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Activity, energy metabolism and postnatal age relationship in low-birth-weight infants

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The relationship between heat production and different activity levels was examined in 30 low-birth-weight (premature and small-for-gestational age) infants.

A low level of spontaneous activity was preponderant, with a gradual shift from activity scores near zero to higher intensities with increasing postnatal age.

There was a close correlation between activity and heat production. Older infants displayed a greater amount of spontaneous activity and a larger variation in heat production and activity-intensity relationship.

The rise in heat production at a given activity intensity was greater in older than in younger infants indicating that the energy cost of identical activity increases with postnatal age.

"Maximum" oxygen consumption increased with postnatal age.

In previous studies [4, 8] dealing with the contribution of different components to the maintenance of energy metabolism of low-birth-weight infants it has been shown that the energy cost of activity displayed under thermoneutral conditions does not exceed 10% of the total. From these studies it was apparent that, in addition to the basal metabolism, the activity quota of heat production showed an increase with postnatal age. In spite of the increasing participation in total daily metabolism, at neutral temperature activity appeared not to be such an important determinant of the energy balance of low-birth-weight infants than in older infants [1, 3, 5]. It should be noted that physical activity increases considerably in a cool environment [7, 9] where it may become a sizable factor of total energy expenditure [4].

Although considerable work has been devoted to the basal energy expenditure of term and preterm infants, few studies have been performed to determine the quantitative importance of physical activity in total energy expenditure [1, 2, 3, 4, 5, 6]. This was the aim of our previous study [8] when the oxygen consumption of small-for-gestational age infants was recorded continuously through a 6—13 hr period while physical activity was quantitated every minute by an observational method using an arbitrary score system. From these observations it was apparent that the low levels of spontaneous activity were preponderant, and constitued the largest component contributing to the extra heat produced above the basal value.

In the present study we have attempted to analyze the data obtained in low-birth-weight infants in view of the relationship between different activity grades and energy metabolism. The effect of postnatal age on the frequency distribution of the activity stages, the amount of activity and the extent to which the activity-energy metabolism relationship may change, have also been studied. The highest level of oxygen consumption observed and the maximum oxygen uptake corresponding to maximum activity intensity as a function of age also appeared to be an interesting aspect of the activity and energy metabolism relationship in low-birth-weight infants. The results described below may serve as a basis for further studies to investigate the effect of age, maturity, body size and growth on the energetics of activity in low-birth-weight infants.

Material and Methods

The data on the relationship between heat production and different activity levels were obtained in 30 low-birth-weight (premature and small-for-gestational age) infants. Their birth weight ranged from 900 to 2400 g and their gestational age from 27 to 40 weeks.

The infants were divided into three age groups representing three series of examinations whose pertinent data are seen in Table I. The first series of exami-

Table I

Gestational age, postnatal age, birth weight and body weight of infants included in the investigations

	First investigation				
	Number of infants	Gestational age wks	Birth weight, g	Postnatal age hr	Body weight g
Mean	20	33.3	1677	25.7	1645
Range		27–38	900–2150	12–44	900–2070
	Second investigation				
	Number of infants	Gestational age wks	Birth weight g	Postnatal age days	Body weight g
Mean	15	36.7	1846	5.6	1826
Range		34–40	1070–2400	2–15	1200–2390
	Third investigation				
	Number of infants	Gestational age wks	Birth weight g	Postnatal age days	Body weight g
Mean	14	36.7	1828	25.2	2169
Range		34–40	1070–2400	16–39	1700–2740

nations was carried out on eleven premature and nine small-for-gestational age infants between 12 and 44 hours postnatally. All these babies were intravenously fed during the observational period since they did not tolerate oral feeding. The second series of examinations included 15 infants aged between 2 and 15 days whose birth weight for gestational age was less than the 10th percentile on our local intrauterine growth chart. The third series of observations was performed between the 16th and 39th day of life on 14 infants who were also represented in the second series of examinations. Five of this group of infants were also tested in the early neonatal period (between 19 and 44 hours after birth).

During the second and third test the infants were fed two or three hourly with a cow's milk formula (73.3 kcal/100 ml). The daily intake of fluid and calories averaged 150 ml/kg/day and 100 kcal/kg/day in the second, 165 ml/kg/day and 106 kcal/kg/day in the third, series of examinations.

Technique

Oxygen consumption and carbon dioxide production were measured by an open circuit method using the Kipp diaferometer which allows continuous measurements of respiratory gas exchanges and of the respiratory quotient. The technique has been described in detail previously [4].

The measurements were started six hours after the last feed in the second and third series of examinations, and readings were made every minute except when reference was made to room air, and when a feed was offered.

Experimental procedure and conditions

Infants included in the first and second series of examination were placed in an incubator under a perspex hood through which room air was drawn at a rate of 1.6—4.0 l/min. The temperature within the incubator was maintained at 32—36 °C depending on the size and postnatal age of the infants. The lower parts of the trunk and legs outside the hood were loosely covered with a nylon sheet attached around the air inlet of the hood ensuring that the infants expire into the air flowing over the face. Relative humidity ranged between 45 and 60%.

In the third series of examinations the infants swaddled in soft down feather quilts were kept at a room temperature of 26—27 °C. The head and upper limbs were under a perspex hood within which the air temperature was 2—3 °C higher than that of the room. Periods during which oxygen consumption was followed varied between 6 and 13 hours.

Body activity was continuously observed during the recording of gaseous metabolism and evaluated every minute by the following scores:

0 = asleep, physically totally quiet;
1 = eyes closed with occasional jerks;
2 = eyes closed, or open with slight movements of the head or extremities;
3 = awake state with moderate activity moving arms and legs;
4 = intensive and more or less continuous activity;
5 = vigorous activity with crying and restlessness.

These arbitrarily chosen criteria of the activity grades proved to be a useful estimate of the different activity levels. Since grading of activity has been established on the basis of the observations of body movements, the different states presented by the score are not sharply defined and there is a narrow range between the grades. Distinction was easier between vigorous and slight than between activities involving moderate movements of the body or extremities. Although the method of quantifying activity is not an objective measure, it was possible to arrive at a reliable estimate of activity in terms of frequency and duration of each stage of the spectrum. The different pattern of visible motility, such as e. g. sustained, intermittent or progressively increasing activity, could easily be assessed by the classification adopted.

Assessment of the average amount of physical activity and its relationship to energy expenditure

In order to derive an overall measure of activity during successive 10-minute periods, the scores recorded for each minute were added and divided by ten. The mean scores of successive 10-minute intervals were used to quantify the changes in activity during measurement of respiratory gas exchange for several hours. A 10-minute score of 5 reflected uninterrupted vigorous activity with crying and restlessness, and zero score indicated that the infant was asleep and totally quiet throughout the 10-minute period of observation. This activity record allowed to relate average motility scores to average oxygen consumption or energy expenditure during the corresponding 10-minute intervals.

The results described in this paper are based upon 2681 periods lasting 10 minutes. Owing to the two minute latency of the diaferometer, activity and oxygen consumption record were paired in time with a 2 minute lag between the two. All the recorded 10-minute periods evaluated for mean activity and oxygen consumption were ranked with respect to activity levels. Regression analysis was used for evaluation of the relationship between the two variables.

Total metabolism was expressed as kcal/kg/min or oxygen consumption ml/kg/min. The caloric values for oxygen used to calculate heat production corresponded to the average RQ of 10-minute intervals on which the determination of the relationship between physical activity and energy expenditure has been based.

Results

Distribution of activity grades and their contribution to total amount of activity

Fig. 1 shows the percentage frequency distribution of 10-minute average activity levels in the three series of observations. It can be seen that very low levels of spontaneous activity were preponderant in each group. The first three activity stages accounted for about 84, 75, 66%, respectively, of all 10-minute intervals. The occurrence of the activity score exceeding 1.0 increased with postnatal age. This gradual shift

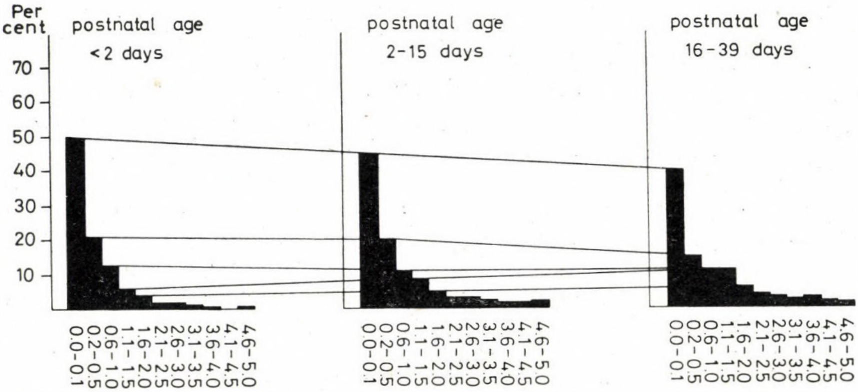

FIG. 1. Relative frequency distributions of 10-minute average activity scores in the three age periods

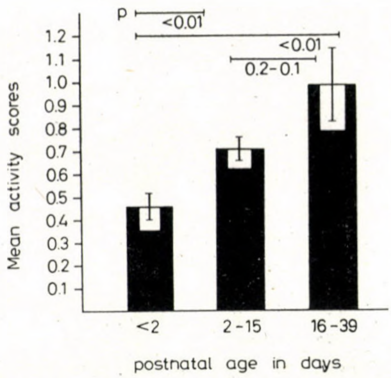

FIG. 2. Mean ($\pm$ SE) activity levels of the whole 6—13 hr observation periods obtained in the three series of examinations

from scores near zero to higher intensities of activity is also reflected by Fig. 2, which demonstrates the increasing average activity score of the whole observational period with postnatal age, on the one hand, and the increasing time of activity grades higher than 1.0, on the other hand.

Relationship between activity levels and energy expenditure

In Figs 3, 4 and 5 mean heat production (kcal/kg/min) calculated for consecutive 10-minute periods of the several-hour metabolic recordings obtained in the three series of examinations are plotted against the corresponding mean activity levels quantitated by the mean 10-minute scores. It can be seen that there was a definite correlation between activity and heat production in the three age periods. Resting metabolism (activity score, < 0.2) increased with postnatal age and there was an increasing relationship of heat production to activity, as shown by the regression lines.

The distribution pattern of activity grades and the variation of total energy expenditure of different activities are also evident from Figs 3, 4 and 5. The frequency of periods of higher activity levels, as well as the range of corresponding total energy expenditure increased with postnatal age. Thus, the older infants displayed a greater amount of spontaneous activity and a larger variations in energy output and activity-intensity relationship.

"Maximum" oxygen uptake

The designation "maximum" refers to the highest level of oxygen consumption associated with spontaneous activity during a long obser vation period and not to the maximum capacity to utilize oxygen in response to physical activity. Hence the highest oxygen value exhibited by a hypoactive, or moderately active

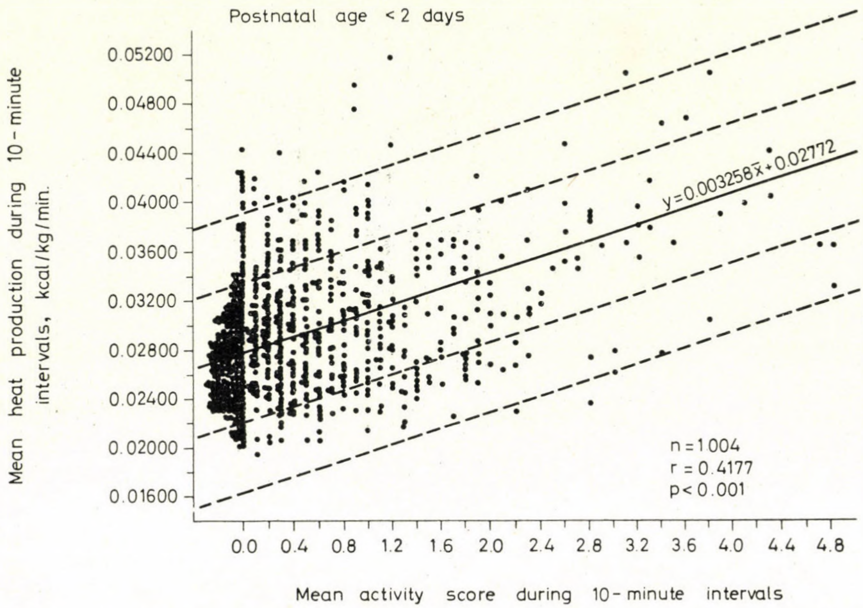

FIG. 3. Relationship between average heat production (kcal/kg/min) during 10-minute periods and corresponding mean activity levels obtained within 2 days of birth

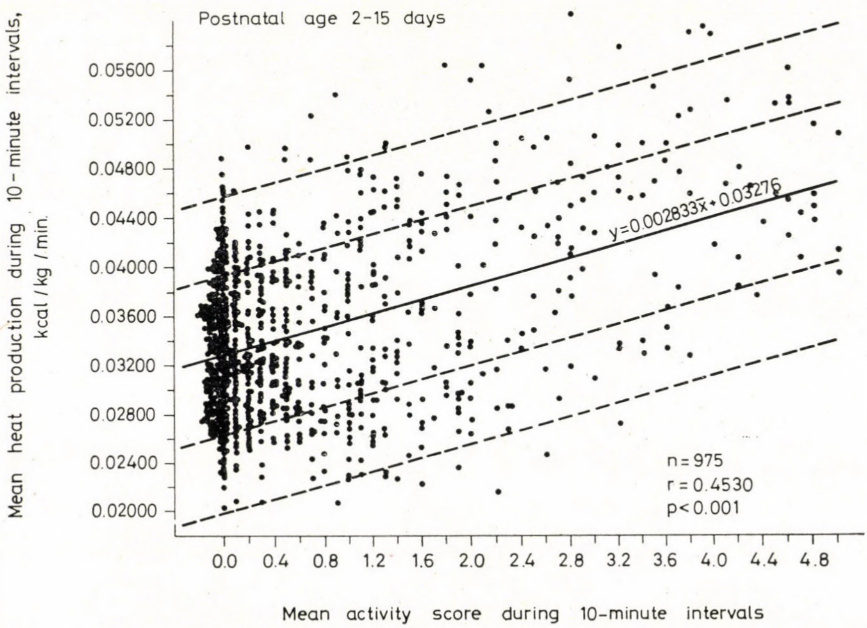

FIG. 4. Relationship of the average heat production (kcal/kg/min) during 10-minute periods and corresponding mean activity levels observed in infants aged from 2 to 15 days

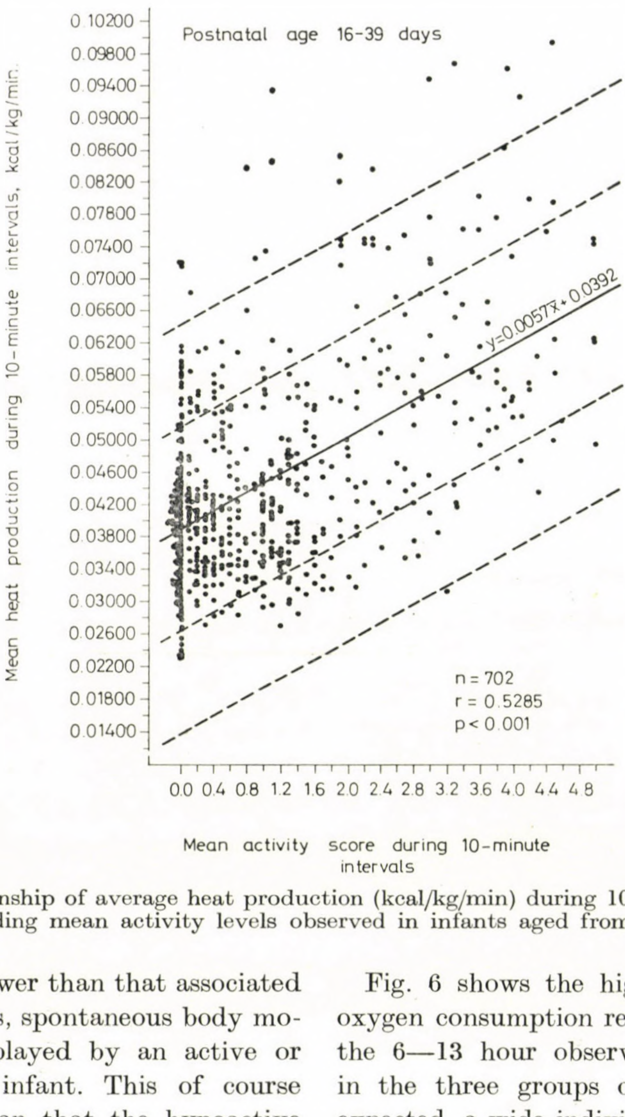

FIG. 5. Relationship of average heat production (kcal/kg/min) during 10-minute periods and corresponding mean activity levels observed in infants aged from 16 to 39 days

infant was lower than that associated with vigorous, spontaneous body movements displayed by an active or hyperactive infant. This of course does not mean that the hypoactive infant would not be able to achieve a higher rate of oxygen consumption by more intensive activity. Thus, the "maximum" oxygen uptake of a given infant under given conditions is, in fact, an index of the intensity of motor behaviour and not a measure of the maximum aerobic metabolic capacity.

Fig. 6 shows the highest rates of oxygen consumption recorded during the 6—13 hour observation periods in the three groups of infants. As expected, a wide individual variation was seen in the different age periods. The highest values tended to increase with postnatal age but only the average maximum rate of oxygen consumption of the infants tested between 16 and 39 days was significantly higher than that obtained in the early neonatal period. However, in a semilogarithmic plot the pooled values

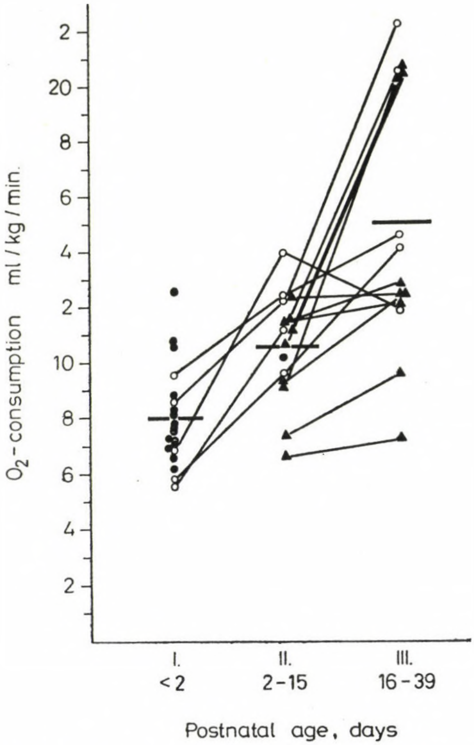

FIG. 6. The highest ("maximum") rate of oxygen consumption recorded during the 6—13 hr observation period in the three age groups of infants. (○—○—○: infants investigated three times; ▲—▲: infants investigated twice; ●: infants investigated only once)

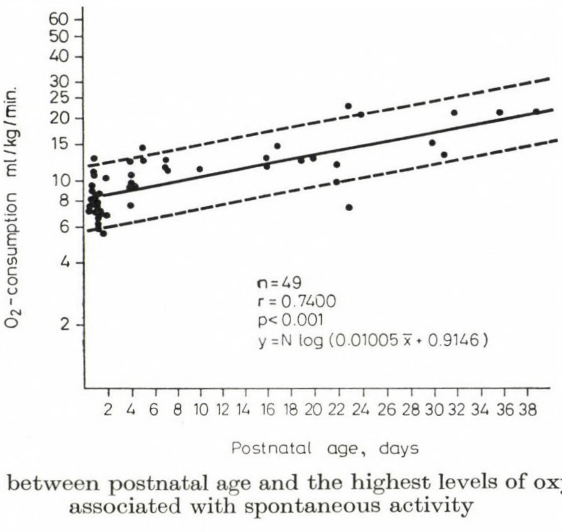

FIG. 7. Relationship between postnatal age and the highest levels of oxygen consumption associated with spontaneous activity

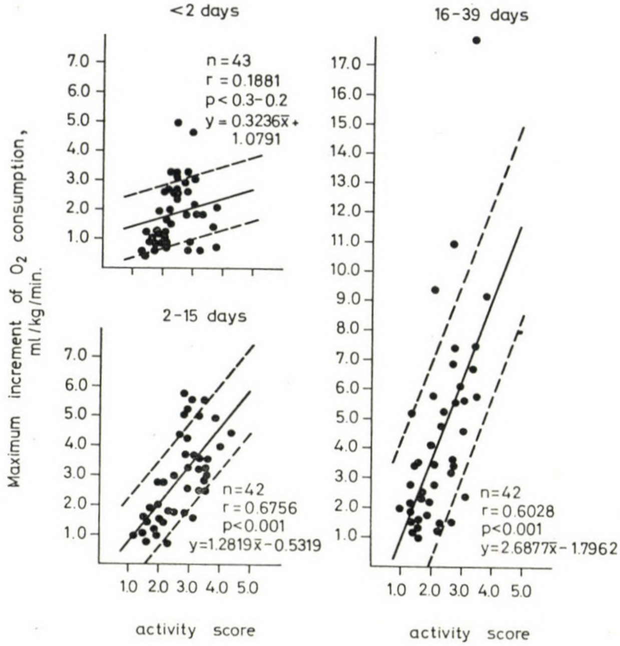

FIG. 8. "Maximum" increments above the resting rate of oxygen consumption related to the corresponding spontaneous activity scores

were closely related to postnatal age (see Fig. 7). A similarly close relationship was obtained when "maximum" oxygen consumption was related to body weight: the heavier the low-birth-weight infant, the higher the "maximum" oxygen uptake during a 6—13 hr period of observation.

Fig. 8 represents the "maximum" increments above the resting rate of oxygen consumption in relation to the corresponding spontaneous activity levels observed in the three groups. In the early postnatal period the "maximum" increment observed was variable and not significantly related to the activity scores. In the two older groups there was a close increasing relationship with the spontaneous activity grades. From the slopes of the regression lines it is also evident that the "maximum" rise in oxygen consumption elicited by a given activity increased with postnatal age.

Discussion

The energy cost of physical activity mostly depends on the extent and duration of activity displayed by the infant in a given period of observation. In the tests of Murlin et al. [5] the mean contribution of activity to total energy metabolism was 27%. There was, however, a great deal of variability: hypoactive infants spent 17% and hyperactive infants 40% of their energy on activity. Benedict and Talbot [1] studied healthy fullterm infants, and found that the mean daily energy cost of activity may be as high as 40% of the total metabolism.

Observations on the partition of maintenance energy metabolism in premature infants in the first extrauterine month [4] have shown that the activity quota is low, particularly in infants kept at neutral temperature (7%). Similarly, a low energy cost of activity in thermoneutral environment (3 kcal/kg/24 hr on the average) was observed in small-for-gestational age infants [8]. In the latter study two "basal" rates of metabolism were distinguished: basal and resting metabolism. The former represented the minimum level of oxygen consumption in the sleeping and fasting infant without visible activity (mean activity score, 0.0), the latter indicated oxygen uptake of fed infants in whom occasional jerks, slight movements of the head and extremities were observed (mean activity score between 0.0 and 0.1). Thus, resting metabolism in addition to the basal metabolic rate also included the energy cost of slight activity and of the specific dynamic action of food. In this group of low-birth-weight infants total energy expenditure and its three components, i. e. basal, resting and activity heat production, were found to be closely related to postnatal age. In view of the contribution of slight activity to the total of metabolism, the increment due to the resting state was the highest component of the heat produced above the basal. The mean quota of more intensive activity was, however, less pronounced.

These findings have prompted us to analyse the metabolic and activity records obtained in low-birth-weight infants in view of the relationship between different activity grades, energy metabolism and postnatal age. Such an analysis appeared interesting with respect to the pattern of spontaneous activity, the distribution of activity scores, the amount of time spent with activity and the highest metabolic level displayed by the infant during the 6—13 hr observation period.

In our report [8] dealing with the different components of maintenance energy metabolism, the metabolic rate corresponding to mean activity scores between 0.0 and 0.1 was utilized as a measure of the so-called resting metabolism. These slight and occasional movements characteristic of the low end of the activity spectrum are not negligible as far as their frequency of occurrence and hence their contribution to the total time spent on activity is concerned. From the present results it is obvious that these low levels of spontaneous muscular activity were preponderant in the three periods examined. Although in the distribution of the activity grades a gradual shift occurred to higher activity intensities with postnatal age, mean scores lower than 0.1 accounted for a large proportion of activity stages obtained in the three age periods. This skewed distribution with the bulk of the observations falling at the low end of the activity scale is also reflected by the "resting" metabolic component above the basal heat production, which exceeded the increment in energy metabolism due to more intensive activity.

The method of quantifying activity appeared useful, since it yielded a fairly good correlation between activity scores and total energy metabolism. In each postnatal age period, at a progressively higher basal level, increasing general activity was associated with increasing heat production. The slope of the increase, and consequently the level of total energy expenditure attained proved, however, higher in the older group than in the younger ones. Thus, the rise in heat production at a given activity was greater in older than in younger infants indicating that the energy cost corresponding to identical activity ratings increases with postnatal age. This is a drawback of using an arbitrary scoring system as an estimate of activity levels, instead of objective criteria, to establish the quantitative relationship between activity and energy metabolism. The energy expended in response to a certain amount of visible movements depends on postnatal age. Thus, a certain amount of activity is not comparable in terms of energy cost unless postnatal age is taken into consideration. The increasing energy cost of the different activity stages is, in all probability, due to the increasing strength of the spontaneous movements and the increasing muscle mass involved. The successive stages of the activity spectrum can easily be distinguished as defined by the classification system adopted; the corresponding responses in energy expenditure can, however, only be estimated if postnatal age is considered too.

The highest level of oxygen consumption recorded and associated with spontaneous activity during a 6—13 hr period of observation was also found to increase with postnatal age. This also shows that age is an important variable in the oxygen consumption and activity intensity relationship. Although in the majority of instances "maximum" oxygen consumption occurred in response to "maximum" spontaneous activity (marked restlessness and crying), in some of the younger infants tested in the early neonatal period "maximum" oxygen consumption was not much higher than the resting level, simply because the infants were hypoactive and did not exhibit higher intensities of activity. This is one reason why wide individual differences were observed in "maximum" oxygen consumption.

Activity is a function of several factors and can be used as a measure of behaviour. Frequency and duration of activity periods, the distribution of activity stages, the amount of time spent with activity, all indicate some aspects of the baby's motor behaviour at the time of observations. The individual differences in the strength of movements, types and patterns of motor behaviour are also reflected by wide variations in the magnitude and duration of responses in oxygen consumption. Hence, the "maximum" response displayed in the course of several hours varies greatly between quiet, hypoactive, moderately active, and hyperactive infants.

The highest oxygen consumption recorded in the three age periods was 12.6, 14.1 and 22.3 ml/kg/min, respectively. In the older group of infants the value of 22.3 ml/kg/min was threefold of the basal level and occurred in response to spontaneous restless activity with vigorous movements and crying. Such high rates of oxygen consumption were usually observed as peak values reached during a long activity period with increasing restlessness and general activity. Since such periods were characterized by activity progressing from stage 1 to stage 5, the peak level attained and maintained during continuous restlessness must have represented the highest level of oxygen uptake in response to the highest spontaneous activity grades displayed by the infants and under the conditions in question. This does not mean that these small premature infants would not have been capable to increase their oxygen consumption above the peak level associated with marked restless and crying activity. Maximum spontaneous activity as defined by the adopted rating scale does not necessarily mean that a maximum effort is made by the infant. The strength of movement, the amount of muscle mass activated, and the muscle tensions achieved can be different even at high activity intensities. In this respect, among others, motivation can be an important variable on which the amount of muscle made to work, the muscle tension, and the level of physical effort might depend.

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