Food intake in a West African village. Estimation of food intake from a shared bowl

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Novel methodology is described for the estimation of food intake in the particularly difficult circumstance where groups of people eat directly from a shared bowl of cooked food. Detailed observation and measurement of meal preparation is combined with food table values for composition to calculate the nutrient content of each meal. The distribution of food between individuals is estimated by a suitable algorithm. The ability of the algorithm to identify seasonal changes in energy intakes is demonstrated by comparison of the calculated energy intakes with values for the total energy expenditure of free-living adult male subjects, as measured by the stable isotope, doubly-labelled water technique. This comparison suggests that the energy intake calculated from detailed observation of two cooked meals per day is equivalent to approximately 80 % of the total energy expenditure and, by inference, total dietary energy intake. The remaining energy intake may well be derived from uncooked 'snack foods', such as raw fruit and vegetables, or from cooked food obtained, by purchase or as a gift, away from the home. This is the first description of a successful method for the estimation of food intake when people eat directly from shared bowls of food.

West Africa: Food intake: Shared bowls: Energy intake: Energy expenditure

Accurate measurement of the food intake of free-living humans is notoriously difficult (Bingham, 1987, 1991; Borelli, 1990). When a group of people eat directly from a shared bowl of food, measurement of the food intake of any individual within that group is impossible. The present paper describes the successful application of novel methodology for the estimation of food intake under these particular circumstances. Validation of the data is one of the problems to be solved in any measurement of food intake. In the work described here the stable isotope, doubly-labelled water technique is used to measure the total energy expenditure of free-living subjects. The values obtained for energy expenditure are used as reference values for comparison with the values for dietary energy intakes, which are derived from detailed studies of food preparation and cooking. Weights of cooked food are used with food table values for composition to calculate the energy content of the food, and various algorithms are examined for calculation of the distribution of food between the individuals who shared it.

SUBJECTS, MATERIALS AND METHODS

Ethical permission for this work was granted by the joint MRC/Gambian Government Scientific Co-ordinating Committee and Ethical Committee.

The studies took place in the West Kiang District of The Gambia, West Africa. The field-work was done by a team of MRC Gambian fieldworkers led by Mr Baba S. N. Jobarteh.

The fieldworkers, who were skilled in dietary surveys, all spoke English and Mandinka (the local language) as well as their own tribal language (mainly Jola).

Study design and subjects

The study was divided into three phases. Phase 1 was a field trial of the methodology, designed to identify potential problems, to act as a survey of co-operation, and to determine whether there was any marked difference in food type or preparation within or between villages. This was done as a population study in 1987. At that time there were 208 sinkiros in Keneba. (A sinkiro is a cooking unit within the family structure. Each sinkiro has its appointed cook(s) and cooking hut, and will provide food for certain members of the family on a regular basis. When there is more than one sinkiro within a family the male head of the household may receive food from each.) Every sinkiro in Keneba was visited at least once, and so were some in the nearby villages of Kanton Kunda and Manduar. There was no obvious difference in type of food or methods of preparation between the villages, and it was decided to limit the next part of the study to Keneba.

Phase 2 took place in 1988 and was confined to twenty families who were identified by the fieldworkers as likely to remain in a more intensive study.

Phase 3 took place in 1989 and was focused throughout on ten families selected for their demonstrated co-operation in earlier studies and their stated willingness to continue. Food intake was measured for all the families. Seven adult males took part in studies of total energy expenditure using the doubly-labelled water method (Coward, 1988; Coward & Cole, 1991); the men received doses of doubly-labelled water on four separate occasions, approximately 3 months apart. Other adult male volunteers provided samples of urine as a control for fluctuations in background levels of enrichment of the stable isotopes ^{18}O and ^{2}H. Anthropometric data were collected on four separate occasions for all family members over the age of 12 years (Hudson, 1992).

Estimation of the distribution between individuals of food from a shared bowl

The method of estimating food intake described here requires detailed knowledge of the composition of each cooked meal. A separate two-letter code was used for the identification of the ingredients of each meal, which allows cross-reference to the compositional data used for the calculation of the energy content of each meal. Some examples of the energy values used, and their origins, are given in Table 1.

Once a value is obtained for the energy content of a bowl of food that is going to be shared by a group of people, the problem to be solved is how to estimate the amount of food that each person is likely to eat.

Observation protocol

'Breakfast' is rarely cooked in Keneba; instead, two meals, referred to here as lunch and dinner, are usually cooked each day. Lunch is a meal eaten at about midday and dinner is the meal eaten in the evening, often quite late at night when small children are asleep; a bowl of food called a seeta is often set aside for children to eat the next day. During the farming season, lunch may be cooked early in the morning and taken to the fields to be eaten later, or a cook may remain in the compound and children will take the food along later. Fieldworkers observed and recorded on pre-printed forms the details of the preparation of the two meals cooked by each sinkiro on each study day. Every ingredient was identified and was weighed just before it was put into the cooking pot. Most meals consisted of rice and a sauce, cooked separately and sequentially on a log fire. Battery-powered electronic scales were used for weighing people (to the nearest 100 g) and for weighing food (to the nearest 0·1 g). The observer (or a relief) stayed in the compound while

Table 1. *Energy values and water contents for ingredients used in the calculation of food intake by subjects in a West African village*

Food	Water content (g/kg)	Energy content (kJ/kg)	Energy content (kcal/100 g)	Reference
Aubergine (*Solanum melongena*)	930	586	14	Paul & Southgate (1978)
Baobab leaf (*Adansonia digitata*)	910	1171	28	Platt (1962)
Baobab milk	880	1925	46	In-house values*
Bitter tomato (*Solanum incanum*)	930	586	14	In-house values*
Bush cassava (*Dioscorea prahensalis/bulbifera*)	600	6402	153	Platt (1962)
Bush mango (*Cordyla africana*)	830	2469	59	Platt (1962)
Cabbage (*Brassica oleracea*)	930	962	23	Platt (1962)
Cassava (*Manihot esculenta*)	600	6402	153	Platt (1962)
Chicken	650	9623	230	Paul & Southgate (1978)
Chilli (*Capsicum frutescens*), fresh	940	628	15	Paul & Southgate (1978)
Chilli, dry	80	12175	291	Platt (1962)
Findo flour (*Digitaria exilis*)	60	14518	347	Platt (1962)
Findo millet	60	15480	370	Platt (1962)
Fish, dry	200	12929	309	Platt (1962)
Green beans (*Vigna unguiculata*)	700	4351	104	In-house values*
Groundnut leaf (*Arachis hypogaea*)	910	1171	28	Platt (1962)
Groundnut oil	0	37656	900	Paul & Southgate (1978)
Groundnut, raw	45	23849	570	Paul & Southgate (1978)
Groundnut, roast	45	23849	570	Paul & Southgate (1978)
Guava (*Psidium guajava*)	830	2594	62	Paul & Southgate (1978)
Honey	230	11966	286	Paul & Southgate (1978)
Jambanduro leaf (*Cassia tora*)	910	1171	28	Platt (1962)
Kucha leaf (*Hibiscus sabdariffa*)	910	1171	28	Platt (1962)
Lime (*Citrus aurantifolia*)	900	1506	36	Platt (1962)
Locust bean (*Parkia biglobosa*)	100	15899	380	Platt (1962)
Maize (*Zea mays*)	120	15188	363	Platt (1962)
Maize flour	120	15146	362	Platt (1962)
Mango (*Mangifera indica*)	830	2469	59	Platt (1962)
Milk, fresh	880	2720	65	Paul & Southgate (1978)
Milk, powdered	30	20501	490	Paul & Southgate (1978)
Milk, sour	880	2270	65	Paul & Southgate (1978)
Milk, tinned	686	6611	158	Paul & Southgate (1978)
Millet (any)	110	14853	355	Platt (1962)
Morongo leaf (*Amaranthus caudatus/viridis*)	910	1172	28	Platt (1962)
Nebedayo leaf (*Moringo oleifera*)	910	1172	28	Platt (1962)
Oil (any)	0	37656	900	Paul & Southgate (1978)
Okra (*Hibiscus esculentus*)	900	711	17	Paul & Southgate (1978)
Okra leaf	910	1172	28	Platt (1962)
Onion (*Allium cepa*)	930	962	23	Paul & Southgate (1978)
Onion leaf	910	1172	28	Platt (1962)
Orange (*Citrus sinensis*)	860	1464	35	Paul & Southgate (1978)
Palm fruit kernel (*Elaeis guineensis*)	40	12845	307	In-house values*
Palm oil	0	37656	900	Paul & Southgate (1978)
Pawpaw (*Carica papaya*)	890	1632	39	Platt (1962)
Pumpkin (*Cucurbita maxima*)	950	628	15	Paul & Southgate (1978)
Rice (*Oryza sativa*)	120	15104	361	Platt (1962)
Rice flour	120	15313	366	Paul & Southgate (1978)
Roast rice	120	15104	361	Paul & Southgate (1978)
Sanyo flour (*Pennisetum typhoideum*)	100	15272	365	Platt (1962)
Sanyo millet	100	15272	365	Platt (1962)
Shellfish	830	2929	70	Platt (1962)
Sora leaf (*Leptadenia lancifolia/hastata*)	910	1172	28	Platt (1962)
Sorghum (*Sorghum gambicum/margaritiferum*)	120	14770	353	Platt (1962)
Spring onion (*Allium cepa*)	870	1464	35	Paul & Southgate (1978)

Table 1. (*cont.*)

Food	Water content (g/kg)	Energy content (kJ/kg)	(kcal/100 g)	Reference
Sugar	0	16485	394	Paul & Southgate (1978)
Suno flour (*Pennisetum gambiense*)	100	15272	365	Platt (1962)
Suno millet	110	14853	355	Platt (1962)
Surro leaf (*Ficus gnecephalocarpa*)	910	1172	28	Platt (1962)
Sweet pepper (*Capsicum annuum* var. grossum)	935	628	15	Paul & Southgate (1978)
Sweet potato leaf (*Ipomaea batatas*)	850	2008	48	Platt (1962)
Sweet potato	700	3807	91	Paul & Southgate (1978)
Tomato (*Lycopersicon esculentum*)	930	586	14	Paul & Southgate (1978)
Tomato paste	657	2803	67	Paul & Southgate (1978)
Wheat flour (*Aestivum triticale*)	140	13682	327	Paul & Southgate (1978)

* Calculated as for Paul & Southgate (1978).

the meal was being cooked, ensuring that no last-minute addition went undetected. When the meal was ready, the weight of each eating bowl was determined when empty, after the addition of the staple, again after the addition of water or sauce, and so on, and each bowl was assigned a number. The age, sex and body weight of each person, and the number of the bowl from which they were going to eat was recorded. The whole procedure took place in the compound where the meal preparation was observed. The time required of each subject was thus short and the procedure seemed to be well tolerated. The observer waited in the compound until people had finished eating inside their houses, and then weighed any food that remained uneaten.

Energy values

The database contains a reference table of the energy content of individual ingredients as far as is possible (see Table 1). Some of the items encountered in this study have not been analysed, and various devices have been adopted. For example, a single value has been used for fresh fish, irrespective of species. The species eaten were all non-fatty fish and differences in energy content are likely to be small. Any flour made from two cereals was assumed to be an equal mixture. The use of these values was infrequent and is unlikely to have had any significant effect on the results.

Calculation of the energy content of each eating bowl of food

Two assumptions are implicit in the calculation of the energy content of each eating bowl of cooked food: (1) all food is removed from the cooking pot; and (2) each element of the meal (e.g. staple, sauce) is homogeneous. Although neither is true, the errors are unlikely to be large and these assumptions greatly simplify the calculations.

The weight of each raw ingredient of the staple element of the meal was recorded. Average compositional data were used to calculate the energy content of each ingredient and hence the total energy content of the staple element of the meal. The weights of the empty eating bowls and the weights of these bowls after the staple has been added allow calculation of the total weight of cooked staple and the proportion of the total cooked staple that is in each bowl. Application of these proportions to the total energy content yields the amount of energy contributed by the staple element to each bowl of food. Similar calculations were used for the sauce and fish/meat elements of the meal.

Various analytical schemes were examined for estimating the distribution of the food, and hence the dietary energy, between the people who ate the food (Hudson, 1992). The chosen scheme was devised to assume a distribution of food that recognized a non-proportional relationship between energy requirements and body weights (Anderson *et al.* 1977). Mathematical factors were calculated for each sex (X)/age (Y) classification using the algorithm:

$$X/Y \text{ factor} = {}^{\text{int}}[(Wt - 10{\cdot}5)/10)] \times 0{\cdot}25 + 1{\cdot}5,$$

where ${}^{\text{int}}[x]$ is the integer of x and Wt is body weight (in kg) for individuals who weigh more than 10·5 kg; subjects who weigh less than 10·5 kg are assigned a factor of 1·0. Any algorithm that is chosen is, of course, arbitrary and some form of reference is needed to decide whether the results obtained by its application are reasonable.

Doses

For each measurement period a single batch of doubly-labelled water was prepared and divided to give the seven doses required. Water enriched for ^{18}O (Isotec Inc., Miamisburg, OH, USA) was mixed with $^{2}H_2O$ (Sigma, Poole, Dorset; 99·8% pure), after each had been passed through a Sartorius Minisart 0·45 μm filter, to give an ^{18}O:^{2}H ratio of 2·4:1. The mixture was divided into screw-top glass bottles and then autoclaved at 103·5 kPa for 50 min. A sample of the mixture was retained in Cambridge for later analysis. The dose volume was chosen to provide 0·07 g ^{2}H and 0·17 g ^{18}O/kg body weight, assuming an average body weight of 60 kg.

Dose administration

Subjects came to the Keneba laboratory and a fieldworker explained carefully what was required. A capped bottle of doubly-labelled water and a plastic drinking straw were weighed to the nearest 100 mg. The bottle was opened and the straw was inserted. The subject drank the labelled water rapidly, followed by approximately 200 ml tap water to ensure that all the dose was swallowed; this procedure took only a few seconds. Immediately, the straw was pushed into the bottle, which was capped and weighed again to ascertain the amount of labelled water ingested by the subject.

Sample collection

Each subject provided a specimen of his second micturition of the day before receiving the dose of doubly-labelled water. This pre-dose sample served as a measure of the background levels of enrichment of the two isotopes for each subject. The subjects returned to provide a further sample of urine between 4 and 6 h after receiving the labelled water. Not all subjects returned to the laboratory on every occasion, and this has been taken into account in the subsequent analysis of the data. The subjects were asked to come to the laboratory to provide a sample of their second micturition on each of the next 10 consecutive days. Again, they did not always do this. Every attempt was made to track down 'missing' subjects but occasionally they had gone away for a few days. Nonetheless, the collections were mostly complete. All samples of urine were obtained by direct passage into a pre-labelled, Sterilin plastic screw-top 25 ml container. Upon receipt of samples in the laboratory, three subsamples of approximately 3·5 ml each were taken by pipette into plastic screw-top 5 ml containers. The containers were labelled and stored at $-20°$, as were the original containers. Two subsamples of each sample were air-freighted to Cambridge for analysis. Unfortunately, some of the subsamples from the April measurements were lost somewhere between Keneba and Cambridge, which influenced the method of analysis chosen for these subsamples.

Measurement of isotope enrichment

The levels of enrichment of the two isotopes in the samples were measured by isotope-ratio mass spectrometry. Different mass spectrometers give different absolute values for the isotopic enrichment of a particular sample. Therefore, observed values are related to international standards. All the enrichment values in this work were in units of $\delta‰$ relative to standard mean ocean water (International Dietary Energy Consultancy Group, 1990). Every analytical batch of samples included a sample of the appropriate diluted dose.

^{18}O was measured with a VG Sira 10 instrument (VG Instruments, Middlewich, Cheshire) for the samples collected in January, July and October, and these values have been used in the analysis of data. ^{2}H and ^{18}O were measured with the VG Aqua Sira instrument for all samples. All these ^{2}H values and the ^{18}O values for the April samples were used in the analysis of data.

RESULTS

The diet

The success of any study of food intake depends on accurate knowledge of the diet, and of the habits and customs associated with the cooking, distribution and eating of food. The approach used in the present work was to record detailed qualitative and quantitative data for the ingredients used in each cooked meal. Average food table values for the energy content of each ingredient (Table 1) were used to calculate the energy content of each meal. At first sight, the diet in Keneba is fairly monotonous, but the variety in the diet is provided by the sauces. Tia durango, a sauce made with roasted groundnuts, is the preferred sauce and is usually replaced by leaf sauces only when stocks of groundnuts are exhausted, so that there are seasonal changes in the nature of the diet (Hudson & Day, 1989). In the present study, every ingredient was identified, weighed and recorded during the preparation of each meal studied. The same information can be used for the calculation of any nutrient of interest if compositional data are available for the ingredients, and such values exist for many of the individual components of the diet described here, none of which is unique to Keneba (Platt, 1962; Paul & Southgate, 1978).

Most families cooked only two meals per day, with surplus from the evening meal being eaten the following morning. Richer families may have food items such as locally baked bread and milk, often soured, for breakfast. Each cooked meal usually consists of a cereal staple and a sauce. Fish or, more rarely, meat may be included in the meal.

No attempt was made to measure snack foods, and so no data for foods like raw fruit, raw carrots, raw groundnuts, dempetengo (parched rice cooked in the fields during the rice harvest) or roast maize cobs were obtained. These types of food are available only seasonally. The diet in Keneba has changed considerably over a decade and continues to do so. The most striking change is in the percentage frequency consumption of rice (Table 2), which represented less than 50% of all cereals in 1981 but more than 90% in 1987 and 1988. This is a reflection of the year-round availability of aid rice and the villagers' ability to buy it. Findo, a cultivated grass known as 'hungry millet', has disappeared from the diet.

Staples

Table 3 shows the average weights of raw staple used per meal in 1987, 1988 and 1989. Crude estimates of the amounts of staple used by a family in a year can be made from these figures. For example: rice represents 85·44% of the staples by frequency; 85·44% of a year is approximately 312 d; the grand mean amount of rice per meal is 1·337 kg; so, the 'average family', consuming two meals per day, eats approximately 834 kg rice/year.

Table 2. *Percentage frequency of occurrence of six staples in the diet of West African villagers**

Staple	1981	1987	1988	1989
Rice (*Oryza sativa*)	47·2	91·0	90·6	78·7
Sorghum (*Sorghum gambicum/margaritiferum*)	14·0	4·5	0·9	1·4
Sanyo† (*Pennisetum typhoideum*)	12·2	2·5	4·4	13·2
Findo† (*Digitaria exilis*)	7·6	—	—	—
Maize (*Zea mays*)	3·1	1·2	3·7	3·7
Cassava (*Mannihot esculenta*)	2·1	—	—	0·1
Other	13·8	0·8	0·4	2·9

* Data for 1981 and 1987 are for Keneba and the neighbouring villages of Kanton Kunda and Manduar; those for 1988 and 1989 are for Keneba only.
† Type of millet.

Table 3. *Mean weights (kg) of raw staple per meal eaten by West African villagers**

	1987		1988		1989	
Staple	*n*†	Mean wt	*n*†	Mean wt	*n*†	Mean wt
Rice (*Oryza sativa*)	446	1·28	518	1·38	656	1·35
Sorghum (*Sorghum gambicum/margaritiferum*)	22	1·04	5	1·60	12	1·35
Sanyo millet (*Pennisetum typhoideum*)	12	1·09	25	1·50	110	1·87
Suno millet (*Pennisetum gambiense*)	2	1·33	2	2·53	—	—
Maize (*Zea mays*)	6	0·39	21	1·53	50	1·94
Cassava (*Manihot esculenta*)	—	—	—	—	1	0·93
Rice/cassava	1	1·08	—	—	—	—
Rice/maize	—	—	—	—	5	1·47
Sorghum/maize	1	1·17	1	4·01	—	—

* Average values are given here; the family size ranged from two adults plus two children to five adults plus eight children (child $\leqslant$ 16 years).
† Number of meals per year based on each staple.

As well as the ingredients in sauces, some items are added as the staple is cooked. These too were weighed and recorded. A summary of these data is given in Table 4.

Sauces

There are five types of sauce: (1) those made with groundnuts, tia durango being the commonest type of groundnut sauce; (2) sauces made with leaves; (3) bukolo (flour sauce) consists of little other than flour, salt, chilli and water, and is usually made only in the dry season when supplies of other ingredients have run out and fresh leaves are not available; (4) suss tulo (oil stew) is cooked more rarely because oil is expensive; (5) dajiwo is not a proper sauce but is the name used for water that something, commonly fish or pumpkin, has been cooked in (jio is Mandinka for water). Dajiwo is often added to futo dishes. Futo is steamed grain, usually sorghum, with a water content of about 40% and either water or sauce must be added to make it palatable. The percentage frequency of sauces recorded over 3 years is given in Table 5, and the frequency of observation and average weights of ingredients used in sauces over the 3 years 1987 to 1989 are given in Table 6. Table 7 shows the percentage frequencies of fish eaten in the 3 years 1987 to 1989.

Table 4. *Mean weights* (Wt_{av}*; g*) *of additions to staple foods used by West African villagers**†

	1987		1988		1989	
	Wt_{av}	*n*‡	Wt_{av}	*n*‡	Wt_{av}	*n*‡
Additions to sorghum		(22)		(5)		(12)
Dry baobab leaves	65	13	71	4	62	5
Additions to maize		(6)		(21)		(50)
Baobab flesh	56	2	—	—	739	2
Dry baobab leaves	40	1	68	11	75	29
Raw groundnuts	—	—	—	—	260	1
Roast groundnuts	—	—	—	—	190	1
Additions to rice		(446)		(518)		(656)
Bitter tomato	120	1	198	2	—	—
Chilli pepper, dry	9	27	8	21	8	18
Chilli pepper, fresh	11	7	15	2	20	17
Onion	46	5	40	6	59	7
Onion leaves	19	2	10	3	—	—
Raw groundnuts	241	48	253	58	263	54
Roast groundnuts	217	10	195	1	240	1
Spring onion	18	6	26	1	44	2
Sweet pepper	29	1	—	—	—	—
Tomato	120	1	—	—	—	—
Locust beans	—	—	36	1	—	—
Okra	—	—	—	—	100	1
Additions to sanyo millet		(12)		(25)		(110)
Baobab leaves, dry	43	2	64	15	69	66
Baobab leaves, fresh	109	1	—	—	—	—
Bene leaves (*Sesamum indicum*)	32	1	—	—	—	—
Chilli pepper, dry	—	—	—	—	7	2
Onion leaves	—	—	—	—	41	1
Raw groundnuts	160	1	—	—	294	2

* Average values are given here; the family size ranged from two adults plus two children to five adults plus eight children (child ≤ 16 years).

† For details of foods, see Table 1.

‡ Number of meals from which Wt_{av} was calculated. The values in parentheses are the total numbers of such meals in the database.

Table 5. *Percentage frequency of consumption of various sauces by West African villagers*

Sauce*	1987	1988	1989
Bukulo	5·1	10·8	15·6
Dajiwo	1·7	4·4	5·9
Domoda	14·8	12·9	12·9
Jambo	13·1	9·3	11·5
Suss tulo	14·4	11·6	5·0
Tia durango	50·9	51·0	49·1
Total number	411	473	697

* Bukulo, flour sauce; dajiwo, thin sauce; domoda, sour-leaf sauce; jambo, leaf sauce; suss tulo, oil sauce; tia durango, groundnut sauce. For further details, see p. 557.

Table 6. *Ingredients occurring in sauces consumed by West African villagers between 1987 and 1989**

Ingredient	Wt_{av}(g)†	*n*‡
1. Groundnut sauce (tia durango)		
Aubergine	279	12
Baobab leaves, fresh	5	2
dry	9	85
Baobab milk	1310	1
Bitter tomato	198	39
Bosingo (shellfish)	225	4
Cabbage	287	6
Cassava	239	1
Challo§	251	15
Chilli pepper, dry	8	336
fresh	14	98
Fish, dry	40	71
smoked	92	13
unspecified	268	3
Furundingo§	355	3
Tambajango§	17	1
Groundnuts, raw	256	54
roast	242	552
Kucha leaves	76	6
Lime, fresh	27	1
Locust bean	48	7
Maggi cube	9	268
Maize flour	72	18
Maize/rice flour	27	1
Maize/suno flour	17	1
Meat	375	8
Okra	35	13
Onion, large	50	8
leaves	15	8
spring	36	34
Palm oil	20	142
Pumpkin	375	2
Rice flour	57	209
Rice/sorghum flour	33	1
Salt	20	527
Sanyo flour	68	104
Sorghum flour	50	43
Sorrel fruit (*Hibiscus* sp.)	4	3
Sugar	138	1
Suno flour	43	8
Sweet pepper	31	29
Tomato paste	38	373
Tomato, fresh	261	171
2. Sour-leaf sauces (domoda)		
Aubergine	397	2
Baobab leaves, fresh	16	1
dry	10	21
Bitter tomato	317	8
Chilli pepper, dry	10	68
fresh	21	23
Fish, dry	36	33
smoked	50	2
Challo§	32	3
Furundingo§	481	2
Groundnuts, roast	196	1
Sweet pepper	18	2
Tomato	185	7
Tomato paste	38	17
Wheat flour	64	1
3. Leaf sauces (jambo)		
Aubergine	160	2
Bitter tomato	189	7
Cabbage	531	6
Cassava leaves	325	4
Chilli pepper, dry	9	69
fresh	15	25
Fish, dry	52	11
smoked	49	3
Challo§	206	8
Furundingo§	29	1
Groundnuts, raw	323	111
roast	320	8
Jambanduro	698	30
Leaves (any)	746	10
Locust bean	16	1
Maggi cube	9	30
Maize flour	203	1
Morongo leaves	649	59
Nebedayo leaves	422	12
Okra	324	3
Okra leaves	38	1
Onion, large	63	27
leaves	40	12
spring	43	31
Palm oil	7	193
Pumpkin	1292	2
Rice flour	39	1
Salt	25	122
Sorghum flour	30	1
Sora leaves	486	2
Sweet pepper	286	7
Tomato paste	22	1
Wheat flour	590	1
4. Oil stews (suss tulo)		
Aubergine	239	14
Bitter tomato	148	11
Black pepper	3	14
Cabbage	362	7
Cassava	225	4
Chilli pepper, dry	9	77
fresh	24	28
Fish, dry	48	4
unspecified	793	2
Challo§	291	3
Furundingo§	380	1
Groundnut oil	56	357
Groundnuts, raw	342	1
Leaves (any)	449	1
Locust bean	30	3
Maggi cube	10	54
Morongo leaves	478	1

Table 6. (*cont.*)

Ingredient	Wt_{av}(g)†	n‡	Ingredient	Wt_{av}(g)†	n‡
Kucha leaves	248	122	Okra	375	6
Locust bean	34	12	Onion, large	95	71
Maggi cube	9	57	leaves	4	3
Maize flour	51	10	spring	78	37
Maize/rice flour	12	1	Palm oil	24	327
Okra	114	22	Pumpkin	473	6
Onion, large	48	3	Salt	21	104
spring	21	2	Sweet pepper	154	13
Palm oil	6	122	Tomato	250	27
Rice flour	49	18	Tomato paste	53	105
Salt	16	102	Vegetable oil	26	300
Sanyo flour	26	4			
Sorghum flour	34	8			
Suno flour	25	1			

* For details of foods, see Table 1.
† Average weight of the ingredient used in the sauce (g).
‡ Number of meals from which Wt_{av} was calculated.
§ Type of fish.

Table 7. *Percentage frequency of fish in the diet of West African villagers*

Type	1987	1988	1989
Catfish	0·7	—	—
Challo	36·7	40·7	35·2
Fetta	0·7	—	—
Furundingo	43·2	32·5	49·1
Kujalo	5·6	4·1	0·5
Mafe jaro	0·7	1·6	0·5
Patamo	1·4	—	0·5
Tambajango	0·7	5·7	3·7
Taro	2·1	4·1	—
Unspecified	7·9	11·4	10·6
n*	139	123	216

* Number of meals that included the fish.

Measurement of total energy expenditure by the doubly-labelled water method

Validity of the data. The quality of the data obtained from the doubly-labelled water studies of total energy expenditure reported here may be judged following the recommendations of the International Dietary Energy Consultancy Group (IDECG) of the International Atomic Energy Agency (IDECG, 1990).

Ratio of the isotope distribution spaces. Total body water space may be estimated from the y intercept of a least-squares fit for the regression of ln isotope enrichment *v.* time. The space determined from the data for the ^2H isotope (N_D) is always larger than that obtained from the data for the ^{18}O isotope (N_O). The ratio of the two values N_D/N_O is characteristically 1·03 ($\pm$0·02), and the IDECG (1990) recommend that any data for which N_D/N_O is outside the range 1·015 to 1·06 should be treated with scepticism.

Coward (1988) published values for the ratio of the isotope distribution spaces in a

Table 8. *Variation in background levels of enrichment of ^{18}O measured in the urine of West African villagers*

	January		July		October	
Subject...	A	B	C	B	E	F
	−0·515	−2·542	−2·470	−2·967	−2·504	−2·858
	−0·560	−2·724	−2·494	−2·123	−2·309	−3·183
	−0·768	−2·612	−2·440	−2·613	−2·784	−3·541
	−0·704	−2·537	−3·040	—	1·495	−2·672
	−0·637	−2·640	−3·024	−2·807	−2·499	−2·741
	+0·364	−2·918	−2·461	−2·683	−2·050	−3·632
	−0·518	−2·683	−2·058	−2·420	−2·178	−3·461
	−0·487	−2·488	−2·274	−1·453	−3·086	−3·238
	−0·307	−2·685	−2·754	−2·224	−2·512	−3·639
	−0·476	−2·896	−1·397	−2·266	−3·382	−3·785
	—	—	−1·997	−2·482	−3·344	−2·934
Mean	−0·461	−2·673	−2·397	−2·404	−2·558	−3·244
SD	0·317	0·144	0·474	0·427	0·568	0·395

variety of subjects with an average value for the ^{2}H distribution space:^{18}O distribution space ratio of about 1·035. Values for the standard deviation ranged from 0·009 to 0·013 for seven groups of subjects but were 0·020 for Cambridge infants of less than 6 months and 0·024 for Gambian men, two groups where water turnover rates are high. The data from The Gambia are taken from a study of men who were road-building in Keneba (Diaz *et al.* 1990). This large value of the standard deviation has been suggested as possibly the result of large changes in day-to-day background levels of enrichment of the two isotopes. If these variations existed they would influence the results obtained from the mathematical model used by Coward (1988), since that model makes a correction for background levels of enrichment for the two isotopes from measurement of the pre-dose sample but then assumes that they are constant throughout the measurement period. The ^{18}O enrichment values were measured for samples collected from the controls in January, July and October, and the assumption was made that any variation in levels would be covariant for the two isotopes. Values obtained on consecutive days for two subjects at each measurement period are given as examples in Table 8, and they suggest that day-to-day variation in background enrichment levels is small.

Table 9 shows the values obtained for the ratio of isotope distribution spaces in these studies. Not all the values meet the IDECG criterion of > 1·015 and < 1·06. In particular, the studies done in July yielded N_D/N_O values ranging from 1·06 to 1·11 for five of the seven subjects. There is no obvious reason why this should be so. Recalculation of the data for all seven subjects in July after removal of paired ^{18}O and ^{2}H values that did not differ from the fitted lines in a covariant manner resulted in an improvement for three subjects, no difference for one, and even more deviant values for the other three (results not shown).

If the twenty-one values for January, April and October are considered together then one value would be rejected because it is considerably greater than 1·03+0·02. The mean value for the remaining twenty studies is 1·0325 (SD 0·017). However, when all twenty-eight studies are included the mean is 1·049 (SD 0·036). Except for the one 'rejected' value in October, all the 'noise' comes from the values obtained in July, for which the mean is 1·09 (SD 0·038); the values range from 1·03 to 1·14. The data have been scrutinized extremely carefully and there is no evidence for a methodological error.

Table 9. *Ratios of isotope distribution spaces in studies of subjects in a West African village**

Subject	January	April	July	October
1	1·02	1·05	1·09	1·13
2	1·05	1·04	1·05	1·01
3	—	1·04	1·03	1·00
4	1·05	1·03	1·11	1·02
5	1·02	1·03	1·11	1·03
6	1·02	1·06	1·14	1·03
7	1·03	—	—	—
8	1·06	1·05	1·07	1·01
		Mean	SD	*n*
Jan+Apr+(Oct – Subject 1)		1·03	0·017	20
All data		1·05	0·036	28
July alone		1·09	0·038	7

* For details, see pp. 560–561.

The implication is that there may be an explanation in physiological terms. Values for N_D/N_O of the order of 1·05 could be expected if there is some physiological mechanism associated with physical exercise whereby deuterium is depleted from the body more rapidly than the ^{18}O isotope. It has been suggested that increased muscular activity leads to higher protein turnover with a concomitant increase in exposure of H atoms for exchange. This is more plausible than the postulate that there is an increase in the pool of exchangeable H atoms in the body at this particular time of year of sufficient magnitude to account for the observed values. However, if the phenomenon of increased protein turnover leads to such values it is curious that they were not seen by Diaz *et al.* (1990) in their studies of men who were engaged in road-building.

Residuals of the disappearance curves. The residuals, the differences between observed values and the line of best fit for the regression of ln isotope enrichment values *v.* time, should be small and covariant; i.e. the sign of the residual should be the same for both isotopes at each time point. The majority of the data, including the July data that lead to peculiar N_D/N_O values, fulfil these criteria. A few residuals were unacceptably large and were omitted from the calculations but there was little evidence for non-covariance in any of the data sets. Figs 1 and 2 show the fits and the residuals for a subject in April, using all the samples for the calculations (Fig. 1), and using just three early and three late time points (Fig. 2) as recommended by Coward (1988). The same analyses and calculations were done for a second subject (results not shown). Essentially the same plots result whether eleven or six data points are used. These data are typical of all the data obtained, except for the unexplained large values for the ratio of water spaces found in July. Once these data were available it was considered reasonable to measure only the first three and last three samples for all other subjects.

Ratios and residuals. A good fit with small residuals for the regression of ln N_D/N_O *v.* time indicates relatively constant rates of CO_2 production and adequate analytical technique. Figs 1(*c*) and 2(*c*) illustrate the fit for the ln ratio values *v.* time and Figs 1(*d*) and 2(*d*) show the residuals for these plots. The fits are good and the residuals are small. The N_D/N_O value is indicated directly as the *y*-intercept of the enrichment ratio plot *v.* time; e.g. an intercept of +0·03 on the logarithmic scale is equivalent to $N_D/N_O = 1{\cdot}03$.

Products and residuals. Examination of the plots for ln enrichment *v.* time provides

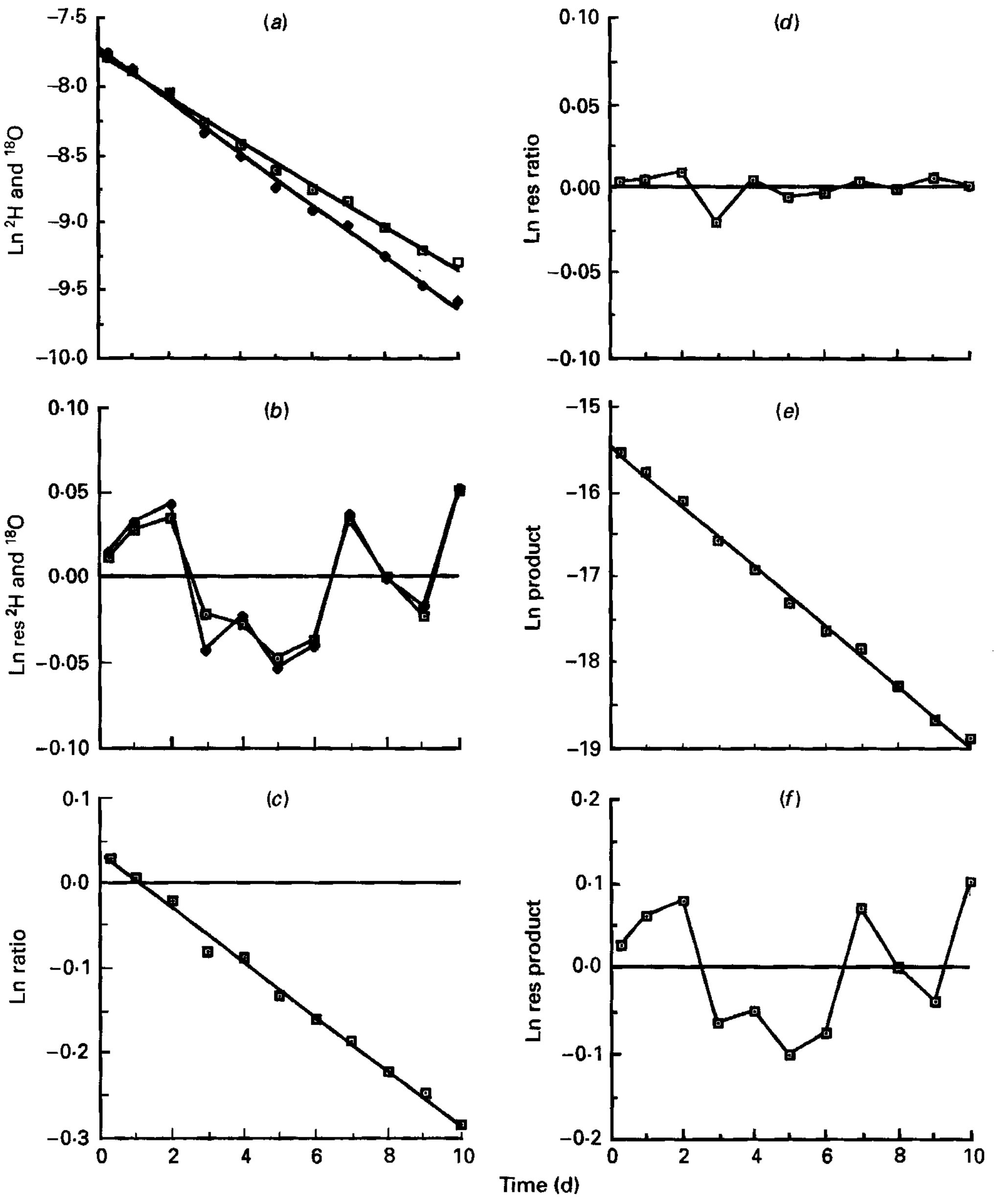

Fig. 1. (*a*) Subject 1, all data. A plot of ln ^{2}H enrichment (□) and of ln ^{18}O enrichment (◆) against time, and the least-squares linear fit for each. (*b*) Subject 1, all data. The residuals (res) from the fitted line for ln ^{2}H and ln ^{18}O enrichment, illustrating the covariance of the deviations. (*c*) Subject 1, all data. A plot of the ratio of the values for ln ^{2}H and ln ^{18}O enrichment, and the least-squares linear fit. (*d*) Subject 1, all data. A plot of the residuals (res) for the deviations from the fitted line for the ratio of the values for ln ^{2}H and ln ^{18}O enrichment. (*e*) Subject 1, all data. A plot of the product of the values for ln ^{2}H and ln ^{18}O enrichment, and the least-squares linear fit. (*f*) Subject 1, all data. A plot of the residuals for the deviation from the fitted line for the product of the values for ln ^{2}H and ln ^{18}O enrichment.

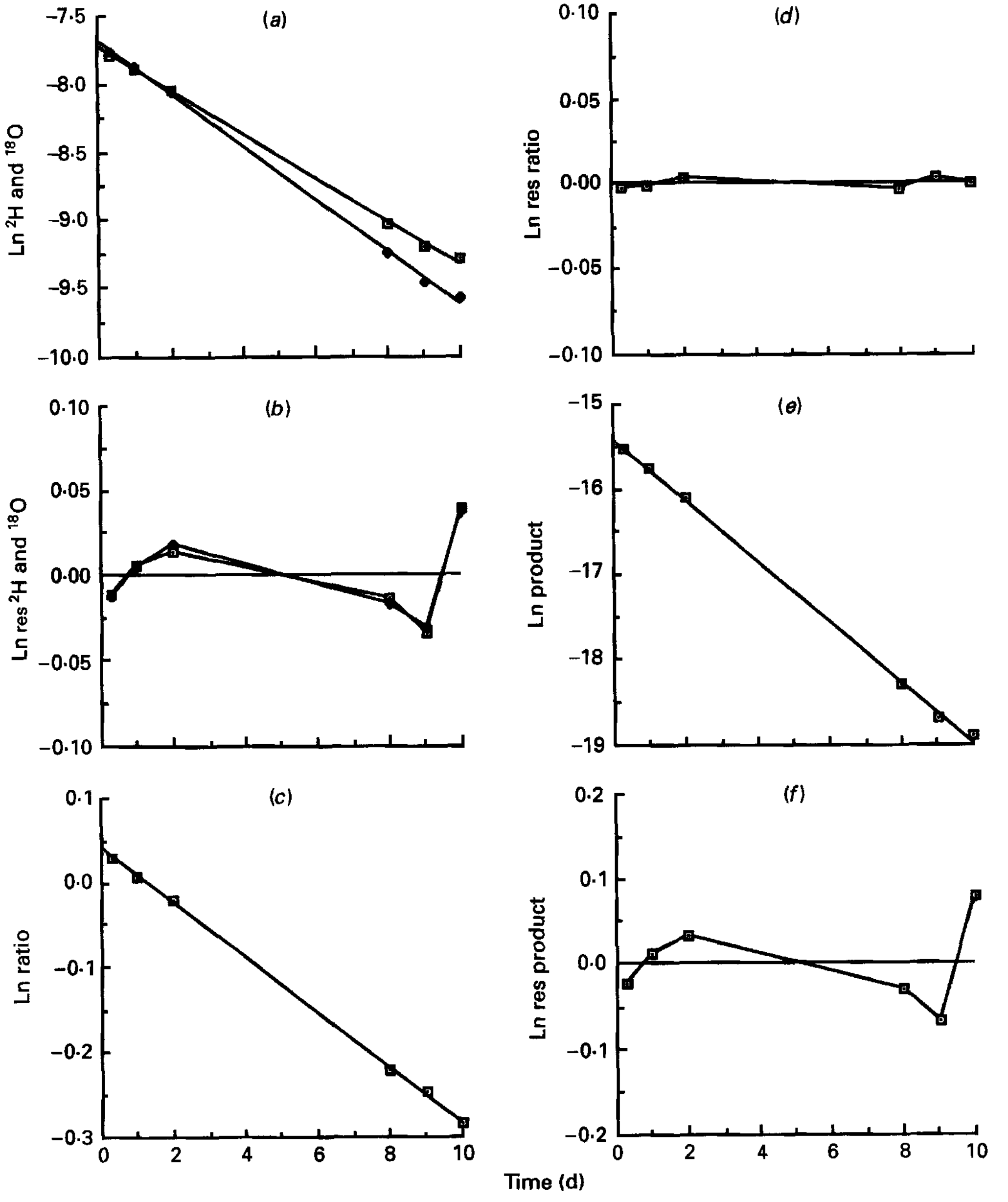

Fig. 2. (*a*) Subject 1, restricted data. A plot of the values for ln ^{2}H enrichment (□) and ln ^{18}O enrichment (◆) against time, and the least-squares linear fit for each. (*b*) Subject 1, restricted data. A plot of the residuals (res) from the fitted lines for ln ^{2}H and ln ^{18}O enrichment, illustrating the covariance of the deviations. (*c*) Subject 1, restricted data. A plot of the ratio of the values for ln ^{2}H and ln ^{18}O enrichment, and the least-squares linear fit. (*d*) Subject 1, restricted data. A plot of the residuals (res) for the deviations from the fitted line for the ratio of the values for ln ^{2}H and ln ^{18}O enrichment. (*e*) Subject 1, restricted data. A plot of the product of the ln ^{2}H and ln ^{18}O enrichment values, and the least-squares linear fit. (*f*) Subject 1, restricted data. A plot of the residuals for the deviation from the fitted line for the product of the values for ln ^{2}H and ln ^{18}O enrichment.

Table 10. *Average energy expenditure and intake for seven men in a West African village during 1989*

	TEE (MJ/d)	Intake (MJ/d)	Intake (% TEE)	Body wt (kg)
Jan	10·3	8·3	80·2	57·5
Apr	11·2	9·0	80·4	57·6
Jul	9·9*	7·9	79·7	57·1
Oct	14·0	8·4	60·3	56·5

TEE, total energy expenditure.
* See p. 566.

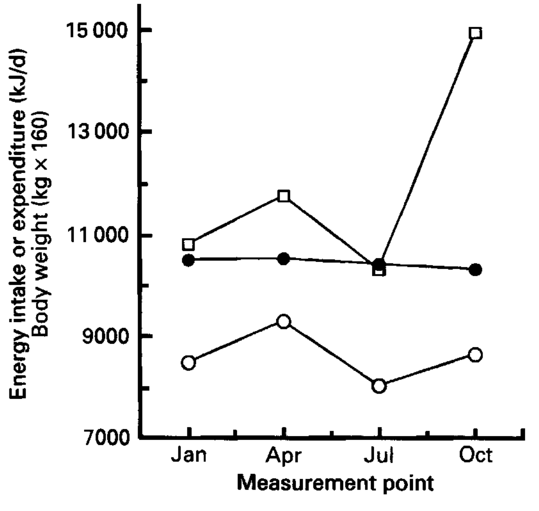

Fig. 3. The relation between the average values for total energy expenditure (□), energy intake (○) and body weight (●) for men in a West African village in January, April, July and October 1989. (The body weights are multiplied by 160 for convenience of plotting on a common *y*-axis.)

information about rates of water turnover. A good fit to the line with small residuals indicates the absence of fluctuations in water turnover. Figs 1(*f*) and 2(*f*) show that the residuals here are quite large. This will not necessarily affect the calculations of total energy expenditure (TEE) since the CO_2 production rates are relatively constant, as shown by the ratio plots, but could result in bias in the calculation of body water space if the intercept is very different from that predicted from the early points. In general, the data obtained in these studies are satisfactory as judged by these criteria.

Compatibility of the observed values for energy intake and expenditure

The measurements of TEE were intended to serve, at least in part, as reference values for the estimates of energy intakes. Here, the average values for TEE, intake and body weight are used to judge the success of the methodology used for estimating energy intakes.

Table 10 shows the average values for TEE measured for seven adult male subjects, the average values estimated for the energy intake of men, both as absolute values and as a

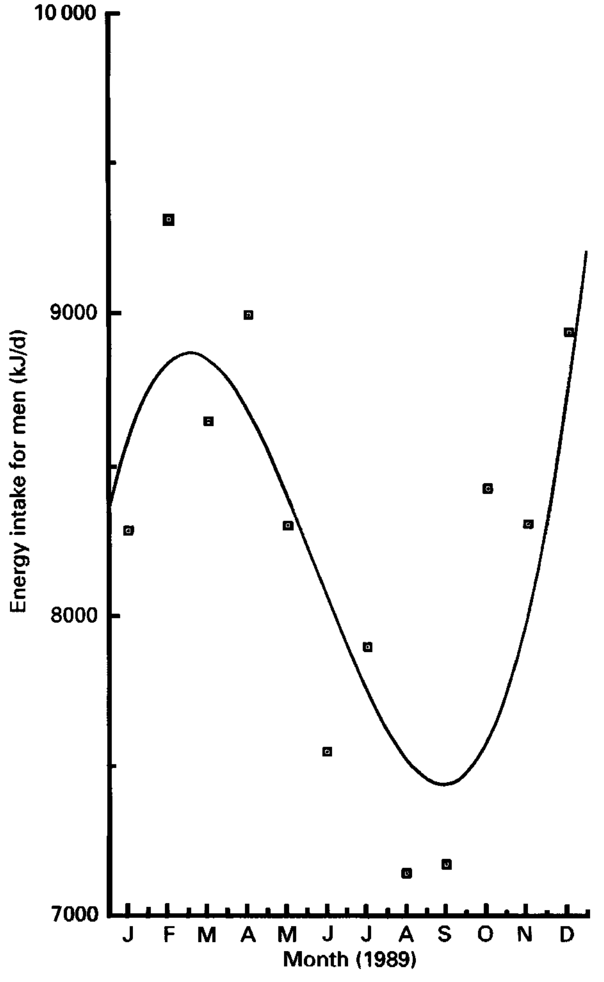

Fig. 4. Seasonal changes in dietary energy intake by men in a West African village, with the best-fit, third-degree polynomial.

percentage of the appropriate TEE value, and the average body weight recorded for all adult males between the ages of 20 and 60 years in January, April, July and October 1989.

The intake values are 80% of the TEE values in January and April, and there is no change in body weight. The same percentage is recorded for the data obtained in July but the TEE value is shown in italic type as a reminder of the discussion of the validity of this value. Nonetheless, the TEE values for January, April and July are similar. There is a marked increase in TEE in October, the value is 30% higher than the average value for January and April. The value for energy intake in October is not very different from that for the other time points and, as a result, is only 60% of TEE. However, the average body weight has decreased by 1 kg from the values recorded in January and April, suggesting that the increase in TEE has resulted in a decrease in body weight in the absence of an increase in energy intake. The relation is illustrated by Fig. 3.

The data for men in 1989 are illustrated by Fig. 4. The data are well described by a third-degree polynomial, emphasizing the seasonal changes. The average values, over all families, in 1987, 1988 and 1989 are given in Table 11.

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Table 11. *Calculated energy intakes (MJ/d) from cooked food by men (M), women (W), boys (≤ 16 years; B) and girls (≤ 16 years; G) in a West African village in the years 1987–1989*

	1987					1988					1989			
	M	W	B	G		M	W	B	G		M	W	B	G
Feb	6·7	5·0	3·5	2·9	Mar	8·0	6·0	3·3	2·9	Jan	8·3	6·8	4·4	3·5
Mar	7·7	7·0	4·8	4·8	Apr	7·4	5·5	2·8	2·8	Feb	9·3	6·1	4·1	3·5
Apr	6·4	6·4	3·4	3·2	May	9·1	5·9	3·4	3·0	Mar	8·6	6·5	3·8	3·3
May*	*5·0*	*3·5*	*3·7*	*3·1*	Jun	7·6	6·0	3·0	2·6	Apr	9·0	7·8	5·0	3·3
Jun	7·7	6·4	4·3	3·0	Jul	8·7	6·1	3·9	3·4	May	8·3	6·0	4·0	3·0
Jul	8·1	6·6	4·0	3·3	Aug	7·9	6·2	3·1	2·5	Jul	7·9	5·8	3·2	2·9
Aug	8·6	6·6	4·1	3·3	Sep	8·8	6·6	3·9	3·1	Aug	7·1	6·5	3·4	2·9
Sep	7·7	6·5	3·7	3·2	Oct	8·9	6·2	3·0	2·4	Sep	7·2	6·0	4·2	3·2
Oct	7·9	6·9	3·6	3·1	Nov	8·2	5·4	4·1	3·0	Oct	8·4	6·5	4·1	3·0
Nov	6·8	5·6	3·8	3·4	Dec	8·7	6·5	3·8	3·0	Dec	8·9	6·1	3·3	3·0

* Ramadan; values shown in italics are for the evening meal only. The April and May values for 1988 and 1989 are for only the non-Ramadan days in those months.

DISCUSSION

Measurement of total energy expenditure with doubly-labelled water

The doubly-labelled water (DLW) method for the measurement of TEE has been developed for use with free-living human subjects on the basis of a model proposed by Lifson & McClintock (1966). Subjects receive a dose of water that is enriched, relative to background, for the two naturally occurring stable isotopes ^{2}H and ^{18}O. The subsequent collection and analysis of body fluid, usually urine, from the subject over a period of time (10–14 d for adult humans) allows the rates of loss of ^{2}H and ^{18}O from the body to be determined. In the model it is assumed: (1) that the isotopes ^{2}H and ^{18}O label body water, and are lost from body water, as if it is a single compartment; and (2) that ^{2}H is lost from the body only as water but that ^{18}O is lost from the body both as water and as CO_2. As a result, the rate of disappearance of ^{18}O from the body is greater than that for ^{2}H, and the difference between the rates of loss is a measure of CO_2 production, which is related to energy expenditure. Underlying the mathematics of the model are three further assumptions: (1) total body water, and output rates of water and of CO_2 are constant; (2) water and CO_2 losses occur with the same enrichment as that coexisting in body water; and (3) background isotope intake rates are constant. If all these assumptions were demonstrated to be true then it would be a simple matter to determine TEE with great accuracy. However, none of the assumptions is true. Coward & Cole (1991) have presented a detailed examination of the likely magnitude of error in the calculated value of TEE contributed by the deviations from these assumptions encountered *in vivo* and concluded '... likely errors can be fairly well assessed for most conceivable subjects and environmental circumstances. Provided this is done, estimates of energy expenditure using double labelled water should prove reliable.'

To provide a reference for the measurements of energy intakes in the present study, seven adult males were recruited for the measurement of TEE by the doubly-labelled water method. Measurements were made on four occasions in 1989 at approximately 3-monthly intervals. A further seven adult males were recruited on each occasion to provide daily samples of urine during the measurement periods as controls for fluctuations in background enrichments.

The methodology developed and applied in these studies yields values for dietary energy intake that are of the order of 80% of values obtained for TEE. This is a highly satisfactory result, since no attempt was made to measure any source of energy intake other than that supplied by two cooked meals per day. This value should be compared with the results reported by Singh *et al.* (1988), who applied the methodology previously used in this community for measuring total food intake and the doubly-labelled water technique for the measurement of TEE. They obtained values for total dietary energy intake that were of the order of only 50% of their values for TEE.

The problem remains of the validation of the intake data. In a study of methodology, Kretsch & Fong (1990) stated 'To validate dietary intake methodology, it is necessary to obtain an independent measure of actual intake. Because this is virtually impossible under field conditions,...' and their solution was to compare methods with subjects living in a calorimeter for 16 consecutive days. In the studies described here the doubly-labelled water technique was used to provide values for TEE over 11 consecutive days, which have been used as an indirect reference for energy intake. The suggestion is made here that the energy intake values recorded are of the order of 80% of true intake. When energy expenditure rose during the farming season the estimated intake was of the order of 60% of expenditure. However, body weight loss was recorded at that time, so the value of 80% of true intake may well be applicable throughout the year. No attempt was made to measure food intake at any time other than at the midday and the evening meals. There are several possible sources of error in these estimations of food intake. For example: (1) the distribution algorithm may be inappropriate. (2) Special meals and/or amounts of food may have been prepared because the cook was under observation. (3) A great deal of food may have been consumed at breakfast or away from the home. (4) Incorrect values for the energy content of foods may have been used in the calculations of intake.

(1) Distribution algorithm: the appropriateness of the algorithm can be judged only by the results obtained; there is no gold standard. Nonetheless, the values obtained by its application are entirely reasonable and in keeping with the subjects' body weights. (2) Given the limited resources and availability of food in this community, it is extremely unlikely that atypical meals were cooked. The food intake of a group of people was studied, not that of an individual, so the preparation and consumption of atypical meals at the two main meal times for the 4 consecutive days of each study period would have required a remarkable degree of co-operation and conspiracy. Further, any significant deviation from normal behaviour would have been noticed by the fieldworkers. (3) Given that the estimated energy intakes are of the order of 80% of TEE throughout much of the year, the consumption of amounts of food representing significantly more than the 'missing' 20% of energy intake would have resulted in weight gain. This was not observed. (4) The energy values for foods used for the calculation of energy intake were taken from a variety of sources, and some were derived, as discussed above. It is unlikely that the use of average compositional values would have introduced significant errors into the calculations.

CONCLUSION

Groups of people eating from a shared bowl of food is not a habit restricted to The Gambia, nor to West Africa. The methodology described here should be readily adaptable to other societies where this particular obstacle to measuring food intake exists. The algorithm used in the present work to estimate the distribution of food within a mixed sex and age group is likely to be appropriate in most circumstances, unless detailed knowledge of local customs suggests otherwise. A combination of the measurement of total energy expenditure by the doubly-labelled water technique and anthropometric data provides reference values to judge the accuracy of values obtained for dietary energy intakes.

The majority of the fieldwork was done by MRC Gambian fieldworkers as a team ably led by Mr Baba S. N. Jobarteh.

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