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Thermic effect of glucose and amino acids in man studied by direct and indirect calorimetry

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1. In order to reinvestigate the classical concept of specific dynamic action of food, the thermic effect of ingested glucose (50 g) or essential amino acids (50 g) or both was measured in seven healthy male subjects dressed in shorts, by using both direct and indirect calorimetry simultaneously. Experiments were performed under conditions of thermal comfort at 28°.

2. Energy 'balance' (heat production minus heat losses) was negative during the control period (mean heat deficit: $-16{\cdot}0 \pm 0{\cdot}8$ kJ/m² per h.

3. Metabolic rate increased $13{\cdot}6 \pm 1{\cdot}8$ % after the glucose load, $17{\cdot}2 \pm 1{\cdot}4$ % after amino acids, and $17{\cdot}3 \pm 2{\cdot}9$ % after both glucose and amino acids: thus there was no additive thermic effect when both nutrients were given together.

4. In contrast to the metabolic rate, heat losses were not significantly altered after nutrient ingestion; consequently, the energy 'balance' became rapidly positive.

5. These results show that: (*a*) the food-induced thermogenesis, for a moderate energy intake, is less dependent on the nature of the nutrients than was classically admitted; (*b*) this increased heat production mainly induces changes in heat storage rather than in heat losses during the first hours following ingestion of a meal.

An increased heat production following food ingestion was described by Rubner (1902) at the beginning of the century. Lusk (1930) showed that the stimulation of heat production varied according to the composition of the diet. Proteins had the greatest effect, increasing the metabolic rate by 30% of the ingested energy, whereas the augmentation was 6 and 4% for lipids and carbohydrates respectively. The term 'specific dynamic action' was used to describe this effect. It is to be emphasized that most of these early experiments were performed on animals given large amounts of nutrients.

The concept of specific dynamic action (SDA) has been recently challenged by various authors (Miller & Mumford, 1967; Ashworth, 1969; Garrow & Hawes, 1972; Garrow, 1973; Miller & Mumford, 1973). According to Miller & Mumford (1973), the term 'thermic effect' appears more appropriate to account for the increased metabolic rate following food ingestion.

Since precise quantitative findings on the thermic effect of food in human subjects are scarce in the literature, the present study was undertaken to measure the energy balance of subjects receiving glucose or amino acids or both. For this purpose, determinations of metabolic rate were made simultaneously with measurements of heat losses in a direct calorimeter.

EXPERIMENTAL

Seven healthy male students were studied. The physical characteristics of the subjects are summarized in Table 1.

Table 1. *Main physical characteristics of the seven male human subjects*

Subject	Age (years)	Height (m)	Body surface (m^2)	Wt (kg)	Percentage of ideal wt (%)
G.N.	22	1·82	1·95	74·7	108
B.D.	19	1·76	1·75	61·0	94
C.J.	20	1·90	2·05	77·7	103
G.P.	25	1·77	1·81	65·4	100
M.M.	23	1·73	1·77	64·0	102
H.M.	20	1·70	1·89	77·9	129
S.J.-Cl.	21	1·82	2·02	81·1	117
Mean	21·4	1·79	1·89	71·7	107·6
SE	0·8	0·03	0·05	3·0	4·5

The seven subjects were given the three following meals: (1) ingestion of 50 g glucose; (2) ingestion of 50 g of a balanced mixture of essential amino acids (Nesmida; Nestlé Company, Vevey, Switzerland); (3) ingestion of 50 g glucose + 50 g of the mixture of amino acids. One subject (G.N.) did not perform the third test.

Subjects were fasted for 12 h before the experiment. After a period of rest of 1 h in a constant-temperature room (at 28° and 30% relative humidity), the fasting subject, dressed in shorts, was introduced into the calorimeter; the ambient conditions in the calorimeter were identical to those of the constant-temperature room. Control measurements were taken during 40 min; then the subject received the test meal and measurements were taken during a period of 2·5 h. The following measurements were made continuously during the tests: internal temperature, by a tympanic probe and a sublingual probe; mean skin temperature, by weighting eight different skin temperatures according to Hardy & Du Bois (1937); metabolic rate and respiratory quotient (RQ) from determinations of ventilation and of the concentration of O_2 and CO_2 in the expired air in an open circuit (Gomez, Jéquier, Chabot, Büber & Felber, 1972).

The amount of protein (or amino acids) metabolized was calculated from the urinary nitrogen excretion (Du Bois, 1924). The non-protein respiratory quotient was then determined, and the tables of Lusk (1924) were used for computing the amounts of carbohydrates and lipids which were oxidized during the test.

The total heat losses were measured by gradient layer direct calorimetry (Spinnler, Jéquier, Favre, Dolivo & Vannotti, 1973); this method enables separate measurements of 'dry heat losses' (radiation + convection) and evaporative heat losses (insensible perspiration and sweating), to be carried out.

Statistical analyses were performed with Student's t test for paired or unpaired results. The threshold of significance was chosen for a $P < 0{\cdot}05$.

RESULTS

After the three test meals, the metabolic rate measured over a period of 150 min increased significantly, by 13·6% of the initial rate for glucose, by 17·2% for amino acids and by 17·3% for the meal of glucose + amino acids (Fig. 1 and Table 2). The increments observed in the three tests (ΔM) are not significantly different.

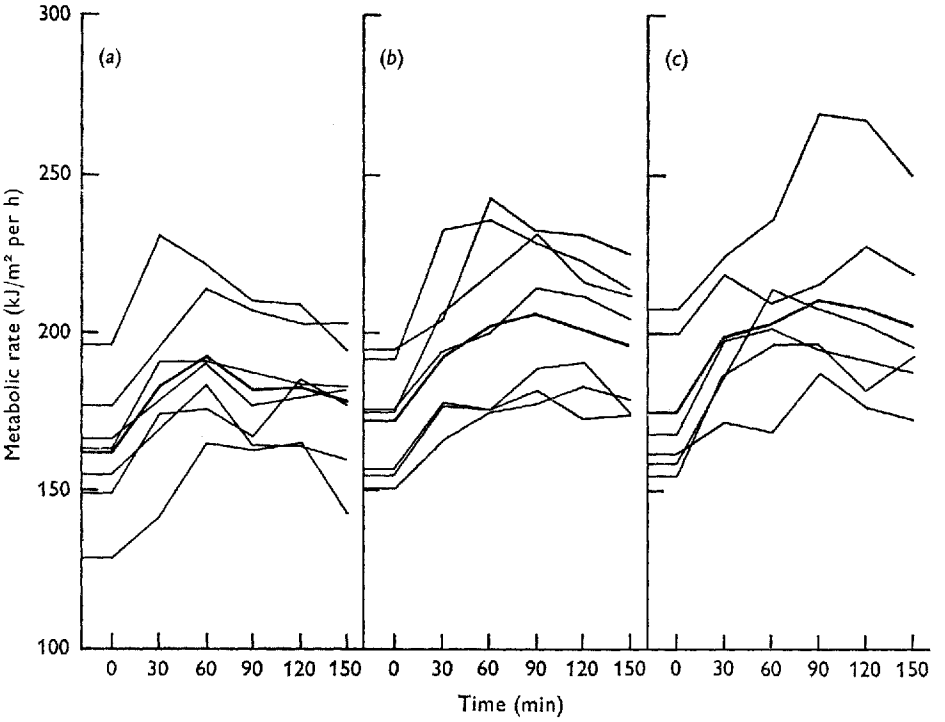

Fig. 1. Metabolic rate of male human subjects during a 40 min control period and during five periods of 30 min after ingestion of: (*a*) 50 g glucose, (*b*) 50 g amino acids and (*c*) 50 g glucose + 50 g amino acids. The thick line represents the mean value for the group. The mean increase in metabolic rate for each meal is given in Table 2. The degree of significance of the variation of the metabolic rate after each meal was: (*a*) $P < 0.001$, (*b*) $P < 0.001$, (*c*) $P < 0.01$. Paired *t* tests on the increase in metabolic rate between the three loads showed no significant differences between them.
Time 0: mean value for the 40 min control period.

It is important to note that we obtained an increase of metabolic rate with the single load of 840 kJ (200 kcal) supplied either as glucose or amino acids similar to the stimulation observed after the double nutrient load (1680 kJ or 400 kcal).

Catabolism of the different substrates is shown in Table 3. After the ingestion of glucose, the oxidation rate of this substrate increased, whereas the catabolism of lipid and protein was about unchanged. After the ingestion of amino acids, the catabolism of these nutrients alone was increased. The combined meal induced an increase in glucose oxidation similar to that in the first test, whereas amino acid consumption was lower than in the second test.

Table 2 shows the metabolic rate and the total heat losses before and after the test meal. During the period following the meal, the total heat losses were not modified; similarly, the insensible perspiration, which represented 27 % of the total heat losses, was unaffected by the meal.

The thermal energy 'balance' (gains or losses in heat) can be determined by calculation of the difference between metabolic rate and heat losses. In all subjects, the energy balance was negative during the control period: their heat losses were larger than their

Table 2. *Heat production, in male human subjects, calculated by indirect calorimetry (ind) and heat losses measured by direct calorimetry (dir) in a 40 min control period and during five 30 min periods after the ingestion of a meal of (a) glucose (50 g) (b) essential amino acids (50 g) or (c) both (kJ/m² per h, ± SE)*

(*a*) Glucose meal

Subject	calorimetry	Before (control)	After (30 min periods) 1	2	3	4	5	Mean	Mean as % of controls*
B.D.	Ind	149±3·3	174±1·7	176±0·7	166±2·0	185±3·3	177±4·0	176±3·1	+18·1
	Dir	155±1·0	161±1·4	160±0·5	145±1·6	159±5·4	173±3·4	160±4·1	+3·2
S.J.	Ind	166±2·0	180±0·6	190±5·1	177±3·2	179±5·0	183±2·7	182±2·2	+9·6
	Dir	187±0·2	178±0·9	186±2·4	185±2·1	177±1·1	175±0·7	181±2·1	−3·2
C.J.	Ind	177±1·4	196±7·3	214±4·6	207±2·6	203±1·1	203±1·8	205±3·0	+15·8
	Dir	180±7·2	192±1·6	206±8·5	211±2·6	206±4·3	205±1·8	204±3·2	+13·3
G.P.	Ind	163±0·6	191±3·6	191±5·5	186±3·1	184±2·4	183±1·4	187±1·8	+14·7
	Dir	195±1·5	189±1·7	186±1·3	186±0·8	185±0·1	185±0·7	186±0·7	−4·6
M.M.	Ind	129±4·9	142±6·8	165±2·2	163±3·7	165±0·6	143±3·1	155±5·4	+20·2
	Dir	171±4·2	177±0·2	185±1·7	186±2·8	181±1·4	179±3·1	182±1·8	+6·4
H.M.	Ind	155±9·1	169±6·9	183±0·6	163±1·5	165±2·6	160±3·1	168±4·1	+8·4
	Dir	210±5·0	175±0·9	182±0·7	183±1·0	183±0·7	184±0·4	181±1·7	−13·8
G.N.	Ind	196±2·2	231±3·5	222±8·6	210±1·2	209±2·7	194±3·6	213±6·2	+8·7
	Dir	185±2·9	191±1·7	194±3·5	193±1·2	192±0·9	185±3·2	191±1·7	+3·2
Mean	Ind	162±7·2	183±10·4	192±7·6	182±7·6	184±6·5	178±7·8	184±7·6	+13·6± 1·8
	Dir	183±6·6	180±4·2	186±5·3	185±7·3	184±5·3	185±4·0	184±5·1	+0·6± 3·3

(*b*) Amino acid meal

B.D.	Ind	157±1·8	177±2·5	176±2·3	182±1·9	173±4·4	174±3·2	176±1·5	+12·1
	Dir	153±2·6	159±2·5	150±0·7	169±3·2	177±2·2	164±1·7	164±4·5	+7·2
S.J.	Ind	175±1·0	194±3·3	200±5·0	215±3·6	202±3·7	195±1·0	201±3·6	+14·9
	Dir	197±7·9	183±1·1	178±0·8	183±1·6	185±2·1	181±0·4	182±1·2	−7·6
C.J.	Ind	195±5·9	204±4·7	243±5·0	232±8·1	231±3·6	225±1·6	227±6·5	+16·4
	Dir	205±0·5	189±3·6	207±3·1	213±6·7	221±0·6	225±0·4	211±6·4	+2·9
G.P.	Ind	155±3·1	178±3·2	176±5·5	189±2·8	191±1·9	185±5·6	184±3·0	+18·7
	Dir	214±0·7	205±1·9	198±1·9	203±1·2	203±1·1	208±4·3	203±1·6	−5·1
M.M.	Ind	193±2·1	233±9·0	236±2·9	229±7·6	223±4·4	214±2·0	227±3·9	+17·6
	Dir	213±2·1	203±1·0	197±2·1	195±2·1	194±2·3	192±1·8	197±1·9	−7·5
H.M.	Ind	151±0·5	166±2·4	175±1·9	178±2·7	183±3·0	179±0·7	176±2·7	+16·6
	Dir	175±1·3	186±3·2	184±1·6	196±2·8	202±0·1	201±0·5	194±3·7	+10·9
G.N.	Ind	175±1·8	205±0·1	219±1·4	231±1·0	216±5·5	212±4·0	217±4·3	+24·0
	Dir	161±1·9	177±2·7	178±2·3	184±3·6	192±3·2	202±0·4	186±4·7	+15·5
Mean	Ind	172±6·9	194±8·5	204±11·3	208±9·2	203±8·4	198±7·6	201±8·9	+17·2± 1·4
	Dir	188±9·6	186±5·6	185±7·1	192±5·5	196±5·3	196±7·4	191±5·8	+2·3± 3·6

Table 2. (*cont.*)

(*c*) Glucose + amino acid meal

Subject	calorimetry	Before (control)	After (30 min periods) 1	2	3	4	5	Mean	Mean as % of controls*
B.D.	Ind	160 ± 2·5	185 ± 2·6	214 ± 9·2	208 ± 3·5	203 ± 2·6	196 ± 1·8	201 ± 5·0	+25·6
	Dir	176 ± 0·2	183 ± 0·3	183 ± 3·4	181 ± 1·9	192 ± 2·5	185 ± 1·8	185 ± 1·9	+5·1
S.J.	Ind	200 ± 0·7	223 ± 3·7	204 ± 5·1	210 ± 8·9	233 ± 0·7	224 ± 5·4	219 ± 5·1	+9·5
	Dir	195 ± 3·2	182 ± 1·4	180 ± 1·0	174 ± 0·8	170 ± 0·7	172 ± 2·7	176 ± 2·3	−9·7
C.J.	Ind	207 ± 0·5	226 ± 1·9	236 ± 5·9	270 ± 9·4	268 ± 6·0	250 ± 9·1	250 ± 8·7	+20·8
	Dir	192 ± 2·4	195 ± 3·3	190 ± 3·1	214 ± 7·8	223 ± 1·9	221 ± 0·9	209 ± 6·8	+8·9
G.P.	Ind	168 ± 1·8	198 ± 1·5	202 ± 1·9	195 ± 0·9	192 ± 4·0	188 ± 0·5	195 ± 2·4	+16·1
	Dir	193 ± 3·9	187 ± 0·8	189 ± 1·7	190 ± 3·3	193 ± 2·4	189 ± 4·7	190 ± 1·0	−1·6
M.M.	Ind	155 ± 1·0	186 ± 2·4	196 ± 1·0	197 ± 4·5	182 ± 4·6	194 ± 0·7	191 ± 3·0	+23·2
	Dir	180 ± 1·2	177 ± 0·3	182 ± 2·0	187 ± 1·5	186 ± 3·4	195 ± 0·7	185 ± 2·9	+2·8
H.M.	Ind	162 ± 0·8	172 ± 2·8	169 ± 3·1	187 ± 4·3	177 ± 4·3	173 ± 3·2	176 ± 3·0	+8·6
	Dir	183 ± 1·7	185 ± 3·0	188 ± 5·8	195 ± 1·9	201 ± 1·1	199 ± 3·0	194 ± 3·0	+6·0
Mean	Ind	175 ± 9·1	198 ± 8·0	203 ± 8·9	211 ± 12·3	209 ± 14·0	204 ± 11·4	205 ± 10·0	+17·3 ± 2·9
	Dir	186 ± 6·7	185 ± 2·4	185 ± 1·7	190 ± 5·7	194 ± 7·2	194 ± 6·6	190 ± 4·5	+1·9 ± 2·7

* Indicates the mean increase in metabolic rate during 150 min given as a percentage of the initial metabolic rate.

Table 3. *Mean oxidation rate (mg/min), in male human subjects, of carbohydrates, fatty acids and amino acids calculated by indirect calorimetry and by urinary nitrogen measurements before and after test meals of glucose* (50 *g*), *essential amino acids* (50 *g*) *or both*

Test meal		Metabolites oxidized: Carbohydrates Mean	SE	Fatty acids Mean	SE	Amino acids Mean	SE
Glucose	Before	108·0	20·7	69·6	7·7	26·8	3·1
	After	173·7	13·8***	58·4	7·1*	26·4	2·7*
Amino acids	Before	134·5	29·7	61·2	6·3	24·8	2·4
	After	145·7	30·0*	70·5	12·1*	41·8	5·5**
Glucose + Amino acids†	Before	124·2	23·0	79·2	12·0	24·9	3·7
	After	187·0	37·5**	63·3	11·3*	36·6	4·8**

† Six subjects only. * Difference not significant.
** Significant difference. $P < 0·05$. *** Significant difference, $P < 0·001$.

heat production. This heat deficit (general mean of $-16·0 \pm 0·8$ kJ/m² per h) is changed into either a heat equilibrium or a slightly positive energy balance after ingestion of the meal. In these conditions, one can observe a trend towards increasing body temperatures, mainly internal temperature (Table 4).

DISCUSSION

This study shows that the thermic effect of food can be demonstrated even with a low amount of ingested energy, whereas most previous studies were performed with greater energy intake (Rubner, 1902; Benedict & Carpenter, 1918; Lusk, 1930; Strang & McCluggage, 1931).

Table 4. *Initial and final temperature (T), internal (int) and cutaneous (cut), of male human subjects measured at 5 min and 145 min respectively after ingestion of a meal*

Test meal		Initial T (°C)	Final T (°C)	ΔT	Paired t test
Glucose	T int	36·59 ± 0·13	36·72 ± 0·08	0·13 ± 0·04	NS
	T cut	33·82 ± 0·11	33·95 ± 0·10	0·13 ± 0·05	NS
Amino acids	T int	33·66 ± 0·10	36·88 ± 0·10	0·22 ± 0·09	NS
	T cut	33·83 ± 0·09	33·94 ± 0·11	0·11 ± 0·07	NS
Glucose + amino acids	T int	36·56 ± 0·10	36·82 ± 0·09	0·26 ± 0·04	$P < 0·01$
	T cut	33·68 ± 0·10	33·83 ± 0·13	0·15 ± 0·05	$P < 0·02$
Mean	T int	36·62 ± 0·06	36·81 ± 0·05	0·19 ± 0·05	$P < 0·01$
	T cut	33·78 ± 0·06	33·91 ± 0·08	0·13 ± 0·05	$P < 0·02$

NS, non-significant.

Since the thermic effect of amino acids lasts longer than that of glucose, a small part of the total effect has not been measured within the test period. However, this appears to be a small cause of error, since most measurements of metabolic rate were on the way to reaching their initial value towards the end of the test. In all individual cases, the value for the last 30 min period is equal to, or more frequently lower than, the mean value for the test period.

We have recalculated our results according to the classical concept for SDA. With a 840 kJ (200 kcal) oral load of glucose, a specific effect of 4 % corresponds to a metabolic increase of 33·5 kJ. In our study, we found 101·9 kJ, or a SDA of 12·1 %. With the 840 kJ amino acid loads, the classically predicted extra metabolism should be 30 % of this ingested energy, or 252 kJ. We found 139 kJ for the test period, or a SDA of 16·5 %. According to Forbes, when glucose and proteins are combined, the dynamic effect is 12·5 % less than that predicted from the sum of their individual effects (Ganong, 1969): therefore, with the glucose + amino acid load (1680 kJ), the extra metabolism should be 29·7 %, or 498 kJ. In this study, we found 142 kJ only, or a SDA of 8·5 %. These results illustrate the protein-sparing effect of carbohydrates in man.

Our results show that, during the test period, the increase in energy expenditure was little affected by the nature or even by the amount of the nutrients and therefore is quite different from that described in the classical concept of SDA.

Our results are in agreement with those of Gomez *et al.* (1972), who observed in human subjects a mean increase in metabolic rate of 11 % during the 3 h following a 1680 kJ (400 kcal) oral glucose load, and with a recent study of Garrow (1973), who studied the thermic effect of three meals with a larger energy content of 2720 kJ (650 kcal). This author observed an increase by 12 % of the metabolic rate with a glucose meal, by 17 % with gelatin, and by 15 % with milk proteins + glucose.

The larger thermic effect of proteins reported in the early literature might be simply explained by the fact that restrained animals (dogs) felt livelier and were more active when they received a large amount of meat than when they got an equivalent amount of energy as carbohydrates.

For a moderate energy intake (840 kJ and 1680 kJ in the present study, and 2720 kJ in Garrow's (1973) study), the thermic effect appears to be relatively independent of the meal size. However, with larger meals, especially in chronically overfed subjects, Miller, Mumford & Stock (1967) described a 'diet-induced thermogenesis' which was related to the meal size. However, in this latter study, the subjects received a large energy intake during a prolonged period (2–3 weeks). Under these conditions, a metabolic adaptation of energy expenditure to its intake occurs.

In conclusion, our results show that the dynamic action of nutrients is less specific than was classically admitted. Moreover, in the range of energy intake studied, the thermic effect of nutrients is not dependent on the total amount of energy given.

Finally, the increased heat production by 'diet-induced thermogenesis' mainly induces changes in heat storage rather than in heat losses during the first hours following ingestion of a meal.

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