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High Levels of Habitual Physical Activity in West African Adolescent Girls and Relationship to Maturation, Growth, and Nutritional Status: Results From a 3-Year Prospective Study

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ABSTRACT This study examines energy expenditure and physical activity levels for a sample of 40 adolescent girls of the Sereer ethnic group of rural Senegal. The girls were 13.3 ± 0.5 years at the start of the study (June 1997) and were followed annually for the next 2 years during puberty. Data collected during each round included: 1) pubertal status (as assessed by breast development and occurrence of menarche); 2) selected anthropometric dimensions (weight, stature, arm circumference, and six skinfolds); and 3) physical activity levels quantitatively assessed using CSA accelerometers. During rounds 1 and 3, activity was also qualitatively reported by direct minute-by-minute observations. A food consumption survey was performed once during the 3rd round, using an individual food weighing method. Girls of this sample had high levels of energy expenditure with daily physical activity levels (PALs) ranging from 1.70 to 1.85 multiples of basal metabolic rate. Energy intakes were, on average, sufficient to meet energy and protein requirements, although micronutrient deficiencies were likely to exist. Activity levels declined with age between the 1st and 3rd rounds. Stepwise regression analyses showed that stature was negatively correlated with both total daily and day-time activity, whereas the body mass index was positively associated with this measure. Pubertal status and subcutaneous fatness were not significant predictors of activity levels. The contribution of these adolescent girls to the everyday tasks of the household was considerable. They spent more than 3 hours 30 minutes per day in domestic duties. Am. J. Hum. Biol. 13:808–820, 2001. © 2001 Wiley-Liss, Inc.

In traditional poor societies, basic needs such as food and energy allocation are satisfied through investment in human labor. Children are frequently involved in daily domestic and agricultural tasks. Social surveys showed that children's work is of economic value; children are constrained to work when this is necessary for household subsistence (Munroe et al., 1984). Children's work provides a cheap and sustainable solution for the survival of the rural poor (Giampietro and Pimentel, 1992). In Africa, girls are precociously trained to undertake strenuous and skilled domestic tasks such as pounding millet or carrying head-supported loads (Bril, 1986). This does not mean that adults are resting, rather, the work load must be shared among all the family members, implying a clear age and sex division. Men are responsible for activities requiring high-muscular power such as hoeing, land clearing, and harvesting (Brun et al., 1981). Women and children are mostly employed in time-consuming tasks that constitute the major part of daily duties. Hence, different levels of analysis, namely ecological, societal, and individual, should be taken into consideration when evaluating energy expenditure in a population from developing countries (Giampietro and Pimentel, 1992). Heavy work loads or a long working day may adversely affect child growth (Ambadekar et al., 1999; Satyanarayana et al., 1986). They also constitute an impendiment to regular school attendance with, as a result, poor school performance and repetition of grades (Jamison and Leslie, 1990). Thus, there is an interaction and sometimes competition between the energetic budget needed to maintain a traditional society and the satisfaction of individual requirements.

Stunting in growth is a common feature of most developing countries whose

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economy is based on human labor. From the WHO database, approximately 38% of children under 5 years of age are stunted in West Africa (de Onis, 1993). African societies have difficulties in meeting their basic nutritional needs, and stunting is thus considered as a general indicator of health nutritional status, and living standard. It has been shown that work capacity and productivity are decreased in children of small body size (Satyanarayana et al., 1977; Spurr et al., 1977). This could explain the vicious cycle of malnutrition: Smaller individuals are less productive than bigger persons. But the relationship is not straightforward and it has been shown that a high level of physical activity is positively associated with an enhanced working capacity even in stunted children (Satyanarayana et al., 1979). On the other hand, a reduction in physical activity was observed in malnourished children (Rutishauser and Whitehead, 1972). This is sometimes considered to be the "first line of defense" of the organism to restore the energy balance as quoted by Spurr and Reina (1987). This explanation is plausible in preschool malnourished children, although in this case, the reduction in activity seems to be more closely related to a delay in locomotor development than to energy restriction (Meeks-Gardner and Grantham-Mcgregor, 1994). In the case of moderate malnutrition affecting older children, a reduction in physical activity in response to malnutrition is rarely reported. In Colombia, moderately stunted girls as well as boys were normally active (Spurr and Reina, 1987). In Senegal, adolescent girls, while presenting appreciable delays in growth and maturation, maintained high levels of activity (Benefice and Cames, 1999).

It is obvious that social or peer pressure and environment conditions influence behavior and physical activity. However, these constraints do not exclude an independent effect of the nutritional status. It is possible that, within malnutrition degrees ranging from light to moderate, relatively large adolescents are more active and thus more productive than smaller adolescents. Therefore, the objective of this study was to examine physical activity levels of adolescent Senegalese girls living in a rural and constraining environment in relation to their growth and nutritional status.

MATERIALS AND METHODS

Study area

Niakar is a Senegalese administrative district located 120 km west of the capital city of Dakar. This district belongs to the Sahelian belt where the climate is characterized by the alternating of a long dry season (November to June) with a short rainy season (July to October). The population was 29,104 inhabitants in 1997, scattered in 28 villages and hamlets. Since 1962 a yearly census is carried out in the area. From 1987 until now, demographic data have been regularly collected and stored in an electronic database (Delaunay, 1998). Birth dates and family composition are thus precisely known. This is important in an area where the administrative records are frequently inaccurate and delayed.

Inhabitants belong mainly to the *Sereer* ethnic group. They subsist by both farming and herding. They grow millet (*Pennisetum* spp and *Sorghum vulgare*) in association with beans (*niébé* or *Vigna unguiculata*) as staple food and peanuts (*Arachis hypogea*) for cash. Cultivation takes place during the wet season. Herding is important. Cattle can graze near the villages during the dry season; in so doing, they manure the fields before millet sowing. During the wet season animals are led, in a long transhumance, towards the *Djoloff* in the northern part of Senegal by the young adolescent males.

This agricultural system is quite intensive and allows peasants to subsist with limited land under constraining environmental and climatic conditions (Lericollais et al., 1999). However, soil degradation, demographic pressure, and persistent dryness lead young adults and adolescents to migrate to cities during the season in search of wage labor.

Sample

Adolescent girls were drawn from a larger sample of approximately 390, followed yearly since 1995 within the framework of a longitudinal study on a growth and maturation events during puberty (Benefice et al., 2001b). The sample consisted of 40 adolescent girls (13.3 ± 0.5 year old at the beginning of the study in 1997) whose activities were monitored for 3 yearly rounds (May–June 1997; June 1998, and March–April 1999). Because of seasonal out-migration to cities, nine girls were missing in 1999 and had to be replaced by girls from the same area and also belonging to the whole sample of 390. There were no differences in growth and maturation between missing adolescents and their substitutes. As a whole, the girls are characterized by slow maturation and growth compared with adolescents from industrialized countries. They also present persistent stunting, although a clear catch-up in body mass, fat mass, and body mass index (BMI) occurs after mid-puberty (Benefice et al., 2001b).

The study protocol was reviewed and approved by the Niakhar project board of the Institut de recherche pour le developpement (IRD) and authorized by the University Ministry of Senegal. The aim of the surveys were explained to the girls and their parents, and individual oral consent was requested.

Growth and maturation

Adolescent girls were weighed at each round, barefoot and lightly clothed, with an electronic scale accurate to 100 g. Their stature, standing upright, was measured with a portable Harpenden anthropometer. Midarm circumference was measured at the left side after marking the site on the skin. Six subcutaneous fatfolds were measured using the Holtain caliper at the tricipital, bicipital, subscapular, supra iliac, umbilical, and calf sites. The sum of these six skinfolds was used as an indicator of total fatness. Each measure was done in duplicate according to recommended techniques (Lohman et al., 1988). Standardization sessions were organized between measurers (the authors of the paper) at the beginning of each round. The interobserver coefficients of variation have already been published: They were within the lower range of data reported in the literature (Benefice et al., 2001b).

Girls were asked about the occurrence of menstruation, and if positive, when it occurred. Only 2 girls of 40 were menstruating at the beginning of the survey, whereas 11 of 40 were menstruating at the end of the survey when they were 15.4 ± 0.4 years old. Thus, 80% of the adolescents were not menstruating during the study. Sexual maturity was determined according to the stage of breast development (Tanner, 1962).

Physical activity assessment

Physical activity was quantitatively assessed using an electronic accelerometer worn by the girls for 3 consecutive days and nights (4 days during the 1st round). The 7164 CSA accelerometer (Computer Science and Applications, Inc., Shalimar, FL) was chosen because of its small size (5×3.8×1.5 cm), light weight (60 g), and ease of use. This apparatus records body accelerations and decelerations (i.e., movements) in a vertical plane with a piezo-electric sensor and produces an electronic signal proportional to the force acting on it. It records accelerations ranging from 0.5 to 2 Gs. Data are stored in a 34-kb non-volatile RAM and then collected in a computer through an interface unit. In this study, the interval time was set at 1 minute. The apparatus was sent to the manufacturer each year for revision and calibration. Eight accelerometers were used for the study. They were worn firmly fitted at the level of the left hip with a linen belt. Girls were instructed on how to fasten and unfasten the belt for toilet or bathing.

During the first and last surveys (June 1997 and March 1999), the nature of the task and the time spent in doing it were also monitored minute by minute for 2 consecutive days by young-women observers. These women were specially recruited and trained to observe the girls at a certain distance to not interfere with their habits. They were regularly controlled by a supervisor. They were divided into two teams working continuously for 6 hours (7 AM–1 PM and 2 PM–7 PM). Results of the first survey were used to validate accelerometry records (Benefice and Cames, 1999). Intensity of activities was coded according to a 10-point scale ranging from 1 (lying in a bed) to 10 (very hard activity such as dancing or sprinting). This scale was inspired by previous work by Bouchard et al. (1983). After adaptation, it was proven to be reliable (Benefice et al., 1999). To assign a practical meaning to the results, energy spent in specific activities were then expressed as multiples of basal metabolic rate according to current recommendations. Metabolic values were compiled from sources relating to developing countries (Bleiberg et al., 1980; FAO/WHO/UNU, 1985; Torùn, 1989). It must be underlined that published values for specific tasks observed in Africa, like pounding, fetching, or carrying water, are very rare. As far as we are aware, there still do not exist specific values for pubescent girls. Daily physical activity was expressed as physical activity level unit (PAL), which is the ratio of energy expenditure to basal metabolic rate (BMR). BMR could be calculated according to age, sex, and weight characteristics and then energy expenditure calculated. In this study, the Schofield equations suggested by the FAO/WHO/UNU (1985) were used.

Validation study and threshold settings of accelerometry counts

From previous studies, there is good agreement between accelerometry counts and either direct observation scores (Benefice and Cames, 1999) or heart rate monitoring (Benefice et al., 2001a). It is difficult to set a cut-off for intensity levels, since values from the literature or those proposed by the manufacturer do not apply to this population of active, lean adolescent girls. It was decided to determine specific thresholds for the surveys. Results from the first round were used for this purpose. Correlation coefficients between accelerometry counts and observed scores were individually calculated for each minute points (1,440 minutes per subjects). The average correlation coefficient was moderate: $r = 0.67 \pm 0.16$, but could be considered acceptable under field condition. After converting the observation score in multiples of BMR from literature data, a regression equation was established as:

1 unit of BMR = $1.437 + (1.30 * 10^{-3}) \times$ counts.min^{-1}; (standard error of the estimate = 0.042).

This equation was used during activity time, defined by counts.min^{-1} > 25. When counts.min^{-1} were <25, a value of 1 unit of BMR was applied instead. Two cut-off points were then calculated to represent activity levels: 3 units of BMR corresponding to 890 counts.min^{-1} (limit between light and moderate activity) and 6 units of BMR, corresponding to 1,890 counts.min^{-1} (limit between moderate and vigorous activity). Interestingly, these limits are close to the cut-off points derived from the heart rate monitoring study (843 counts.min^{-1} for light activity and 2,240 counts.min^{-1} for moderate activity) (Benefice et al., 2001a). The percent of time spent at light, moderate, or vigorous activities was calculated for the daytime period (7 AM–22 PM).

Dietary habits of adolescent girls

During the last round (March 1999), a detailed food consumption survey was performed (Caius, 2000). The survey was done with a precise weighing technique of food prepared for the meal, before and after cooking, and of the leftovers. Because the Sereer population is used to sharing a common dish, adolescents were given plates to ascertain their individual consumption. Plates were weighed before and after eating, just as were the leftovers. In this way, the proportion of the meal taken by the girl could be calculated. Eight specially trained Sereer women were in charge of the survey. Food eaten outside the household was recorded by interview in the evening. Dietary intakes were measured for 3 to 4 consecutive weekdays. For bibliographic sources used to convert quantities eaten into nutrient values and for requirement estimation, see Table 1.

Energy adequacy was calculated on an individual basis. Total daily energy expenditure was derived from the activity survey and BMR calculated for each girls using the Schofield equation suggested by the FAO/OMS/UNU report as indicated over. Because these girls were moderately stunted and wasted and also had an important work loads, their daily energy expenditure was increased by 10% to obtain an energy requirement in accordance with a normal growth and maturation status. Finally, percent of adequacy was calculated as the ratio of the observed intakes to the individual requirements. For nutrients, because of the inaccuracy of food tables, percent of adequacy was calculated only at a group level.

Statistical analysis

Analysis consisted of descriptive statistics, multiple regression and stepwise regression analysis, and analysis of variance and co-variance. The NCSS statistical software was used (Hintze, 1998). Analyses were performed after taking into account changes in body dimensions and physical activity patterns from one visit to the other by adjustments on age.

RESULTS

There was a significant increase in weight, height, BMI, and arm circumference but not in skinfolds among adolescents during the 3 years of follow-up (Table 2). Only active, apparently healthy girls were chosen for the surveys. Despite this selection, a close examination of their anthro-

TABLE 1. Daily intakes and nutritional value of food consumed by Sereer adolescent girls

Energy and nutrients[1]	Mean of observed intake	Standard deviation	Min.	Max.	% of energy supplied	Requirement[2]	Adequacy (%)
Calories (Kcal)	2,681	795	1,201	4,700		2,398[a]	113
(Vegetal origin)	2,543	789	1,127	4,490	95		
(Animal origin)	138	93	9	400	5		
Protein (g)	85	21	39	126	13	40.6[b]	209
						49.2[c]	173
(Vegetal origin)	63	21	26	124			
(Animal origin)	22	13	2	53			
Fat (g)	61	24	16	113	20	47 to 71[d]	85 to 139
(Vegetal origin)	57	23	14	106			
(Animal origin)	4	3.6	0.2	19			
Carbohydrate (g)	448	156	215	867	67	292 to 318[d]	104 to 150
Fibers (g)	10	5	3	30			
Calcium (mg)	54	37	11	181		650[e]	8
(Vegetal origin)	43	34	8	175			
(Animal origin)	11	12	1	65			
Iron (mg)	36	14	17	78		40[f]	90
(Vegetal origin)	34	14	14	77			
(Animal origin)	2	1	0.2	6			
Phosphorus (mg)	196	54	98	338		800[e]	25

[1]Nutritional values of food were calculated using food composition tables for West Africa (FAO, 1970; Toury et al., 1967). For certain rare foods other sources were referred to (FAO, 1976; Favier et al., 1993).
[2]Adolescents requirements in energy and nutrients were calculated according to recent recommendations compiled from various sources (Dwyer, 1981; FAO/WHO/UNU, 1985; Giovannini et al., 2000; King and Burgess, 1993). Percent of adequacy was calculated as (observed intake/requirement) × 100.
[a]FAO/WHO/UNU, 1985. Energy requirements calculated as exposed in the text.
[b]Protein intake as been set at 0.94 g protein/kg day for a mean weight of 43.2 kg among the adolescents.
[c]After correction for protein quality of foods, the requirement is 1.14 g/kg day (Giovannini et al., 2000).
[d] Total fat should be between 20 to 30% of total calories. Carbohydrates should be between 55 to 60% of total calories (Giovannini et al., 2000).
[e]Adapted from Dwyer, 1981.
[f]Value proposed for a low iron availability diet (King and Burgess, 1993).

TABLE 2. Anthropometric characteristics of the Sereer adolescent girls during the survey

Variables	1st visit: June 1997 (n = 40)	2nd visit: June 1998 (n = 40)	3rd visit: March 1999 (n = 40)	F (2,119) (P)	Mean values for pooled variables
Age (year)	13.3[a]	14.3	15.4		14.4
	0.5[b]	0.5	0.5		1.0
Weight (kg)	35.4	40.3	43.2	11.1	39.7
	6.1	9.2	7.0	(P < 0.0001)	8.2
Height (cm)	149.2	152.0	156.6	93	152.7
	7.2	8.8	7.6	(P < 0.0001)	8.5
BMI (kg/m^2)	15.8	17.3	17.6	6.7	16.9
	1.9	2.8	2.2	(P < 0.0001)	2.5
Arm circumference (cm)	20.7	21.1	22.1	3.76	21.4
	2.0	2.8	2.1	(P < 0.02)	2.4
Triceps skf (mm)	8.6	9.9	9.8	1.41	9.4
	3.6	4.1	3.5	n.s	3.8
Sum 6 skf (mm)	48.4	49.9	50.1	0.11	49.5
	16.5	20.3	15.5	n.s[c]	17.4

[a]Mean.
[b]Standard deviation.
[c]not significant.

pometric indices denoted a certain degree of growth retardation compared with the usual references for their age and sex group. After pooling all values across the rounds (last column, Table 1), the average weight was between the 5th and 10th percentile and height was just at the 10th percentile of the NCHS reference (Hamill et al., 1979). The BMI was under the 15th percentile (Must et al., 1991) and arm circumference below the 5th percentile (Frisancho, 1981). Finally, the triceps skinfold was just over the 10th percentile (Johnson et al., 1981). According to these standards, adolescents could be considered as lightly-to-moderately stunted and wasted. During the last visit (1999), 29 adolescents (72%) were reaching the end of puberty (breast stage B4 and B5), but only 11 (27%) had experienced menstruation.

Results of the dietary survey are summarized in Table 1. During the survey 75 different food items were identified. Generally, girls ate three times per day with quantities evenly distributed between meals. A rich variety of different recipes, more then 20, was recorded generally associating a cereal (millet or rice) and a sauce made with either peanuts, beans, fresh and dried fish, or, exceptionally, goat or chicken meat. Consumption of milk products was very low, and eggs were never eaten. The most frequently eaten meals consisted of rice with dried fish for lunch (*Tieebu guedj*) and a gruel of millet, called couscous, with peanuts, niébé or dried fish (*Tiéré Neuxeul* or *Bassé*) for dinner. Subjects used the leftovers from the evening meal for breakfast.

As a whole, girls met their basic energy and protein needs (Table 1). Individual calculations showed that their total daily expenditure was 2,180 ± 291 kcal giving a requirement of 2,398 ± 320 kcal. The percent of adequacy in energy was thus equal to 112.9 ± 34.2%. However, the range of values was wide, and 41% of the girls did not meet their own energy requirements. It is important to note that 95% of the food energy originated from plant origin. Adolescent energy intake essentially stemmed from cereals with low fat and animal protein contribution. Approximately 67% of the calories were from carbohydrates, only 20% from lipids, and 13% from proteins. Intakes of micronutrients like calcium and phosphorus were insufficient. This could be explained by the very low consumption of milk and meat. Iron intakes were also insufficient with reference to the low bioavailability of iron from nonanimal foods.

Day-to-day reliability of accelerometers has been checked on the basis of the intraclass correlation coefficient (ICC) (Baumgartner, 1989). Coefficients were calculated separately at each round. In June 1997, ICC was equal to 0.67 for 1 day and 0.89 for 4 days. Because the improvement between the 3rd and 4th days was minimal (0.85 to 0.89), only 3 days of monitoring were un-

TABLE 3. Indices of physical activity among Sereer adolescent girls (n = 40 at each visit)

Parameters	Mean	SD	*F* (2,117)	*P*
Total daily activity (PALs)				
1st visit	1.84	0.24	5.89	0.003
2nd visit	1.72	0.18		
3rd visit	1.68	0.16		
Activity during day (PALs)				
1st visit	2.13	0.33	3.52	0.033
2nd visit	2.01	0.26		
3rd visit	1.97	0.24		
Activity during night (PALs)				
1st visit	1.24	0.13	16.08	0.000
2nd visit	1.16	0.10		
3rd visit	1.11	0.08		
Time spent in light activity (%)				
1st visit	70.88	9.22	2.25	0.110
2nd visit	74.30	7.94		
3rd visit	74.46	8.50		
Time in moderate activity (%)				
1st visit	21.08	6.07	2.02	0.137
2nd visit	18.79	6.26		
3rd visit	18.61	6.12		
Time in vigorous activity (%)				
1st visit	8.04	4.19	1.24	0.294
2nd visit	6.92	3.21		
3rd visit	6.93	3.57		

dertaken in the subsequent surveys. In 1998, ICC was 0.56 for 1 day and 0.79 for 3 days. Finally it was 0.82 for 1 day and 0.93 for 3 days in 1999. This denotes an excellent reliability of the method. Interestingly, values of the coefficients seemed to increase from 1997 to 1999, suggesting more monotony in the physical activity pattern and less variety of the tasks to be undertaken.

Mean values of the different indices of activity according to the year of visit are indicated in Table 3. As a whole, physical activity intensity expressed in PAL was high: 1.7 to 1.8 multiples of BMR. Interestingly there was a significant decrease from the 1st visit to the last. This decline was especially clear-cut for the nighttime period (defined as the period between 22 PM and 6:59 AM). After separating activity intensity into three categories, a non-significant increase in time spent at light activity (≤3 multiples of BMR) and a decrease in moderate (3–6 multiples of BMR) and vigorous activity (>6 multiples of BMR) could be observed. After pooling together values of the 2nd and 3rd rounds, differences with the 1st round became significant in time spent at light activity: 70.8 ± 9.2% versus 74.3 ± 8.1% ($t = 2.12$, $P < 0.03$), and at moderate activity: 21.0 ± 6.6 versus 18.7 ± 6.1 ($t = 2.01$, $P < 0.04$). Time spent at vigorous activity did not change. On an average, time spent at moderate and vigorous activity was consider-

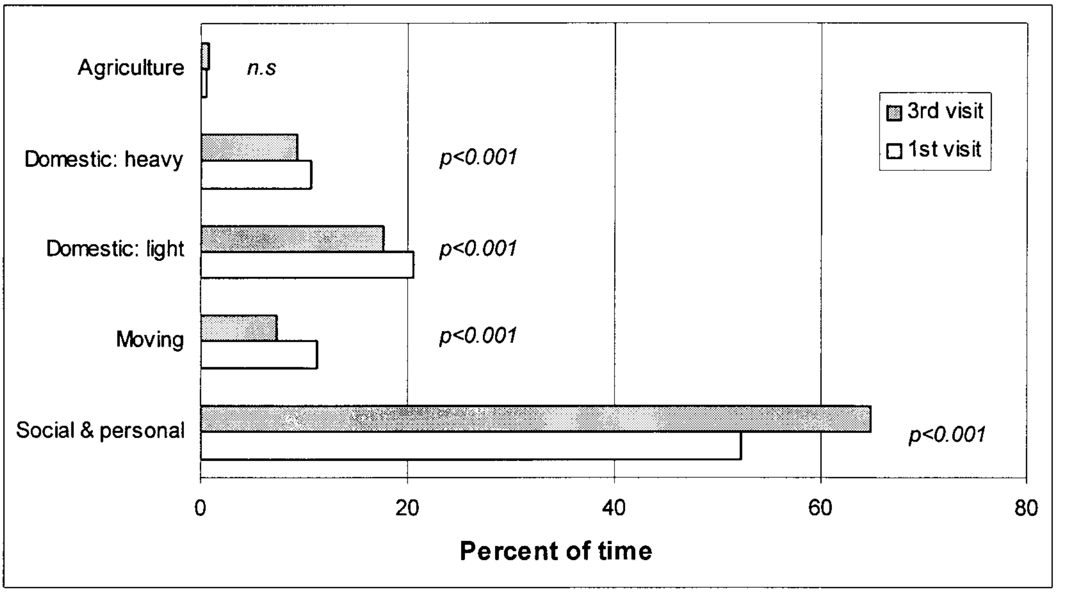

Fig. 1. Percent of time spent in different groups of activities by adolescent Senegalese girls.

able: it represented more than 2 hours 30 minutes per day of moderate activity and 50 minutes of vigorous activity.

From the observational surveys organized during the 1st and 3rd visit, it was possible to investigate which group of activities changed over time. Results are summarized in Figure 1. Activities were classified into six principal groups. Differences were tested with Fisher's exact test and found to be significant between visits for all activity groups except agricultural production. When younger, adolescent girls spent less time at personal occupations (including school and rest time) and more at domestic tasks. Time spent performing agricultural activities was always low (0.6–0.7% of the daily observations, less than 5 minutes). It must be emphasized that there was virtually no agricultural activity during the dry season, apart from cattle herding and watering, which were performed by boys.

To study the relationship between physical activity indices and individual characteristics of adolescent girls, a stepwise regression was performed. Because body dimensions and maturity status progressed from one visit to the other, analysis was performed using age as a weight variable. Results are presented in Table 4. The following variables were entered into the model: breast stage, stature, BMI, arm circumference (as a proxy for muscle mass), and the sum of six skinfolds (as a proxy for adiposity). There was a moderate but significant relationship, explaining 7 to 9% of the variance, between indices of physical activity and stature and BMI. The BMI was a significant and positive predictor of 24-hour energy expenditure and energy expended during the daytime, whereas stature had a negative effect on those indices. Shorter girls were more active than taller girls, and those with a greater BMI were also more active than the leaner girls. The breakdown of activity in different levels provides another insight. Stature and BMI were again the unique predictors of time spent at light or moderate activity, but the signs of the regression coefficients were opposite. While light activity was positively associated with a small size and negatively with the BMI, the reverse was true for moderate activity. Vigorous activity levels were not predicted by any of the individual characteristics entered in the model. Interestingly, pubertal development, subcutaneous fatness, and arm circumference were not predictive of activity levels.

BMI is considered a useful indicator of nutritional status in adolescents (de Onis and Habicht, 1996). In the present study, it

TABLE 4. Results of a stepwise regression between indices of physical activity and stature, pubertal stage, BMI, arm circumference, and the sum of 6 skinfolds (using age as a weight variable to take account differences in body dimensions between visits)

Independent variables[a]	Standardized regression coefficient	t^b	P	$R^{2\ c}$
Total 24-h activity				
Stature	−0.27	2.7	0.007	0.08
BMI	0.19	2.0	0.04	
Activity during daytime				
Stature	−0.27	2.9	0.003	0.08
BMI	0.18	2.0	0.04	
Activity during nighttime				
	No variables selected			
% time spent in light activity				
Stature	0.27	2.9	0.005	0.08
BMI	−0.20	2.2	0.028	
% time spent in moderate activity				
Stature	−0.26	2.8	0.005	0.09
BMI	0.24	2.6	0.011	
% time spent in vigoroous activity				
	No variables selected			

[a]Only selected variables with significant effect are presented in the table.
[b]Test of significance for the variable.
[c]Coefficient of determination for the current model.

had an independent effect on energy expenditure estimates and physical activity levels. To make this effect more evident, girls were divided into three groups according to their specific age percentile rank: <5th percentile, 5–15th percentile, >15th percentile, using values of Must et al. (1991). For greater contrast, only low BMI girls (BMI < 5th percentile) and normal BMI girls (BMI > 15th percentile) were compared. Comparisons were done after adjusting for age by covariance analysis. Total 24-hour energy expenditure and energy expended during the daytime were greater for normal BMI girls than for low BMI girls. Interestingly, there was a significant interaction between age and activity level during the night. Slopes between age and energy expenditure at night were compared between the two BMI groups and found to be different. Separate analysis proved that, whatever their corpulence, younger adolescents expended more energy then older adolescents during the night. Finally, normal BMI girls spent more time in moderate activity and less in light activity than low BMI girls. There was no difference in vigorous activities between BMI groups.

DISCUSSION

This study confirms the high level of daily energy expenditure of these adolescents, already reported for the Sereer population (Benefice and Cames, 1999; Benefice et al., 2001a). During the first round, they reached the "heavy" activity category (PAL $\geq$ 1.85 multiples of BMR) suggested by Torun et al. (1996). In subsequent rounds, they lay between the "moderate" and "heavy" categories (1.65–1.85 multiples of BMR). However, it must be underlined that these values are only an indirect estimate of energy expenditure under field conditions and do not strictly represent the current situation.

Limitations of accelerometers have already been described. Accelerometer counts reflect changes in kinetic energy according to Newton's mechanical laws rather than energy expenditure in a thermodynamic sense (Meijer et al., 1991; Tryon and Williams, 1996). Energy expenditure during static work such as carrying a load or lifting an object may be considerable and is not accurately recorded by motion sensors, especially those with a single axis. Static work constitutes an important part of daily domestic tasks. These tasks are apparently better captured with a triaxial accelerometer (Westerterp, 1999). However, in real-life conditions, both kinds of apparatus report equally spontaneous activity (Trost, 2001). The most commonly observed static tasks, like supervising the cooking of meals or waiting a turn at the tap during water collection, generally do not entail an important

TABLE 5. Comparison of physical activity indices between constrasted groups of BMI, after adjusting for age difference by covariance analysis

Physical activity indices	BMI < 5th percentile (n = 38)	BMI > 15th percentile (n = 55)	F (1,90) (P)
Total daily EE (Mets)	1.67[a] 0.03[b]	1.77 0.02	5.01 0.02
EE during day (Mets)	1.94 0.04	2.07 0.02	4.3 0.04
EE during night[c] (Mets)	1.14 0.01	1.19 0.01	3.7 0.05
% Light activity	76.0 1.3	72.4 1.1	4.08 0.04
% Moderate	17.3 0.9	20.1 0.8	4.8 0.03
% Vigorous	6.6 0.6	7.4 0.5	1.1 ns

[a]Adjusted Mean
[b]Standard error of the mean.
[c]Significant interaction with age.

energy cost, but because of their frequency (girls spent approximately 20% of their time in light domestic activity), energy expenditure reported here was certainly underestimated. However, it should be emphasized that until now, no field method has been accurate enough to measure oxygen consumption of children at low ventilation rate. The doubly labeled water method, considered to be the gold standard, gives a global estimate for several days but does not distinguish different levels of activity during the day. If the outcome sought more the physical activity patterns than the energy expended, as is the case in this study, accelerometry is a method of choice (Trost, 2001). In population studies, accelerometers have important advantages, especially for children: they are light to carry, not cumbersome and do not disrupt spontaneous activity (Janz, 1994). A recent paper found a good correlation between accelerometry counts and energy calculated from indirect calorimetry (Eston et al., 1998).

A recent compilation of studies on energy expenditure using different methods (doubly labeled water, observation, or heart-rate recording) indicates that for 14- to 15-year-old girls from both industrialized countries and developing countries, the average PALs are between 1.33 and 1.66 (Torun et al., 1996). These values are well below those presented here. This is not surprising since African studies usually report a high level of energy expenditure among rural women (Bleiberg et al., 1981; Henderickx et al., 1990; Lawrence and Whitehead, 1987; Schultink et al., 1993; Singh et al., 1989). Unfortunately, to our knowledge, there exist no specific studies on rural African adolescents for comparison purposes.

The absence or presence of a relationship between body composition or fatness and indices of activity remains a controversial issue. Generally the relationship is weak with results depending on the choice of method used (Rowlands et al., 2000). In children there is a small negative although significant relationship between activity when recorded with motion sensors and fatness (LeMura et al., 2000; Rowlands et al., 1999). A similar relationship exists but it is weaker when a heart-rate monitoring method is used instead (Janz et al., 1992). Almost all studies done were carried out in industrialized countries. Their conclusions do not necessarily apply to developing countries where the relationships between maturation, growth, body composition, and activity are obscured by the presence of chronic malnutrition. This is apparent in the present study where subcutaneous fatness had no independent effect on activity; instead, BMI, sometimes considered to be an adiposity indice, was positively associated with energy expenditure. In these slightly malnourished adolescent girls, a limited amount of fat mass does not constitute an overload during moving or weight lifting activities, as could be the case in fatty adolescents where fat mass constitutes a brake to spontaneous activity. On the contrary, a higher BMI, which is a marker of either muscle or fat mass, reflects a better nutritional status and is positively associated with greater intensity of activity.

The decline in activity throughout the years reported in Table 3 is in line with other observations on adolescents (Sallis, 1993). This decline is especially clear-cut during the nighttime. The most plausible explanation is that during the first round, younger girls have to get up early (between 5 and 6 AM) to prepare millet for pounding. They have to extract the ears from the loft and to separate the grains. Husking and pounding, two especially heavy tasks, are mostly in charge of women or older adolescents thereafter. A sharp peak in the daily curve of accelerometry counts could be noted at that time (Benefice and Cames, 1999).

Smaller, younger girls were more active than taller, older adolescents. But for a given size, those with a higher BMI displayed higher indices of activity. Smaller girls spent also more time in light than moderate activity, and time spent in vigorous levels of activity was apparently independent of body dimensions. Thus, a complex interaction between behavioral or social and physiological influences appears to take place. The younger girls are prompted to be active, but within limits assigned by their own nutritional status. This energy adjustment seems to be more efficient for children than for adults. In an experimental study done in a respiratory chamber, no differences in energy expenditure or basal metabolic rate (BMR) nor other evidence of metabolic adaptation were found between male Gambian farmers having low or normal BMI after adjusting for differences in fat-free mass (Bianca et al., 1994). A decrease in energy expenditure and BMR was observed in rural Benin (West Africa) during a field study but only in very thin women having a BMI < 18 kg/m^2 (Schultink et al., 1993). Results from population studies are also conflicting. In a nutritionally deprived rural area of Ethiopia a significant association between low levels of activity and low BMI has been reported in adults. Men, but not women, were nevertheless able to increase their energy expenditure during the pre-harvest period (Alemu and Lindtjorn, 1995). In central Mali, in an area obviously less nutritionally stressed than Ethiopia, adult males lost body weight and at the same time increased their energy expenditure during the rainy season (agricultural works). They were able to recover a normal body and muscle mass thereafter. Seasonal variations were less marked among women. The authors concluded that farmers responded by modest weight loss to the seasonal energy imbalance (Adams, 1995).

All these studies tended to show that adults could adapt easily to a range of energy stresses without restraining their activity. However, the consequences of weight lost are certainly much more serious among children in terms of growth and development of functional capacity. This implies a more precise mechanism of energy regulation to protect them from environmental constraints. This regulation seems to be completed by either cultural or behavioral adjustments. Younger, weaker girls are more active but in less energy-demanding tasks, and by biological conformation, stronger girls expend more energy in activity. This implies a well-structured society with a fair sharing of tasks within the household. The importance of the household as a determinant of child nutritional and health status has recently been stressed (Panter-Brick, 1998).

The dietary survey performed once in March 1999 showed that adolescents correctly met their energy requirements. This is interesting, since an important deficit in energy intake is often reported in African studies (Bleiberg et al., 1981; Singh et al., 1989). This could be due to precise individual weighing method used. However, it must be pointed out that approximately 41% of the girls did not meet their energy requirements and that the survey was performed after harvest when grain provisions were sufficient. The situation tends to deteriorate at the end of the dry season. A food frequency questionnaire used in June 1998 indicated less variability in foods consumed, whereas the quantities eaten were considered to be insufficient by the children. In some cases, the number of meals was reduced from 3 to 2 (Sernit, 1998). In the present survey, there existed deficiencies in important nutrients like calcium and iron and probably vitamin A. The vitamin A content of foods consumed was not calculated here because values proposed by the foot tables were not obtained with modern techniques of determination. However, vitamin A deficiency was documented in the area: 20% of 865 preschool children examined during an epidemiological survey were considered to be at-risk of vitamin A deficiency and 11% were classified as deficient (Carlier et al., 1991). Local consumption of food rich in retinol precursors such as papaya or mango fruits is seasonal and marginal, due to the dryness.

It is quite certain that nutritional stress occurred during the rainy season in this adolescent group, where a slight decrease in arm circumference, triceps skinfold, and BMI has already been reported (Benefice and Cames, 1999). However, their growth and maturation processes were not arrested. Sereer farmers used efficient subsistence strategies, for example, the outmigration to the cities when the situation worsened minimizes the nutritional impact on adolescent health (Benefice et al., 1999).

The working activity of adolescent girls plays an important role in everyday life. Their participation in productive agricultural tasks was minimal during the surveys (4.0 and 4.5 minute per day), but they spent between 194 and 223 minutes (more than 3 hours 30 minutes per day) in domestic activities. This no doubt constitutes an important help to the mothers. Very often, it is stated that African women are overburdened by their multiple domestic and extradomestic activities (McGuire and Popkin, 1988). This is true, but the contribution of children and adolescents of both sexes is considerable and should be accounted for in the energy budget of the household. Younger adolescent girls are not spared and are involved in heavy domestic tasks such as carrying loads, washing clothes, winnowing grain, and pounding. However, present findings show that the weaker girls are more often engaged in light and less in moderate activities than the stronger girls. Along this line, the work pace is an important aspect of this activity. It has been shown that working a long time but at a low level of intensity, with frequent rests, is an efficient way to avoid exhaustion and to decrease energy expenditure (Panter-Brick, 1998).

In conclusion, these adolescent girls play an important role in the maintenance of the energy homeostasis of the household. They are able to sustain their activity despite suffering from light-to-moderate degrees of malnutrition. However, their workloads seem to be well adjusted to their physical capacity.

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LITERATURE CITED

Adams AM. 1995. Seasonal variations in energy balance among agriculturalists in central Mali: compromise or adaptation? Eur J Clin Nutr 49:809–823.

Alemu T, Lindtjorn B. 1995. Physical activity, illness and nutritional status among adults in a rural Ethiopian community. Int J Epidemiol 24:977–983.

Ambadekar N, Wahab S, Zodpey S, Khandait D. 1999. Effect of child labor on growth of children. Public Health 113:303–306.

Baumgartner T. 1989. Norm-referenced measurement: reliability. In: Safrit M, Wood T, editors. Measurement concepts in physical education and exercise science. Champaign, IL: Human Kinetics, p 45–72.

Benefice E, Cames C. 1999. Physical activity patterns of rural Senegalese adolescent girls during the dry and rainy seasons measured by movement registration and direct observation methods. Eur J Clin Nutr 53:636–646.

Benefice E, Cames C, Simondon K. 1999. Growth and maturation of Sereer adolescent girls (Senegal) in relation to seasonal migration for labor. Am J Hum Biol 11:539–550.

Benefice E, Garnier D, Ndiaye G. 2001a. Assessment of physical activity among rural Senegalese adolescent girls: influence of age, sexual maturation and body composition. J Adolesc Health 28:319–327.

Benefice E, Garnier D, Simondon K, Malina RM. 2001b. Relationship between stunting in infancy and growth and fat distribution during adolescence in Senegalese girls. Eur J Clin Nutr 55:50–58

Bianca PD, Jéquier E, Schutz Y. 1994. Lack of metabolic and behavioral adaptations in rural Gambian men with low body mass index. Am J Clin Nutr 60:37–42.

Bleiberg F, Brun T, Goihman S, Gouba E. 1980. Duration of activities and energy expenditure in dry and rainy seasons in Upper-Volta. Br J Nutr 43:71–82.

Bleiberg F, Brun T, Goihman S, Lippman D. 1981. Food intake and energy expenditure of male and female farmers from Upper-Volta. Br J Nutr 45:505–515.

Bouchard C, Tremblay A, Leblanc C, Lortie G, Savard R, Thériault G. 1983. A method to assess energy expenditure in children and adults. Am J Clin Nutr 37:461–467.

Bril B. 1986. The acquisition of an everyday technical motor skill: the pounding of cereals in Mali (Africa). In: Wade M, Whitting H, editors. Themes in motor development. Dordrecht, The Netherlands: Martinus Nijhoff, p 315–326.

Brun T, Bleiberg F, Goihman S. 1981.Energy expenditure of male farmers in dry and rainy seasons in Upper-Volta. Br J Nutr 45:67–75.

Caius N. 2000. Etude de la consommation alimentaire des adolescents de Niakhar, Sénégal rural. Mémoire de Maîtrise des Sciences Sanitaires et Sociales. Montpellier: Université de Montpellier III.

Carlier C, Moulia Pelat JP, Ceccon JF, Mourey MS, Ameline B, Fall M, Ndiaye M, Amedee Manesme O. 1991. Prevalence of malnutrition and vitamin A deficiency in the Diourbel, Fatick and Kaolack regions of Senegal: epidemiological study. Am J Clin Nutr 53:70–73.

de Onis M. 1993. The worldwide magnitude of protein-energy malnutrition: an overview from the WHO global database on child growth. Bull WHO 71:703–712.

de Onis M, Habicht J. 1996. Anthropometric reference data for international use: recommendations from a World Health Organization Expert Committee. Am J Clin Nutr 64:650–658.

Delaunay V. 1998. La situation démographique et épidémiologique dans la zone de Niakhar au Sénégal 1984–1996. Dakar: Institut de Recherche pour le développement (IRD), 131 p.

Dwyer J. 1981. Nutritional requirements of adolescence. Nutr Rev 39:56–72.

Eston RG, Rowlands AV, Ingledew DK. 1998. Validity of heart rate, pedometry and accelerometry for predicting the energy cost of children's activities. J Appl Physiol 54:362–371.

FAO.1970.Table de composition des aliments á l'usage de l'Afrique. Rome: Food and Agricultural Organization.

FAO. 1976. Table de composition des aliments á l'usage de l'Asie de l'Est. Rome: Food and Agricultural Organization.

FAO/WHO/UNU. 1985. Energy and protein requirements: report of a joint expert consultation. Geneva: World Health Organization.

Favier J, Ireland-Ripert J, Laussucq C, Feinberg M. 1993. Répertoire général des aliments. Tome 3: Table de composition des fruits exotiques, fruits de cueillette d'Afrique.Paris: Orstom, Lavoisier, Inra éditions.

Frisancho A. 1981. New norms of upper limb fat and muscle areas for assessment of nutritional status. Am J Clin Nutr 34:2540–2545.

Giampietro M, Pimentel D. 1992. Energy efficiency and nutrition in societies based on human labor. Ecol Food Nutr 28:11–32.

Giovannini M, Agostini C, Gianni M, Bernardo L, Riva E. 2000. Adolescence: macronutrient needs. Eur J Clin Nutr [Suppl 1] 54:S7–S10.

Hamill P, Drizd T, Johnson C, Redd R, Roche A, Moore W. 1979. Physical growth: National Center for Health Statistics percentiles. Am J Clin Nutr 32:607–629

Henderickx H, Callens K, D'Haese L. 1990. The estimation of the energy requirement of two communities in rural Burundi (Africa). Ecol Food Nutr 24:149–156.

Hintze J. 1998. NCSS 2000: Statistical System for Windows. Kaysville, Utah: NCSS.

Jamison D, Leslie J. 1990. Health and nutrition considerations in education planning: II. The cost and effectiveness of school-based interventions. Food Nutr Bull 12:204–214.

Janz K. 1994. Validation of the CSA accelerometer for assessing children's physical activity. Med Sci Sports Exerc 26:369–375.

Janz K, Golden J, Hansen J, Mahoney L. 1992. Heart rate monitoring of physical activity in children and adolescents: the Muscatine study. Pediatrics 89:256–261.

Johnson C, Fulwood R, Abraham S, Bryner J.1981. Basic data on anthropometric measurements and angular measurements of the hip and knee joints for selected age groups 1–74 years of age: vital health statistics. Washington, DC: Department of Health and Human Services Publication.

King F, Burgess A. 1993. Nutrition for developing countries. Oxford: Oxford University Press.

Lawrence M, Whitehead R. 1987. Physical activity and total energy expenditure of child-bearing Gambian village women. Eur J Clin Nutr 42:145–160.

LeMura L, Andreaci J, Carlonas R, Klebetz J, Chelland S. 2000. Evaluation of physical activity measured via accelerometry in rural fourth-grade children. Perc Mot Skills 90:329–337.

Lericollais A, Milleville P, Pontié G. 1999. Crise de l'agriculture dans le Sine et stratégies paysannes élargies. In: Lericollais A, editor. Paysans sereer: dynamiques agraires et mobilités au Sénégal. Paris: Institut Français de Recherche pour le développement (IRD), p 579–591.

Lohman TG, Roche A, Martorell R. 1988. Anthropometric standardization reference manual. Champaign, IL: Human Kinetics.

McGuire J, Popkin B. 1988. The zeo-sum game: a framework for examining women and nutrition. Food Nutr Bull 10:27–32.

Meeks-Gardner J, Grantham-McGregor S. 1994. Physical activity, undernutrition and child development. Proc Nutr Soc 53:241–248

Meijer G, Westerterp KR, Verhoeven F, Koper H, ten Hoor F. 1991. Methods to assess physical activity with special reference to motion sensors and accelerometers. IEEE Trans Biomed Eng 38:221–229.

Munroe R, Munroe R, Shimmin H. 1984. Children's work in four cultures: determinants and consequences. Am Anthropol 86:369–379.

Must A, Dallal G, Dietz W. 1991. Reference data for obesity: 85^{th} and 95^{th} percentiles of body mass index (W/ht^2): a correction. Am J Clin Nutr 54:773.

Panter-Brick C. 1998. Biological anthropology and child health: context, process and outcome. In: Panter-Brick C, editor. Biosocial perspectives on children. Cambridge: Cambridge University Press, p 66–101.

Rowlands A, Eston R, Ingledew D. 1999. Relationship between activity levels, aerobic fitness, and body fat in 8- to 10-yr-old children. J Appl Physiol 86: 1428–1435.

Rowlands A, Ingledew D, Eston R. 2000. The effect of type of physical activity measure on the relationship between body fatness and habitual physical activity in children: a meta-analysis. Ann Hum Biol 27: 479–497.

Rutishauser I, Whitehead R. 1972. Energy intake and expenditure in 1-3 year-old Ugandan children living in a rural environment. Br J Nutr 28:145–152.

Sallis J.1993.Epidemiology of physical activity and fitness in children and adolescents. Crit Rev Food Sci Nutr 33:403–408.

Satyanarayana K, Naidu AN, Chatterjee B, Rao BN. 1977. Body size and work output. Am J Clin Nutr 30:322–325.

Satyanarayana K, Naidu AN, Rao BN. 1979. Nutritional deprivation in childhood and the body size, activity, and physical work capacity of young boys. Am J Clin Nutr 32:1769–1775.

Satyanarayana K, Prasanna Khrishna T, Narasinga Rao BS. 1986. Effect of early childhood undernutrition and child labour on growth and adult nutritional status of rural Indian boys around Hyderabad. Hum Nutr Clin Nutr 40C:131–139.

Schultink J, VanRaaij J, Hautvast J. 1993. Seasonal weight loss and metabolic adaptation in rural Beninese women: the relationship with body mass index. Br J Nutr 70:689–700.
Sernit H. 1998. Comparaison de la croissance d'adolescentes sénégalaises selon leur milieu rural ou urbain et étude de leur activité physique. Diplôme d'Etudes Supérieures Spécialisées. Nutrition et Alimentation dans les Pays en Développement. Montpellier: Université de Montpellier II.
Singh J, Prentice A, Diaz E, Coward W, Ashford J, Sawyer M, Whitehead R. 1989. Energy expenditure of Gambian women during peak agricultural activity measured by the doubly-labelled water method. Br J Nutr 62:315–329.
Spurr G, Barac-Nieto M, Maskud M. 1977. Productivity and maximal oxygen consumption in sugar cane cutters. Am J Clin Nutr 30:316–321.
Spurr G, Reina J. 1987. Marginal malnutrition in school-aged Colombian girls: dietary intervention and daily energy expenditure. Hum Nutr Clin Nutr 41C:93–104.
Tanner J. 1962. Growth at adolescence, 2nd edition. Oxford: Blackwell Scientific.
Torùn B. 1989. Energy cost of various physical activities in healthy children. In: Schurch B, Scrimshaw NS, editors. Activity, energy expenditure and energy requirements of infants and children. Lausanne, Switzerland: Nestlé Foundation. p 139–183.
Torun B, Davies P, Livingstone M, Paolisso M, Sackett R, Spurr G. 1996. Energy requirements and dietary energy recommendations for children and adolescents 1 to 18 years old. Eur J Clin Nutr 50 [Suppl 1]:S37–S81.
Toury J, Giorgi R, Favier J, Savina J. 1967. Aliments de l'Ouest Africain: tables de composition. Annales de Nutrition et d'Alimentation 21:73–124.
Trost S. 2001. Objective measurement of physical activity in youth: current issues, future direction. Exerc Sport Sci Rev 29:32–36.
Tryon WW, Williams R. 1996. Fully proportional actigraphy: a new instrument. Behav Res Methods Instrum Comput 28:392–403.
Westerterp K. 1999. Physical activity assessment with accelerometers. Int J Obes 23 [Suppl 3]:S45–S49.