our software excluded 25% of recordings through failing to achieve the minimum number of days and the minimum number of minutes per day of valid recording, after deletion of missing data. Hence, misclassification errors due to missing data being counted as inactivity have been minimized. Our figure of 25% exclusion is considerably higher than that of Pate et al. (17), who report a figure of 6.3% exclusion over a 7-d recording period. Our figure may be higher due to our process of deleting missing data—which in some children is substantial.

We believe therefore that we have minimized the residual errors described above and that the level of error likely to have been introduced does not significantly compromise the validity of the data.

In this multinational study, it can be seen that physical activity levels are remarkably consistent across the four countries. Age and gender differences in activity levels are also mirrored across the four countries. This is remarkable, given that the countries differ widely in geography, socioeconomic circumstances, culture, and climate. This suggests that physical activity habits in children may be determined by biological factors as much as by environmental factors.

Possibly the most interesting finding of this study is that the great majority of children fulfill current health-related recommendations for healthy levels of activity. It should be noted that the guidelines refer to children being active at the recommended levels “on most days of the week.” We report the number of children who are sufficiently active on each of the 3/4 d measured in this study. However, as 4 d of measurement has been shown to be representative of a full week’s activity (24), we believe our figures are a realistic estimation of the proportion of children who meet current recommendations.

These data raise some fundamental questions. First, if the recommendations are accurate and appropriate, then we might presume that nearly all 9-yr-olds and 50–75% of 15-yr-olds are sufficiently active to achieve optimal health benefits. However, this assertion would be based on a number of untested assumptions. First, accelerometer data cutpoints for moderate-intensity activity that are appropriate for children of different age, gender, and body size are yet to be ascertained. Second, the selection of 3 METs as an appropriate intensity cut-point for health is in itself arbitrary. Further, existing studies that have established cutpoints (25) have utilized laboratory activity (treadmill) exercise protocols. Results from such controlled activities may not be representative of the more natural, sporadic, wholebody movements entailed in activities performed by free-living children during the course of each day. Accordingly, only a very approximate cut-point for moderate-intensity activity is possible. We are therefore left with three uncertainties. First, are the majority of children really active...
enough to achieve health benefits? Second, are the current recommended activity levels correct? It should be noted that the current recommendations are not based on a large body of empirical evidence (27). Third, how accurate are the accelerometer data cut-points in terms of the moderate-intensity threshold? At this point, the answers to such questions are unknown. However, despite these uncertainties, our data do suggest that children accumulate more activity of at least moderate intensity than we may have previously thought. For example, studies from the early 1990s using heart rate monitoring to measure activity reported that the majority of children failed to achieve 30 min of moderate activity per day (19) and that sustained periods of activity of at least moderate intensity were extremely rare in children (1).

We are aware of only two reports (17, 25) that have assessed the prevalence of physical activity in relatively large numbers of children using the accelerometers. Trost et al. (25) assessed activity levels in 375 children aged 7–15 yr. Gender differences in moderate to vigorous activity levels were observed ranging between 8 and 19%. The average gender difference was 11%. Morearked differences—up to 44%—were observed for vigorous activity. Mean values of moderate to vigorous activity per day ranged from 50 to 200 min—a figure in keeping with our data (70–200 min d⁻¹). The marked age-related decline reported by Trost and colleagues is also seen in our data.

In a further analysis, Pate et al. (17) reported the proportion of children meeting various health-related activity recommendations—including those established by the United Kingdom Expert Consensus Group (3) used in our study. The proportion of children meeting the recommendations averaged 69% across age and gender groups. However, proportions were as high as 100% in younger children and as low as 25% in older girls. Again, boys were observed to be more active than girls.

Studies of activity levels in children that use more precise, objective measures enable us to make more valid estimates of children’s engagement with health-enhancing physical activity. Hence, they constitute a benchmark against which previous studies using self-reports of activity can be judged. This is critical if we are to utilize such studies in the formulation health policy. Pate et al. (17) report “dramatic discrepancies” between self-reported and objectively measured estimates of activity. Specifically, self-reported levels appear much higher. However, they refer to more vigorous activity that children are known to overestimate (20). Further, the MTI(CSA) accelerometer is known to underestimate vigorous activity, as described earlier. It should be noted that vigorous activity is infrequently performed by children, indicating that underestimation by the accelerometer may be only a minor deficiency. However, given the above, we should be cautious in comparing self-reported and objectively measured levels of physical activity.

In contrast, when moderate-intensity activity is considered, children appear to be more active when activity levels are measured objectively compared with self-reported estimates. For example, the 1997 Health Survey for England (5) reported that 78% of boys and 70% of girls participate in at least 60 min of moderate activity on at least 5 d of the week—levels approximating current recommendations. The National Diet and Nutrition survey (10) reported that 70% of boys aged 7–10 yr and 44% boys aged 15–18 yr achieved 60 min of moderate activity per day. Equivalent figures for girls were 49% and 31%. It can be clearly seen that these figures are much lower than the objectively measured estimates observed in this study. The likely explanation for this discrepancy is that moderate activity tends to be more sporadic, nonplanned, and therefore less memorable and quantifiable, especially in children. As such, it is not collected by self-report methods. Moderate-intensity activity levels reported by such methods are therefore likely to be underestimates. A review by Epstein et al. (9) and a substantial study by SLEEP and Tolfrey (22) using heart rate monitors provide further support for the hypothesis that objective measures provide higher estimates of moderate activity compared with self-report. Using heart rate monitoring, Ekelund et al. (6) compared the activity levels of 82 adolescent children aged 14–15 yr against health-related activity recommendations. In this study, approximately 30% of adolescents appeared to be insufficiently active.

We therefore speculate that children may engage in considerably more moderate-intensity physical activity than previously thought. However, despite knowing more about the absolute levels of activity in children, the question of whether this is “enough” to provide health benefits is still uncertain. The increasing prevalence of overweight and obesity in children (13) suggests that this may not be the case. In terms of public health policy, our data suggest that it may now be necessary to question whether the current activity recommendations are appropriate. Further analyses from this study—as assessing dose-response relationships between activity and health risk factors—may provide more clinically based activity recommendations.

This study has also demonstrated that the use of motion sensors is feasible in epidemiological, field-based studies. Such instruments can provide physical activity data at a level of precision and detail that has not been achieved before. This higher order of data is critical as it enables activity data to be translated into health policy with greater confidence than has previously been the case (28). In further analyses, we will also be able to produce better estimates of the true association between physical activity and health risk factors (29) and will be able to better adjust for physical activity in multivariable models (30). Accordingly, we provide support to previous authors who considered this methodology to be the best way to improve our understanding of children’s physical activity (12, 23).

In conclusion, accelerometers have been shown to be a feasible and accurate instrument for use in large epidemiological studies of children’s activity. The more precise and detailed data obtained confirm that boys are more active than girls, and there is a marked reduction in activity over the adolescent years. Using this measurement technology, the majority of younger children are shown to achieve
current physical activity recommendations, whereas fewer older children do so—especially older girls.

This study was supported by the following grants—Denmark: Danish Heart Foundation, Danish Medical Research Council, Health Foundation, Danish Council for Sports Research, Foundation of 17-12-1981, Foundation in Memory of Asta Florida Bolding née Andersen, and Faculty of Health Sciences, University of Southern Denmark; Estonia: Estonian Science Foundation grant nos. 3277 and 5208; Norway: Norwegian Council of Cardiovascular Diseases and Eckbo Legacy; Portugal: European Social Fund.

REFERENCES