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Description and validation of the ActiReg®: a novel instrument to measure physical activity and energy expenditure

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The ActiReg® (PreMed AS, Oslo, Norway) system is unique in using combined recordings of body position and motion alone or combined with heart rate (HR) to calculate energy expenditure (EE) and express physical activity (PA). The ActiReg® has two pairs of position and motion sensors connected by cables to a battery-operated storage unit fixed to a waist belt. Each pair of sensors was attached by medical tape to the chest and to the front of the right thigh respectively. The collected data were transferred to a personal computer and processed by a dedicated program ActiCalc®. Calculation models for EE with and without HR are presented. The models were based on literature values for the energy costs of different activities and therefore require no calibration experiments. The ActiReg® system was validated against doubly labelled water (DLW) and indirect calorimetry. The DLW validation demonstrated that neither EE calculated from ActiReg® data alone (EE_{AR}) nor from combined ActiReg® and HR data (EE_{AR-HR}) were statistically different from DLW results. The EE_{AR} procedure causes some underestimation of EE >11 MJ corresponding to a PA level $>2{\cdot}0$. This underestimation is reduced by the EE_{AR-HR} procedure. The objective recording of the time spent in different body positions and at different levels of PA may be useful in studies of PA in different groups and in studies of whether recommendations for PA are being met. The comparative ease of data collection and calculation should make ActiReg® a useful instrument to measure habitual PA level and EE.

Energy expenditure: Physical activity: Activity pattern

There is increasing evidence for a positive effect of physical activity (PA) upon human health, and for the existence of a dose-dependent relationship between PA and health (Surgeon General's Report, 1996). However, the precise amount and type of PA required to achieve specific health-related outcomes remains unclear (Haskell, 1994). The need for precise quantification of PA levels and energy expenditure (EE) during daily living conditions has led to the development of several measurement methods (Lamonte & Ainsworth, 2001). Each method has strengths and limitations for its use in assessing daily living activities.

Doubly labelled water (DLW) can be used to estimate EE in individuals under habitual living conditions over periods typically of 1–2 weeks and is useful for the calculation of energy requirements. However, this methodology only provides a single value for EE over the measurement period with no information on temporal variation in EE or the pattern of PA. Furthermore, the high cost of the isotopes and the cost and complexity of the MS isotope analysis limit the applicability of DLW to relatively small-scale studies. The DLW method can, however, be very useful in validating more cost-effective methods that are applicable to large population scale studies (Leenders *et al.* 2000, 2001).

The introduction of portable equipment for long-term heart-rate (HR) recording, and the well-known relationship between HR and PA level, has led to extensive use of HR recordings in order to estimate EE. Many studies have been performed, but the results have been disappointing, the main reason being that HR and EE correlate well only at rather high PA levels (Consolazio *et al.* 1971; Freedson & Miller, 2000). The need to develop individual HR *v.* EE calibration curves to estimate EE accurately also limits the usefulness of the method. HR monitoring, however, may be useful as part of a multi-system approach to PA and EE assessment, where HR is integrated with other physiological variables related to EE (Haskell *et al.* 1993; Healey, 2000).

Accelerometers measure the rate and magnitude of the displacement of the body's centre of mass during movement. Although data from accelerometers can be used to

Abbreviations: AF, activity factor; DLW, doubly labelled water; EE, energy expenditure; EE_{AR}, energy expenditure calculated from ActiReg® data alone; EE_{AR-HR}, energy expenditure calculated from combined ActiReg® and heart rate data; EE_{DLW}, energy expenditure calculated from doubly labelled water data alone; EE_{IC}, energy expenditure calculated from indirect calorimetry data alone; HR, heart rate; PA, physical activity.

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assess the frequency, duration and intensity of PA, the specific type of PA is unknown. The EE that result from activities involving only movement of the extremities or increased resistance to body movement (e.g. uphill walking) and/or static muscle work is not well accounted for (Haskell *et al.* 1993). Large discrepancies have recently been reported among different accelerometers in estimating the energy cost of habitual PA under free-living conditions (Ainsworth *et al.* 2000*a*; Welk *et al.* 2000).

It is important to realize that EE depends both upon body movement and position. There are considerable differences in the energy costs of lying, sitting and standing activities. When EE is expressed as multiples of BMR, we find that EE seldom exceeds 1·5 × BMR during normal sitting activities, whereas the energy cost of on-foot activities may be much greater (Food and Agriculture Organization/World Health Organization/United Nations University, 1985; Ainsworth *et al.* 1993, 2000*b*). It has indeed been demonstrated that daily EE is highly related to the time spent in standing activities (James *et al.* 1988).

The estimation of EE may therefore be improved by combining information about body movement and position. We have developed an instrument, ActiReg® (PreMed AS, Oslo, Norway; ola.ro@telia.com), capable of collecting such information continuously for many days. In the present paper we describe the design and function of the ActiReg® and the validation of the ActiReg® against indirect calorimetry and DLW. The ability of the ActiReg® system to analyse and describe PA patterns is also presented.

Instrument description

The ActiReg® system consists of two components:

A new electronic device, ActiReg®, which records body position and movement, and a computer program (ActiCalc®) for processing and presenting the ActiReg® data and calculating EE. Optionally, the ActiReg® can be used simultaneously with equipment for HR recording (Sport Tester PE3000; Polar Electro Oy, Kempele, Finland). The EE calculation is then based upon the combined information about HR, body position and motion.

The ActiReg® has two body position sensors (tilt switches) and two motion sensors connected by cables to a battery-operated storage unit. Each pair of one tilt switch and one motion sensor is secured to a plastic bracket measuring 20 × 30 mm. During recording one bracket is attached by medical tape to the chest (on the sternum) and the other is fastened on the front of the right thigh approximately midway between the knee and the hip. The tilt switches (CM1421-0; ASSEMTech Europe Ltd, Clacton-on-Sea, Essex, UK) operate according to the on–off principle (on in the vertical position and off in the horizontal position). They go from the on to the off condition when they deviate by more than 45° (±15°) from the vertical position. The motion sensors (CM4400-0; ASSEMTech Europe Ltd) operate according to the all or none principle; they register either motion or no motion. The storage unit is fixed to an elastic belt worn around the waist. The unit measures 85 × 45 × 15 mm and weighs 60 g.

The logical principle of the ActiReg® is illustrated in Fig. 1. The state of the tilt switches and motion sensors is checked every 1 s. The sensors discriminate between the four body positions sit, stand, bent forward or lie, and between the four states of no motion, motion on either chest or thigh sensor, or both. This gives a matrix of $2^4 = 16$ possible combinations with ActiReg® codes from 0 to 15, as illustrated in Fig. 1.

The storage capacity of the ActiReg® is sufficient for more than 30 d of continuous registration of normal PA.

After a recording period, the stored data are transferred to a personal computer by connecting the ActiReg® to the serial port of the computer.

ActiCalc® converts the data in the ActiReg® output file into information about body motion, body position and position changes for each minute. By a majority decision among the sixty recorded codes, one main body position is assigned to each min. When the state of the motion sensors is checked every second, they give information about whether there has been motion or not, but not about the intensity of the motion. It is the pattern of the sixty codes recorded per min that provides information about the PA level. ActiCalc® uses this information to calculate an activity factor (AF). Each code is given a certain weight. Codes for no movement get the weight 0·0, while codes showing movement on only one sensor get the weight 0·5 and codes for motion on both sensors will have the weight 1·0. The AF of a given minute is the mean value of the weights of the sixty codes. Thus, AF will attain values between 0·0 and 1·0.

The function of ActiReg® is demonstrated by an experiment in which one of the investigators (B.-E. H.) wore the instrument during seven sessions on a treadmill. The results are presented in Table 1. AF was 0·0 when standing still, and increased to 0·3 (SD 0·12) when walking at 1 km/h. A value

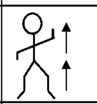
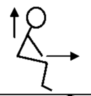
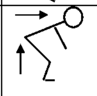
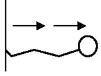
Body position				Signal stored			
	Sw on↑			Activity on movement sensors			
	Sw off→	C_{Sw}	T_{Sw}	NM	C	T	C + T
Stand		On	On	0	4	8	12
Sit		On	Off	1	5	9	13
Bent forward		Off	On	2	6	10	14
Lie		Off	Off	3	7	11	15

Fig. 1. The logical principle of the ActiReg® (PreMed AS, Oslo, Norway). Sw, tilt switch; C_{Sw}, tilt switch on the chest; T_{Sw}, tilt switch on the thigh; NM, no movement; C, chest; T, thigh; C + T, chest and thigh. The four body positions stand, sit, bent forward and lie are illustrated by the drawings. The arrows show the orientation of the tilt switches on the chest and thigh, while columns C_{SW} and T_{SW} show the actual state (on or off). Column NM shows the codes for each body position when no movements are recorded. Columns C, T, and C + T show the corresponding codes used when movement is recorded by either the chest or thigh sensor, or both.

of AF ≥0·9 was reached at speeds of 3–4 km/h. When the speed was ≥5 km/h, all instruments showed AF equal to the maximum possible value (AF 1·0).

These results demonstrate that AF may be used to categorize PA into the following three levels: very low PA, 0·0 ≤ AF < 0·1; low PA, 0·1 ≤ AF < 0·9; moderate to high PA, 0·9 ≤ AF ≤ 1·0.

For most people, normal walking speed is 4–6 km/h. Walking will therefore fall in the medium to high PA range according to this classification.

Table 1 also demonstrates the body position changes. No changes appeared before the speed was 5 km/h, and the number then increased with treadmill speed.

The main body position per min was invariably recorded as ‘stand’ up to a speed of 5 km/h. At ≥7 km/h, where the number of position changes increased, some minutes with the body positions ‘sit’ or ‘lie’ were also recorded. These recordings show that the state of the position sensors is influenced by acceleration forces during rapid movement, such as running, in addition to the effect of the position angle.

Another treadmill experiment was performed to test the response to walking at increasing inclines. The same investigator (B.-E. H.) wore the ActiReg® during nine walking sessions at 3 km/h for 4 min at each of the treadmill inclines: 0, 6, 11, 17, 22 and 28 %. However, increasing the incline did not influence AF, the body position or the number of body position changes (results not shown).

Calculation of the energy expenditure

Two different procedures for calculation of EE are available in ActiCalc®. The first (Fig. 2) is based upon ActiReg® data alone (EE_{AR}) and the second (Fig. 3) uses the combined information from ActiReg® and HR recordings (EE_{AR-HR}).

The calculation procedure for EE_{AR} (Fig. 2) has two steps. The first step starts by distributing the data into the three activity levels (very low PA; low PA; medium to high PA). The calculation within each level is based on the estimated energy cost for the actual body position, expressed as RMR factors and taken from published reference values (Food and Agriculture Organization/World Health Organization/United Nations University, 1985; Annex 5). In the very low PA range, the following factors were selected: lie still: 1·0 × RMR; sit still: 1·2 × RMR; stand still–bent forward: 1·4 × RMR. The low PA range extends from moving very slowly to walking at about 3 km/h, and we chose 2·5 × RMR as the average energy cost of standing activities. This is the energy cost given for ‘walking around or strolling’. The factor for sitting and lying activities, which are non-weight-bearing activities, is set somewhat lower at 2·0 × RMR. The dominant activity in the medium to high PA range during the daily life of most people is walking. The reported energy cost of ‘walking at normal pace’ is 3·2 × RMR. In addition, there will be a variable amount of more energy-requiring activities, such as walking upstairs or uphill, walking while carrying loads and performing exercise. The factor 5·0 × RMR is therefore chosen as the average energy

Table 1. Characteristics of the ActiReg® function during treadmill walking and running*

(Mean values and standard deviations for seven sessions)

	AF		PC (*n*)		
Treadmill speed (km/h)	Mean	SD	Mean	SD	Recorded positions
0	0·00	0·00	0·0	0·0	Stand
1	0·31	0·12	0·0	0·0	Stand
2	0·76	0·16	0·0	0·0	Stand
3	0·93	0·10	0·0	0·0	Stand
5	1·00	0·00	3·8	5·2	Stand
7	1·00	0·00	11·5	6·7	Stand (sit or lie)
9	1·00	0·00	23·6	13·3	Stand (sit or lie)
12	1·00	0·00	32·8	8·1	Stand (sit or lie)

AF, activity factor; PC, position changes.
* For details of the ActiReg® (PreMed AS, Oslo, Norway) and procedures, see p. 1002.

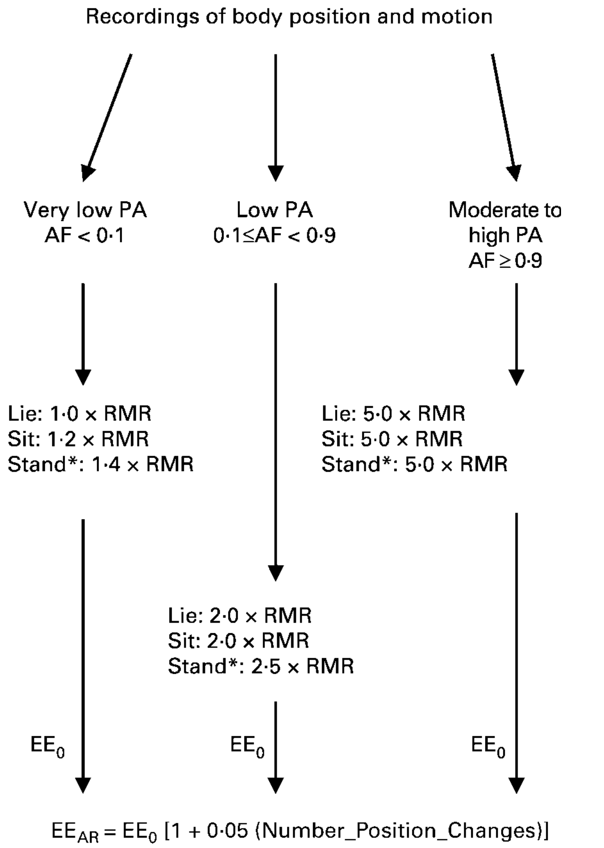


Fig. 2. The calculation procedure for energy expenditure (EE) based on ActiReg® (PreMed AS, Oslo, Norway) data alone (EE_{AR}). *Standing position including the bent forward position. In the first step the data are distributed according to the activity factor (AF) value into the three activity levels (very low physical activity (PA), low PA and moderate to high PA). The calculation within each level is based on the estimated energy cost for the actual body position, expressed as the RMR factors shown. The result of this first calculation step is denoted EE_0. The second step takes the number of body position changes into account by applying the algorithm shown, where EE_{AR} is the final result for the actual minute. The constant 0·05 determines the weight given to the number of body position changes, here designated as ‘Number_Position_Changes’. For details of the calculation see p. 1003.

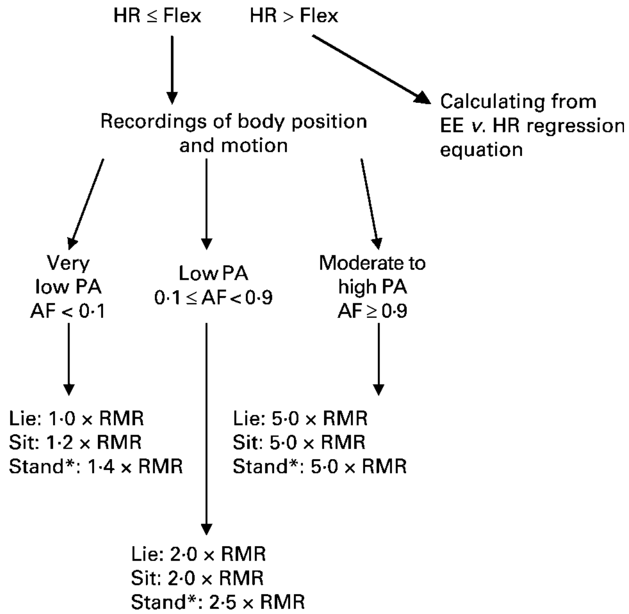


Fig. 3. The calculation procedure for energy expenditure (EE) based on the combined information from ActiReg® (PreMed AS, Oslo, Norway) and heart rate (HR) recordings (EE_{AR-HR}). PA, physical activity; AF, activity factor. *Standing position including the bent forward position. HR is used to estimate EE above a pre-determined and individual limit, FLEX HR, by using the predetermined linear regression equation with HR as predictor. If HR is equal to or below FLEX HR, the calculation is equal to the first part of the procedure in Fig. 2. The number of position changes is not used, because the high activity periods now are calculated according to HR.

cost of all medium to high PA activities. It is applied for all body positions, since the body-position recording may be erroneous during high PA, as shown in Table 1.

The treadmill experiment also demonstrated that the number of body position changes increased with PA, above the level where AF reached the maximum value (AF 1·0). The second calculation step takes the number of position changes into account by using the algorithm given in Fig. 2.

The calculation procedure for EE_{AR-HR} is based on the ‘Flex HR’ concept (Spurr *et al.* 1988) and is explained in Fig. 3.

Materials and methods

The indirect calorimetry validation study

Students at Aberdeen University, Scotland, UK, were recruited by personal approach. They were informed about the study and signed the standard written consent form for human volunteers at the Rowett Research Institute, Aberdeen. The Joint Ethical Committee of the Grampian Health Board and the University of Aberdeen approved the project. The subjects (six female and four male) were non-smokers without diseases known to affect EE. Their physical characteristics were: age 23·3 (SD 2·1) years; body weight 65·2 (SD 9·0) kg; height 1·68 (SD 0·09) m; BMI 23·1 (SD 3·0) kg/m^2.

The experiments were performed in the two whole-body respiration chambers at the Human Nutrition Unit at the Rowett Research Institute (McNeill *et al.* 1989). The accuracy of the whole system was tested by burning butane gas in each chamber. The temperature was kept constant at 25·0 ± 0·5°C by an air-conditioning system (Acoven Air Conditioning Unit, Thame, Oxon., UK).

RMR was measured after an overnight fast with a ventilated hood system (Deltatrac® Metabolic Monitor; Datex Instrumentarium Corp., Helsinki, Finland). The subjects arrived by taxi in the morning and rested for 20 min before the 25 min measurement period started.

Each participant underwent three measurements on non-consecutive days in the calorimeter during the experimental period of 2–4 weeks. Dietary energy intake was restricted to 1·4 × BMR on measurement days, and two-thirds of the estimated requirement was served as breakfast and lunch in the calorimeter. Water, decaffeinated tea and coffee were served *ad libitum*. The participants arrived at 08.00 hours on measurement days. They were in the post-absorptive state. The ActiReg® was fitted, and the subjects were weighed and let into the chamber. Breakfast was then served. After a 2 h equilibration period, measurements started at 11.00 hours.

The participants followed a strict behaviour schedule on days 1 and 2 (5 h), which contained a series of defined activities in different body positions, while the schedule on the third day (3 h and 45 min) gave some more room for self-selected activities. The schedules are shown in Table 2.

The doubly labelled water validation study

Twenty-one female students participated in the study. They were recruited by an announcement of the project within the Oslo University area. After being informed about the experiment each subject gave her written consent. The regional ethical committee approved the study protocol. The physical characteristics of the subjects were: age 24 (SD 2) years; body weight 63 (SD 9) kg; height 1·69 (SD 0·06) m; BMI 22 (SD 2) kg/m^2.

All subjects participated in two separate experiments. A 10 d measurement of total EE by doubly labelled water (EE_{DLW}) was performed concurrently with minute-to-minute recording of HR and body position and movement by the ActiReg®. Variation in RMR during the menstrual cycle has been reported previously (Bisdee *et al.* 1989). Therefore, all subjects kept track of their menstrual cycle with the experimental measurements undertaken during the follicular phase. In addition, individual calibration experiments were undertaken during the same period of the next menstrual cycle including measurements of RMR, and two treadmill sessions were undertaken to define the relationship between HR, EE and the ActiReg®.

The measurement period always started on a Monday or Tuesday in order to include one weekend in the measurements. On arriving at the Institute (day 0) after an overnight fast the subjects were weighed in their underwear to the nearest 0·1 kg on an electronic scale (Seca 708; Seca, Hamburg, Germany). They received a pre-weighed dose of DLW followed by 50 g tap water. The dose given was 0·16 g 100 % ^{18}O/kg body weight and 0·18 g 100 % ^{2}H/kg body weight. Blood samples

Table 2. Activity schedule in the metabolic chamber

Days 1 and 2		Day 3*	
Activity	Time (min)	Activity	Time (min)
Lie still	15	Mixed activities	20
Sit still	15	Free†	55
Stand still	15	Mixed activities	15
Free†	10	Lunch	30
Walk 40‡	15	Sit comfortably	30
Free	5	Mixed activities	15
Walk 60‡	15	Free†	10
Lunch	30	Step 100‡	15
Sit and write	15	Sit still	35
Free†	5	Total time	225
Walk 80‡	15		
Free†	5		
Step 60‡	15		
Free†	10		
Sit and lift	15		
Free†	5		
Walk 92‡	15		
Free†	20		
Step 80‡	15		
Free†	10		
Sit and read	15		
Free†	5		
Step 112‡	15		
Total time	300		

* On day 3 there were periods with mixed activities and a 55 min period with self-selected activity.
† Free means a period of self-selected behaviour between the scheduled activities.
‡ Walk 40, walk 60 etc. denotes the stride frequency during walking in a figure of eight, while step 60, step 80 etc. give the step frequency per min up and down a 200 mm high wooden step. A metronome standardized both the walking and the stepping activities.

were taken before drinking the labelled water (baseline) and 3 h later. A sample of urine was obtained from the second voiding of the day throughout the DLW period. The plasma samples and urine samples from day 1 and day 10 were analysed for ^{18}O and ^{2}H on SIRA-10 and Series-II isotope ratio MS (VG, Middlewich, Ches., UK) relative to a series of laboratory reference waters previously calibrated against international standards (Vienna standard mean ocean water and standard light Antarctic precipitation; Haggarty *et al.* 1994*a*,*b*). Fat-free mass was calculated from the $H_2{}^{18}O$ dilution space assuming that body water = $H_2{}^{18}O$ space/1·01 and fat-free mass = 0·732 × body water and body fat = body weight − fat-free mass. The mean proportion of water loss that was fractionated was estimated (Haggarty *et al.* 1994*b*, 1997). The RQ was taken to be equivalent to the food quotient (Black *et al.* 1986) and was determined from a food-frequency questionnaire completed by the subjects after the experiment. EE_{DLW} was calculated from CO_2 (l/d) production and the RQ using the following rearrangement of the Weir (1949) equation: $EE_{DLW} = 4{\cdot}598 \times CO_2 + 16{\cdot}302 \times (CO_2/RQ)$.

Full details of analysis, calculations and assumptions are presented elsewhere (International Atomic Energy Agency, 1990; Haggarty *et al.* 1994*b*, 1997).

Recording of HR (Polar Sports Tester 3000; Polar Electro OY) and ActiReg® data were started when the subjects had taken the DLW dose and continued day and night for the whole 10 d experiment. The subjects reported to the investigators each day for down-loading of HR and ActiReg® data and resetting of the instruments.

Calibration experiments

On the calibration day, the subjects arrived at 07.30 hours after an overnight fast. They rested for 30 min before RMR was measured for 30 min in an open-hood calorimetric system (Deltatrac™ II Metabolic Monitor; Datex Instrumentarium Corp.). Body weight (SOEHNLE 7307.60; Soehnle, Murrhardt, Germany) and height (KaWe, Asperg, Germany) were then measured, and the ActiReg® instrument and the Polar Sport Tester™ 3000 (Polar Electro OY) were fitted. The subjects then had breakfast and a 90 min break before the first treadmill test started. This consisted of walking at a relative low speed (0·5–4·7 km/h) and inclination of 1 %. The O_2 uptake was measured by Deltatrac™ using a specially constructed hood. EE was measured for 11 min on each of seven workloads with a 10 min break between workloads four and five.

The second treadmill test started after lunch and a 90 min break. The subjects walked and/or ran for 5 min on each of the following workloads: at 4·8 km/h and inclinations of 1, 4, 6 and 9 %, and at 7·4 km/h and inclinations of 1, 4 and 6 %. The O_2 consumption (EOS-Sprint; Jaeger GmbH, Haechberg, Germany) and HR (Cardiac Monitor 573; KONE, Helsinki, Finland) were measured. The Polar Sport Tester™ 3000 (Polar Electro OY) was not used during these measurements due to electromagnetic disturbances.

Determination of FLEX heart rate

The calibration results were applied to calculate individual linear regression equations between EE and HR. We then calculated the FLEX HR from the EE *v.* HR linear regression equations and the measured RMR. FLEX HR was defined as the HR the subject would attain while performing at a workload of 3·3 × RMR. The mean FLEX HR for the group was 98 (range 76–115).

Statistical analysis

The agreement between the results obtained by two different methods was tested by the method of Bland & Altman (1986). Paired two sample *t* test was used to test the difference between the group mean values (SPSS for Windows version 11.0.0; SPSS Inc., Chicago, IL, USA). The significance level was set at $P<0{\cdot}05$. The correlation of linear regression is given as r^2.

Results

The indirect calorimetry study

EE_{AR} was calculated according to the procedure shown in Fig. 2, where the measured RMR values have been used. Each participant had three measurements performed in the calorimeter, and the mean value for EE_{AR} and EE measured by indirect calorimetry (EE_{IC}) were calculated. The group mean value of the mean values for EE_{AR} and

EE_{IC} were 618 and 625 kJ/h respectively and the difference was not significant ($P=0·76$).

In Fig. 4 the results are compared in a Bland–Altman plot. The mean difference was −8 kJ/h. The limits of agreement (mean difference ±1·96 SD) were −168 and 152 kJ/h respectively.

The doubly labelled water study

Three of the twenty-one subjects had higher than normal values for isotope elimination rates and implausibly low values for the DLW-derived EE (EE_{DLW}/RMR 1·10, 0·86 and 0·40 respectively). A blind re-analysis of the same samples from these subjects confirmed the initial values for EE, suggesting possible mislabelling or contamination of samples rather than analytical error. These three subjects were excluded from subsequent analysis.

The physical characteristics of the remaining eighteen subjects were: age 23·7 (SD 2·5) years; body weight 63·3 (SD 9·2) kg; height 1·69 (SD 0·07) m; BMI 22·2 (SD 2·6) kg/m^2.

The mean values for RMR, EE_{DLW}, EE_{AR-HR}, EE_{AR} and PA level (EE_{DLW}/RMR) were respectively: 5·42 (SD 0·45) MJ/d, 9·25 (SD 1·94) MJ/d, 10·03 (SD 1·36) MJ/d, 9·66 (SD 1·15) MJ/d, 1·71 (SD 0·32). There was no significant difference between EE_{AR-HR} and EE_{DLW} ($P=0·17$) or between EE_{AR} and EE_{DLW} ($P=0·45$).

In Figs 5 and 6 EE_{AR} and EE_{AR-HR} are compared with EE_{DLW} in Bland–Altman plots. The mean difference between EE_{AR} and EE_{DLW} shown in Fig. 5 is 0·41 MJ and the limits of agreement are 3·10 and −2·30 MJ. The mean difference between EE_{AR-HR} and EE_{DLW} was 0·78 MJ, and the limits of agreement are 3·20 and −1·66 MJ respectively (Fig. 6). Fig. 5 demonstrates that the EE_{AR} procedure causes underestimation of EE >11 MJ corresponding to PA level >2·0. This underestimation is reduced by the EE_{AR-HR} procedure (Fig. 6).

In addition to EE estimation, ActiCalc® gives information about the PA pattern from the distribution of time spent at different PA levels and in different body positions. The mean time spent at moderate to high PA was 62 (SD 15) min/d, and 342 (SD 61) min/d were spent in standing activities. Fig. 7(A) demonstrates a positive correlation (r^2 0·70, $P<0·00$) between time spent in moderate to high PA and PA level. The mean time (min/d) spent in the standing position, regardless of PA level, is plotted against the PA level values in Fig. 7(B). The linear regression shows a positive correlation (r^2 0·52, $P<0·001$). This demonstrates the significance of time spent standing as a predictor of the PA level.

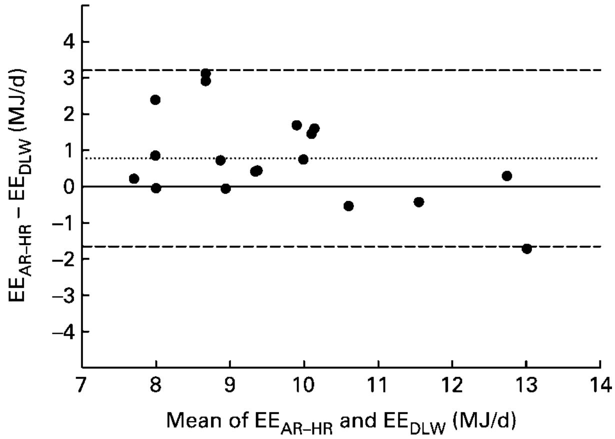


Fig. 5. Energy expenditure (EE) calculations based upon ActiReg® (PreMed AS, Oslo, Norway) data alone (EE_{AR}) and energy calculated from doubly labelled water (EE_{DLW}). The mean difference (.......) between EE_{AR} and EE_{DLW} was 0·41 MJ and the limits of agreements (- - - -) were 3·1 and −2·3 MJ respectively (*n* 18). For details of subjects and procedures, see p. 1004.

Discussion

The ActiReg® system uses the combined recording of body position and motion to estimate EE and to describe the PA pattern. The development was based on the assumption that the distribution of time spent in different body positions,

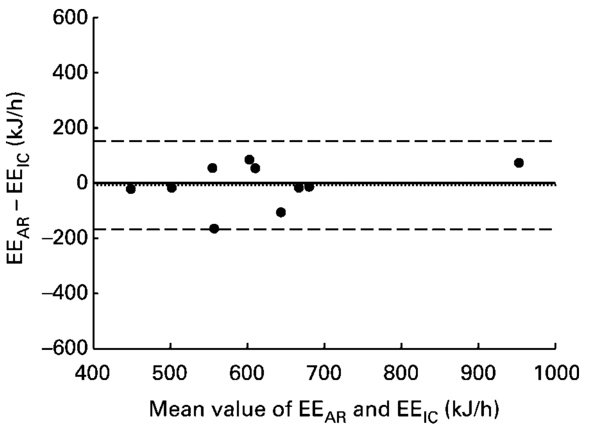


Fig. 4. Total energy expenditure (EE) measured by indirect calorimetry in the metabolic chamber (EE_{IC}) compared with that calculated from ActiReg® (PreMed AS, Oslo, Norway) data according to the procedure given in Fig. 2 (EE_{AR}). The mean difference was −8 kJ/h (.......). The limits of agreement (mean difference ±1·96 SD) were −168 and 152 kJ/h respectively (- - - -). For details of subjects and procedures, see p. 1004.

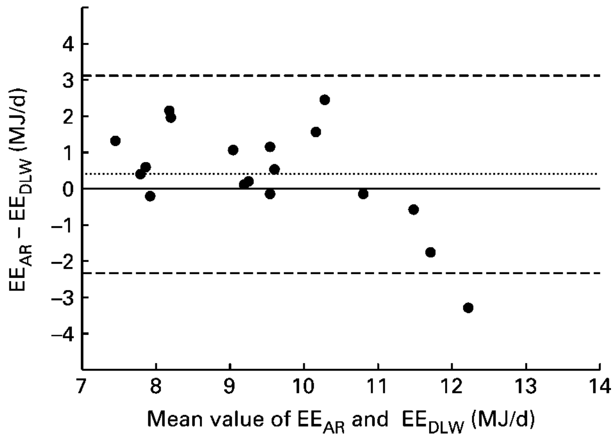


Fig. 6. Energy expenditure (EE) calculations based upon the combined information from ActiReg® (PreMed AS, Oslo, Norway) and heart rate recordings (EE_{AR-HR}) compared with EE calculated from doubly labelled water (EE_{DLW}) in a Bland–Altman plot. The mean difference (.......) between EE_{AR-HR} and EE_{DLW} was 0·78 MJ, and the limits of agreement (- - - -) were 3·2 and −1·66 MJ respectively (*n* 18). For details of subjects and procedures, see p. 1004.

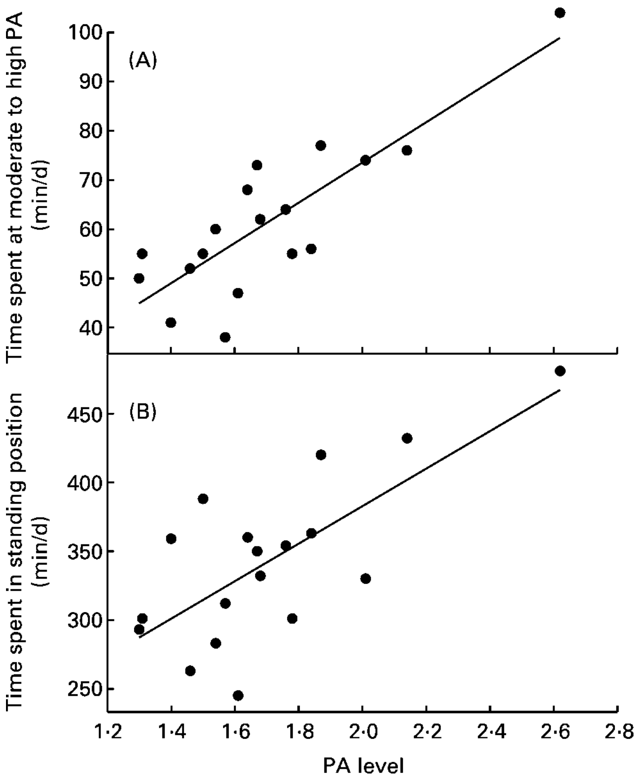


Fig. 7. (A), mean time (min/d) spent in standing position for the group, regardless of physical activity (PA) level, plotted against the PA level values for the 10 d observation period. The linear regression shows a positive correlation (r^2 0·52, $P<0·001$). (B), mean time (min/d) spent at moderate to high PA level plotted against the PA level values. The linear regression line shows a positive correlation (r^2 0·70, $P<0·00$; n 18). For details of subjects and procedures, see p. 1004.

particularly standing, is a predictor of EE and PA. This assumption is supported by the results shown in Fig. 7(B). The correlation between daily time in standing position and the PA level demonstrated in this figure confirms previous observations (James *et al.* 1988).

The rather crude information from the motion sensors is used to categorize activity into the three levels (very low PA; low PA; moderate to high PA) according to the magnitude of AF. The treadmill experiments showed that AF plateaus at the maximal value (AF 1·0) when the walking speed exceeds about 5 km/h. However, at increasing speed the rising number of body position changes is adequate to discriminate between the higher levels of PA. The calculation procedure for EE_{AR} (Fig. 2) utilizes the combined information about PA level, body position and position changes. The calculation is simplified by using general values for the energy cost of different body positions and activities in the calculation model. Separate calibration experiments to establish individual factors are therefore unnecessary, in contrast to the situation when HR recording or accelerometers are used to estimate EE (Spurr *et al.* 1988; Trost *et al.* 1998; Ekelund *et al.* 2001). The validation experiments against indirect calorimetry and DLW both demonstrate that EE_{AR} provides an estimate of EE at the group level that is comparable with the results from HR and accelerometer recordings (Davidson *et al.* 1997; Ekelund *et al.* 2001), although like these methods, ActiReg® shows considerable variation at the individual level.

The treadmill test, where the incline was increased while the walking speed was constant, demonstrated that the increased EE of uphill walking is not well accounted for. This is also the case for arm work or increased EE as a result of carrying loads (results not shown). We therefore reasoned that combined recording of HR and ActiReg® data and calculation of EE_{AR-HR} (Fig. 3) might improve the estimation of EE in the DLW experiment. However, there was no improvement resulting from the inclusion of HR in the calculation of EE_{AR-HR} except for active individuals with PA level $>2·0$. It is therefore likely that the EE_{AR-HR} validation would have been more impressive in a more active group. However, the majority of individuals in industrialized societies are not very active. The subjects in the DLW study had a moderate PA level, with a group mean PA level 1·7, and therefore are likely to be representative of most populations in which the method will be applied.

Accelerometers also have shortcomings in motion recording (Lamonte & Ainsworth, 2001; Brage *et al.* 2003*b*). The recent publication of experiments with combined accelerometer and HR recording is therefore interesting (Brage *et al.* 2003*a*). It remains to be seen whether this technique will improve measurements of EE and PA in daily living conditions compared with the accelerometer alone. Recently, a new device for measurement of human PA and EE has been introduced (Zhang *et al.* 2003, 2004). Like the ActiReg®, information from several sensors on different parts of the body are transmitted via cables to a recording unit worn on a belt. The laboratory test results are interesting, but no information about the reliability and performance during long-term recording of habitual human PA has been reported so far.

The distribution of time spent in the three PA levels (very low PA; low PA; moderate to high PA) provides information about the PA pattern. Of particular interest is the time spent in the moderate to high PA level, since the treadmill experiments demonstrated that walking at normal or faster speed will fall in this category. Such activity as part of daily life is recommended for maintenance of health (Pate *et al.* 1995). Recording of the time spent in moderate to high PA may therefore be useful in studies of the habitual level of PA in different groups, and whether recommendations for PA are being met. Such use of the ActiReg® may be an alternative to accelerometers for this purpose (Ainsworth *et al.* 2000*a*; Schutz *et al.* 2002; Schmidt *et al.* 2003). The moderately active group of female students in the DLW experiment spent from 38 to 104 min/d (mean value 62 min/d) at this PA level, and this time correlates positively with the total PA level (Fig. 7(A)).

In conclusion, the results reported here, and the comparative ease of data collection and calculation, should make ActiReg® a useful instrument to measure habitual PA and EE.

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