

Influence of urbanisation on physical activity and dietary changes in Huli-speaking population: a comparative study of village dwellers and migrants in urban settlements

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The influence of urbanisation on physical activity and dietary changes was examined in a Papua New Guinea Highland population. Adult male and female subjects (n 56) were selected, including twenty-seven rural villagers and twenty-nine urban migrants. BMR was calculated from values measured in similar samples of Huli-speaking population, according to gender and body weight. Total daily energy expenditure (TEE) was assessed by 24 h heart rate (HR) monitoring (flex-HR method) and physical activity level (PAL) calculation was based on BMR. Energy, protein and fat intakes were measured by weighing food on a single day. Urban subjects were heavier and taller than their rural counterparts; significant differences were found in stature in men ($P < 0.05$) and body weight in women ($P < 0.05$). Urban subjects had longer sedentary periods ($HR \leq \text{flex-HR}$) and shorter active periods ($HR > \text{flex-HR}$) than rural subjects. Consequently, the former had lower TEE and PAL than the latter; significant differences were found in women (TEE, $P < 0.05$, PAL, $P < 0.01$) but not in men. Total daily energy intake and TEE were well balanced ($< 7\%$) in all groups, whereas protein and fat intakes were considerably higher in urban subjects than rural subjects. Reduced PAL and increased fat intake by urban dwellers may increase the risks of obesity and chronic degenerative diseases.

Physical activity: Energy balance: Urbanisation

Non-communicable diseases such as obesity, diabetes and cardiovascular disorders have long been the main health problems in developed countries, while in recent decades the prevalence of these diseases and their antecedent risk factors have rapidly increased in developing countries, known as 'health transition' (Sinnott *et al.* 1992; Taylor *et al.* 1992; Hodge *et al.* 1996). These changes are caused to a large extent by Westernised dietary changes and a reduction in daily physical activity in relation to socio-economic and living environmental conditions (King & Collins, 1989; Dowse *et al.* 1994; Hodge *et al.* 1995).

Although a large number of studies have evaluated the dietary changes in various urban populations in developing countries, little is known about the physical activity levels (PAL) in these populations (Stein *et al.* 1988; Spurr *et al.* 1996). This situation is mainly due to the difficulties in measuring energy expenditure (EE), particularly total daily energy expenditure (TEE), in free-living situations (World Health Organization/Food and Agriculture Organization/

United Nations University (FAO/WHO/UNU), 1985; Durnin, 1990). In fact, there are only a few studies that have quantitatively compared the patterns of physical activity between urban and rural dwellers who shared the same genetic traits and cultural background (often seen in rural–urban migrants and rural residents of the same group). Such comparisons are useful for determining the effect of urbanisation.

The subjects of this study were Huli-speaking villagers in their homeland in Papua New Guinea (PNG) Highlands and their migrants who lived in settlements (i.e. spontaneously developed residential areas) in Port Moresby, the national capital city of PNG; field work was conducted from July to September in 1994 for the former and from July to September in 1995 for the latter. We monitored the heart rate (HR) and measured the amounts of all foods consumed among adult samples of the two groups. The aims of the study were: (1) comparison of nutritional status (body weight and BMI) between rural villagers and urban

Abbreviations: EE, energy expenditure; HR, heart rate; PAL, physical activity level; PNG, Papua New Guinea; TEE, total daily energy expenditure; TEI, total daily energy intake; WHO/FAO/UNU, World Health Organization/Food and Agriculture Organization/United Nations University.
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migrants; (2) comparison of daily PAL between the two groups, with special interest in possible reduction of physical activity in the migrant group; (3) comparison of energy and major nutrient (protein and fat) intakes between the two groups, with special emphasis on dietary changes by urbanisation.

Subjects and methods

Study populations

The Huli, one of the largest language groups in PNG, have inhabited the Tari basin located 1600 m above sea level between 142°70' and 143°30' east longitude and between 5°70' and 6°20' south latitude in the central part of Southern Highlands Province, PNG. They have subsisted on agriculture of sweet potatoes (*Ipomoea batatas*) and pig husbandry (Kuchikura, 1999; Umezaki *et al.* 1999; Yamauchi *et al.* 2000). Most migration of the Highlanders, including the Huli, to Port Moresby has progressively increased since the 1970s, particularly since the time of independence of PNG in 1975. Migrants from rural villages reside in settlements in Port Moresby by ethnic groups. The houses are built by the migrants themselves using second-hand or makeshift materials. Most of the migrants have not been able to obtain jobs in the formal sector, and thus have depended for their livelihood on income from informal sector jobs such as collection of empty bottles and selling of betel-nuts (nuts of *Areca catechu*), cigarettes and/or cooked meat in markets or settlements. The major socio-economic differences between the Huli rural and urban groups can be summarised as follows: (1) change in occupational activities from subsistence agriculture in rural villages to cash-earning work in urban settlements; (2) change in dietary pattern, represented by changes in staple foods from sweet potato and leafy greens in the former to purchased foods such as rice, tinned fish and lamb chops in the latter.

Subjects

Married men and women, fifty-six in total, volunteered to participate in the present study. They included twenty-seven villagers (fifteen men and twelve women) from two villages, and twenty-nine urban dwellers (fourteen men and fifteen women) from three settlements in Port Moresby. The rural subjects represented almost the entire adult populations of these two areas during the study period. The urban subjects were selected to match the age distribution of their village counterparts. All urban subjects were born and grew up in their homeland in the Tari basin. The average length of living in Port Moresby was 15 (range 0–35) years for men and 7.1 (1–20) years for women. In addition, the average ages of these individuals when they migrated to Port Moresby were 21.6 and 26.4 years for men and women respectively. Elderly subjects over 60 years and pregnant women were not sampled due to the difficulty of conducting the step test (see p. 66). Ten lactating women (four in the rural sample and six in the urban sample) were included in the present study; there were no problems in collecting data from them and so their records were

analysed without any special treatment. One of the authors (T.Y.) explained the purpose of the investigation to the participants in Tok Pisin (pidgin English, the lingua franca in PNG), with occasional assistance of interpreters.

Anthropometry

Before breakfast in the early morning, the body weight of each subject was measured using a portable scale with a precision of ± 0.1 kg. Stature was measured to the nearest 1 mm using a portable field anthropometer (GPM, Switzerland). For rural samples, stature data were collected from twenty subjects (eleven men and nine women) who participated in the food consumption survey conducted in January 1995. Unfortunately, height was not measured in the remaining seven subjects in the HR monitoring survey conducted between July and September 1994. Their stature, however, was on average not markedly different from that of the other twenty rural subjects.

Heart rate monitoring

Using a cardio-frequency meter (Vantage XL; Polar Electro, Kempele, Finland), HR of each subject was monitored for 24 h from about 18.00 hours to the same time on the following day for most subjects, or from early morning (from 06.00 to 08.00 hours) to the same time on the following morning for some urban subjects. The HR monitoring system consisted of an electrode-belt transmitter and a wrist microcomputer receiver, which digitised and stored the recorded pulse. This system was light (<100 g) and did not disturb the subject's behaviour. The pulse was recorded at 1 min intervals and the maximum recording capacity of the system was 2020 min. Some HR profiles were excluded from analysis due to faulty electrode contact. Subsequent analysis of the HR and behavioural data indicated that transmission problems, recognised as zero or spikes, occurred during both rest and exercise and were not specific to given activities (Panter-Brick *et al.* 1996; Yamauchi *et al.* 2000). The recordings in these short gaps were replaced with the average HR calculated from the data on either side of the gap (Leonard *et al.* 1995; Yamauchi *et al.* 2000).

Step test

On the day of investigation each subject was requested to do two different step tests (stepping-1 and stepping-2) following the author's instructions in Tok Pisin or Huli language. The duration of each step test was 3 min and the height of the step was 0.3 m. In stepping-1 and stepping-2 tests each subject stepped up and down at a constant pace of fifteen and thirty steps per min respectively. A metronome was used to achieve a steady-state condition for stepping exercises. The HR value in the final minute was used for analysis.

BMR, resting metabolic rate and energy cost of step test

BMR and EE at rest (lying, sitting and standing) and during step tests were determined based on the subject's body

weight, gender and the energy costs, which were measured in Huli-speaking individuals using the Douglas bag technique of indirect calorimetry (Douglas, 1911) on other occasions; the gender- and weight-specific BMR values used for estimation were 77.8 and 70.8 J/kg per min for rural (n 9) and urban (n 9) men respectively, and 75.8 and 66.5 J/kg per min for rural (n 7) and urban (n 8) women respectively (Yamauchi & Ohtsuka, 2000). Resting metabolic rates were determined as the mean of energy costs measured when lying, sitting and standing (Katzmarzyk *et al.* 1994; Leonard *et al.* 1995; Murayama & Ohtsuka, 1999).

Determination of flex-heart rate points and estimation of total energy expenditure

There is no standard procedure for determination of the flex-HR point which discriminates between resting and exercise HR values (Panter-Brick *et al.* 1996). In the present study, we used the method described previously by our laboratory (Yamauchi *et al.* 2000). Flex-HR was determined as the mean of the mean HR of the three resting activities (lying, sitting and standing) and the lowest HR during stepping exercise (i.e. stepping-1). The recorded HR values were then converted to energetic equivalents using each subject's EE v. HR regression line.

TEE was estimated by the flex-HR method (Spurr *et al.* 1988; Ceesay *et al.* 1989) and EE during sleeping was assumed to equal BMR (Goldberg *et al.* 1988). For HR values which were equal to and below the flex-HR point (i.e. 'sedentary' HR), the RMR determined as the mean EE values for lying, sitting and standing was assumed to represent their energy costs. Values above the flex-HR point ('active' HR) were converted to energy costs based on a regression line which was calibrated for each subject. The TEE was then calculated using the following formula:

$$\text{TEE} = \Sigma(\text{sleeping EE}) + \Sigma(\text{sedentary EE}) \\ + \Sigma(\text{active EE}).$$

PAL (TEE/BMR; James *et al.* 1988) was also determined. The use of PAL allows comparison of individuals of

different body size. PAL values are a universally accepted way of expressing EE and they help to convey an easily understandable concept (Ferro-Luzzi & Martino, 1996).

Dietary intake

Dietary consumption was studied for each subject on the same day as HR monitoring. All foods consumed were weighed with a portable beam scale or a spring scale before cooking throughout the daytime period. In addition, the subjects were asked in the morning about the types and amounts of foods consumed during the previous night. Sweet potatoes and green leaves, which were most frequently eaten in the villages, were sampled in the Huli villages and their food compositions were determined in the laboratory in Japan. For other foodstuffs, the energy and major nutrient contents were estimated using food composition tables of Hongo & Ohtsuka (1993) and other available data for PNG and the surrounding areas (Umezaki *et al.* 1999).

Statistical analysis

Data were expressed as means and standard deviations. Differences between groups were examined for statistical significance using the unpaired *t* test. $P < 0.05$ was considered significant.

Results

Table 1 shows the number of subjects listed by age-group and their physical characteristics. Since rural subjects did not know their exact age, they were categorised into three groups (20–30, 30–40 and >40 years) according to the census data of the PNG Institute of Medical Research (Tari branch) and the authors' interviews. Urban women, but not men, were significantly heavier than their rural counterparts ($P < 0.05$), while urban men were significantly taller than their rural counterparts ($P < 0.05$).

BMR, TEE, PAL and the level of work classified according to PAL (WHO/FAO/UNU, 1985) are presented in Table 2. No significant difference was found in BMR in

Table 1. Age distribution and physical characteristics of the Papua New Guinea Highland subjects participating in the study (Mean values and standard deviations)

Age-group (years)	Men				Women			
	Rural (n 15)		Urban (n 14)		Rural (n 12)		Urban (n 15)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
20–30	5 (33)†		3 (21)†		3 (25)†		7 (47)†	
30–40	7 (47)		7 (50)		5 (42)		6 (40)	
>40	3 (20)		4 (29)		4 (33)		2 (13)	
Age (years)	NA		36.1	10.0	NA		31.4	8.2
Weight (kg)	63.6	7.3	70	9.5	53.3	7.6	59.7*	6.4
Height (m)‡	1.58	0.03	1.63*	0.05	1.50	0.05	1.53	0.05
BMI (kg/m ²)‡	24.8	1.6	26.4	3.3	23.2	3.0	25.5	3.1

NA, not available.

Mean values were significantly different from those of rural subjects: * $P < 0.05$.

† Values in parentheses are the percentage of the total number of subjects for each group.

‡ Mean values for eleven rural men and nine rural women.

Table 2. BMR, total daily energy expenditure (TEE), physical activity level (PAL) and work level of men and women in rural and urban populations of Papua New Guinea†

	Men				Women			
	Rural (n 15)		Urban (n 14)		Rural (n 12)		Urban (n 15)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
BMR (MJ/d)	7.13	0.82	7.13	0.97	5.82	0.83	5.71	0.61
TEE (MJ/d)	13.13	2.12	12.20	2.01	11.04	2.60	9.31*	1.27
PAL	1.84	0.22	1.71	0.21	1.88	0.26	1.63**	0.19
Level of work‡	M–H		M		H		M	

Mean values were significantly different from those of rural women: * $P < 0.05$, ** $P < 0.01$.

† For details of subjects and procedures, see Table 1 and p. 66.

‡ Level of work classified according to PAL into light, moderate (M) and heavy (H) categories (World Health Organization/Food and Agriculture Organization/United Nations University, 1985).

either sex. In men there were no significant differences in TEE or PAL. In contrast, significant differences were found in these indices in women (TEE, $P < 0.05$, PAL, $P < 0.01$). According to the work levels of WHO/FAO/UNU (1985), PAL were moderate to heavy for rural men, moderate for urban men and women, and heavy for rural women. These results suggested that urban men and women were less active than their rural counterparts, although not significantly so for men.

Using flex-HR as the cut-off point, the recorded data (1440 min) were divided into three categories: sleeping, sedentary (HR \leq flex) and active (HR $>$ flex). The active category was further subdivided into 'moderately-active' (flex $<$ HR $\leq 1.2 \times$ flex) and 'highly-active' (HR $> 1.2 \times$ flex) (Table 3). The cut-off points (i.e. $1.2 \times$ flex) were determined by considering that the mean HR of lying down (the lowest intensity among the observed activities) was about 80 % flex-HR and the same rate (20 %) below or above the flex-HR point (i.e. 0.8 or $1.2 \times$ flex). There were considerable differences between rural subjects and urban subjects, and both men and women had a similar tendency in the pattern of their time allocation when rural subjects and urban subjects were compared. Data analysis showed that sedentary time was longer (men, $P < 0.05$, women,

$P < 0.005$) and active time shorter among women ($P < 0.005$) for urban subjects than for rural subjects. Urban men spent a shorter time sleeping (by 65 min, $P < 0.05$) than rural men, although the sleep time was identical in rural women and urban women.

PAL value was also divided into four categories, as described earlier, in order to compare the differences between rural and urban subjects (Fig. 1). Specifically:

$$\begin{aligned} \text{PAL} &= \text{TEE}/\text{BMR}, \\ &= ((\Sigma \text{sleeping EE}) + (\Sigma \text{sedentary EE}) \\ &\quad + (\Sigma \text{ACT-1 EE}) + (\Sigma \text{ACT-2 EE}))/\text{BMR}, \\ &= ((\Sigma \text{sleeping EE}/\text{BMR}) + (\Sigma \text{sedentary EE}/\text{BMR}) \\ &\quad + (\Sigma \text{ACT-1 EE}/\text{BMR}) \\ &\quad + (\Sigma \text{ACT-2 EE}/\text{BMR})), \\ &= \text{PAL}_{\text{sle}} + \text{PAL}_{\text{sed}} + \text{PAL}_{\text{ACT-1}} + \text{PAL}_{\text{ACT-2}}, \end{aligned}$$

where PAL_{sle} , PAL_{sed} , $\text{PAL}_{\text{ACT-1}}$, $\text{PAL}_{\text{ACT-2}}$ are the sleeping, sedentary, moderately-active and highly-active components respectively. As illustrated in Fig. 1, the active component of PAL (sum of $\text{PAL}_{\text{ACT-1}}$ and $\text{PAL}_{\text{ACT-2}}$) was lower in urban women than in rural women ($P < 0.05$), while the sedentary component (PAL_{sed}) was significantly higher in both urban men and women ($P < 0.05$).

Activity profiles (24 h) were compared for each 2 h period (00.01–02.00, 02.01–04.00, 04.01–06.00 hours, etc.), averaged minute-by-minute, to derive the physical exertion index, i.e. average HR value/flex-HR $\times 100$ (Yamauchi *et al.* 2000) for each 2 h period. This analysis was based on the presence of systematic and substantial gender differences in raw HR values. The average 24 h activity profiles for each sample are depicted in Fig. 2. Considerable differences between rural and urban subjects were found in the morning in both sexes. The physical exertion index values were relatively stable throughout the day at <100 in urban subjects, while they fluctuated throughout the day in rural subjects, showing peak values in the morning, although the levels in other periods were similar to those seen in urban subjects.

Dietary energy, protein and fat intakes and daily energy

Table 3. Time (min/d) spent in the different categories of physical activity by men and women from rural and urban populations of Papua New Guinea†

	(Mean values and standard deviations)							
	Men				Women			
	Rural (n 15)		Urban (n 14)		Rural (n 12)		Urban (n 15)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Sleep	536	69	472*	94	523	36	520	47
Sedentary	623	129	741*	117	602	101	731**	71
Active	281	95	227	94	315	112	189**	76
ACT-1	197	59	209	87	241	71	169*	64
ACT-2	85	46	18***	15	74	57	20**	17

ACT-1, moderately-active subdivision of active category (flex $<$ heart rate ≤ 1.2 times flex); ACT-2, highly-active subdivision of active category (heart rate > 1.2 times flex).

Mean values were significantly different from those of rural subjects: * $P < 0.05$, ** $P < 0.005$, *** $P < 0.0001$.

† For details of subjects and procedures, see Table 1 and p. 66.

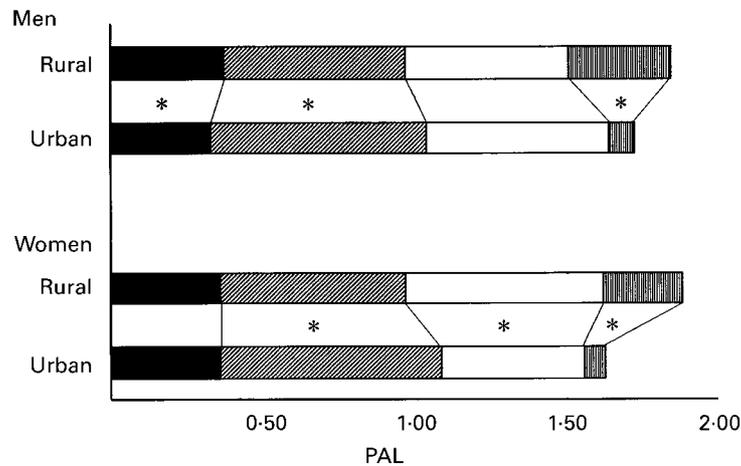


Fig. 1. Sleep (■), sedentary (▨), moderately-active (□) and highly-active (▤) components of daily physical activity levels (total energy expenditure/BMR; PAL) of men and women from rural and urban populations of Papua New Guinea (n 56). Mean values were significantly different between urban dwellers and rural villagers: $*P < 0.05$. For details of subjects and procedures, see Table 1 and p. 66.

balance (total daily energy intake (TEI) – TEE) are shown in Table 4. Extra energy and protein are recommended for lactation (WHO/FAO/UNU, 1985). In fact, Norgan *et al.* (1974) have reported that the lactating women among PNG Highlanders (Lufa) had a significantly higher energy intake (by 0.75 MJ/d) than the non-pregnant non-lactating women. In the present study, the values for energy and protein intake were adjusted for lactating women (four rural and six urban women) by reducing energy intakes by 2.1 MJ/d and protein intakes by 17.5 g/d (for the first 6 months postpartum) or 13.0 g/d (after 6 months postpartum) according to WHO/FAO/UNU (1985). The unadjusted energy and protein intakes were 11.20 (SD

2.83) MJ/d and 53 (SD 27) g/d respectively for rural women and 10.43 (SD 1.97) MJ/d and 71 (SD 23) g/d respectively for urban women. Since the percentage of lactating women was relatively low (37, n 10) and adjusted values were levelled, the difference between adjusted and unadjusted values was small (6–8 %) and considered negligible. Here we used the adjusted values for comparison between rural and urban subjects (Table 4). No significant differences were found in TEI and TEI/BMR between rural and urban subjects for both sexes. Protein and fat intakes were, on the other hand, higher in the urban samples for both sexes, although the protein intake for women was not significantly different between the two groups. The balance between TEI and TEE was <7 % in each group.

Discussion

Differences in body size between rural and urban subjects

Urban men and women in the present study were taller and heavier than their rural counterparts. However, no significant difference was found in BMI between the two groups because the increased body weight in urban subjects was offset by increased stature. According to another survey conducted by our laboratory using a large sample of rural villagers and urban migrants which included almost all subjects in this study (eighty-six rural men, 127 rural women, 101 urban men and thirty-nine urban women), the mean values for body weight, height and BMI were almost identical to those of the present study, although the differences between rural and urban subjects were more marked (Table 5). Table 5 shows the data of two anthropometric surveys conducted for the same Huli-speaking group. The first was conducted in August 1995 as a part of a large study on cardiovascular risk factors of migrants in Port Moresby (Natsuhara *et al.* 2000). In that study almost all adult Huli migrants who resided in five settlements in Port Moresby were invited to participate.

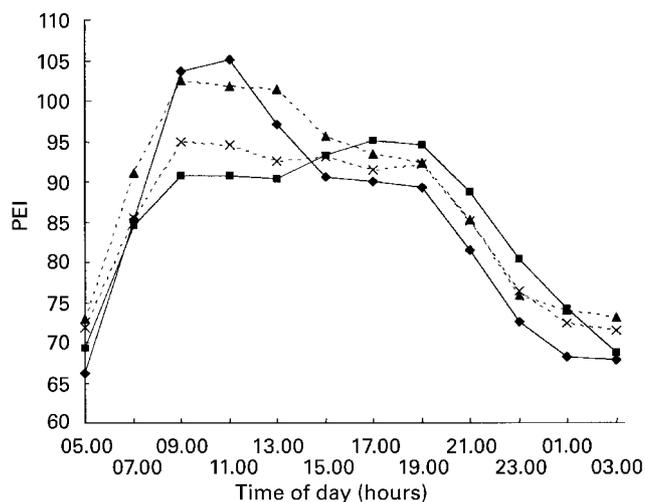


Fig. 2. Daily activity profiles of men and women from rural and urban populations of Papua New Guinea (n 56). Physical exertion index (average heart rate/flex-heart rate \times 100; PEI) values were calculated for consecutive 2 h periods over 24 h. (◆), Rural men; (■), urban men; (▲), rural women; (×), urban women. For details of subjects and procedures, see Table 1 and p. 66.

Table 4. Dietary energy, protein and fat intakes and daily energy balance in men and women from rural and urban populations in Papua New Guinea†

(Mean values and standard deviations)

	Men				Women			
	Rural (n 15)		Urban (n 14)		Rural (n 12)		Urban (n 15)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
TEI (MJ/d)‡	12.23	4.20	11.65	2.75	10.53	2.35	9.62	2.65
TEE (MJ/d)	13.13	2.12	12.20	2.01	11.04	2.60	9.31*	1.27
Balance§	-0.97	3.63	-0.57	2.36	-0.54	2.74	0.29	2.56
TEI/BMR	1.69	0.51	1.64	0.34	1.82	0.36	1.67	0.36
Protein intake (g/d)‡	49	30	73*	21	48	23	65	28
Fat intake (g/d)	18	21	82**	48	23	24	84***	36

TEI, total energy intake; TEE, total energy expenditure.

Mean values were significantly different from those of rural villagers: * $P < 0.05$, ** $P < 0.0005$, *** $P < 0.0001$.

† For details of subjects and procedures, see Table 1 and p. 66.

‡ Adjusted for lactating women (n 10).

§ Energy balance = TEI - TEE.

The second study was conducted in July and August 1998 with rural adults in Tari basin, including the two villages of the present study. Thus, the lack of significant difference in body weight and BMI for men and in stature and BMI for women in the present study is probably due to the small sample size. Furthermore, the finding that urban subjects who were born and raised until pubescence or adolescence in their home villages had a significantly larger body size, especially in height, suggests that well-nourished individuals had selectively migrated to the capital city (Port Moresby). It is possible, however, that a long adolescent growth spurt also contributed to the difference between the height of urban and rural groups (Heywood & Norgan, 1982; Norgan, 1995).

Reduced daily physical activity level in urban subjects

PAL of the subjects participating in the present study were comparable with those described by Ferro-Luzzi & Martino (1996) who reviewed fifty-five studies of about 1550 subjects in free-living conditions in more than twenty developed and developing countries. According to their study the PAL values of Third World subjects were 1.84 (SD 0.31) for male subjects and 1.65 (SD 0.17) for female subjects whereas those of Western subjects were 1.74 (SD 0.15) for male subjects and 1.64 (SD 0.18) for female

subjects. Compared with Third World subjects, PAL values for rural Huli villagers were similar for men and higher for women, reflecting the gender inequality in labour commonly observed in PNG Highlands (Waddell, 1972; Strathern, 1982; Allen *et al.* 1995). This factor has been discussed in detail in our recent report (Yamauchi *et al.* 2000). For the Huli urban subjects, on the other hand, PAL values were lower than those of Third World subjects, and even Western subjects. According to the review of Ferro-Luzzi & Martino (1996) on Third World populations, including both subsistence and urban populations, the highest two or three PAL values for male or female subjects in urban Third World populations were similar to or lower than those of the urban migrants in the present study (for men; Philippines drivers 1.64, Philippines textile mill workers 1.64; for women: Guatemala urban resettled of lower socio-economic status 1.58, Philippine typists 1.60, Philippine housewives 1.57). Thus, the lower PAL values of the Huli urban migrants are considered to reflect a general tendency that urban dwellers in developing countries are less active than those in developed countries.

What are the mechanisms of low PAL observed in urban subjects? Several studies have shown a close relationship between PAL and the percentage of time spent above the flex-HR point (Livingstone *et al.* 1990; Leonard *et al.* 1995; Murayama & Ohtsuka, 1999). In the present study

Table 5. Body weight, height and BMI of rural and urban men and women from a larger study population in Papua New Guinea, including subjects from the present study†

(Mean values and standard deviations)

	Men				Women			
	Rural‡ (n 86)		Urban§ (n 101)		Rural‡ (n 127)		Urban§ (n 39)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Weight (kg)	59.8	9.5	65.5***	7.2	50.8	7.1	62.1***	11.3
Height (m)	1.58	0.07	1.62***	0.05	1.50	0.05	1.52*	0.05
BMI (kg/m ²)	24.0	2.8	25.0**	2.4	22.7	2.5	27.0***	4.5

Mean values were significantly different from those of rural villagers: * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

† For details of subjects and procedures, see Table 1 and p. 66.

‡ Surveyed in 1998.

§ Surveyed in 1995 (Natsuhara *et al.* 2000).

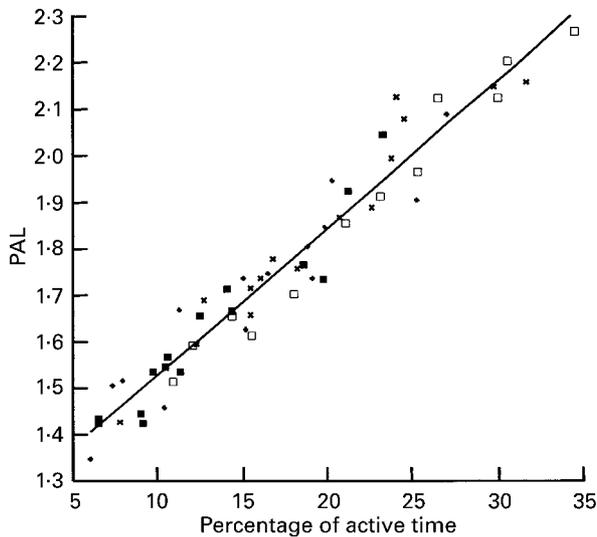


Fig. 3. Correlation between daily physical activity level (total energy expenditure/BMR; PAL) and percentage of time spent being active (average heart rate > flex) for men and women from rural and urban populations of Papua New Guinea (n 56). Rural men (\times) urban men ($+$), rural women (\square), urban women (\blacksquare). PAL = 0.032 (%) + 1.212, r 0.97. For details of subjects and procedures, see Table 1 and p. 66.

there was a significant positive correlation (r 0.97, $P < 0.0001$) between PAL and the percentage of active time (HR > flex; Fig. 3). In fact, in urban subjects who had lower PAL than rural subjects active time decreased and sedentary time (HR \leq flex) increased (Table 3); consequently, the active component of PAL was reduced and sedentary component of PAL was increased in urban subjects (Fig. 1). It was clear that the low active component of PAL in urban dwellers, due to a reduced active time, was the main factor in reducing the EE as a whole. This phenomenon is considered as the most typical effect of urbanisation from the energy viewpoint. Furthermore, in view of the progressive change in the intensity of physical activity in each sample throughout the day, considerable differences between rural and urban subjects were found in the morning in both sexes (Fig. 2). The high levels of physical activity recorded in the morning in rural subjects reflected intensified agricultural activities, especially in women ($P < 0.01$; Table 2).

Energy balance and methodological assessments

Rural subjects consumed low-protein low-fat meals containing mainly sweet potatoes and local greens. In contrast, urban subjects depended totally on purchased food such as rice, tinned fish and chicken, leading to increased intakes of protein and fat (Table 4). Ulijaszek (1992, 1995) reviewed the mean energy intake and EE in non-industrialised populations. In six of twelve samples the reported energy intake was more than 1 MJ below EE, a difference that cannot be explained by possible seasonal fluctuations in work output and food availability. In the present study, a negative energy balance was noted in three of the four groups (Table 4). Although a large negative energy balance

such as that described earlier (>1 MJ/d) was not found in any group, it is possible that we have underestimated the energy intake in the present study. Under-reporting of energy intake was not likely because subjects were under observation during the daytime and all food was measured just before it was consumed. Admittedly, the observer effect cannot be completely excluded, i.e. subjects might eat less on the day of investigation because they are under constant observation. However, TEI and protein and fat intakes for rural subjects in the present study were similar to or even higher than those for twenty-eight households of a Huli-speaking sample studied using a consecutive 6 d food weighing survey (daily *per capita* intakes: 11.0 MJ/d, 39.3 g protein/d, 13.1 g fat/d; Kuchikura, 1999). Thus, we believe that the small negative energy balance observed in the present study was not influenced by an observer effect, the small sample size or the short observation period.

In fact, TEE might have been overestimated due to overestimation of EE during the step test. In the present study, EE values during step tests were not obtained from the study subjects but were estimated using gender-and-weight-specific equations for similar samples of Huli-speaking people (Yamauchi & Ohtsuka, 2000). In that study, the net mechanical efficiency values for three levels of the step tests were compared with those for worldwide populations reported in previous studies (Katzmarzyk *et al.* 1996). Net mechanical efficiencies of the Huli-speaking population (16 and 15 % for rural men and women respectively, and 17 % for both urban men and women) were comparable with those of previous studies and WHO standards (i.e. 16 %; Shephard, 1967; Shephard *et al.* 1968; Anderson *et al.* 1971). Thus, we conclude that the EE of the step tests, and consequently TEE for present participants, are unlikely to be overestimated.

A further explanation of the small negative energy balance in rural subjects may be due to the fact that rural subjects from two villages (Heli and Wenani) suffered from an extended rain season during the study period, and the food intake or energy intake of Heli villagers was unusually low. This issue was discussed in detail in our previous report (Umezaki *et al.* 1999). In fact, we found significant differences in energy intake between the subsamples in both rural men and women (9.72 and 15.04 MJ/d in Heli and Wenani men respectively, $P < 0.01$; 8.79 and 12.22 MJ/d in Heli and Wenani women respectively, $P < 0.005$).

The results of the food and nutrient intake survey demonstrated a well-maintained daily energy balance, especially in urban subjects. However, low TEI and TEE, which were observed in urban subjects, are considered to be risk factors for obesity and cardiovascular disorders (King & Collins, 1989; Dowse *et al.* 1994; Hodge *et al.* 1995). For instance, Ferro-Luzzi & Martino (1996) suggested that a PAL of 1.8 was the threshold for triggering such diseases. Fat intake in urban subjects, which was markedly higher than that of rural subjects, was comparable with that in subjects from a PNG coastal population (Wanigela) who migrated to a settlement in Port Moresby (men 71 g/d, women 65 g/d), and the fat consumed was reported to be predominantly saturated fat (Hodge *et al.* 1996). Taking into consideration that more than 60 % of the fat intake of

Huli migrants in Port Moresby was provided by sheep meat, butter and chicken, the fat intake pattern appears to be almost identical to that of Wanigela migrants. These findings imply that the level of EE of urban dwellers (whose energy intake was balanced), together with higher intake of saturated fat, tended to increase the risks of degenerative disorders following migration to, and settlement in, an urban environment.

In conclusion, lifestyle changes in urban migrants were examined in the present study by comparing their food intake and EE data with those of their rural counterparts. The effects of urbanisation on daily physical activity were evident in the considerably lower PAL in urban subjects than in rural subjects, especially in women. Large increases in protein and fat intakes were noted in urban subjects due to dietary changes from local to purchased foods. The reduction in PAL among urban dwellers, perhaps together with increased fat intake, is considered to increase the risks of obesity and chronic degenerative diseases.

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