THE INFLUENCE OF ACTIVITY ON THE METABOLISM OF THE CHILD

TOGETHER WITH REMARKS ON THE ARTICLE,¹ "SOME FUNDAMENTAL PRINCIPLES IN STUDYING INFANT METABOLISM," BY FRANCIS G. BENEDICT AND FRITZ B. TALBOT

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While former authors have bestowed but little attention on the question of how the subjects of their investigations regarding metabolism behaved while under observation — whether they were still or moved — this circumstance of increased or decreased activity is of the most vital interest the moment we include respiratory metabolism in our investigation. The decomposition of N-containing matter is only to a slight degree influenced by activity, especially in the case of infants; but the decomposition of nitrogen-free matter, and with it the elimination of CO₂ rises immediately, as soon as the subject makes any action, moves or cries. Even in the second experiment which Rubner and Heubner² carried out on infants in the Pettenkoffer apparatus, these two authors attached very slight value to the performance of the child. They said:

Physical rest and activity on the part of the subjects may be regarded as nearly, if not entirely, alike: considerable performance is, indeed, quite out of the question. In our estimation the normal child was somewhat more active than the weakly, emaciated child. Such differences, however, may be more or less completely compensated for by sleeping time and depth of sleep. In these slight differences of course is included also that which might at the time be termed individual characteristics. Hence with the matter under consideration one will be in a position to judge with all possible acuteness the effects of various forms of nourishment on the child.

We see that here *the significance of the child's accomplishments is still completely undervalued*. Here also a parallel is drawn between the normal child and the emaciated one in computing the transformation, a thoroughly inadmissible comparison, as we know to-day, for it is just the emaciated child that because of the abnormality of its superficies shows an abnormal giving-off of heat. In the first experiment of Rubner

1. Benedict, F. G., and Talbot, F. B.: JOUR. DIS. CHILD., September, 1912.

2. Rubner and Heubner: The Artificial Nourishment of a Normal and an Emaciated Child. Ztschr. f. Biol., 1899, xxxviii, 315.

and Heubner³ these authors go so far as to state that the infant does not accomplish mechanical work to any extent worth mentioning.

But the importance of the child's activity is already recognized later by Rubner and Heubner themselves. In their third experiment they had an unusually sturdy and well-developed boy to deal with, who, by his activity, added extraordinary difficulty to their experiment. This child in the four days of observation put on 1.49 gm. N. According to this, an increase in weight of 70.5 might have been expected, instead of which the weight remained stationary and N-free substance was eliminated. Quite logically, Rubner and Heubner concluded from the figures obtained, above all from the fact that more C was eliminated than absorbed, that it is true albumin was formed, but that on the other hand, N-free substance, that is, fat or glycogen, was exhausted. The child must certainly have behaved itself in an excessively refractory manner while under observation. Heubner⁴ says on this point:

On the first day the child began to express in lively fashion his dissatisfaction with the new situation in which he found himself, not only by crying, but by literally raving, exerting all his sturdy muscles most strenuously in order to free himself from his imprisonment. On the next day, when he had accustomed himself to his new surroundings, he certainly cried less, but nevertheless as long as he was awake he was in a state of ceaseless muscular activity, now with his legs, now with his arms. Only during the hours of quiet and usually quite healthy sleep, which took place without interruption at night, were the child's muscles at rest.

Heubner thereupon points out that in this experiment the accomplishment of external muscular work has come to light, and that the consideration of this momentum in the balance of energy, and the possibility of its measurement by a comparison with the formerly observed infants are the most interesting conclusions of this last experiment. He closes his communication with the words that in the future, in judging the effect of nourishment, it will be permissible to take the consideration of the daily performance of crying and rest, and such like, more into account than has been, up to now, frequently the custom. In this publication, then, the significance of outward activity for the energy transformation of the infant is in general and in theory recognized, but the right conclusion as a basis for further investigations is not drawn. This conclusion must run as follows: *In physiological respiration experiments outward activity must either be totally excluded or we must measure the quantum of this activity and consider it in our calculation.*

3. Rubner and Heubner: The Natural Nourishment of an Infant. Ztschr. f. Biol., 1898, xxxvi.

4. Heubner: A Further Contribution to the Knowledge of the Balance of Energy in the Infant. Verhandl. d. Gesellsch. Kinderh., 1904, xxi. Published by I. F. Bergmann, Wiesbaden.

In the observations undertaken by us, we have for years excluded, as far as possible, the outward activity of the subject. But as, indeed, the kind and quantity of the nourishment taken influences the excretion of CO_2 and the consumption of O , we set ourselves to carry out our experiments on sleeping and fasting children. From the outset it seemed difficult to let a child fast for over twenty-four hours, without its subsequently spoiling the experiment by restlessness. But it was found that these things are easier to carry out in practice than they would appear in theory. If, for example, a breast-fed baby is accustomed to take the mother's milk not directly from the breast, but from a bottle, the milk having been drawn from the mother, then it is easy to give this breast-fed baby, now accustomed to the bottle, a bottle filled with water that has been sweetened by saccharin instead of the bottle of milk. It must only be endeavored to suit the saccharin substitute to the child's taste. Let infants but consume the necessary quantity of fluid, and they bear hunger at times splendidly; i. e., they do not notice their hunger at all; they are not conscious of the fact that their life depends on their reserve

Fig. 1.—Explanation of signs. (See Fig. 3.)

forces. Of course, the natures of children, just like their temperaments, are different, and for such experiments one must be able to find out the suitably phlegmatic ones. Whoever is to a certain extent acquainted with the psychology of children will seldom miss the mark in the choice of his subjects.

Our procedure is, as a rule, that the child last receives nourishment at 7 o'clock in the evening, then in the morning, and all the next day it has water and saccharin and is petted a great deal. Older infants are played with and as far as possible kept happy, so that they soon go to sleep after having been put in the apparatus; or they are allowed to go to sleep beforehand and the experiment is begun with the sleeping child. Generally, we begin the experiment at 7 o'clock in the evening; the child has then fasted for twenty-four hours, and the effect of nourishment on the organism is eliminated. If one has good luck now and the child sleeps quietly in the apparatus for some hours, the experiment may be considered as an excellent one: *absolute physical rest in a fasting con-*

dition. The value of the excretion of CO_2 and the consumption of O, which we have ascertained in this manner, give us a glimpse of the *fundamental transformation of the infant. Fundamental transformation is the transformation of a person, reposing and fasting, that finds himself in comfortable, warm surroundings.*

Every movement made by the child increases the transformation of matter, and so increases the excretion of CO_2 and the consumption of O. For a physiological experiment, repose is the unconditional assumption, and we fully share the view recently expressed by Benedict: "Only periods of complete muscular repose are of any value." In their article in this Journal, also, Benedict and Talbot say very rightly:

While it is not necessary to show that the metabolism of an active crying infant must of a necessity be considerably higher than that of a quiet child, it is not so well known that it is wholly illogical to compare metabolism of an active, restless, normal baby with that of a quiet, sick baby, since the amount of carbon dioxide excreted depends on the degree of muscular activity.

In order now to register whatever movements the children make while under observation, Benedict and Talbot⁵ have described an apparatus which mechanically makes a graphic record of the child's movements. We have devoted the greatest attention to these movements in our researches, but have adopted another method of registering them. Thus Benedict and Talbot are not correct in writing:

In all previous determinations of infant metabolism, either of direct energy transformations or by means of the direct calorimetry, either no recognition has been given to the significance of muscular movements on the part of the child, or it has been assumed that the child, when not crying or obviously restless, was quiet and with constant muscular activity. In other words, the notes accompanying these reports said, that the baby was either crying or quiet, i. e., asleep. The difficulties incident to securing long experimental periods of constant muscular activity with infants are only too well known, and yet an examination of the literature shows that almost invariably all of the longer experiments on infant metabolism have included periods of obviously great muscular restlessness and activity, as well as periods of crying.

We, on the contrary, have in all our researches in later years observed the child, and recorded the behavior of the child from quarter minute to quarter minute by quite definite signs. In Figure 1 is given the explanation of the signs employed by us. Figure 2 shows an ideal experiment, in which during three hours our child only twice made quite a slight movement in its sleep; and Figure 3, on the other hand, shows an experiment in which the child was decidedly restless. As has been said, all the experiments that we have published in the last few years show clearly how the child has behaved from minute to minute. Indeed, we adhere to the point of view that it is of absolutely no value to carry out and publish respiration researches in which this fundamental requirement is not complied with.

5. Benedict: Deutsch. Arch. f. klin. Med., 1912, cvii, 192.

It may appear questionable which is the better: the graphic method which we employ, which depends on individual observation of the child and on notes made two to four times per minute, or the mechanical record of Benedict and Talbot. Against our method it may with reason be objected that the judgment is exposed to the unavoidable vacillations of the observer. One and the same movement will be at one time recorded as being of a greater degree and at another time as being of a lesser degree, or *vice versa*. On the other hand, it is certainly to be remarked that the principal participators in our researches, since we have been working in Düsseldorf, are always the same persons, and not only the two authors of this article, but also the analyst of the laboratory and the

Fig. 2.—An ideal experiment, in which during three hours the infant (L) only twice made a slight movement in its sleep.

attendant. Hence a certain uniformity in the observance of the children's condition is assured and a possibility obtained of comparing the various experiments with each other.

But the method of Benedict and Talbot has also its disadvantages. The crying of the children, for instance, indicates a very considerable degree of activity, which is mainly performed by the respiratory muscles. But this activity will make slighter marks on the tambour than a movement of the leg or arm, in which less mechanical work is performed. Sucking movements of the child's lips will be not at all, or scarcely at all, visible, because a movement of the support under the child will not be affected by such an action, confined as it is to a single group of muscles. In short, a mechanical record, also, with all the aids to be had

therewith, will just as little render possible an absolutely exact view of the accomplishment, as the recording of personally observed movements. But under all circumstances — whichever method is used — exact observation of the activity in experiments with the respiration apparatus must be ensured, and included in the publication of these researches, if the observation is to have real value. On this point there is between Benedict and Talbot, on the one hand, and ourselves on the other hand, a perfect conformity of view.

Perhaps we may be allowed to take this opportunity of informing our American colleagues that it was possible for us to ascertain the worth of the fundamental transformation of the infant, which may be of value for further researches as standard figures. We found⁶ that an infant of 4,325 gm., fasting and in complete repose, exhausted

9.03 gm. albumin
12.88 gm. fat and
28.32 gm. glycogen

of its physical reserves; that is, 273 calories. Fundamental transformation is accomplished in the cases of various infants, *ceteris paribus*, in proportion to the superficies; 1 sq. m. infant superficies has thus a fundamental transformation of 859 calories. By this means we can deduce the fundamental transformation of any normal infant with whose superficies we are acquainted, or whose superficies we can compute from its weight. The fundamental transformation of the infant fully synchronizes, moreover, with that of the adult, if here also the bodily superficies is reckoned as the basis of comparison; for Atwater found in adults a fundamental transformation of 840 calories per square meter, a figure which coincides ideally with that ascertained by us.

Now that we know the fundamental transformation, we can obtain a genuine conception of the accomplishment of the infant. One child whom we had under observation⁷ cried during a part of the experiment, and at the same time made lively movements. In so doing, it exhausted per hour 2.764 liters more O than during the time of rest, that gave us a result *re* the fundamental transformation. From the increased consumption of oxygen, and from the increased formation of CO₂ it may be deduced that the child in this hour of unrest transformed 13.27 calories more. That is, then, 13.27 times 425 = 5,640 kg. of chemical

6. Schlossman and Murschhauser: The Fundamental Transformation and Nourishment Requirement of the Infant According to Researches on Gaseous Exchange. *Biochem. Ztschr.*, 1910, xxvi.

7. As regards the behavior of this child while under observation, our report says: "It behaved itself in a very refractory manner, moved energetically, cried so that it grew red, and was not to be pacified." This description is strikingly similar to that which Heubner gives of the restless infant that he and Rubner had under observation.

energy, which were used in the activity of crying and during activity. Even if only the third or fourth part of these 5,640 kg. is to be accounted as really mechanical work, then this child of $5\frac{1}{2}$ kg. accomplished work to the extent of from 1,400 to 1,900 kg. In another case we were able to ascertain that a fretful child of 2,680 gm. exhausted 0.785 liters more O per hour by crying. That, with a respiratory quotient of 0.90, corresponds to 3,899 calories, or 1,657 kg. of chemical energy transformed. Thus that would signify an actual attainment of about 500 kg., which this child of 2.68 kg. achieved by crying.⁸

If we, judging from our knowledge of the infant's fundamental transformation, consider the two breast-fed babies that served Rubner

Fig. 3.—Experiment in which the child (P) was extremely restless. See Figure 1 for explanation of signs.

and Heubner in their experiments, in which the respiratory exchange, at least with regard to the excretion of carbonic acid, was ascertained, the following is shown: The first breast-baby, with a weight of 5,250 gm. and a superficies of 0.3500 square meters, absorbed 379.95 calories and decomposed 351.78 calories per day. The requirement for the fundamental transformation for this child amounted, according to our researches, to 300.65 calories. Thus there were used for activity expended 51.13 calories, and the fundamental transformation was exceeded by the accomplishment by 17 per cent. That corresponds to a chemical energy of 21.730 kg., or an attainment of over 5,000 kg. per day, if we assume an

8. Schlossmann and Murschhauser: On the Influence of Crying upon the Respiratory Metabolism of the Infant. *Biochem. Ztschr.*, vol. xxxvii.

exhaustion of chemical energy of 25 per cent. for activity and 75 per cent. for formation of heat. The child elevated its weight about 1,000 meters in twenty-four hours, if we think of the manifold movements simply as a work of elevation. As the child at the same time slept a great deal, it accomplished during its waking hours extremely important mechanical work, contrary to the opinion of Rubner and Heubner that the infant does not perform mechanical work to an appreciable extent. The second breast-baby that Rubner and Heubner observed⁹ was a perfect little acrobat. He weighed 9.77 kg., his superficies amounted to 0.5464 square meters, and he decomposed 660.5 calories. According to our researches, the fundamental transformation of this child amounts to 469.4 calories; consequently, the child transformed 191.1 calories more than were necessary for maintenance. But a total energy of 81,217.5 kg. is transformed from a potential state to a kinetic one, thus an effective work of around 20,000 kg. So the child elevated his own weight in twenty-four hours about 2,000 meters. The increase of the force transformation compared to the fundamental transformation amounted to 47.1 per cent. If one assumes that the child was absolutely quiet for twelve hours, it transformed in the twelve hours of activity about 100 per cent. more than when at rest; and so accomplished exactly as much as a child under our observation that cried for an hour and made energetic movements.

The description which so eminent an observer as Heubner gives of his subject, characterizes it as an excellent accomplishment. He says: "The child cries almost incessantly, has a reddened face, great beads of perspiration on face and arms," etc., all an indication of unusually strong, physical exertion, for which our figures give us abundant proof.

From all that has been said here it is proved of what great importance is the observation of children with regard to their movements and behavior during the carrying out of metabolism researches. Therefore, there was forced on us the importance of proving that we have ascertained by exact research the actual transformation during repose, and that for years in all our researches we have made exact records of the manner and intensity of movements on the part of our subjects.

9. *Ztschr. f. Biol.*, 1898, xxxvi; *Ztschr. f. exper. Pathol. u. Therap.*, vol. i.