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Assessment of physical activity using accelerometry, an activity diary, the heart rate method and the Indian Migration Study questionnaire in South Indian adults

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Abstract

Objective: To validate questionnaire-based physical activity level (PAL) against accelerometry and a 24 h physical activity diary (24 h AD) as reference methods (Protocol 2), after validating these reference methods against the heart rate–oxygen consumption ($HRVO_2$) method (Protocol 1).

Design: Cross-sectional study.

Setting: Two villages in Andhra Pradesh state and Bangalore city, South India.

Subjects: Ninety-four participants (fifty males, forty-four females) for Protocol 2; thirteen males for Protocol 1.

Results: In Protocol 2, mean PAL derived from the questionnaire (1·72 (SD 0·20)) was comparable to that from the 24 h AD (1·78 (SD 0·20)) but significantly higher than the mean PAL derived from accelerometry (1·36 (SD 0·20); $P < 0{\cdot}001$). Mean bias of PAL from the questionnaire was larger against the accelerometer (0·36) than against the 24 h AD (−0·06), but with large limits of agreement against both. Correlations of PAL from the questionnaire with that of the accelerometer ($r = 0{\cdot}28$; $P = 0{\cdot}01$) and the 24 h AD ($r = 0{\cdot}30$; $P = 0{\cdot}006$) were modest. In Protocol 1, mean PAL from the 24 h AD (1·65 (SD 0·18)) was comparable, while that from the accelerometer (1·51 (SD 0·23)) was significantly lower ($P < 0{\cdot}001$), than mean PAL obtained from the $HRVO_2$ method (1·69 (SD 0·21)).

Conclusions: The questionnaire showed acceptable validity with the reference methods in a group with a wide range of physical activity levels. The accelerometer underestimated PAL in comparison with the $HRVO_2$ method.

Keywords
Questionnaires
India
Validation studies
Physical activity

Most methods that assess physical activity in individuals are not feasible in large epidemiological studies due to their high cost, need for technical expertise or their limited ability to capture habitual activity in free-living conditions(1,2). Despite certain limitations(3), physical activity questionnaires are among the most widely used methods to assess physical activity in large epidemiological studies. Most questionnaires assess specific domains, in particular, leisure-time discretionary activity(4,5). In rural India, leisure-time discretionary activity (exercise and games) may not be a major physical activity domain. Manual labour in rural populations is high in occupational and household activities(6). Use of either job description or reported occupation as a measure of overall physical activity has been shown to be inadequate(7). The frequency and intensity of activities across the various physical activity domains are also likely to vary between men and women(8). Hence, in India, questionnaires that capture information across multiple domains of physical activity would be ideal. Some published questionnaires do assess multiple domains of physical activity, but list activities that are uncommon to India(9). Other questionnaires require individuals to determine the intensity of various activities and categorize them into moderate or vigorous intensity(10). This may be a problem, since we have demonstrated earlier that perception of intensity of an activity is dependent on age and familiarity with the activity(11).

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Previously, we developed a questionnaire specific for an urban Indian community that assessed physical activity across multiple domains[12]. This questionnaire was subsequently modified for the Indian Migration Study (IMS) in order to obtain an estimate of physical activity in both rural and urban communities[13].

The main aim of the present study was to examine the validity of a physical activity questionnaire to assess physical activity level (PAL; the ratio of total energy expenditure to estimated BMR)[14] using accelerometry recordings and a 24 h physical activity diary (24 h AD) as reference. Prior to the study addressing the main aim, we also performed a validation study of the accelerometer and 24 h AD against the heart rate–oxygen consumption ($HRVO_2$) method[15] and data from this are also provided.

Methods

Physical activity assessment methods

Physical activity questionnaire

The questionnaire assessed physical activity of the past month across multiple domains including discretionary leisure time, household chores, work, sleep, sedentary activities and other common daily activities. The frequency and average duration for each activity were documented. Frequencies were ascertained using fixed categories of 'daily', 'once a week', '2–4 times a week', '5–6 times a week', 'once a month' and '2–3 times a month'. When all reported activities did not cumulatively account for 24 h, a standard MET (metabolic equivalent) of 1·4 was applied to the 'residual time', as in previous studies[12]. For manual occupational activity, the integrated energy index (IEI) of the activity was applied instead of the MET value. Unlike MET, IEI accounts for 'rest' periods that participants are likely to take when engaged in manual activities[14]. PAL cut-offs have been described to classify physical activity patterns into sedentary/light, moderately and vigorously active lifestyles[16].

24 h activity diary

Participants documented their activities in blocks of 10 min. Illiterate participants were included in the study if an educated family member working in close proximity with the participant could document the activities. Participants and family members were instructed to document additional details of activities such as posture (sitting, standing, walking, etc.), walking speed (slow, normal, brisk) and the average weight of loads, where required. A pen attached to a string, worn around the neck, reminded participants to document the 24 h AD regularly. The 24 h AD was scrutinized after completion and the ambiguities clarified directly with the participants.

Accelerometry

Twenty uniaxial accelerometers (model 7164; Manufacturing Technology Incorporated, Shalimar, FL, USA) were used in the study. The accelerometers were initialized for 1 min epochs. Between-instrument variation was assessed by comparing counts after they were fixed in batches (ten in each batch) to a simple barrel mixer and rotated for a period of 15 min at 45 rpm. One accelerometer produced counts out of range in comparison with the other accelerometers and was not used in subsequent studies. The CV of the counts for the remaining nineteen accelerometers was 1 %. The workings of the accelerometer and the computations used to arrive at physical activity measures have been described previously[17]. PAL was calculated as the average of the hourly MET over 24 h obtained using the customized software ActiGraph Software Analysis version 3·2 (ActiGraph LCC, Pensacola, FL, USA).

Heart rate–oxygen consumption method

Oxygen consumption (VO_2) was measured using indirect calorimetry (model VMax 29; SensorMedics Corp., Yorba Linda, CA, USA). Heart rate (HR) was measured using a heart-rate monitor (Polar S720; Polar Electro Oy, Kempele, Finland). Details of the $HRVO_2$ protocol measurements have been described elsewhere[18]. Briefly, steady-state resting VO_2 (4 h after breakfast) was measured for each individual, after which they performed a set of standard activities for 5–6 min which included lying down at rest, sitting quietly, walking at 2·4 and 4·8 km/h on a treadmill (no gradient) and spot jogging of 120 steps/min. Steady state was defined as '10 minutes during which the volume of oxygen consumed, ventilatory rate, and respiratory quotient does not vary by greater than 10 %'[18]. After a steady state was achieved, the mean value of VO_2 over the time period of each task was used to determine the linear relationship between VO_2 and HR. This relationship was in turn used to predict the VO_2 from the HR[15].

As it is possible that there is a breakpoint in the relationship between HR and oxygen consumed per minute (VO_2), a critical HR called the FHFLEX was identified below which the RMR was used to represent the metabolic rate[19]. In that study, which compared total daily energy expenditure (TEE) from the $HRVO_2$ method with that from whole-body calorimetry, the closest estimates of TEE were obtained when an arbitrary value of FHFLEX + 10 beats/min was used as the breakpoint in the relationship between HR and VO_2. All recorded HR below the breakpoint were assigned a metabolic rate that was equivalent to the measured VO_2 at rest, while all HR above the breakpoint were used in an equation relating HR to VO_2 for activities equal to and above slow walk, obtained by calibrating these two variables for each individual. For this study, 'FHFLEX + 10' was used as the method to obtain TEE using the Weirs equation ($TEE = [3{\cdot}941 + (1{\cdot}106 \times 0{\cdot}9)] \times VO_2$, where 0·9 is the assumed respiratory quotient and VO_2 is volume of oxygen consumed) to subsequently derive PAL[20].

Protocol of experimental studies

Protocol 1: preliminary study to validate physical activity level derived from accelerometry and the 24 h activity diary against the heart rate–oxygen consumption method

All subjects recruited for the experimental protocols below completed a sociodemographic questionnaire. Height and weight of each participant were recorded.

A convenience sample of thirteen participants who were employees from our academic institute (St. John's Medical College, Bangalore, India) was recruited. The study was conducted in the metabolic laboratory of the institute. Participants were required to stay overnight in the metabolic ward. This posed a problem in recruiting women as they were unable to participate due to social commitments or restrictions. Hence all participants were males, aged between 19 and 49 years (mean 28 (SD 8) years).

The accelerometer and heart-rate monitor were strapped to the participants on the experimental day. Steady-state VO_2 was measured and the protocol for the $HRVO_2$ method was followed as described above. After completion of the standard activities, participants continued with their daily routine activities while continuing to wear the accelerometer and the heart-rate monitor for a period of 24 h. During this period, the participants also maintained the 24 h AD. Participants were instructed to have a sponge bath instead of a regular bath and to contact the study coordinator if the accelerometer or the heart-rate monitor became dislodged from its normal position.

Protocol 2: validation of the questionnaire against accelerometry and the 24 h activity diary

A convenience sample of ninety-four participants (fifty males and forty-four females; forty-five urban and forty-nine rural) were recruited in this protocol. Of the eligible participants initially contacted, 95 % agreed to participate in the study. The urban participants included employees from our academic institute (teaching staff, clerks, attenders, cleaners, etc.) and residents living in nearby urban localities. The rural participants were recruited from two villages in Palamner Taluk in Chittoor district, Andhra Pradesh, about 140 km from Bangalore, and consisted of housewives, agricultural labourers and farmers, among others. Participants unwilling to wear the instrument for the entire 24 h period and those with lower-limb deformities were excluded from the study. The recruitment of urban participants was restricted to weekdays. The rural participants were recruited all through the week as their activities were similar throughout the week.

Participants were administered the physical activity questionnaire, strapped with the accelerometer and were instructed to continue with their daily routine activities and simultaneously maintain the 24 h AD. Eighty-three participants were finally included for analysis as data of eleven participants were excluded due to inadequate documentation of the detailed 24 h AD (n 9) or malfunctioning of the accelerometer (n 2). The mean age of participants in this protocol was 39 (SD 13) years (range 19–61 years).

Ethical approval

The studies were approved by the local institution ethics review board. Written informed consent was obtained from the participants after a detailed explanatory statement of the study was provided.

Statistical analyses

Data for continuous variables are presented as means and standard deviations. The mean PAL values estimated from the accelerometer, questionnaire, $HRVO_2$ method and the 24 h AD were compared using repeated-measures ANOVA and *post hoc* evaluation using the t test with Bonferroni correction. Pearson's correlations were used to evaluate the relationship between the PAL values estimated from the physical activity methods. The Bland–Altman method with limits of agreement was used to assess the bias in the mean PAL estimated using the physical activity methods[21]. In Protocol 2, the physical activity methods were administered on weekdays and weekends in the rural group as opposed to only during weekdays in the urban group. The mean bias of PAL estimated between the methods in the two groups was compared using an independent t test. The mean bias between the questionnaire with the detailed 24 h AD and with the accelerometer in the urban and rural groups was not significantly different; hence the urban and the rural data were combined for all analyses. A linear regression was performed to assess if age, gender or BMI predicted the mean bias estimated from the above methods. The validity of the questionnaire in ranking participants into sedentary/light, moderate and vigorously active lifestyles using standard cut-offs was assessed by evaluating the proportion of participants falling into the same and extreme categories when compared with the detailed 24 h AD[16].

The model that best predicted the relationship between the accelerometer counts for specific activities reported in this community with their intensities obtained from published sources was assessed using a linear and a curve fit model. For all tests, the level of significance of two-sided tests was set at the 5 % level. All analyses were performed using the SPSS statistical software package version 13·0 (SPSS Inc., Chicago, IL, USA).

Results

Protocol 1: preliminary study to validate physical activity level derived from accelerometry and the 24 h activity diary against the heart rate–oxygen consumption method

Mean BMI of the participants was 19·5 (SD 2·9) kg/m^2. The mean PAL of the $HRVO_2$ method (1·69 (SD 0·21)) was not significantly different from the mean PAL of the 24 h

Table 1 Comparison of physical activity level (PAL) derived from accelerometry, the detailed 24 h activity diary (24 h AD), the heart rate–oxygen consumption ($HRVO_2$) method and the physical activity questionnaire

	Accelerometer		24 h AD		$HRVO_2$ method		Questionnaire	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Validation of accelerometer and 24 h AD (*n* 13)*	1·51‡	0·23	1·65	0·18	1·69	0·21	–	–
Validation of the questionnaire (*n* 83)†	1·36§	0·20	1·78	0·20	–	–	1·72	0·20

*Subjects were males from Bangalore city, South India.
†Subjects were males and females from two villages in Andhra Pradesh state and Bangalore city, South India.
‡Mean value was significantly different from that of the detailed 24 h AD and the $HRVO_2$ method ($P<0·001$).
§Mean value was significantly different from that of the detailed 24 h AD and the questionnaire ($P<0·001$).

AD (1·65 (SD 0·18)), but was significantly higher than that derived from the accelerometer (1·51 (SD 0·23); $P<0·001$; Table 1).

The mean bias and limits of agreement of PAL derived from the accelerometer were larger (−0·17; −0·28, −0·06) than those obtained for the 24 h AD (0·04; −0·10, 0·01) when compared with the $HRVO_2$ method. The PAL derived from the accelerometer showed a correlation of 0·64 ($P=0·018$), while with that from the 24 h AD was higher at 0·91 ($P<0·001$), when compared with the $HRVO_2$ method.

Protocol 2: validation of the questionnaire against accelerometry and the 24 h activity diary

The mean BMI of this group was 22 (SD 3) kg/m^2 (13 % underweight, 15 % overweight). The mean PAL of the questionnaire (1·72 (SD 0·20)) was not significantly different from the mean PAL of the 24 h AD (1·78 (SD 0·20)), but was significantly higher than the mean PAL of the accelerometer (1·36 (SD 0·20); $P<0·001$; Table 1). Correlations of PAL from the questionnaire with that of the accelerometer ($r=0·28$; $P=0·01$) and the 24 h AD ($r=0·30$; $P=0·006$) were modest.

Using Bland–Altman plots (Fig. 1a and 1b), the mean bias of the PAL from the questionnaire was larger against the PAL from the accelerometer (0·36) than against the 24 h AD (−0·06), but with large limits of agreement against both (−0·14, 0·85 and −0·59, 0·47). Age, gender or BMI did not predict the mean biases that were obtained between the above methods.

Participants were ranked into three categories of PAL (sedentary/light activity = 1·40–1·69, moderately active = 1·70–1·99, vigorously active = 2·00–2·40) obtained from published sources[16]. Fifty-five per cent of the participants were correctly categorized by the questionnaire (using 24 h AD as the reference method) and 8 % were misclassified into extreme categories (sedentary/light activity to vigorously active lifestyle or vice versa).

Assessment of the relative validity of the accelerometer counts for individual activities

Various individual activities reported by the participants were extracted out of the 24 h AD along with the simultaneously recorded accelerometer counts from those activities. For each individual reporting an activity, the

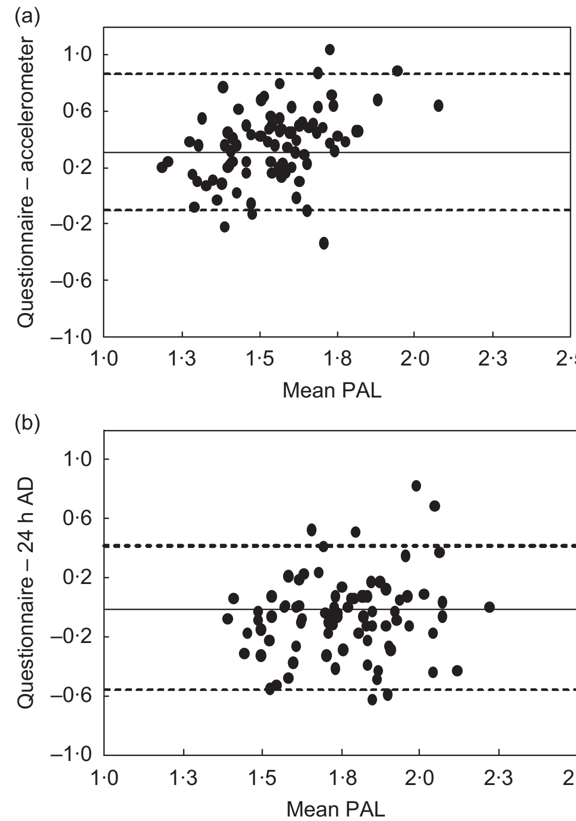

Fig. 1 Bland–Altman plots showing the mean bias (—) and limits of agreement (- - -) for physical activity level (PAL) measured between (a) the questionnaire and the accelerometer and (b) the questionnaire and the detailed 24 h physical activity diary (24 h AD) among eighty-three participants from two villages in Andhra Pradesh state and Bangalore city, South India

average 2 min counts were computed, and the median of all the means of individuals reporting the same activity were used in the analysis.

First, the accelerometer counts were compared with known accelerometer count cut-offs from published sources[22]. For example, an accelerometer count of less than 1952 corresponds to a MET of 3, i.e. 'light' intensity category (Fig. 2). Second, the relationship of the accelerometer-derived counts with the intensity of these activities was determined using MET values of these activities from published sources[16,23].

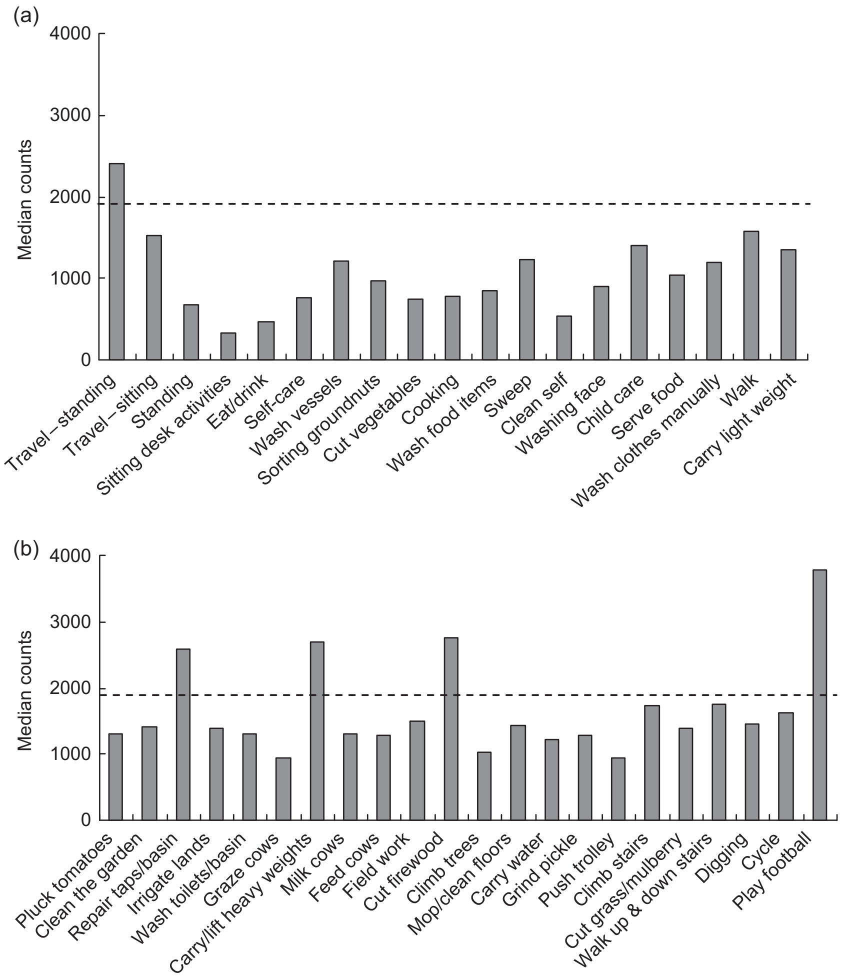

Fig. 2 Median accelerometer counts of specific activities: (a) activities with intensity between 1·0 and 3·0 MET (metabolic equivalents) and (b) activities with intensity between 3·1 and 8·0 MET, among eighty-three participants from two villages in Andhra Pradesh state and Bangalore city, South India. The horizontal line at 1952 counts represents the upper limit for light activities based on Freedson's equation

There was a significant positive correlation between the accelerometer counts of the specific activities with their published MET values ($r = 0{\cdot}56$; $P < 0{\cdot}001$). The scatter plot of this relationship indicated that activities at higher intensities did not fit into a linear relationship. A cubic curve fit model between the accelerometer counts and the MET values ($R^2 = 0{\cdot}41$; $P < 0{\cdot}001$) predicted the relationship better than a linear model ($R^2 = 0{\cdot}31$; $P < 0{\cdot}001$; Fig. 3).

Discussion

The questionnaire-derived PAL had significant, modest correlations with the PAL derived from the accelerometer and the detailed 24 h AD. The strength of the correlations is similar to those observed in the validation of questionnaire-derived physical activity parameters elsewhere[24,25]. It is conceivable that correlations between the questionnaire and other methods would be stronger if a larger number of measurement days of the reference methods (accelerometer, 24 h AD) were obtained to better reflect the one month recall period captured by the questionnaire. It is also likely that the questionnaire may in fact have stronger correlations with the 24 h AD than obtained in the present study (Protocol 2), since the 24 h AD was filled out in some instances by a family member rather than the individual (because of illiteracy). This is suggested by the rather higher correlation between accelerometer-derived PAL and 24 h AD when the 24 h AD was filled in by the participant alone ($r = 0{\cdot}64$, Protocol 1) as compared with a modest correlation of $r = 0{\cdot}37$ (Protocol 2) when the 24 h AD was filled in by a combination of participants and family members. In the present study, PAL from the accelerometer was significantly lower than that from the $HRVO_2$ method and the detailed 24 h AD. The underestimate of PAL by the accelerometer was confirmed when compared with the 24 h AD in the study group where the questionnaire was validated. The underestimate of PAL by the accelerometer

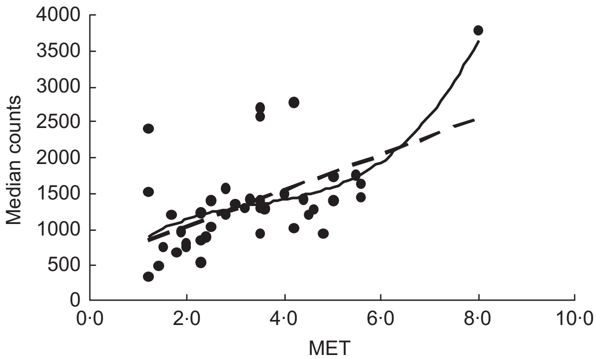

Fig. 3 Regression line for median accelerometer counts of reported individual activities (determined among eighty-three participants from two villages in Andhra Pradesh state and Bangalore city, South India) and published MET (metabolic equivalents). – – –, linear fit regression model ($R^2 = 0{\cdot}31$, $P < 0{\cdot}001$); ——, cubic curve fit model ($R^2 = 0{\cdot}41$, $P < 0{\cdot}001$)

may in part be due to the underestimation of accelerometer counts for the various moderate to vigorous-intensity activities observed in our study. Similar problems have been reported for this accelerometer (formerly Computer Science and Application Inc.) and for other accelerometers as well[26–28]. In contrast, the mean PAL from the questionnaire compared well with that obtained with the 24 h AD although 24 h AD is prone to over-reporting as it relies on self-report[29].

An obvious limitation in the current study is that free-living activities and published, rather than actually measured MET were used to compare with the accelerometer-derived counts. It is conceivable that the published MET compiled from various sources may have been different from the true value due to variations in the descriptions of the activities, varied methodology in measuring MET and in the estimation of BMR to derive MET[30]. However, it is unlikely that the underestimation of the intensity for the whole range of activities captured by the accelerometer can be explained by these limitations alone. Evidence shows that physical activities that are more complex (having a combination of both dynamic and static movements), static activities and activities involving upper-body movements are poorly captured by accelerometers[26,27]. To overcome these, studies have used triaxial accelerometers, but with little improvement in assessing these activities[31].

In summary, the present study demonstrates that the questionnaire has reasonable validity, concordant with other published studies that capture the patterns of physical activity across a wide range of behaviours (sedentary to heavily active) in large epidemiological studies[24,25]. MET values of the free-living activities, if measured, would have provided accurately the underestimations of the accelerometer and also revealed if existing published MET are valid for this community. The impact of the day-to-day variation of physical activity (within-subject) in the estimation of PAL derived from the accelerometer and the 24 h AD would have been possible if additional days of physical activity recordings were captured. Although the questionnaire is designed to also capture individual physical activity components (occupation, household activities, etc.), its validity for this purpose needs to be ascertained. There is also a need to assess the performance of this questionnaire in other regions in India.

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References

1. Lamonte MJ & Ainsworth BE (2001) Quantifying energy expenditure and physical activity in the context of dose response. *Med Sci Sports Exerc* **33**, 6 Suppl., 370S–378S.
2. Haskell WL & Kiernan M (2000) Methodologic issues in measuring physical activity and physical fitness when evaluating the role of dietary supplements for physically active people. *Am J Clin Nutr* **72**, 2 Suppl., 541S–550S.
3. Shephard RJ (2003) Limits to the measurement of habitual physical activity by questionnaires. *Br J Sports Med* **37**, 197–206.
4. Richardson MT, Ainsworth BE, Wu HC, Jacobs DR Jr & Leon AS (1995) Ability of the Atherosclerosis Risk In Communities (ARIC)/Baecke questionnaire to assess leisure-time physical activity. *Int J Epidemiol* **24**, 685–693.

5. Helmert U, Herman B & Shea S (1994) Moderate and vigorous leisure-time physical activity and cardiovascular disease risk factors in West Germany, 1984–1991. *Int J Epidemiol* **23**, 285–292.
6. Kanade AN, Rao S, Yajnik CS, Margetts BM & Fall CHD (2005) Rapid assessment of maternal activity among rural Indian mothers (Pune Maternal Nutrition Study). *Public Health Nutr* **8**, 588–595.
7. Vaz M & Bharathi AV (2004) How sedentary are people in 'sedentary' occupations? The physical activity of teachers in urban South India. *Occup Med* **54**, 369–372.
8. Vaz M & Bharathi AV (2000) Practices and perceptions of physical activity in urban, employed, middle-class Indians. *Indian Heart J* **52**, 301–306.
9. Chasen Taber LJ, Erickson B, Nasca PC, Chasan-Taber S & Freedson PS (2002) Validity and reproducibility of a physical activity questionnaire in women. *Med Sci Sports Exerc* **34**, 987–992.
10. Craig CL, Marshall AL, Sjostrom M, Bauman AE, Booth ML & Ainsworth BE (2003) International physical activity questionnaire: 12-country reliability and validity. *Med Sci Sports Exerc* **35**, 1381–1395.
11. Vaz M & Bharathi AV (2004) Perceptions of the intensity of specific physical activities in Bangalore, South India: implications for exercise prescription. *J Assoc Physicians India* **52**, 541–544.
12. Bharathi AV, Sandhya N & Vaz M (2000) The development and characteristics of a physical activity questionnaire for epidemiological studies in urban middle class Indians. *Indian J Med Res* **111**, 95–102.
13. Lyngdoh T, Kinra S, Shlomo YB *et al.* (2006) Sib-recruitment for studying migration and its impact on obesity and diabetes. *Emerg Themes Epidemiol* **3**, 2.
14. James WPT & Schofield EC (1990) *Human Energy Requirements: A Manual for Planners and Nutritionists*. Oxford: Oxford University Press.
15. Kurpad AV, Raj R, Maruthy KN & Vaz M (2006) A simple method of measuring total daily energy expenditure and physical activity level from the heart rate in adult men. *Eur J Clin Nutr* **60**, 32–40.
16. Food and Agriculture Organization of the United Nations/World Health Organization/United Nations University (2001) *Human Energy Requirements. Report of a Joint Expert Consultation. FAO Food and Nutrition Technical Report Series* no. 1. Rome: FAO.
17. Bassett DR Jr, Ainsworth BE, Swartz AM, Strath SJ, O'Brien WL & King GA (2000) Validity of four motion sensors in measuring moderate intensity physical activity. *Med Sci Sports Exerc* **32**, 9 Suppl., S471–S480.
18. Horner NK, Lampe JW, Patterson RE, Neuhouser ML, Beresford SA & Prentice RL (2001) Indirect calorimetry protocol development for measuring resting metabolic rate as the component of total energy expenditure in free-living postmenopausal women. *J Nutr* **131**, 2215–2218.
19. Spurr GB, Prentice AM, Murgatroyd PR, Goldberg GR, Reina JC & Christman NT (1988) Energy expenditure from minute-by-minute heart-rate recording: comparison with indirect calorimetry. *Am J Clin Nutr* **48**, 552–559.
20. Weirs JBD (1949) New methods for calculating metabolic rate with specific reference to protein metabolism. *J Physiol* **109**, 1–9.
21. Bland JM & Altman DG (1986) Statistical methods for assessing agreement between methods of clinical measurements. *Lancet* **1**, 307–310.
22. Freedson PS, Melanson E & Sirard J (1998) Calibration of the Computer Science and Applications, Inc. accelerometer. *Med Sci Sports Exerc* **30**, 777–781.
23. Ainsworth BE, Haskell WL, Whitt MC *et al.* (2000) Compendium of physical activities; an update of activity codes and MET intensities. *Med Sci Sports Exerc* **32**, 9 Suppl., S498–S504.
24. Ainsworth BE, Bassett DR Jr, Strath SJ, Swartz AN, O'Brien WL, Thompson RW, Jones DA, Macera CA & Kimsey CD (2000) Comparison of three methods for measuring the time spent in physical activity. *Med Sci Sports Exerc* **32**, 9 Suppl., S457–S464.
25. Taber LC, Schmidt MD, Roberts DE, Hosmer D, Markenson G & Freedson PS (2004) Development and validation of a pregnancy physical activity questionnaire. *Med Sci Sports Exerc* **36**, 1750–1760.
26. Leenders NYJM, Sherman WM & Nagaraja HN (2000) Comparison of four methods of estimating physical activity in adult women. *Med Sci Sports Exerc* **32**, 1320–1326.
27. Crouter SE, Clowers KG & Bassett DR Jr (2005) A novel method for using accelerometer data to predict energy expenditure. *J Appl Physiol* **100**, 1324–1331.
28. Hendelman D, Miller K, Baggett C, Debold E & Freedson P (2002) Validity of accelerometry for the assessment of moderate intensity physical activity in the field. *Med Sci Sports Exerc* **32**, 9 Suppl., S442–S449.
29. Irwin ML, Ainsworth BE & Conway JM (2001) Estimation of energy expenditure from physical activity measures: determinants of accuracy. *Obes Res* **9**, 517–525.
30. Vaz M, Karolis N, Draper A & Shetty P (2005) A compilation of energy cost of physical activities. *Public Health Nutr* **8**, 1153–1183.
31. Welk GJ, Blair SN, Wood K, Jones S & Thompson RW (2000) A comparative evaluation of three accelerometry based physical activity monitors. *Med Sci Sports Exerc* **32**, 9 Suppl., S489–S497.