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ORIGINAL COMMUNICATION

The extent to which breakfast covers the morning energy expenditure of adolescents with varying levels of physical activity

M Vermorel[1]*, A Bitar[2], J Vernet[1], E Verdier[3] and J Coudert[4]

[1]*Energy and Lipid Metabolism Research Unit, St-Genès Champanelle, France;* [2]*Department of Biology, Applied Physiology Laboratory, Faculty of Sciences, El Jadida, Morocco;* [3]*Human Nutrition Laboratory, Clermont-Ferrand, France; and* [4]*Physiology and Sports Biology Laboratory, Medical Faculty. Centre for Research in Human Nutrition in Auvergne, Clermont-Ferrand, France*

Background: Energy intake at breakfast affects the performance of creativity tests, memory recall and voluntary physical endurance in children before lunch, and food craving during the whole day.
Objectives: To assess the adequacy of breakfast energy supply (BES) and energy expenditure (EE) in adolescents during a schoolday without or with 2 h of physical education lesson (PEL) in the morning.
Design: Sixty adolescents (four groups of 14–16 boys and girls aged 12–16 y) participated in a cross-sectional study. Activity patterns and EE were determined by whole-body calorimetry during 36 h and in free-living conditions during 5 days using both a diary and the validated heart rate recording method. BES was determined by weighing individual foods. The pyloric energy flow was assessed using a model of fractional stomach emptying.
Results: BES averaged 24.9% (s.d. = 6.1) of daily EE in the four groups of subjects. It covered the mean morning EE on a schoolday without PEL, but not in a schoolday with 2 h of PEL in any group. When PEL took place from 8–10 am the cumulative EE exceeded the cumulative pyloric energy flow after 105–150 min, that is during the PEL session, and the energy deficit increased until lunch. With a light breakfast (BES − 1 s.d.) energy deficiency happened after 90 min.
Conclusion: The results stress the need for a heavy breakfast for children and adolescents on the days with PEL in the morning, and a carbohydrate rich snack at 10 am to improve attention, memory and willing participation in physical activities.
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Keywords: adolescents; breakfast; energy expenditure; physical activity

Introduction

A substantial energy intake at breakfast is known to reduce the feeling of hunger during the morning and food craving over the whole day (Delargy *et al*, 1995; Hubert *et al*, 1997). In other respects, a high-carbohydrate breakfast can bring the daily carbohydrate and fat intakes to the recommended dietary allowances (RDA; Holt *et al*, 1996; Kirk *et al*, 1997), and consequently has beneficial effects on body composition (Macdiarmid *et al*, 1996). In addition, energy intake at breakfast seems important for some kinds of schoolwork, even when the daily energy intake is adequate, because the reserves of glucose in the body are low and the glucose demand by the central nervous system and for muscular activity is high, especially in children. An overnight and morning fast, particularly in nutritionally at-risk children, resulted in increased errors, slower stimulus discrimination, and slower memory recall during psychological tests (Pollitt *et al*, 1998). Similarly, voluntary physical endurance and the performance of creativity tests were significantly better after a breakfast which supplied over 20% compared with 10% of daily RDA (Wyong *et al*, 1997). Breakfast consumption did

*Correspondence: M Vermorel, Energy and Lipid Metabolism, Research Unit, INRA Theix, 63122 St-Genès Champanelle, France.
E-mail: vermorel@clermont.inra.fr
Guarantors: M Vermorel and J Coudert.
Contributors: MV was responsible for all stages of the study, including the study design, measurements, assessment of nutrient supply, interpretation of results and writing the paper. AB participated in the measurements, analysed the data of energy supply and expenditure and participated in the discussion. JV participated in the calculation of energy expenditure and was responsible for statistical analysis. EV, dietician, was responsible for the menus and calculated nutrient intakes. JC, medical doctor, participated in the discussion of the study design, recruited the volunteers, supervised the study, and participated in the discussion.
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not affect performance on an intelligence test, but influenced tasks requiring aspects of memory. Furthermore, the decline in performance associated with not eating breakfast was reversed by consumption of a glucose-supplemented drink (Benton & Parker, 1998).

The aim of the present study was to assess the adequacy of absorbed energy and energy expenditure (EE) of adolescents during the morning with or without physical education lesson (PEL), depending on energy intake at breakfast. EE has been determined both in standardized conditions (Bitar *et al*, 1999) and in free-living conditions (Vermorel *et al*, 2002).

Subjects and methods

Subjects

Sixty adolescents participated in this study. They were distributed among four groups of 14–16-y-old subjects according to sex and age: 12–13 or 14–16 y (Table 1). The volunteers were recruited from two high schools in the suburb of Clermont-Ferrand, France. Before the study began, the purpose and objectives were carefully explained to each subject and his or her parents. Written informed consent was obtained from all adolescents and their parents. The experimental protocol was approved by the University Ethical Committee on Human Research for Medical Sciences. All subjects had a thorough physical examination, and a medical history was taken. Their usual activity (number of hours per week of physical training at school and in clubs and usual types of leisure) was estimated by interview in the presence of their parents to make sure that they had normal physical activity. Height was measured to the nearest 0.5 cm with an anthropometric plane. Weight was measured to the nearest 0.1 kg with a portable digital metric scale, which was calibrated by using standard weights (Bitar *et al*, 1999).

Assessment of energy expenditure and physical activities

EE was assessed both in standardized and in free-living conditions. Volunteers spent 36 h in two comfortably equipped open-circuit calorimetric chambers: one evening and one night for adaptation to the environment followed by 24 h measurement of gas exchanges and heart rate (HR). They could see each other and talk. They followed a standardized activity programme including four 15 min periods of exercise (at 09:30, 11:00, 15:00 and 17:30) at four intensities on a cycloergometer, and simulating their usual activities (schoolwork, reading, parlour games, video games and watching television). Volunteers were offered *ad libitum* balanced diets (breakfast at 08:00, lunch at 13:00, a snack at 16:00, and dinner at 19:30). They went to bed at 22:00. EE was calculated over 5 min periods during exercise and 15 min periods for the rest of the day (Bitar *et al*, 1999). Individual relationships were calculated between data for EE and HR recorded both in the whole-body calorimeters during 24 h and during laboratory tests for usual activities (walking, jogging, stepping) which could not be performed in the calorimeters (Vermorel *et al*, 2002).

In free-living conditions adolescents had breakfast at 07:00 and lunch at 12:30. Thus, the time interval between breakfast and lunch was similar in free-living conditions and in the calorimetric chambers. EE and physical activity were assessed using the HR-recording method and an activity diary, during five consecutive days including a weekend, Monday (a schoolday without PEL), Tuesday (a schoolday with 2 h PEL, from 08:00 to 10:00 or from 10:00 to 12:00), and Wednesday (school in the morning and free activities in the afternoon). HR was monitored using Sport Testers (PE 4000, Polar Electro KY, Kempele, Finland) with pulse rate recording at 1 min intervals. Each volunteer had a detailed explanation and demonstration of the activity diary form and method, and was instructed to write down regularly and carefully all activities (type,intensity, times of beginning and end of each activity). Volunteers were visited at home every evening. The activity records were compared with the HR graphs to check the agreement of both recordings. In case of disagreement the activity record was immediately re-examined with the subject (Vermorel *et al*, 2002). EE was calculated each minute from HR recordings using the individual relationships between HR and EE. In the present study EE was summed over 30 min periods.

Assessment of nutrients and energy intake and pyloric flows

For breakfast in the calorimetric chambers volunteers had foods they ate usually, and they were advised to consume the same quantities of each food as usual. The quantities of each food offered and not eaten were determined using an accurate balance (±0.1 g). The nutrients and energy intakes at

Table 1 Physical characteristics and body composition of adolescents[a]

	12–13 y		*14–16 y*		P		
	Boys (n = 15)	*Girls (n = 15)*	*Boys (n = 16)*	*Girls (n = 14)*	*Sex*	*Age*	*Sex×age*
Age (y)	$12.6^b \pm 0.15$	$12.5^b \pm 0.16$	$15.0^a \pm 0.15$	$14.9^a \pm 0.16$	0.42	0.001	0.92
Body weight (kg)	$45.1^b \pm 2.0$	$43.2^b \pm 2.1$	$54.6^a \pm 1.9$	$51.3^a \pm 2.1$	0.20	0.001	0.72
Height (cm)	$153.5^b \pm 1.8$	$153.8^b \pm 1.8$	$167.9^a \pm 1.7$	$165.6^a \pm 1.8$	0.58	0.001	0.48
Body mass index (kg/m^2)	19.0 ± 0.6	18.2 ± 0.6	19.3 ± 0.6	18.7 ± 0.6	0.27	0.51	0.86

[a]Least-squares mean ± s.d. Values in the same row with different superscript letters are significantly different, $P < 0.05$.

each meal were assessed using the GENI software (Gestion d'Enquêtes Nutritionnelles Informatisées, Villers les Nancy, France) based on the nutritive value of foods (Southgate, 1978; REGAL, 1996).

In addition, the pyloric flows of nutrients and energy were assessed using the model of digestive transit of solid and liquid food components elaborated by Bernier *et al* (1988) and validated for standard meals supplying 820–2600 or 6900 kJ. Butter and milk fat, which tend to float in the stomach, and milk proteins which curdle or precipitate in the form of fakes in the stomach, were considered as solid food components like bread and cereals, whereas lactose, jam, fruit juice and sucrose were considered as liquid food components. The pyloric flows of nutrients and energy were calculated for each volunteer over 30 min periods during 5.5 h from breakfast (at 07:00) to lunch at 12:30. They were then summed over the 5.5 h.

Statistical analysis

Data were analysed by ANOVA using PROC GLM of SAS (1989) software with the following model:

$$y = \mu + (\alpha sex + \beta \text{ age} + \text{sex} * \text{age} + \varepsilon \quad (1)$$

to study the effects of these variates on BES, EE, BES − EE. Adjusted means were computed and compared using 'LSMEANS' and 'TDIFF' options of PROC GLM. Differences were considered as significant for $P < 0.05$.

Results

Physical characteristics of subjects

The distribution of subjects according to age and stage of puberty, as well as their physical capacities have been published elsewhere (Bitar *et al*, 1999). Physical characteristics and body composition of subjects are presented in Table 1. In spite of great inter-individual differences, none of the subjects was obese. Subjects practiced 3 h PEL at school and 0–8.5 h of other sport activities per week, that is, on average 84 (s.d. = 48) and 59 (s.d. = 35) min of sport activities per day at 12.6 and 15.0 y of age, respectively (Vermorel *et al*, 2002).

Energy expenditure in standardized and free-living conditions

Daily energy expenditure (DEE) measured in the whole-body calorimeters averaged 10.16 (s.d. = 1.40), 9.27 (s.d. = 1.12) MJ in boys and girls, respectively, at 12.6 y of age, compared to 11.78 (s.d. = 1.46) and 9.52 (s.d. = 1.01) MJ at 15.0 y of age. EE from 07:00 h to 12:30 h in the calorimeters and in free-living conditions are presented in Table 2. In the calorimeters EE was stable during the periods of rest, but doubled during the periods of exercise. It amounted to 28.2% of DEE, on average. Within each group the coefficient of variation of EE averaged 12.4%. In other respects, EE increased by 12.4% ($P < 0.02$) between 12.6 and 15.0 y of age in boys, but did not vary significantly in girls.

Because of imperfect HR recording in 12 of the 60 subjects, especially during the periods of physical activity, DEE in free-living conditions could be estimated in only 12 subjects per group. During the schoolday without PEL, DEE was similar to DEE in the calorimeters (− 0.5%, s.d. = 3.0%), but 13.9% (s.d. = 3.7) lower than during the day with 2 h PEL. EE during the four exercises in the calorimeters was equivalent to EE during walking from home to the bus stop, in the school and during recreation.

In free-living conditions, EE during the morning without PEL was slightly but not significantly lower than in the standardized conditions in three groups of subjects but 17.5% lower ($P < 0.05$) in the 15.0-y-old girls. These girls were more inactive than the subjects of the three other groups during the free time as shown by their lower coeffi-

Table 2 Breakfast energy supply (BES), energy expenditure (EE) of subjects from 07:00 to 12:30 h in standardized conditions (calorimeters; 15 or 16 subjects per group) and in free-living conditions (12 subjects per group) one schoolday without PEL and one schoolday with 2 h PEL, and differences between breakfast energy supply and energy expenditure (BES − EE; means, s.d.) and range

		Age = 12.6 y		*Age = 15.0y*		P		
Conditions	*Balance (MJ)*	*Boys*	*Girls*	*Boys*	*Girls*	*Age*	*Sex*	*Age×sex*
Standardized conditions	BES	2.86 (0.73)[b]	2.14 (0.85)[c]	3.51 (0.70)[a]	2.31 (0.91)[c]	0.048	0.0001	0.24
	EE	2.91 (0.42)[b]	2.62 (0.37)[c]	3.27 (0.37)[a]	2.69 (0.28)[bc]	0.025	0.0001	0.12
	BES-EE	−0.05 (0.94)[b]	−0.48 (0.69)[b]	+0.24 (0.81)[a]	−0.38 (0.90)[b]	0.36	0.018	0.66
	Range	−1.65→+1.23	−2.04→+0.53	−1.04→+2.04	−2.64→+0.83			
Free-living schoolday without PEL	BES	2.89 (0.90)[b]	2.34 (0.73)[b]	3.57 (0.73)[a]	2.53 (0.66)[b]	0.023	0.0007	0.15
	EE	2.73 (0.41)[b]	2.52 (0.44)[bc]	3.14 (0.71)[a]	2.22 (0.30)[c]	0.69	0.0004	0.02
	BES-EE	0.16 (1.12)	−0.18 (0.86)	0.43 (0.83)	0.31 (0.68)	0.11	0.47	0.84
	Range	−1.37→+1.81	−1.76→+1.47	−2.17→+1.69	−1.17→+1.46			
Free-living schoolday with 2 h PEL	BES	2.89 (0.90)[b]	2.34 (0.73)[b]	3.57 (0.73)[a]	2.53 (0.66)[b]	0.006	0.0001	0.12
	EE	4.02 (0.66)[b]	3.53 (0.80)[b]	5.23 (1.34)[a]	3.50 (0.67)[b]	0.04	0.0003	0.03
	BES-EE	−1.13 (0.95)	−1.19 (0.99)	−1.66 (1.54)	−0.98 (0.99)	0.93	0.42	0.38
	Range	−2.36→+0.22	−2.60→+0.80	−3.19→+0.11	−2.93→+0.06)			

Values in the same row with different superscripts are significantly different ($P < 0.05$).

cient of variation of EE: 13.5 *vs* 17.5%. Two hours of PEL in place of seated lessons increased by 52.7% (s.d. = 11.0) the morning EE. The coefficient of variation of EE averaged 21.0%, indicating high inter-individual variations: for instance EE ranged from 3.39 to 8.03 MJ in the 15.0-y-old boys, depending on intensity of exercises.

Breakfast energy supply

Food intake at breakfast was determined twice during the stay in the calorimeters. The quantities of foods ingested by subjects during those two meals were very similar. Among the 62 subjects, 60 consumed bread (107.5, s.d. = 30.5 g/day in boys, and 85.2, s.d. = 39.0 g/day in girls), whereas two ate cereals (40 and 88 g/d); 56 consumed semi-skimmed milk (340, s.d. = 88 and 228, s.d. = 101 g/day in boys and girls, respectively). It is noticeable that five of the 15 oldest girls did not drink milk at breakfast. The same number of subjects consumed cocoa powder (Nesquik, 15.0, s.d. = 7.1 g/day), 21 ate sugar (8.2, s.d. = 6.4 g/day), 54 ate jam (49.8, s.d. = 20.8, and 33.6, s.d. = 20.1 g/day in boys and girls, respectively), and among the 62 subjects only three of the 15-y-old girls drank fruit juice.

Breakfast supplied, on average, 25.8% (s.d. = 4.6, range 16.4–34.8, and 23.9% (s.d. = 7.3, range 3.4–32.4) of daily energy intake in boys and girls, respectively. In addition, the contribution of carbohydrates, lipids and protein to breakfast energy supply was similar in the four groups of subjects and averaged 65.3, 24.2 and 10.5%, respectively. The breakfast energy supply was slightly but not significantly higher at 15.0 than at 12.6 y of age in girls, but 22.7% higher in boys ($P < 0.02$, Table 2). However, within each group the inter-individual variability was high (22.5% in boys and 39.5% in girls). The energy supply range was 1.35–4.50 MJ in boys and 0.33–3.24 MJ in girls.

Is the breakfast energy supply adequate to cover morning energy expenditure?

In the standardized conditions the mean BES covered the mean EE in boys (Table 2). However, there was a great inter-individual variability, since the differences between BES and EE ranged from − 55 to + 88% of EE. However, in girls, BES was, on average, 16.2% lower than EE, and the differences between BES and EE ranged from − 84 to + 27% of EE.

On the schoolday without PEL, the mean BES covered the mean EE of boys and girls (Table 2). However, a light breakfast (mean − 1 s.d.) covered only 64–84% of EE in girls and 73–90% of EE in boys. Furthermore, on the schoolday with 2 h PEL, the mean BES did not cover EE in any of the four groups of subjects and the energy deficit averaged 1.25 MJ. A light breakfast (mean − 1 s.d.) covered only 45–55% of EE in the four groups of subjects.

The estimated pyloric energy flow decreased slowly and regularly during the first 4.5 h following breakfast, then rapidly during the 5th and the 6th hours (Figure 1). Accord-

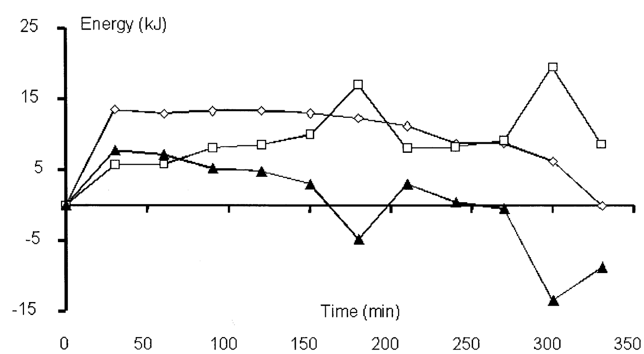

Figure 1 Variations of the pyloric energy flow (◇) corresponding to the mean breakfast energy supply, energy expenditure (□) in the calorimeters, and difference (▲) between the pyloric energy flow and energy expenditure in 15-year-old boys

Table 3 Estimated duration between breakfast time and time at which the cumulative energy expenditure exceeded the pyloric energy flow in adolescents, depending on subjects physical activity and breakfast energy supply: (1) mean BES + 1 s.d.; (2) mean BES; (3) means BES − 1 s.d.

			Mean duration (min)		
				School day with 2 h PEL	
Age	*Sex*	*BES (MJ)*	*Standardized conditions*	*from 10 to 12 am*	*from 8 to 10 am*
12.6	Boys	(1) 3.59	> 360	270	180
		(2) 2.86	330	225	120
		(3) 2.13	270	195	90
12.6	Girls	(1) 2.99	> 360	300	255
		(2) 2.14	285	240	150
		(3) 1.29	180	150	90
15.0	Boys	(1) 4.21	> 360	270	120
		(2) 3.51	330	240	105
		(3) 2.81	285	195	90
15.0	Girls	(1) 3.22	> 360	300	150
		(2) 2.31	300	255	120
		(3) 1.41	150	180	90

ing to the model used, the pyloric energy flow should approach zero after 260–290 and 310 min for the mean BES -1 s.d., mean BES, and mean BES $+1$ s.d., respectively, in boys. The corresponding durations should be 280–300 and 310 min in the 15.0-y-old girls, and only 210–210 and 240–min in the 12.6-y-old girls.

The estimated pyloric energy flows have been summed over 5.5 h for the mean BES (eg average breakfast), BES -1 s.d. (eg light breakfast), and BES -1 s.d. (eg heavy breakfast). Similarly, EEs of subjects were summed over 5.5 h during the stay in the calorimeters, and in free-living conditions, the day without PEL and the day with 2 h PEL. The comparison of the cumulative curves of pyloric energy flow and EE permitted to estimate the time when the cumulative EE exceeded the cumulative pyloric energy flow (Figure 2).

In the standardized conditions, the mean BES covered EE during 330 min in boys and 285–300 min in girls (Table 3). However, BES -1 s.d. covered EE during 270–285 min in boys, and only 150–180 min in girls. The situation was similar in free-living conditions on the day without PEL. However, overstepping happened earlier on the day with 2 h PEL (Figure 2). When PEL took place from 10 to 12 am, the cumulative EE exceeded the cumulative pyloric energy flow from the mean BES after 225–240 min in boys, and after 240–255 min in girls, that is in the middle of the PEL, and the energy deficit increased until lunch. With a light breakfast (BES -1 s.d.), overstepping happened after 150–195 min, that is before the beginning of PEL. The situation was worse when PEL took place from 8 to 10 am; with the mean BES, overstepping happened after 105–150 min in boys and girls, that is during the PEL session, and the energy deficit increased until lunch. With a light breakfast (BES -1 s.d.), overstepping happened after 90 min, and the energy deficit was between 2 and 3 MJ before lunch (Figure 2).

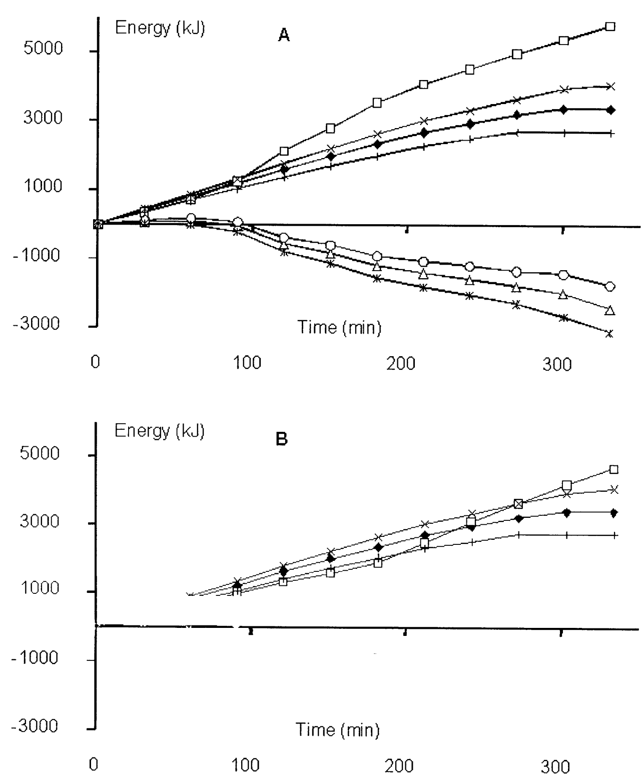

Figure 2 Variations of the cumulative pyloric energy flows corresponding to the mean breakfast energy supply (◆), mean - 1.SD (+), and mean + 1.SD (x), the cumulative energy expenditure, and the differences (△, x , o) between the cumulative energy flows and the cumulative energy expenditure (□) in 15-year-old boys, when the physical activity lesson takes place either from 8 to 10 am (A) or from 10 to 12 am (B)

Discussion

This study allowed to assess the energy balance in male and female adolescents over the morning period, depending on BES and physical activity of subjects in the same period of time. In addition, the time at which the cumulative EE exceeded the cumulative pyloric energy flow could be estimated depending on BES and time of physical education lessons.

Energy expenditure was determined both in standardized conditions using whole body calorimetry, and in free living conditions during days without or with PEL using the validated HR recording method. The mean daily energy expenditures of adolescents in free-living conditions over a week were similar to those obtained in six other studies quoted by Vermorel *et al* (2002), which underlines the relevance of the results of the present study.

The pyloric energy flow was assessed using an empirical model of fractional stomach emptying which differentiates liquid and solid food components. The model is based on simple physiological concepts and was calibrated using the results obtained with various types of meals (Bernier *et al*, 1988). The pyloric energy flows obtained in the present study were compared with those obtained using the model of postmeal stomach energy content quoted by de Castro (1993). According to the latter model the pyloric energy flow depends on stomach food energy content, but not on liquid and solid components of the meal. Consequently it decreases linearly with time. It is higher than the energy flow estimated using the model of Bernier *et al* (1988) during the first 2 h following breakfast, and the difference decreases from 33 to 3%. Thereafter, the pyloric energy flow is lower than that predicted by the model of Bernier *et al* (1988). The estimated cumulative pyloric energy flows meet after 240 min, on average, that is 1.5 h before lunch. Thereafter, energy expenditure is better covered according to the model of Bernier *et al* (1988). The latter seems to be more appropriate to predict the pyloric energy flow, since it differentiates liquid and solid components, carbohydrates and fat.

However, nutrient absorption may be delayed by 15–30 min compared with the nutrient pyloric flow. The enzymatic digestion of carbohydrates is very rapid since almost all glucose is absorbed in the duodenum and the first 50–75 cm of the jejunum (Bernier *et al*, 1988). Similarly, milk protein and lipids are rapidly digested since aminoacidemia and triglyceridemia increase about 20 to 60–90 min, respectively, after ingestion of a complete diet (Boirie *et al*, 1997).

Energy intake at breakfast was the mean of the values obtained during two consecutive days. It was close to 25% of daily energy intake in the four groups of adolescents, but exhibited a great inter-individual variability, especially in girls because some of them had no or a very light breakfast. A BES corresponding to 25% of the mean daily energy expenditure covered EE of adolescents until lunch on the schooldays without PEL in the morning. This result supports the recommended dietary allowances (Martin, 2001). However, a BES corresponding to 15% of DEE covered only 56% of the morning EE, on average. In addition, the cumulative EE exceeded the cumulative pyloric energy flow 3 to 3.5 and 2–2.5 h after breakfast, that is, 2–2.5 and 3–3.5 h before lunch time in boys and girls, respectively.

The situation was worse on the schoolday with 2 h PEL in the morning because EE was increased by 53% on average. With the mean BES corresponding to 25% of DEE, subjects were in negative energy balance 3–4 h before lunch time when the PEL was from 08:00 to 10:00 am, and about 1.5 h before lunch time when the PEL was from 10:00 to 12:00 am A BES corresponding to 37 to 44% of mean DEE would have been necessary to cover the morning EE, but this is not compatible with the French eating habits.

Body tissues do not use only nutrients as energy sources and the energy deficit is not covered only by the mobilization of body lipids and liver glycogen stores, and by enhanced neoglucogenesis. During physical activities of moderate or medium intensity, such as PEL, exercising muscles use mainly muscle glycogen and triglycerides as energy sources (Romijn *et al*, 1993). Muscle glycogen and triglycerides stores depend on the training state of subjects that are probably linked to their usual physical activity, and the intensity of exercise during PEL. Decreased muscle glycogen store may be associated with fatigue and decrease in exercise intensity (Leveritt *et al*, 1999).The activity of the sympathetic nervous system is stimulated and liver glycogenolysis and gluconeogenesis are enhanced. Plasma glucose utilization is also increased during exercises, which tends to lower glycaemia (Romijn *et al*, 1993). This may impair attention, memory and mental performance of adolescents during the 2 h of school activities between PEL and lunch (Benton & Parker, 1998; Pollitt *et al*, 1998).

These results stress the need for a heavy breakfast for children and adolescents on the days with PEL in the morning. The breakfast should be balanced in macronutrients and contain dietary fibres to slow stomach emptying. Furthermore, a carbohydrate rich snack at 10:00 am would be beneficial for all adolescents when PEL takes place from 08:00 to 10:00 am, to improve their attention, memory and mental performance before lunch time. It would also be beneficial for those adolescents who have a light breakfast when they have PEL from 10:00 to 12:00, to allow them to participate willingly in physical activities during 2 h (Wyon *et al*, 1997).

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