EPIDEMIOLOGY

The level and tempo of children's physical activities: an observational study

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ABSTRACT

BAILEY, R. C., J. OLSON, S. L. PEPPER, J. PORSZASZ, T. J. BARSTOW, and D. M. COOPER. The level and tempo of children's physical activities: an observational study. *Med. Sci. Sports Exerc.*, Vol. 27, No. 7, pp. 1033–1041, 1995. We develop an observation system that quantifies the duration, intensity, and frequency of children's physical activities. We use this system to assess the level and tempo of energy expenditure under free-ranging, natural conditions experienced by 15 children aged 6–10 yr in southern California. Observations were recorded every 3 s during 4-h time blocks from 8:00 a.m.–8:00 p.m. Agreement among observers using the coding system was 91%. Using indirect calorimetry, calibration studies in the laboratory determined $\dot{V}O_2$ ($ml \cdot min^{-1} \cdot min^{-1}$) during each coded activity, and activities were categorized by intensity (low, medium, or high). Subjects were found to engage in activities of low intensity 77.1% of time and activities of high intensity 3.1% of time. The median duration of low and medium intensity activities was 6 s, of high intensity activities only 3 s with 95% lasting less than 15 s. Children engaged in very short bursts of intense physical activity interspersed with varying intervals of low and moderate intensity. These findings may be important for discovering how children's activity patterns under natural conditions influence physiological processes leading to growth and development. This study demonstrates the advantages of using an observational system that captures more than the intensity and frequency of children's activities to include duration and the length of intervals between activities of varying intensity.

ENERGY EXPENDITURE, EXERCISE, RELIABILITY, ASSESSMENT, $\dot{V}O_2$

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Assessment of physical activity and energy expenditure has become increasingly important with growing awareness of the association between physical activity, health, growth, and development (3,9,16,21,29,31). Yet many problems persist in the accurate characterization and quantification of energy expenditure in nonlaboratory settings under natural conditions. A variety of techniques has been developed, including self-administered recall, interview-administered recall, diaries, motion sensors, heart rate monitors, doubly labeled water, and direct observations. The advantages and disadvantages of each are well reviewed (3,14,22,26,32), and it is clear that there are still limitations to the available techniques.

Despite several major limitations of direct observation as a technique for assessing physical activity (25), there are distinct advantages over other methods to be used in the field. Through direct observations the investigator can capture the social and physical context of activity. Numerous studies have demonstrated strong social influences on physical activity (27), and many studies have indicated a variety of physical environment factors influencing physical activity. Thus, direct observational methods are especially useful in studies that aim to go beyond pure assessment of physical activity to include the study of physical and social environmental influences.

Another advantage of observational methods is their ability to measure the duration, intensity, and frequency of specific activity events. Other methods of assessment are capable of capturing some portion of these components of activity, but direct observations are the most comprehensive. For example, the doubly-labeled water technique may be the most accurate method for assessing total energy expenditure over a period of days or weeks (30), but it will not produce information on the duration or frequency of activity events. Motion sensors may be used to measure intensity of activity, but cannot be relied upon to measure duration (1). Heart rate monitors, on the other hand, may be accurate for capturing duration and intensity of exercise, but they record frequency within a limited time frame and cannot provide information about the activity events that produced the physiological response. Thus, investigators are increasingly recognizing that direct observations, by capturing not just the level of physical activity, but also duration and frequency, provide the most comprehensive information about physical activity under field conditions.

Despite this, the methods used to date have not exploited the full capability of observational techniques for capturing the patterning of activities by frequency, duration, and intensity. For the sake of brevity and clarity we refer to this patterning as the *tempo* of physical activity. It is important to recognize that tempo is different from frequency because it consists of not just the number of times an event occurs per unit time (i.e., rate) but also of the varying intervals between activity events. Tempo, then, describes *variation* in rate and thus includes the intervals between activity events of different intensity and duration.

The purposes of this study were to (a) develop a practical direct observation system that would include assessment of the "tempo" of physical activity under natural field conditions; (b) evaluate the reliability of the observation system; (c) calibrate codes used in the recording system with laboratory determinations of energy expenditure; and (d) use the observation system to assess the tempo of energy expenditure under free-ranging, normal conditions experienced by a sample of healthy children in southern California.

METHODS

Subject recruitment and scheduling of observations. Subjects were recruited from two Los Angeles elementary schools through a letter inserted into each school's monthly newsletter. Approximately 5% of families responded to the initial letter; 70% of these participated in the study. An initial meeting in the home of each subject with all family members present provided the opportunity for research staff to explain the study, to answer any questions, and to become familiar with the subjects and layouts of the home. The parents or legal guardians of the subjects signed letters of informed consent. No subject dropped out of the study once s/he agreed to participate. Fifteen subjects (8 male, 7 female), ages 6–10, participated in the study. All aspects of the study were in accordance with the policy statements of the American College of Sports Medicine.

Since the purpose of the study was to acquire a representative sample of the full range of daily activities of the subject children, observations were preformed in the full variety of settings experienced by the subjects, including in the home, at school, in the car, at friends' homes, at sports events, in the dentist's office, in restaurants, and elsewhere throughout the day. The 12-h day was divided into 4-h time blocks, called observation periods (8:00 a.m.–12:00 noon, 12:00 p.m.–4:00 p.m., and 4:00 p.m.–8:00 p.m.), and the subject child was observed wherever s/he went during an observation period. Nine, 4-h observation periods, three within each time block, were obtained for each of the 15 subjects. By design, two-thirds of observations occurred on school days; one-third occurred on weekend days, holidays, or summer vacation days. Observation periods were scheduled randomly within strata according to school days and nonschool days. Subject families were given sufficient notice of time and day of observation periods to obtain their prior permission. No more than one observation period per day was performed on the same child.

Direct observation methods. Each 4-h observation period was divided into consecutive 30-min time blocks. During the first 24 min of each time block, posture and intensity codes were recorded every 3 s. Three seconds was determined as the shortest interval possible between observation records without loss of recording accuracy. To improve speed of recording, a computer-based system of recording was tested, but due to the difficulty involved in correcting recording errors during an observation, reliability proved low. Thus, pencil and a prepared check sheet were used. A microcassette tape recorder equipped with an earphone cued the observer every 3 s. Six-minute breaks between each 24-min time block provided observers with a brief respite and with time to review their records and turn over the tape. Each 4-h observation period thus resulted in 192 actual minutes of recorded observation time.

The coding system used to record the children's physical activities was developed by building on that described by Klesges et al. (18). Fourteen categories, called postures, were established to reflect the physical activities of the free-ranging children. These categories were developed during hundreds of hours of preliminary observations by multiple observers. Each posture code was precisely defined and designed not to capture the level of energy expenditure, but to be descriptive of the child's behavior and mutually exclusive of any other posture

code. Coding did not require observers to make instantaneous judgments about the level of energy expended by the child. This improved replicability of coding across observers.

For each posture code, there were three possible levels of intensity: low, moderate, and intense. Several criteria were used to distinguish levels of intensity for each posture code. The speed and number of limbs involved, weight supported or carried, and incline of trajectory were all taken into account in determining intensity level. For example, a subject carrying an object estimated as greater than 10% of her body weight would have her intensity level increased, as would a subject moving on a substrate with an incline greater than 20°.

In addition to physical activity, the recording system was also designed to capture the geographic and social setting in which behaviors took place, as well as the influences of others on the child's activity. Following Klesges et al. (18), the observer recorded whether the subject was *encouraged* or *discouraged* to engage in an activity, by whom, and whether the subject responded by increasing or decreasing activity. Moreover, at the beginning of each 24-min time block, the weather (clear, cloudy, or raining), the setting, and the numbers of individuals present within various age-sex-relatedness categories were recorded.

All codes were recorded in pencil on a checksheet using easily recognizable abbreviated alphanumerics. Observers followed the subject at a distance and attempted to remain as inconspicuous and unintrusive as possible. Some initial problems of reactivity occurred. Younger subjects initially tended to view the observer as a playmate or baby-sitter and sought to engage the observer. Other members of the family, child caretakers, neighbors, and teachers sometimes attempted to engage the observer, and some parents initially tried to treat the observer as a potential baby-sitter. However, most of these difficulties were neutralized after two initial observation periods by which time the subjects, their teachers, families, neighbors, and classmates all became informed and habituated to the observer's presence. Missed observations due to "subject not visible" were recorded, as were observations missed due to a lapse of concentration on the part of the observer or some technical difficulty.

Observer training and interobserver reliability. Two female observers were involved from the beginning of the project in developing the coding and data recording system. Development and refinement of the system lasted 5.5 months. It first entailed observations of children in public areas, including playgrounds, malls, restaurants, and organized soccer practices. Later, pilot observations were conducted in and around homes of volunteer children. Videotape recordings of volunteer children engaging in free ranging activities were collected and viewed repeatedly to reach agreement on particular codes. Simultaneous viewing of video tape recordings was also used to determine interobserver coding reliability. The actual study did not begin until observers achieved or exceeded 90% agreement.

During the study, observers met weekly for several hours to discuss and resolve difficulties encountered in the field, and to perform reliability tests. Interobserver reliability was computed by comparing each observer's independent simultaneous coding on every 3-s observation during a 24-min time block (agreements divided by agreements + disagreements). During the study, mean percent agreement during 24-min time blocks was 91% (N = 16) and ranged between 89.2% and 91.7%. The average interobserver coefficient was a 0.90 kappa (12).

Calibration studies. The coding system was designed to accurately describe the physical activities of children under free-ranging conditions in such a way as to maximize reliability and replicability of recording. The level of energy expenditure represented by each activity code was determined after and independently of development of the coding system. Each code was assigned to one of three different levels of energy expenditure intensity (low, moderate, or high) on the basis of laboratory studies of four subjects (2 males, ages 8 and 10; 2 females, ages 7 and 8) using indirect calorimetry.

These four children first performed a progressive cycle ergometer exercise to determine the maximal oxygen uptake ($\dot{V}O_{2max}$) and lactic acidosis threshold as previously described (7). Thirty of the 42 different possible activity/intensity codes were replicated as precisely as possible within constraints imposed by the laboratory environment. The subjects performed these activities while breathing through a mouthpiece for gas exchange measurements while wearing EKG leads for heart rate (HR) monitoring. Metabolic rate as $\dot{V}O_2$ was measured breath-to-breath and HR beat-to-beat using well-established techniques for children and adults (5,7). Assessments of energy expenditure for activities were compared using HR and $\dot{V}O_2$ by calculating for each the increase above resting values using the following formula:

$$y = \frac{X_{activity}}{(X_{max} - X_{rest})} \times 100,$$

where y is the percent increase in activity level above resting values; $X_{activity}$ is the value of either HR or $\dot{V}O_2$ for one of the 30 activities studied; X_{max} and X_{rest} represent the maximal and resting values, respectively.

The activities were selected for several reasons: the ability to closely replicate the naturally occurring activity in the laboratory; the potential to control the intensity of the activity; and the ability to measure the metabolic rate directly in the laboratory during the activity. The remaining 12 activity codes were added to the ranking based on the amount and intensity of movement involved in comparison to the measured activities.

TABLE 1. Descriptive characteristics of subject children.

	Boys (N = 7)		Girls (N = 8)		Total (N = 15)	
	Mean	SD	Mean	SD	Mean	SD
Age (yr)	8.5	1.59	8.1	1.07	8.3	1.31
Height (cm)	127.4	11.50	126.5	11.75	126.9	11.61
Weight (kg)	29.0	6.45	29.3	9.43	29.1	7.76

Data entry and analyses. Observational codes were entered into a PC using WordPerfect 5.0 with specially programmed macros to avoid repetition and to streamline the entry process. Data were analyzed using commercially available statistical software (SAS). Nonpaired t-tests were used to detect gender differences in subjects' age, height, and weight. Some continuous bouts of the same activity were interrupted either by the end of an observation period or by a disruption of data collection for some other reason. For the purposes of calculating the duration of activity bouts of different intensities (low, moderate, high), interrupted bouts were discarded from the sample. By this method 1,979 of the 63,313 (3.1%) total bouts were discarded. All values are presented as mean ± SD.

RESULTS

Description of subjects. Characteristics of the 15 subjects are shown in Table 1. There were no significant gender differences in any of the characteristics shown.

Calibration studies. The $\dot{V}O_2$ values and HR as percent of maximal HR for the 30 activities measured by indirect calorimetry are shown in Table 2. The correlation between the $\dot{V}O_2$ and HR assessments of activities measured in the laboratory was high (r = 0.95; Fig. 1). The activities are ranked in ascending order by $\dot{V}O_2$. Those activities not replicated in the laboratory are also shown (no data). $\dot{V}O_2$ values for the 30 activities were normalized to body weight and ranged from below 7.25 $ml \cdot min^{-1} \cdot kg^{-1}$ (sitting, standing, and lying) to over 40.0 $ml \cdot min^{-1} \cdot kg^{-1}$ (running and cycling). Activities defined as *low intensity* had $\dot{V}O_2$ values below 11 $ml \cdot min^{-1} \cdot kg^{-1}$; those defined as *moderate intensity* were between 11.00 and 24.5 $ml \cdot min^{-1} \cdot kg^{-1}$, and *high intensity* activities were defined as those above 24.5 $ml \cdot min^{-1} \cdot kg^{-1}$, which approximates published values of lactic acidosis threshold (LAT) for children under 10 yr of age (6). Recent data show that high-intensity exercise above LAT is accompanied by increases in blood lactate and catecholamine (8).

Frequency and intensity of activities. The mean percent of time spent by boys and girls in each of the 42 activities is shown in Table 3. For 2.2% of the time subjects were observed, activities were not recorded due either to the subject moving out of the observer's view (e.g., go to the bathroom) or the observer not watching the child for some other reason (e.g., to adjust equipment). The most frequent activities observed were sit 0 (42.6%), stand 0 (15.7%), and walk 0 (12.4%). Gender differences occurred in just two activities. Girls spent significantly more time than boys in lying 1 (P = 0.03) and sitting 1 (P = 0.02).

TABLE 2. Children's coded activities ranked by $\dot{V}O_2$.

Rank	Activity	$\dot{V}O_2$ ($ml \cdot min^{-1} \cdot kg^{-1}$)	% Peak $\dot{V}O_2$	Intensity Level[a]
1	Sit 0	6.74	15.8	L
2	Stand 0	6.81	15.0	L
3	Kneel 0	7.00	13.0	L
4	Lie 0	7.17	15.5	L
5	Swim 0	No data	No data	L
6	Skate 0	No data	No data	L
7	Bike 0	8.20	15.1	L
8	Bend 0	8.21	15.2	L
9	Crawl 0	9.92	17.3	L
10	Climb 0	No data	No data	L
11	Kneel 1	9.92	18.6	L
12	Squat 0	10.39	18.9	L
13	Stand 1	10.43	22.9	L
14	Sit 1	10.45	24.5	L
15	Lie 1	10.71	23.5	L
16	Squat 1	13.18	24.6	M
17	Crawl 1	13.96	25.8	M
18	Walk 0	14.63	26.8	M
19	Bend 1	14.84	27.5	M
20	Swim 1	No data	No data	M
21	Lie 2	15.02	33.0	M
22	Skate 1	No data	No data	M
23	Jump 0	No data	No data	M
24	Climb 1	No data	No data	M
25	Crawl 2	17.55	34.3	M
26	Sit 2	18.29	42.2	M
27	Walk 1	18.87	42.7	M
28	Stand 2	19.95	46.0	M
29	Squat 2	23.21	43.4	M
30	Kneel 2	24.76	45.4	H
31	Bend 2	25.36	47.4	H
32	Bike 1	25.40	47.6	H
33	Walk 2	26.58	57.9	H
34	Jump 1	No data	No data	H
35	Run 0	32.29	73.9	H
36	Run 1	35.99	80.4	H
37	Skate 2	No data	No data	H
38	Climb 2	No data	No data	H
39	Run 2	40.34	89.5	H
40	Swim 2	No data	No data	H
41	Jump 2	No data	No data	H
42	Bike 2	30.66–46.35	90.8	H

[a] L = low; M = moderate; H = high.

The mean percent of time spent in activities categorized by intensity are shown in Table 4. For the great majority (77.1 ± 3.8%) of their time, children engaged in activities of low intensity. Activities defined as moderate intensity accounted for 19.7 ± 3.5% of the children's time, while activities of high intensity accounted for just 3.1 ± 1.0% of their time. There were no significant differences between boys and girls at any of the three levels of activity intensity. Within activities of high intensity, running (run 0 and run 1) was the most frequent (59%), while walking (walk 0 and walk 1) was the most common (81%) activity of moderate intensity.

Figure 2 illustrates the distribution of observations by the energetic cost of activities as $\dot{V}O_2$ $ml \cdot min^{-1} \cdot kg^{-1}$. Mean $\dot{V}O_2$ per observation by the 15 children was 9.77 ± 18.5 $ml \cdot min^{-1} \cdot kg^{-1}$. There was no difference between

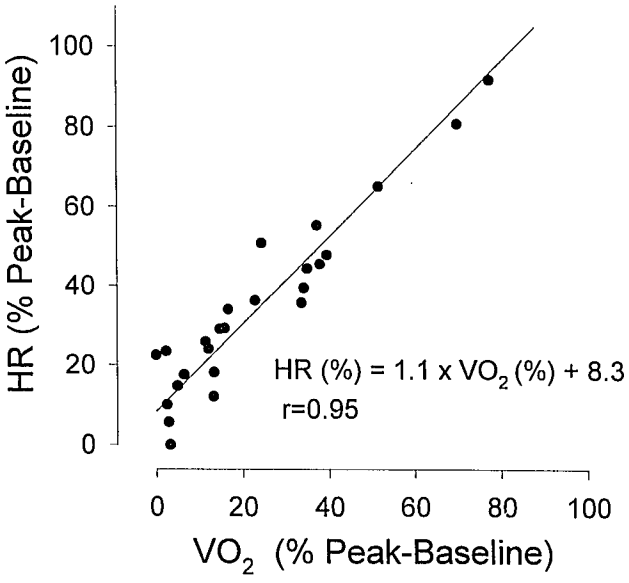

Figure 1—Correlation between energy expenditure of 30 activities as measured by heart rate (HR) and $\dot{V}O_2$. The two methods were highly correlated under laboratory conditions.

boys and girls in mean $\dot{V}O_2$ consumption, nor did mean $\dot{V}O_2$ consumption differ between 1-yr age groups.

Duration of activities. Table 4 shows the median duration of activities within each intensity category. Very striking is the short duration of activity events irrespective of intensity, indicating the highly transitory nature of the children's activity levels. The median duration of activity events of low and medium intensity was 6 s. Events of high intensity lasted only 3 s, which is the minimal interval detectable by our observation recording methods. Figure 3 shows the distribution of high intensity activities by their duration. 95% of high intensity activity events lasted fewer than 15 s and just 10 of 6,672 (0.1%) lasted more than 1 min. The longest bout of high intensity activity observed during the 384 h of observations was 4 min 27 s. These results indicate that high intensity activities are consistently short in duration.

Intervals between high-intensity activities. There were 5936 intervals between high-intensity activity events. Interval lengths were highly variable, ranging from 3 s to 21 min 15 s. Median interval length was 18 s; 75% of intervals lasted 54 s or less and 95% lasted less than 4 min 15 s. These results indicate that intervals between activities of high intensity are long in proportion to the short duration of intense activity events, and the intervals are highly variable.

Tempo of activity. Patterns of the frequency, duration and intensity of activities and the intervals between them constitute the tempo of energy expenditure. Figure 4 illustrates the tempo of energy expenditure during three different 10-min segments for three different children. Figure 4A is the profile of $\dot{V}O_2$ for a 9-yr old girl sitting during 10 min of class time at school. None of the activities of the child reached LAT, represented by the straight line at 24.5 $ml \cdot min^{-1} \cdot kg^{-1}$; and she experienced only brief spurts of moderate activity with long intervals of low energy expenditure.

Figure 4B shows the 10-min energy expenditure profile of the same 9-yr-old girl engaged in moderate levels of activity at her home. The levels of energy expenditure were highly transitory. The longest duration at any one level of $\dot{V}O_2$ was 18 s. There were very brief spurts of energy expenditure above her estimated LAT, resulting in the girl being above LAT 5.0% of the time. She reached LAT ten times during the 10 min. The longest continuous bout above the LAT was 6 s.

TABLE 3. Percent of time spent by boys and girls in coded activities.

Activity Code	Boys (N = 7)		Girls (N = 8)		Total (N = 15)	
	Mean	SD	Mean	SD	Mean	SD
Skate 0	0.5	1.41	0.2	0.35	0.4	0.97
Skate 1	0.2	0.41	0.3	0.43	0.2	0.41
Skate 2	0	0.03	0	0.01	0	0.02
Bend 0	0.4	0.34	0.6	0.41	0.5	0.38
Bend 1	1.2	0.44	0.9	0.47	1.1	0.46
Bend 2	0	0.03	0	0.03	0	0.02
Crawl 0	0.2	0.20	0.3	0.22	0.2	0.21
Crawl 1	0.3	0.17	0.4	0.18	0.3	0.17
Crawl 2	0.1	0.06	0.1	0.08	0.1	0.07
Swim 0	0.6	1.04	0.5	0.66	0.5	0.83
Swim 1	0.3	0.69	0.4	0.65	0.4	0.64
Swim 2	0.1	0.23	0.3	0.52	0.2	0.40
Jump 0	0.1	0.15	0.1	0.08	0.1	0.11
Jump 1	0.2	0.07	0.3	0.21	0.2	0.17
Jump 2	0	0.02	0	0.02	0	0.02
Bike 0	0.2	0.39	0.3	0.58	0.2	0.49
Bike 1	0.2	0.40	0.3	0.48	0.2	0.43
Bike 2	0.0	0.04	0.1	0.11	0	0.08
Lie 0	2.5	3.00	3.9	4.98	3.3	4.09
Lie 1	0.5	0.46	1.1	0.83	0.8	0.73
Lie 2	0	0.04	0.2	0.13	0.1	0.12
Climb 0	0.3	0.24	0.3	0.17	0.3	0.20
Climb 1	0.5	0.45	0.3	0.15	0.4	0.33
Climb 2	0.1	0.12	0.1	0.06	0.1	0.09
Kneel 0	0.7	0.45	1.2	0.74	0.9	0.66
Kneel 1	0.7	0.41	0.7	0.34	0.7	0.36
Kneel 2	0	0.01	0.1	0.04	0	0.03
Squat 0	0.2	0.18	0.5	0.32	0.4	0.28
Squat 1	0.3	0.15	0.4	0.32	0.4	0.25
Squat 2	0	0.01	0	0.02	0	0.02
Sit 0	45.3	7.06	40.3	5.49	42.6	6.56
Sit 1	4.6	1.06	6.3	1.35	5.5	1.49
Sit 2	0.1	0.04	0.2	0.15	0.1	0.13
Stand 0	15.2	5.41	16.2	3.70	15.7	4.46
Stand 1	3.0	1.06	3.4	0.80	3.2	0.92
Stand 2	0.1	0.08	0.2	0.08	0.1	0.08
Walk 0	13.1	3.13	11.7	2.83	12.4	2.95
Walk 1	3.2	0.47	3.9	1.29	3.6	1.03
Walk 2	0.2	0.12	0.2	0.09	0.2	0.10
Run 0	1.0	0.36	1.0	0.59	1.0	0.48
Run 1	0.9	0.38	0.9	0.43	0.9	0.39
Run 2	0.1	0.06	0.1	0.10	0.1	0.08
Not observed	2.7	1.68	1.9	0.70	2.2	1.28

TABLE 4. Proportion of time children spent in activities of low, moderate, and high intensity and duration of activity events by intensity.

Intensity	% of Time		Duration (s)	
	Mean	SD	Median	Range
Low	77.1	3.8	6	3–1362
Moderate	19.7	3.5	6	3–339
High	3.1	1.0	3	3–579

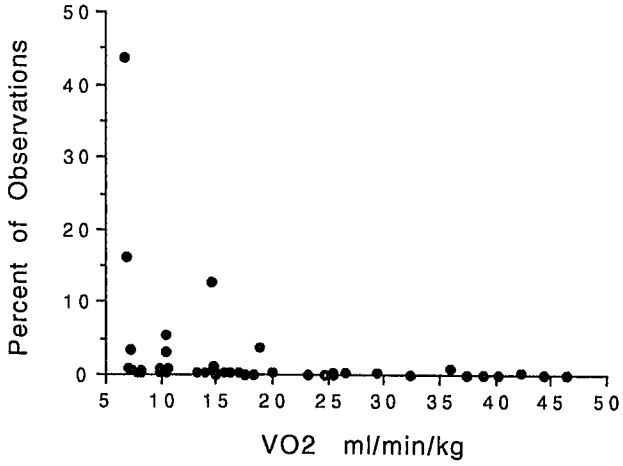

Figure 2—The proportion of observations of children's activities as a function of $\dot{V}O_2$ ($ml \cdot min^{-1} \cdot kg^{-1}$). Each point represents the percent of time children were observed engaging in a specific activity requiring a specific amount of energy expenditure. Those activities engaged in most frequently required relatively little energy expenditure.

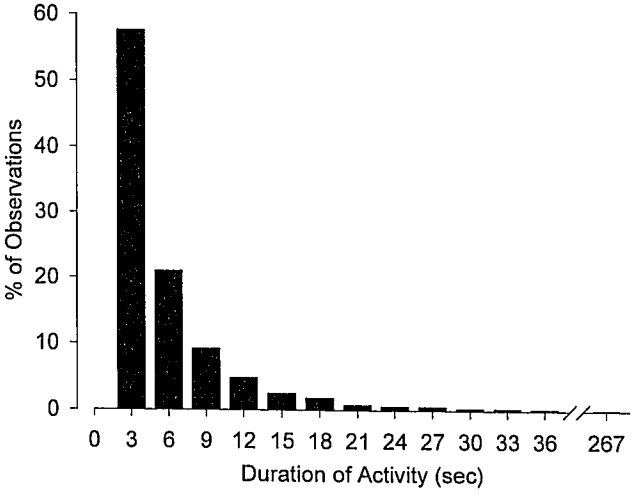

Figure 3—The distribution of children's high intensity activities by the duration of the activity in seconds. The median duration of high intensity activities was 3 s and 95% of high intensity activities lasted fewer than 15 s.

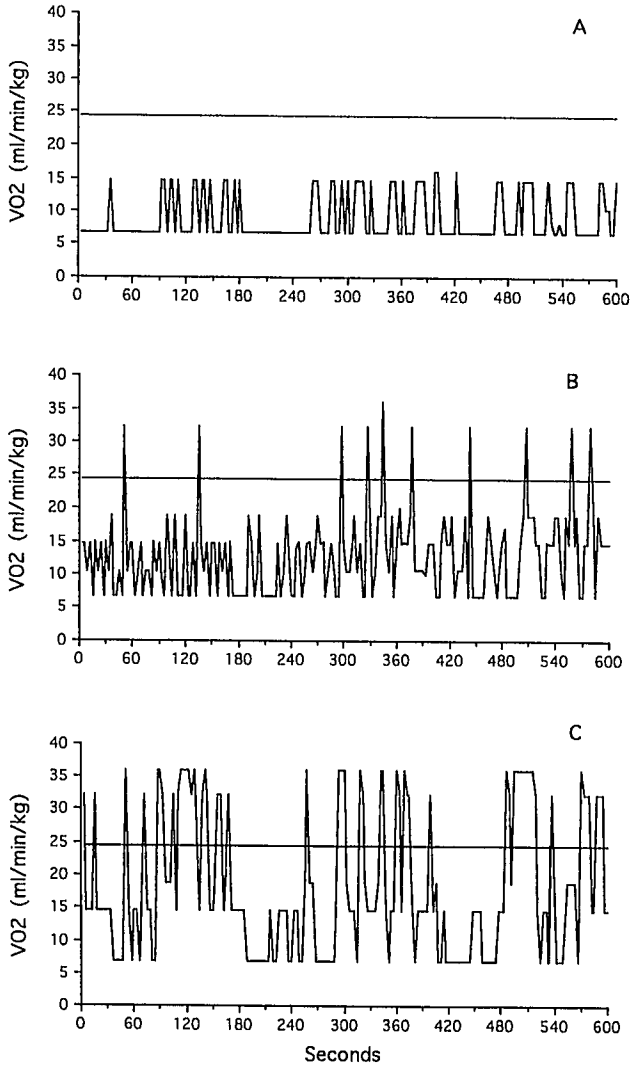

Figure 4—Profiles of children's $\dot{V}O_2$ during 10-min periods. The *solid line* represents LAT. A) Profile of a girl's $\dot{V}O_2$ during a representative 10-min period of relatively low activity. B) Profile of a girl's $\dot{V}O_2$ during a representative 10-min period of relatively moderate activity; 5% of observations are above LAT. C) Profile of a boy's $\dot{V}O_2$ during a 10-min period of relatively intense activity; 26.5% of observations are above LAT.

Figure 4C shows the 10-min energy expenditure profile of a 9-yr-old boy during a morning soccer practice. It again illustrates the transitory nature of children's energy expenditure. This was among the five most intensively active 10-min segments in our entire sample of 384 h of observations, yet the mean energy expenditure (18.44 $ml \cdot min^{-1} \cdot kg^{-1}$) was not above LAT. The total time above the estimated LAT was 159 s or 26.5% of the time. The longest duration of any one bout of activity above the LAT was 24 s.

DISCUSSION

The results of this study are based on an observational system that was designed to be reliable and to capture the tempo of children's energy expenditure, including the type, frequency, duration, and intensity of physical activities in the full variety of settings experienced by children. The system was evaluated across all seasons of the year, during all hours of the waking day (8:00 a.m. to 8:00 p.m.), in every situation encountered by children in southern California, including home, classroom, playground, soccer practice, swim and dance classes, friends' homes, dentist's office, restaurants, and neighborhood streets. The percent agreement between paired observers in continuous, observation-by-observation recording during 24-min sessions was high (91%, range 89%–94%, $N = 13$ sessions). This is equal to or higher than agreements reported for other observational systems (18,25), which used fewer categories of activities, recorded fewer

observations per unit time, and were not able to record sequences of physical activities.

There are several advantages to this system over other observational systems designed to capture children's physical activity. First, the codes used are as much as possible purely descriptive of the physical activities engaged in by children. Codes do not incorporate *a priori* judgments about the amount of energy expended. Thus, recorders are not required to make instantaneous judgments about a subject's energy expenditure; rather, they need only to judge the posture and movement of the subject at the instant of the observation. This coding system leaves less room for recording error compared to systems in which the recorder is required to assign behaviors to a few categories intended to reflect levels of energy expenditure (25), and it depicts reliably finer variations among observed activities. As Table 3 indicates, the number of codes used in this system could be reduced without significant loss of ability to estimate energy expenditure. There are only nine codes that each account for more than 1% of the time recorded, and three codes account for 72.7% of time. Thus increased reliability might be possible through reduction in number of codes. However, there would be a loss in ability to record specific activities, most of which would be of high intensity.

The greatest advantage over other observational systems is the high resolution with which physical activities are recorded. Physical activities are recorded almost continuously with 3-s intervals between recording events. Other observational systems either practice interrupted time interval sampling (18), limit the number of different activities that can be recorded per minute (24,25) or arrive at some average activity level per unit time. The high resolution of this system results in more accurate estimation of the true frequency and duration of different activities, of the sequencing of different activities, and of the intervals between activities of varying intensity. In other words, this observational system permits a more reliable assessment of the tempo of children's physical activities.

The limitations of this system as a technique for assessing physical activity are similar to other observational methods. It requires a substantial investment of time in staff training and in actual data collection. Data recording is somewhat cumbersome, although the more automated techniques we attempted compromised reliability. The necessity to enter data twice—once on checksheets and again into a computer—is time-consuming and increases chances of error. Thus, this system is probably not appropriate for large population studies. It may be useful as a validation tool for other field assessments and for assessment of activity patterns in specific groups such as children with chronic diseases. It is most valuable when variables of interest are more than just aggregate *levels* of activity and include duration, frequency, intensity, or intervals between different activities.

A possible limitation of this study is that the calibrations of $\dot{V}O_2$ with coded activities were based on a sample of just four children. With a larger sample the estimations of $\dot{V}O_2$ attributed to some activities may change; however, such changes would not alter the overall findings of the study, suggesting that the levels of intensity of children's activities are predominantly low, that they change rapidly, and that high intensity activities are brief. Nevertheless, before further studies are performed using this coding system, additional calibration studies should be performed to confirm or modify the $\dot{V}O_2$ values used here.

The results of this study suggest that children spend most of their time engaged in activities of low intensity. This is consistent with other studies using a variety of methods to assess children's physical activity. For example, Baranowski et al. (2) observed 24 third to sixth grade children during two weekdays per child. They observed no events they considered to be of aerobic activity, and only roughly one half the children engaged in activities requiring trunk movement for 14 consecutive minutes. Gilliam et al. (15) assessed minute-by-minute heart rates over a 12 h period in forty 6- to 7-yr old children. They reported that over 75% of the day was spent at heart rates less than 120 bpm and less than 3% of the day was spent at heart rates > 160 bpm. The findings of Freedson (13), who recorded heart rates of sixty-six 3- to 5- yr-olds over 12-h periods, were very similar. She reported that nearly 68% of children's days were spent at heart rates less than 121 bpm and less than 2% at heart rates in excess of 160 bpm. Durant et al. (10) reported that their sample of 3- to 5-yr-olds spent between an average of 33.5% and 39.2% of the day at heart rates > 120 bpm, and Klesges et al. (19) found sedentary activity for most of their 3- to 6-yr-old children. While direct comparisons with these and other studies are not possible due to differences in assessment methods, in subjects' ages, in geographic location, and in possible ethnic or socioeconomic differences, the consistency between the results of previous studies and the results of our study showing 77% of 6- to 10-yr-olds time spent in low intensity activities and just 3.1% of time in activities with $\dot{V}O_2$ over the lactic acidosis threshold, is striking.

Over a 12-h day, subjects spent a mean of 22.3 min in high-intensity activities, but the median duration of an intense activity event was very short–just 3 s. No bout of intense activity lasting 10 consecutive minutes was ever recorded, and 95% of intense activity events lasted less than 15 s. These results indicate that children engage in very short bursts of intense physical activity interspersed with varying intervals of activity of low and moderate intensity. This seems to be the case even during relatively active periods during the day, including sports practice, dance or swimming classes, or school recess. Other stud-

ies have been suggestive of the brief duration of children's intense activities (2,15,17) but the techniques for assessing the timing of such events have not been available.

This is the first study that has documented the extent to which children's activities at all levels of intensity are highly transitory. The median duration of an activity at any level (low, medium, or high) was 6 s. Even activity events of low intensity were brief, with a median duration of 6 s and lasting no longer than 22.5 min. Intervals between events of different levels of intensity were brief, but highly variable. The tempo of children's physical activities that emerges is thus one of rapid change: very short bursts of intense activities are interspersed with brief but variable intervals of activities of low and moderate intensity.

The rapidly changing tempo of children's physical activities we found in this study has important implications for the physiology of children's growth and development. Little is understood about cardiovascular and metabolic responses to exercise in children, yet it is likely that cardiorespiratory, hormonal, metabolic, substrate, thermoregulatory, cardiovascular, and lipid responses vary according to different patterns of exercise in children. If the predominant tempo of exercise experienced by children under natural everyday conditions, including during organized athletics, is one of rapid change with only very brief bursts of intense activity, then the physiological mechanisms linking tissue anabolism and ultimate growth and development operate in ways not yet understood. It is known, for example, that exercise is a physiologic stimulator of growth hormone (GH) (11), suggesting that exercise modulates tissue anabolism by actions of GH and, in turn, the synthesis and release of insulin-like growth factor I (IGF-1). GH release in humans is pulsatile. In rats pulsatile GH administration results in growth rates greater than when equivalent doses are given in a nonpulsatile, continuous manner (20). Possibly, the pulsatile exercise input pattern we found in these 15 children optimizes the anabolic effects of exercise in the growing child. Growth related hormones have varying responses to the tempo of exercise, but what patterns of exercise elicit what responses has yet to be determined.

It has been underappreciated that intervals between bouts of exercise of varying intensity may be important to understanding the effects of activity on cardiovascular and metabolic function. It is known that there is variation in recovery time for heart rate, ventilation, and CO_2 production, with children recovering much faster than young adults, and unfit people showing slowed adjustments to exercise. Thus, one likely determinant of the overall tempo of physical activity is simply how quickly a child recovers from a single burst or series of bursts of exercise. It remains to be seen whether the tempo of physical activity observed under natural conditions is correlated with dynamic cardiorespiratory and metabolic responses, but our knowledge of physiological processes would suggest that intervals between bursts of exercise will be an important parameter to take into account.

Increasingly, researchers are recognizing that different patterns of physical activity may have different physiological effects, yet there are few studies of the patterns (e.g., type, frequency, duration, and intensity) of physical activity of boys and girls of different ethnicity and socioeconomic backgrounds (3,23,27,28). This lack of data is in part due to the limitations of methods of assessment that have been available until now. If future studies of children from a variety of ethnic and socioeconomic backgrounds confirm our results indicating that the normative tempo of children's physical activities is one of rapid change from one short activity event to another, from one level of intensity to another, then studies attempting to uncover the physiological mechanisms linking fitness, growth, and development with physical activity may have to be redirected. Currently, standardized exercise tests are designed to have children exercise either at an increasing rate to maximum work rate or at a constant work rate for periods ranging from 6–30 min (4). Such research designs do not reflect the patterns of activity we have observed under free-ranging conditions. To uncover the biological significance of these observed patterns new protocols will be needed to measure responses to both very brief spurts of exercise and rapidly changing levels of exercise over sustained periods.

For behavioral and health scientists aiming to promote health-related fitness, recognition of this normative tempo of physical activity could guide the development of new activity promotion interventions that may be both more appealing and more effective.

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